The Gateway Arch

GATEWAY ARCH NATIONAL PARK
ST. LOUIS, MO

CONSERVATION MANAGEMENT PLAN

AUGUST 2020

PREPARED BY **BVH ARCHITECTURE** FOR THE **ASSOCIATION FOR PRESERVATION TECHNOLOGY, NATIONAL PARK SERVICE,** AND THE **GETTY FOUNDATION**

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Acknowledgments

GATEWAY ARCH NATIONAL PARK

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Executive Summary

I.

OVERVIEW

This extensive study builds on three previous studies—*Gateway Arch Corrosion Investigation-Part 1, May 2006; Jefferson National Expansion Memorial Gateway Arch Historic Structure Report, June 2010; Gateway Arch Corrosion Investigation-Part 2, September 2012; and Gateway Arch Corrosion Investigation-Part 3, February 2015*—and entails the investigation, testing, and development of preservation protocols that can be utilized by the National Park Service to clean, possibly refinish, and generally conserve the stainless steel skin of the Gateway Arch in St. Louis.

The grant was administered by the Association for Preservation Technology International (APT) with the cooperation of the Gateway National Park, a unit of the US National Park Service (NPS), Department of the Interior, and an expert team lead by BVH Architecture (BVH). The work is a continuation of comprehensive technical studies and a Historic Structure Report that were begun in 2004.

The Gateway Arch is soiled, and this soiling is particularly apparent at the lower reaches of the legs. Visitors can touch the monument where it meets the ground and experience its abstract simplicity close up. Consequently, there are body oils, perspiration, and chemical pollutants from touching by hand, soiling collected on these residues, and graffiti that is either incised, etched, or pounded into the stainless steel. Tools of ferrous and other metals were used in making this graffiti and corrosion residue of these dissimilar metals are pitting the stainless steel and if left unchecked will cause serious damage.

The previous studies have also given confidence that the staining that appears on the upper reaches of the monument are atmospheric pollutants and not corrosion-related as was originally feared. There is superficial corrosion near the base due to street and de-icing salts. These pollutants appear as unsightly vertical streaks, which begin at welds between arch segments. The NPS has decided to consider cleaning the lower reaches of each leg of these atmospheric pollutants. Cleaning the entire monument is cost prohibitive at this time because of the immense costs of access.

The challenge, therefore, is cleaning and possibly refinishing the monument without affecting the reflectivity and visual quality. Small-scale cleaning mockups using traditional and mildly abrasive techniques were installed at the base of the north leg in 2014, but there are also other and newer technologies that were evaluated for both cleaning and refinishing.

OUR STUDY & EVALUATION

Previous reports dated 2006, 2010, 2012 and 2015 that were related to the Gateway Arch and issues with its exterior skin were reviewed.

A superficial examination of the Arch on the exterior skin at the base was performed on August 3, 2018 to determine the average grid size and type used to create the original surface in order to match the depth, frequency, and coarseness of the existing surface. This initial examination aided in categorizing and quantifying incised graffiti at the lengths and provided enough data to begin the discussion on cleaning and refinishing techniques that would be the least intrusive.

An expert workshop was held on site on October 2-4, 2018 that was attended by renowned experts in the fields of fabricating, cleaning, refinishing and the evaluation of stainless steel surfaces. During the three-day workshop, goals of the project were further defined; ideas for cleaning, refinishing and conserving stainless steel skin were discussed at length; and appropriate methods to perform mockups were established. It was determined that further cleaning mockups would not be carried out at the monument but in a laboratory setting. Procurement of appropriate stainless steel panels, the methods to distress them, and the methods to create superficial corrosion were established. It was determined that we would not be able to create atmospheric pollutants in a laboratory setting.

Small-scale stainless steel mockups duplicating the deterioration found at the base of the Arch were prepared at the Zahner Metalab facilities, and the evaluation took place on March 25-27, 2019. The evaluations were quite involved and included a visual or aesthetic assessment; a gentleness assessment using specular gloss, surface roughness and microscopic evaluations; and in the economic feasibility assessment. Results of these assessments are summarized in an evaluation matrix. It was revealed that water cleaning was unsatisfactory and that chemical cleaning provided superior results. Laser cleaning also showed promise but will require further research and development. A mockup was also performed on a stressed panel to evaluate potential refinishing techniques in areas with incised graffiti. This testing revealed that the legs of the Gateway arch at the base that have been marred with incised graffiti could be successfully refinished, but that the techniques would require further development.

Conservation policies have been developed within the framework of existing historic preservation guidelines that have been established by the Department of the Interior. Important considerations such as mitigating the propagation of further incised graffiti is the present graffiti is removed and limiting the ability of visitors to touch the monument are discussed.

Finally, a prioritized action plan has been presented providing initial and future steps to clean, potentially refinish, and generally conserve the stainless steel skin of the Gateway Arch.

All data collected from this intensive study has been incorporated within this Conservation Master Plan. It is our hope that the information provided will allow the National Park Service to move ahead confidently with cleaning and possible refinishing mock-ups of the monument. Another important aspect of the project is the dissemination of the findings within the international community that is tasked with the care and conservation of our modernist heritage. The Association for Preservation Technology International (APT) as the grant management entity, will in conjunction with the Getty, assist with the dissemination of information through publication and symposia as a shared benefit of the project collaboration.

SOURCE: D. WORTH

History

II.

A. SUMMARY OF HISTORICAL RESEARCH & SIGNIFICANCE ASSESSMENT

ST. LOUIS, GATEWAY TO THE WEST

This section was taken from the National Park Service Jefferson National Expansion Memorial Gateway Arch Historic Structure Report - Volume 1, June 2010—prepared by BVH Architecture, Wiss, Janney, Elstner Associates (WJE), and Alvine and Associates.

Throughout its history, St. Louis has defined itself as the "Gateway to the West." Located fifteen miles south of the confluence of the Mississippi and Missouri Rivers, St. Louis was established by Pierre Laclede in 1764 as a French fur-trading post. The site had a high limestone bluff extending approximately two miles along the river which provided a suitable location for a settlement protected against flooding.

In 1803 during Thomas Jefferson's presidency, the Louisiana Territory including the village of St. Louis was purchased from France, nearly doubling the size of the United States. In the years following the Louisiana Purchase, the western frontier remained a place for mountain men, fur-trappers, and explorers. St. Louis was a major post where frontiersmen could sell their goods or acquire supplies before venturing further west. In 1809, the town of St Louis was incorporated.

The development of the steamboat fueled St. Louis' success as an inland port economy. In 1817, the *Pike* was the first steamboat to arrive in St. Louis, introducing the city to commercial steamboat commerce. During the decades that followed, St. Louis was at the crossroads of steamboat traffic. The Missouri River linked the city to the western frontier. The Ohio River, running primarily east-west, proved an effective thoroughfare that directly connected St. Louis to eastern markets and extended to urban centers in the northeast. The Mississippi River provided a north-south backbone for the river network, giving access from the northern frontier of Minnesota as well as downriver to markets in New Orleans and the waters beyond. By 1850, St. Louis was the second largest port by tonnage in the United States and the largest city west of Pittsburgh. It was the center of steamboat traffic on the Mississippi River, the terminus for stage coach lines from the east and had established itself as a gateway to the western frontier (Figure 2-1).

Figure 2-1—Lithograph of Old St. Louis in 1855. Source: Yale University Archives, Eero Saarinen Collection, Manuscript Group 593

In the second half of the 19th Century, the development of the railroads accelerated, and steamboat traffic decreased. The shift in the economy was nowhere more apparent than in the downtown business district of St. Louis. The historic city core was left to industrial and warehouse uses. The river's edge was dominated by railroad traffic navigating its way across the Mississippi River bridges.

As the country expanded and transportation and technology improved, the role of St. Louis as the link between the east and the west evolved and was reflected in its built environment. The development and role of St. Louis in the expansion of the country is illustrated by its historic riverfront district and memorialized and symbolized through Eero Saarinen's Gateway Arch.

GATEWAY ARCH NATIONAL PARK

Initiated in the Depression era, the Jefferson National Expansion Memorial (JNEM) project was first proposed as a means of rejuvenating the St. Louis riverfront and providing economic relief to the city. The project rapidly achieved national attention and public support, concurrent with the development of financial difficulties and legislative disputes. After four decades of debate, controversy, and delays the memorial was completed, culminating in a monument that not only commemorated the vision of Thomas Jefferson and the struggles of the traders, frontiersmen, and pioneers but also the determination and persistence of individuals who were instrumental in the development of the national historic site.[1]

Creation of a National Historic Site

In 1933 St. Louis attorney Luther Ely Smith that led to the establishment of JNEM. Smith was troubled by the appearance of the decaying historic riverfront district and felt that the creation of a monument could bring economic development, provide work relief, and revitalize the historic waterfront area. In April 1934, the Jefferson National Expansion Memorial Association (JNEMA) was organized. The title of the association reflected a focused direction for the project as a monument of national scope that would commemorate the vision of Thomas Jefferson and the sacrifices of pioneers in opening the West. JNEMA, under the guidance of a determined Smith and with the political savvy of St. Louis Mayor Bernard Dickmann, became the driving force in obtaining support, soliciting funding, and developing a memorial plan. Early in the process, a consensus was reached to raze the majority of the warehouse and industrial buildings in the historic St. Louis riverfront district.

In June 1934, the U.S. Congress established the fifteen-member United States Territorial Expansion Memorial Commission to oversee the feasibility of a national monument in St. Louis. On April 13, 1935, the anniversary of Thomas Jefferson's birthday, the commission's executive committee, having reviewed the progress made by JNEMA, approved the plan for the memorial. This plan included a national design completion, commemoration of events of both national and local historical significance, and an estimated budget of $30 million for land acquisition, development, and planning.

On September 10, 1935, a St. Louis city bond issue to partially fund the memorial was passed by voters. The city was prepared to contribute up to $7.5 million to the construction of the memorial, with one dollar contributed by the city for every three dollars contributed by the federal government.

At the federal level, the decision was made to designate the project location a national historic site to allow for federal funding of construction and future maintenance. Executive Order 7253, signed by President Franklin D. Roosevelt on December 21, 1935, made JNEM the country's first National Historic Site under the Historic Sites Act.[2]

The land would serve as

> . . . a permanent memorial to the men who made possible the territorial expansion of the United States, particularly President Thomas Jefferson and his aides, Livingston and Monroe, who negotiated the Louisiana Purchase, and the hardy hunters,

[1] Sharon A. Brown, *Administrative History: Jefferson National Expansion Memorial National Historic Site* (Washington, D.C.: National Park Service, June 1984).

[2] Historic Sites Act of 1935, 16 USC 461 to 476.

[3] Brown, Chapter 1, 2, citing Pro Forma Decree of Incorporation of Jefferson National Expansion Memorial Association, June 11, 1934, JNEMA.

> trappers, frontiersmen, and pioneers and others who contributed to the territorial expansion and development of the United States of America.[3]

The Executive Order authorized the NPS to acquire thirty-eight city blocks encompassing the site of Old St. Louis (Figure 2-2) and to develop and preserve the site as JNEM. Within the site, 40 percent of the buildings were unoccupied in 1936. Given the decayed state of the neighborhood, the NPS acquired the land by means of condemnation as opposed to purchase. By September 1938, review of all properties within the historic site boundary had passed through the courts and all the buildings were under condemnation. Legal processes surrounding condemnation continued until January 27, 1939, when the United States Circuit Court of Appeals declared the federal government's attempts to condemn the land as a valid delegation of its legislative power. On June 14, 1939, federal funds totaling $6.2 million, the entirety of the contracted land agreements, were dispersed to property owners.

While early efforts focused on the acquisition of land, the NPS started preliminary work on the interpretation of the site based on its concept of a memorial to Thomas Jefferson's vision of territorial expansion.

In 1936, the Old Courthouse was a vacant and dilapidated structure sited just outside the proposed boundary of JNEM. The Greek Revival-style building, constructed in 1839-1862, served as the county courthouse until 1930, when it was decommissioned and became vacant. The Old Courthouse displayed significant architectural merit as an example of Greek Revival-style civic architecture as well as historical interest as the site of two influential court cases regarding discrimination and human rights. In 1847 and 1850, the courthouse was the focus of debate as the site of the Dred Scott case. The pivotal law suit tested the rights of slaves who had once resided in free territories to seek their own freedom. On July 1, 1937, the City of St. Louis decided the building could serve as a suitable museum and office space for the NPS.

Figure 2-2—Aerial view of the St. Louis riverfront and downtown, 1930s. The Eads Bridge is at the extreme right edge of the photograph.

Source: JNEM archives, image V106-4822

History

The Mississippi River was an integral part of the history of St. Louis as a gateway to the western territory. Thus, the success of any memorial commemorating national expansion would depend on its relation to the waterway.

For decades, St. Louis had thrived as a hub for railroad traffic. By the 1930s, three surface and two elevated tracks had been built on the levee and dominated the riverfront. The railroad tracks defined the eastern boundary of the memorial site and separated it from the riverfront. In August 1938, St. Louis Board of Public Service President Baxter Brown submitted a plan for relocation of the railroad tracks. The proposal combined a new tunnel to conceal the relocated tracks and re-grading of the site to elevate it over the tunnel. These modifications would eliminate the elevated and surface tracks and open up the views to the river.

On October 10, 1939, the first signs of visible progress on JNEM were made as Mayor Bernard Dickmann initiated the demolition process with the removal of three bricks from an abandoned warehouse building (Figure 2-3). Demolition of most of the buildings on the memorial site was completed by 1942 (Figure 2-4). A few buildings considered to be of historic interest were not demolished, including the Old Cathedral (Figure 2-5) and the Old Rock House, an 1818 stone warehouse built by fur-trader Manuel Lisa at the corner of Wharf and Chestnut Streets.[4] Historic American Buildings Survey documentation of many of the structures on the memorial site was completed prior to demolition.

Figure 2-3—Demolition of buildings on the memorial site, circa 1940. Source: JNEM archives, image V106-501a

Figure 2-4—Aerial view of the memorial site, October 1946, U.S. Navy photograph. The Old Cathedral is visible near the center of the memorial site, while the Old Rock House remains near the river's edge adjacent to the railroad viaduct. Source: JNEM archives, image V106-4844

Designing & Financing the Arch

The long tenure of JNEM Superintendent Julian Spotts from 1940 to 1959 was characterized by two significant events that shaped the development of the memorial. First, JNEMA sponsored a national design competition that captured the imagination of the public. The resulting winner, Eero Saarinen, created a simple yet dramatic design that was both commemorative and inspirational.

[4] Portions of the building may have been built as early as 1767

Second near the end of Julian Spotts' superintendency an agreement was made between the City of St. Louis, TRRA, and the NPS. The long awaited compromise was followed by the authorization of federal funding and extensive preparations for the first phase of construction on the Gateway Arch.

During World War II, progress on the JNEM site was limited as efforts to establish a memorial were suspended as the country focused funds and attention on the war.

The Design Competition

Since its inception, JNEMA had planned to sponsor a national design competition for a suitable memorial, "transcending in spiritual and aesthetic values."[5] The competition was officially announced in January, 1945, and the design parameters focused on providing a fitting memorial while invigorating the riverfront and developing a setting integral with the downtown community. The requirements included the building of an architectural memorial, preserving the site of Old St. Louis through a museum and reconstruction of Old St. Louis buildings, creating a living memorial to Thomas Jefferson, accentuating recreational opportunities, providing access to parking, relocating railroad tracks, and accommodating a new interstate highway.

In August 1946, George Howe, the Philadelphia architect responsible for the PSFS Building and other influential American modernist structures, was recruited to be the professional advisor for the competition. The competition jury consisted of seven members; S. Herbert Hare, Fiske Kimball, Louis LeBeaume, Charles Nagel, Jr., Richard Neutra, Roland Wank, and William Wurster, many of whom had sensibilities influenced by the International style of architecture. Howe's appointment, combined with the assignment of modernist architects to the jury, was an indication of the desired design aesthetic for the memorial.

Figure 2-5—Old Cathedral in its urban context, Walnut Street near Third Street, April 9, 1934. Source: Alexander Piaget

The two-stage contest consisted of an initial review by judges at which time five finalists were selected. The finalists were then given $10,000 and three months to develop the second stage of design. Throughout the process, the identity of the competitors was kept secret. The winner would be selected following the second stage of design and be determined by secret ballot.

By the September 1, 1947, deadline, 172 architects and

[5] Brown, Chapter 4, citing a Report, Smith to Jefferson National Expansion Memorial, November 4, 1944, JNEMA.

engineers had submitted designs for consideration. Entry No.144, Eero Saarinen's design, was given much praise as a beautiful and inspired design; Charles Nagel described the design as "an abstract form peculiarly happy in its symbolism." However, criticism arose in regard to its practicality (Figure 2-6).

Entries for the second stage of competition were due February 17, 1948. Upon first review of the designs, the jury submitted votes and unanimously selected Eero Saarinen as the winner. The selection was announced on February 18 by JNEM; however, it was not until May 25, 1948, that the United States Territorial Expansion Memorial Commission voted to recommend the design for approval by the Department of the Interior and Congress (Figure 2-7).[7]

Eero Saarinen was born in Finland in 1910 and immigrated to the United States with his family in 1923. His father, renowned architect Eliel Saarinen, was the first president of the Cranbrook Institute of Architecture and Design in Bloomfield Hills, Michigan. After studying sculpture in Paris and Architecture at Yale University, Eero Saarinen joined his father's firm in 1937.[8] Saarinen's entry into the JNEM competition combined his sculpture background and architecture education, characteristics which would become the trademark of his designs.

The Saarinen design consisted of the central Arch with a tree-lined mall and arcade. Saarinen's catenary arch was derived from his initial concept of a three-legged structure. He was intent on using a simple iconic form, characteristic of the Jefferson Memorial or Washington Monument, realized in modern materials.

Saarinen's design was used to generate support and excitement for the JNEM park. The inspirational design was well received by critics, with limited dissent among the general public. Some St. Louis residents referred to it as

Figure 2-6—Photograph of the scale model of Saarinen's competition entry. Source: Yale University Archives, Eero Saarinen Collection

Figure 2-7—Saarinen (shaking hand on the left) accompanied by (left to right) J. Henderson Barr, associate architect; Alexander Girard, painter; Dan Kiley, landscape architect; and Lily Saarinen, wife and sculptor, awarded first prize by William Wurster (far right) at the JNEMA banquet on February 18, 1948. Source: Yale University Archives, Eero Saarinen Collection

[6] Brown, Chapter 4, citing Charles Nagel, Jr., *A Sketch Report of the Jury Proceedings, Jefferson National Expansion Memorial*, September 23–26, 1947, JNEMA.

[7] Brown, Chapter 4

[8] Laura Soullière Harrison, *National Register of Historic Places Nomination Form: Gateway Arch* (Washington, D.C.: NPS, 1985). This National Register nomination serves as documentation for the National Historic Landmark listing of the structure.

a “stupendous hairpin” or “stainless steel hitching post.”[9] The most severe criticism came from Gilmore Clarke, Chairman of the National Commission on Fine Arts, who perceived a resemblance between the design for the Arch and an exhibition structure in Rome, proposed under Mussolini in 1942.[10]

Railroad Relocation

Upon completion of the competition, attention was redirected toward the difficult and arduous task of resolving the dispute over the relocation of the railroad tracks. The City of St. Louis was in favor of a Levee-Tunnel plan that placed the tracks along the riverfront. Saarinen and the NPS objected to this proposal, as it would obscure the relationship between the Arch and the water. Saarinen supported a Hill-Tunnel plan, which positioned the tracks on the west end of the site. After much debate, the parties agreed upon the removal of the five existing tracks along the levee and replacement with three tracks. The railroad lines were to be positioned in a tunnel, no larger than 3,000 feet long and eighteen feet tall, approximately fifty feet west of their existing elevated location.[11] A concession of the new plan was the demolition of the Old Rock House.

Progress toward development of JNEM was delayed by the start of the Korean War. During the war period, government spending was restricted and attempts to appropriate funds were temporarily halted. The future of JNEM was further compromised by the death in 1951 of Luther Ely Smith who had founded and directed the Association in its efforts to commemorate Jeffersonian Expansion.

Following the conclusion of the Korean War in 1953, and despite a lack of funds, in 1954 Congress authorized the appropriation of $5,000,000 for construction of Saarinen’s Memorial.[12] In 1956, an additional $2,640,000 was allocated to the JNEM project for the relocation of the elevated railroad tracks.[13] Allocation of these funds was the first step to preparing the site for the construction of the Arch. On September 7, 1958, the determination of the JNEMA, the patience of the City of St. Louis and the NPS, and the inspiration of Saarinen were rewarded when President Eisenhower signed legislation amending the 1954 authorization to provide for the construction of JNEM in its entirety. A total of $17,250,000 was allocated for construction.

Structural Design

Following the appropriation of funds, renewed excitement and energy surrounded the JNEM project. Eero Saarinen and Associates generated construction documents for the development of the levee and refinements were made to the design of the Arch and surrounding landscape.

Saarinen focused on developing the correct proportion and scale for the Arch, to achieve the desired iconic appearance, as well as the required structural stability throughout the construction process. Saarinen had originally envisioned a 590-foot-tall Arch, but as the St. Louis skyline increased in height, so did the Arch. By 1959, a 630-feet-tall Arch was planned with a width equal to its height (Figure 2-8). Saarinen consulted Fred Severud, his long-time structural engineer, and Hannskarl Bandel of Severud, Elstad, Kreuger Associates of New York City to develop a structural solution to capture Saarinen’s refined vision.

Fred Severud was an innovative civil engineer who had immigrated to the United States from Norway. Severud had worked on the Raleigh Coliseum, Madison Square

[9] Regina Bellavia, historical landscape architect and Greg Bleam, landscape architect consultant, Cultural Landscape Report for Jefferson National Expansion Memorial (Omaha, Nebraska: Government Printing Office, 1996)

[10] Ibid.

[11] Approval was given by MPSC on August 7, 1952.

[12] Public Law 361 (H.R. 6549) May 17, 1954. The law specified the expenditure of funds on the Arch itself.

[13] Brown, Chapter 6

[14] Saarinen sketches from Yale University Archives. Record Group 593; Series IV; Box 97.

Garden, and the Yale Hockey Rink, developing some of the first cable-supported roof structures in the United States.[15]

Hannskarl Bandel, Severud's chief engineer, worked closely with him on the Arch design. Bandel was raised in Germany by a father who was an architect and a mother whose family owned the Bechtel Construction Company. Before immigrating to the United States after World War II, Bandel had gained experience as an engineer in the steel industry.

The structural concept for the Arch was a collaborative effort between Severud's and Saarinen's offices. During the design competition, Saarinen indicated that the Arch would be a steel structure filled with concrete. Severud introduced orthotropic design principles, which were new for the period.[16] Following these principles, the Arch structure was designed to be supported by its skin. A carbon steel inner shell and stainless steel outer shell were set at slightly different weighted catenary curves and connected through stiffener plates. The interstitial space between these shells was filled with post-tensioned concrete at the lower half of the Arch. The two interconnected skins thus helped support each other.

Bandel was responsible for reproducing Saarinen's soaring catenary shape in the structural design. When Saarinen tried to demonstrate his intent with a chain suspended in his hands, he could not achieve the slightly elongated effect he wanted. Bandel replaced some of the constant-sized links in the chain with variable links, thus changing the weight, its distribution, and the resulting shape—a weighted catenary. Saarinen then modified the design of the Arch through scale models and weighted catenary studies. The Arch structure developed as an equilateral triangle cross-section that measured 54 feet across at the base, tapering to 17 feet across at the top (Figures 2-9 and 2-10).[17]

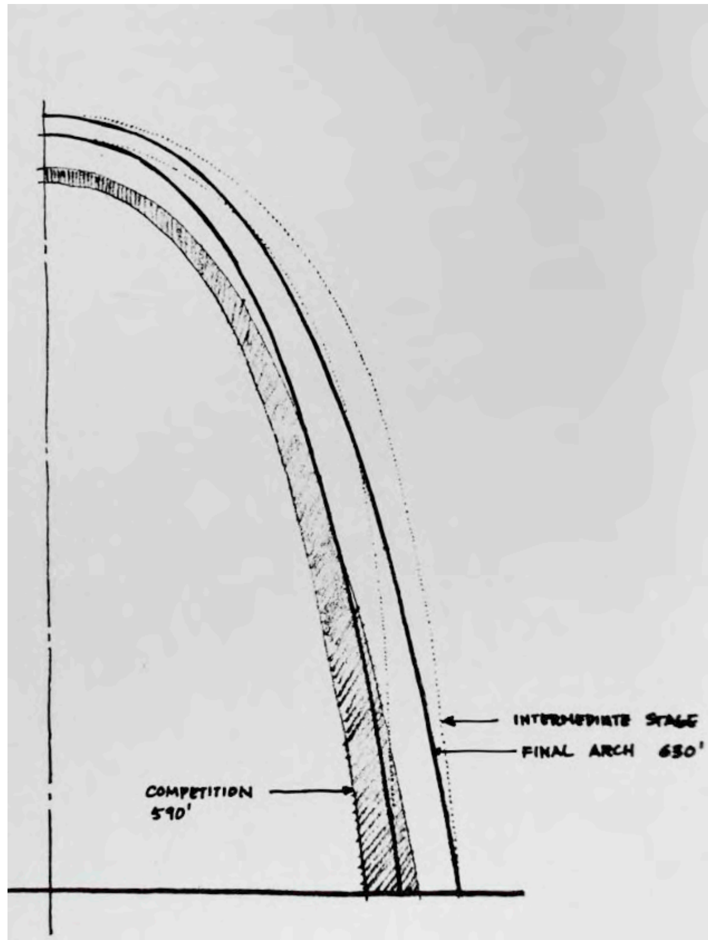

Figure 2-8—Evolution of the Arch height and shape from competition to final design. Source: Yale University Archives, Eero Saarinen Collection

[15] Richard G, Weingardt, Engineering Legends: Great American Civil Engineers (Reston, VA.: American Society of Civil Engineers, 2005).

[16] In structural engineering design, orthotropic refers to a structure where an exposed steel plate surface is the primary structural element and is stiffened by perpendicular elements to improve its overall load-bearing capacity.

[17] An-Di Nguyen, Jefferson National Expansion Memorial. *Spans*, July 2003, 1–3

Bandel was instrumental in determining the specific calculations for the weighted catenary form that were required for the Arch to be fabricated as designed. The angle of the curve, thickness of the legs, and relationship between the inner and outer skin were constantly changing. Bandel determined the mathematical formula by which the weighted shape could be calculated.[18]

Because of the difficulty inherent in constructing an arched structure without centering, the legs of the Arch had to be designed to act as two cantilever structures. Eventually, the legs would be joined at the top, upon which the overall strength of the Arch would be substantially increased. The design had to consider the loadings, stresses, and structural action at the various stages, while also addressing the practicalities of construction. Finally, since the Arch was too tall for conventional cranes, the cantilevered legs had to be designed to support climbing cranes which would ride on rails attached to the outside face of the Arch legs.

Figure 2-9—Eero Saarinen with several study models, circa 1959. Source: Yale University Archives, Eero Saarinen Collection

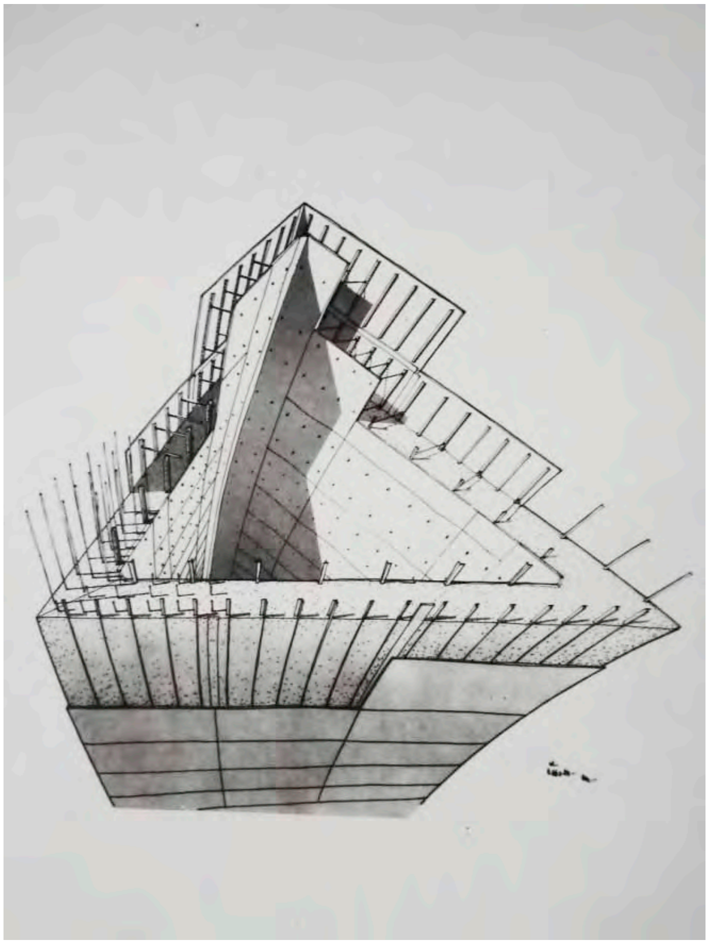

Figure 2-10—Equilateral cross-section of the Arch with inner and outer skin and post-tensioned concrete core. Source: Yale University Archives, Eero Saarinen Collection

[18] Deborah Slaton and Mike Ford, interview with Bruce Detmers, April 1, 2009.

Preparation for Arch Construction

George Hartzog, Jr., began work as the superintendent of JNEM on February 1, 1959. His forty-two month tenure was instrumental in developing the groundwork and making preparations for JNEM under a strict timeline and budgetary constraints. By the completion of Hartzog's appointment, the railroad relocation was approaching completion and a four-phase development program had been outlined for construction. Despite the limited funding, the project was kept on schedule through the scaling back of landscape and museum design components.

The NPS and the City of St. Louis imposed an ambitious construction schedule with the hope of completing the project in 1964, the bicentennial of the founding of the city. Phase I consisted of the relocation of the railroad tracks and construction of the tunnel. Phase II involved the completion of exhibit research and planning, redevelopment of the levee, and excavations for the foundation of the Arch, museum, and visitor center. Phase III consisted of the construction of the Arch, museum, and visitor center. The project was scheduled to be complete in 1964 when Phase IV, final landscaping, was concluded.

Saarinen considered the Arch to be the most important component of the memorial site, followed by the landscaping and then the museum. The priorities differed slightly for Hartzog, as was reflected in the phased construction schedule. Hartzog agreed that the Arch was the defining element of the project but required the museum to serve as an interpretive tool. The landscaping was a tertiary feature and the extent of its completion would be based on available funds. Thus, final site work was to be completed by the NPS as the final phase of construction.

As the design phase for the project reached completion, the project was met with tragedy. On September 1, 1961, Eero Saarinen died of a brain tumor in Ann Arbor, Michigan. Saarinen and Associates partners Joseph Lacy, John Dinkeloo, and Kevin Roche were entrusted with the task of completing the project.

The relocation of railroad tracks was the first phase of construction in the outlined four stage construction of JNEM. Construction of the tunnel and approach bridges and related levee redevelopment were completed in September 1963.

Construction of the Arch

Bids were accepted for the construction of the Gateway Arch and opened in a public ceremony held in the east courtroom of the Old Courthouse on January 22, 1962. The engineers of Eero Saarinen and Associates estimated that construction would take 875 days at a cost of $8 million. The lowest bid was set by MacDonald Construction Company at $11.9 million.[19]

The Arch was designed as a 630 foot weighted catenary arch with an orthotropic structure. The arch had two skins, an interior and exterior, which had slightly different curves that worked to structurally support each other. Additionally, the skins were connected through reinforcement bars and the cavity between them was filled with post-tensioned concrete up to a height of three hundred feet. The Arch was set on a concrete foundation and constructed of one hundred and forty-three prefabricated double-wall carbon steel and stainless steel segments.[20]

Excavation for the Arch foundations required creating a pit for each leg at least seventy-five feet by ninety feet wide that extended to bedrock, approximately forty-four

[19] Ibid., Chapter 7, 16.

[20] Throughout this document, the term *segment* is used to refer to the three-sided prefabricated elements that were placed one atop another to construct the Arch. The size of each segment decreases from the bottom of the Arch to the top. The term station is used to refer to specific locations on or within the Arch, numbered from Station 0 at the peak of the Arch to Station 71 at the base of each leg, as shown on the original construction drawings. Each station corresponds to the field weld installed to join adjacent segments during construction of the Arch. The numbering of stations and segments is such that Segment 63, for example, was placed on top of the gridline at Station 63.

feet below grade. The vertical thrust of the catenary-shaped Arch relied on the stability of the bedrock and strength of the concrete foundation. Construction of the Arch began on June 27, 1962, when MacDonald Construction Company poured concrete for the south leg foundation. The foundation was constructed in five foot increments each of which demanded a continuous monolithic pour that took up to twenty-three hours and required 1,700 cubic yards of concrete (Figure 11).[21]

As the foundations reached ten feet high, post-tensioning bars were installed. A second group of post-tensioning bars were started when the foundation reached twenty feet. In total, two hundred and fifty-two vertical post-tension bars were set into each foundation to stabilize the Arch during construction.[22] The Arch foundation was completed by February 1963.

Placement of the first steel sections on February 12, 1963 (Figure 2-12) introduced some minor difficulties to the project. The position of the foundation and post-tensioning bars were not in alignment with the angle of the steel segment. To rectify the situation, the post-tensioning bars were slightly adjusted and bent to fit within the segment. Hannskarl Bandel of Severud, Elstad, and Kruger recommended that additional reinforcing be added to compensate for the subsequent reduction in strength.[23]

The contractors quickly established a systematic method and process of construction. The north and south legs of the Arch were erected simultaneously. Segments were assembled, hoisted into place, welded to the segment below, filled with concrete, and post-tensioned.[24]

Figure 2-11—Construction of the Arch foundation, December 3, 1962. Source: JNEM archives, image V106-3938

[21] Don Haake, interview with Ted Rennison, March 24, 1981, 6–8.

[22] Ibid.

[23] Rennison, 8.

[24] Ibid., Chapter 7, 21–22

The Pittsburgh-Des Moines Steel Company was responsible for the fabrication and assembly of the steel segments. The first four segments were all entirely shop assembled as one large triangular segment then shipped to the site and erected into place. The larger segments above the first four were fabricated as three double-wall flat panels and were assembled on site by installing a continuous vertical weld at each of the three corners. The remaining segments were partially fabricated in the shop and welded together in their final configuration on site (Figure 2-13). Pick points were welded at the inside intrados corners to accommodate the creeper crane lift cables. All segments above the 300 foot level were fabricated as three L-shaped pieces. Field welds for the upper segments were made on the faces of the panels, not at the corners.[25]

After the steel segments were hoisted into place and aligned, both the interior and exterior skins were tack welded into place and allowed to sit overnight while the survey team verified the height and location.[26] In the following days, the segment was secured with a continuous weld. Because welding was done on a vertical surface with access from only one side, numerous weld passes and grindings were required to guarantee a complete, 100 percent, weld. A backup bar was installed on the back side of the steel prior to setting each segment to assist in the effectiveness of the welding process. Random samples of the welds were X- rayed to verify quality. The process was labor intensive and demanded skilled welders who would work in the extreme heat and confined environment.[27] Welders with experience at Titan II missile construction sites were brought in to work on the Arch.[28]

Once the concrete had adequately cured to 4,000 psi strength, the post-tensioning bars were torqued up to seventy-one tons each (Figure 2-14).[29] The process of post-tensioning made the concrete more effective

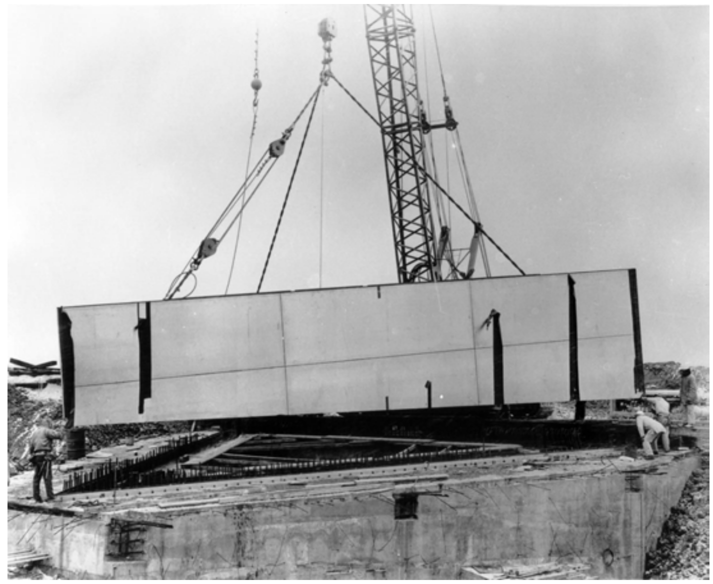

Figure 2-12—Placement of the first segment, February 12, 1963, at the south leg. Source: JNEM archives, image V106-3962

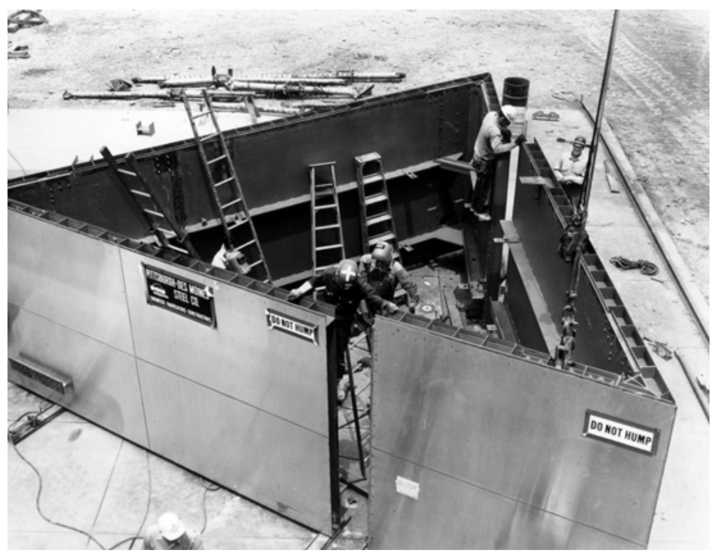

Figure 2-13—Assembly of an Arch segment from prefabricated L-shaped pieces, with field welding on the face of each side. This segment was installed above the 300 foot level. Source: Ken Kolkmeier

[25] Worth, Kelley, and Moore, interview with Ken Kolkmeier, January 14, 2009, 3.

[26] Ibid., 4–5.

[27] Rennison, 9–10.

[28] Worth, Kelley, and Moore, interview with Kolkmeier, January 14, 2009.

at handling tensile stresses applied by the partially completed Arch legs. The post-tensioning bars were connected by a threaded sleeve and encased in a hollow steel sleeve to allow for uniform elongation. Any unforeseen bends, inconsistencies in integrity, or non-uniform torque of the bars could greatly affect its tensile strength.[30]

In July 1963, when the Arch reached 60 feet in height, creeper cranes were built to complete the construction process (Figure 2-15). The creeper cranes were designed by Richard Gardens and fabricated by the Pittsburgh-Des Moines Steel Company. Each leg of the Arch had its own crane that was used for hoisting the steel segments and putting them in place. Dual tracks were constructed along the face of each Arch leg, and platforms were assembled to support the cranes. As the creeper derricks proceeded up the Arch, the back legs could be adjusted so that the work platforms remained level.[31] The cranes were controlled from operator's cabins on the ground. The operators often could not see what they were doing and relied on telephone communication from the derricks to navigate the cranes.[32]

Figure 2-14—Applying tensile stress to the post-tensioning bars, 1963. Source: JNEM archives, image V106-3974

Station 45 Structural Stability

At Station 45, approximately 300 feet high, plans called for a change in the structural assembly of the Arch. Below Station 45, the cavity between the interior and exterior steel skin was filled with concrete and post-tensioned steel. At this point in the construction process, the legs were designed to lean 49 feet towards the center. According to Severud, Elstad, and Kruger, the reinforcing system allowed the unrestrained legs of the Arch to remain stable during erection. The Arch was designed so that structural reinforcing established in the first segments of the structure could maintain the stress and strain yet provide the flexibility required for the remainder of the construction process.

Figure 2-15—The Arch legs under construction with the creeper cranes in place, late summer 1963. Source: JNEM archives, image V106-4034

[29] Ibid.; Rennison, 8.

[30] Rennison, 16.

[31] Moore oral history interview with Ken Kolkmeier, 4.

[32] Bill Quigley, interview with Robert Moore, October 28, 1995.

Above the concrete-filled cavity, the interior and exterior skins were connected by "L" brackets with the short leg spot welded to the inner skin and the long leg securing the outer skin. Upon installation of Segment 45 on the north leg on September 27, 1964, it was noted that ripples in the stainless steel skin occurred every two feet in accordance with the locations of the diaphragm brackets. This segment was removed on October 30, 1964, and various attempts were made to resolve the warping. Under the direction of Hannskarl Bandel, who was concerned that the various repair attempts may have compromised the structural integrity of the segment, Segment 45 was reinstalled on November 17, 1964, and the wall cavity filled with a lightweight concrete in an effort to stabilize the segment. Segment 45 on the south leg was also filled with concrete to match the north leg.[33] Subsequent segments were installed with L-brackets, and the associated ripples were accepted.

Completing the Arch

As the Arch approached 530 feet in height (approximately Station 22), work proceeded to install the stabilizing strut designed to prevent excessive leaning (Figures 2-16 and 2-17). The legs were leaning 150 feet inwards, and together with the extra weight of the creeper cranes, additional support against overturning was required as part of the design. The Pittsburgh-Des Moines Steel Company had proposed the construction of a high-strength, light-weight stabilizing strut that would bridge between the two legs, allowing them to stabilize each other. The 225-foot-long, bridge-like stabilizing strut structure was assembled on the ground and hoisted into place on the morning of June 17, 1965; this effort became a media event. The stabilizing strut forced the legs of the Arch to be jacked outward 6 feet.[34]

Figure 2-16—View of Arch construction and the stabilization strut. Source: Bruce Detmers

Throughout the construction of the Arch, there was concern that the two legs would not meet at the center. Minute discrepancies in weld thickness or placement of the steel segments could dramatically affect the structural stability and final installation of the keystone segment. To monitor the progress, nightly measurements were made, using a theodolite and geometric calculation, to verify the consistency of construction. Throughout the construction process, the difference between the heights in the two legs, as taken at night, remained less than one inch.

Discrepancies between the height of the north and south legs were observed during the daylight hours. Throughout the day, the heat of the sun, shining more directly on the south leg, caused that leg to elongate and deflect downward 14 inches below the level of the north leg. For

[33] Ibid., 21.

[34] Rennison, 21–24.

this reason, the Arch project team requested that the final piece be installed at night, when temperatures were consistent and the height of the legs was even.[35] However, this approach was rejected by the City of St. Louis, and the installation of the final segment was performed during daylight hours so that a public ceremony could be held at the completion of the Arch structure.

On October 28, 1965, the Arch hosted a "topping out" ceremony when the final 8-foot-wide segment was inserted into the Arch (Figure 2-18). The media event was attended by Undersecretary of the Interior John Carver and presided over by Superintendent LeRoy Brown. Members and supporters of the project team, as well as those who had expressed doubt of the structural stability, politicians, the media, and hundreds of onlookers waited in anticipation for the events of the day. For Eero Saarinen and Associates; Severud, Elstad, and Kruger; and the NPS, the topping out was the culmination of a vision that had been decades in the making and a validation of their faith in the controversial and innovative structural design.

The ceremony was scheduled for the morning before the south leg was heated by the sun. The local fire department sprayed the leg with cold water to keep the Arch cool. With the application of 500 tons of pressure using hydraulic jacks between the creeper cranes, the topmost segments of the north and south legs were pried 6 feet apart. The final piece had been temporarily retrofitted with five inch pins to help secure a quick fit with the north and south segments. As the segment was lowered, the pins were inserted into the north segment and pushed into place. The south segment was raised approximately five inches until it was aligned with the keystone piece, and as the five hundred ton pressure was relieved, the gap between the south leg and center segment disappeared. The legs lined up perfectly.[36]

After the keystone segment of the Arch was inserted, final cleaning, repair, and polishing could begin (Figures 2-19 and 2-20). The stainless steel panels were washed and polished by hand. Bolt holes in the exterior skin were

Figure 2-17—The Arch nears completion with the stabilizing strut in place, September 9, 1965. Source: JNEM archives, image V106-4124

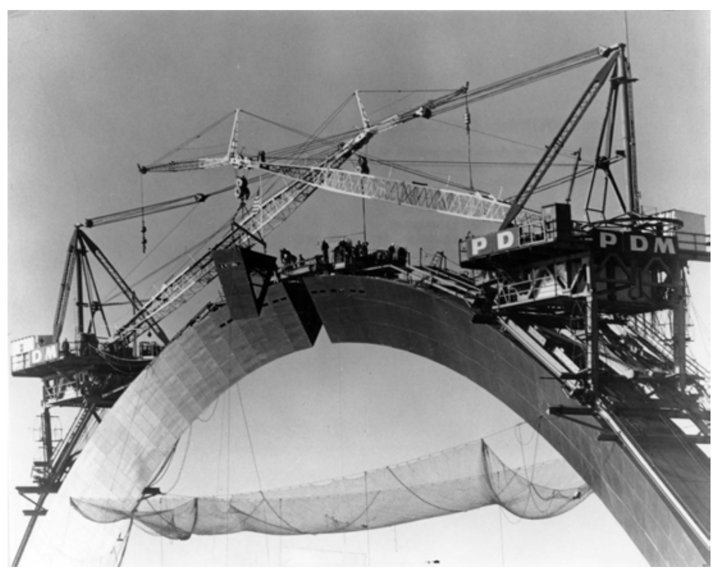

Figure 2-18—Installing the final segment of the Arch, October 28, 1965, at the top of the north leg. Source: JNEM archives, image V106-4131

[35] Rennison, 25.

[36] Ibid., 25–26.

plugged with stainless steel punches salvaged from the Pittsburgh-Des Moines Steel Company manufacturing plant during fabrication. The stainless steel plugs were welded and ground smooth. The cleaning created some inconsistencies in the finish. Hand polishing never seemed to produce the same result as the shop finish, and patched areas remained visible to the discerning eye. The locations of the stabilization struts required extensive cleaning and polishing in order to have an aesthetically pleasing appearance. The winter weather complicated the cleaning process, as water-based products turned to ice. Final preparations of the stainless steel skin continued as the creeper derricks inched their way down the Arch.[37] In the fall of 1966, the derricks were disassembled and the cleaning of the Arch was complete.

Once the Arch structure was completed, focus was placed on construction of the visitor center, mechanical systems, tram, and landscaping. By October 1965, limited progress had been made on all three components as the subcontractors were forced to work around the schedule of the structural construction.

Figure 2-19—Cleaning the Arch and removing the creeper cranes, February 7, 1966. Source: JNEM archives, image V106-4147

Figure 2-20—Aerial view of the top of the Arch during cleaning. Source: Yale University Archives, Eero Saarinen Collection

Dedication

By 1968, the Arch, internal transportation system, and visitor center were complete. The NPS had exceeded spending limits provided by the federal government and the bonds issued by the city of St. Louis. Completion of the museum, restoration of the Old Courthouse, and final landscaping would have to wait until new funds could be appropriated.

The day for the final dedication of the Arch was set for May 25, 1968, the twentieth anniversary of the United States Territorial Expansion Memorial Commission's acceptance of Eero Saarinen's original design for the Gateway Arch. A two-day celebration was planned to dedicate the Memorial, commemorate the vision of westward expansion, and honor the determination and persistence of those who tirelessly contributed to the creation of JNEM.

[37] Rennison, 38.

When the day arrived, the guests were greeted with an unusually heavy downpour. Water drenched the site, washed down the entrance ramps and flooded the visitor center. There were no alternate plans in case of inclement weather and many of the festivities would be canceled. Inside the visitor center, the dedication ceremony continued and culminated with Vice President Hubert H. Humphrey's address. Although weather precluded the glorious event envisioned by Mayor Alfonso Cervantes and Secretary of the Interior Stewart Udall, the ceremony was a symbol of the hard work, sacrifice, and passion from which the Memorial project had grown (Figure 2-21).

Figure 2-21—Visitors at the observation level, circa 1968.

Source: JNEM Photo Reference Collection, image VPRI-1379

[38] Brown, Chapter 7, 46–47.

Gateway Arch Corrosion Investigation - Part I

In the beginning of the 21st century, the National Park Service had observed discoloration and streaking at the stainless steel exterior and the corrosion of carbon steel elements at the interior. Due to the many changes in methods, design, and materials during construction of the Arch, some suspected that these revisions may be the source of the discoloration observed principally above the 300' level, at welds and at interior surfaces. *The Gateway Arch Corrosion Investigation - Part I* was meant to be a non-intrusive procedure that would guide the future scope of work that would be developed from the recommendations from this study that may include further detailed analyses, non-destructive evaluations, materials sampling, close up inspection and monitoring which will also aid in the development of final treatment recommendations.

Figure 2-22—Phase I Corrosion Investigative team including Stephen Kelley, Al O'Bright, and Dan Worth. Source: S. Kelley

The team was led by BVH Architecture (BVH) with consultants Wiss, Janney Elstner Associates, Inc. (WJE) and Vertical Access (VA) (Figure 2-22). The following project goals were determined: identify suspected phenomena to help determine the causes of corrosion and discoloration to the stainless steel and carbon steel skins; analyze and prepare recommendations for further detailed investigations which will assist in developing long-term treatment recommendations for the preservation of the Monument; and determine how best to treat or protect the stainless steel base segments at grade from vandalism.

METHODOLOGY

The Part I investigation and report development consisted of on-site investigations, archival research, document research and review, and interviews with Gateway Arch National Park and NPS personnel. On-site investigations were conducted on October 5, 6, and 7, 2005. The following methodology was followed:

1. The Gateway Arch National Park Archives, located in the Old Courthouse, were visited and several important collections of materials were made available to the team. Original contract documents were reviewed including drawings, specifications, addenda, and change orders. Correspondence files from several different collections were reviewed which included design, bidding, construction, correspondence, memoranda, etc. A second visit to the archives occurred in January 2006. Copies of original shop drawings were examined and briefly reviewed. Submittals of stainless steel welds, carbon steel and various finishes were also viewed.
2. NPS staff was interviewed about maintenance procedures, observations of existing conditions, areas of corrosion that they have noticed or repaired, any previous reports or corrective measures that they have undertaken. Discussions were also held about the interior environmental conditions and seasonal behavior of the Arch.
3. Exterior surfaces were visually inspected from the ground and from the Old Courthouse dome using binoculars and spotting scopes. Copies of drawings obtained from the original contract documents were used to map areas of corrosion or discoloration. The interior of the north

and south legs of the Arch were accessed via stairways leading from the top to the base and visually inspected (Figure 2-23). The top of the Arch was accessed through the hatch and the windows in the top of monument public viewing area (Figures 2-24 and 2-25).

Figure 2-23—Close up inspection of the interior carbon steel skin from the interior stairs. Source: S. Kelley

Figure 2-24—Access to the top of the Arch from the visitors' viewing area. Source: S. Kelley

Figure 2-25—Inspection of the skin from a window of the visitors' viewing area.

Source: S. Kelley

II.

CONCLUSIONS

All conclusions were speculative and called for further investigation.

The stainless steel skin was found to be discolored and stained to a different degree depending on the surface condition and represents a variety of phenomena. The well cleaned south to north surfaces (extrados), due to their direct exposure to rain, have minimum staining, while the other (intrados) faces have minor to moderate discoloration. Suspected corrosion of welds was observed as well as pitting at the base of the structure. The extent of possible corrosion is hard to determine at higher elevations due to difficulty of access. It is possible that corrosion at welds or at contaminated areas is taking place aggressively.

As the structure is subject to dynamic stress cycles and there is a possibility that welds have failed locally generating points of water leakage into the interstitial space. Corrosion products of carbon steel may then have stained the stainless steel surface.

For the carbon steel, the greatest threat is water from leakage, condensation, and deliquescence. Coring into the interstitial space and close inspection is needed to clarify such concern.

At the base of the Arch, grinding and polishing is necessary to remove most of the scratches and damage to the Arch skin at the base. However, extreme care would be needed because such work may change the appearance of the lower portion of the arch and reduce its thickness. Repeated grinding and polishing could result in an unacceptable loss of section.

A wax treatment may be beneficial to reduce the corrosion of stainless steel at the scratches in the surface. The wax will also fill surface voids and porosity further protecting the surface.

PART I RECOMMENDATIONS

Since the Arch is a unique monument in typology and material, a more scientifically informed understanding of its behavior needs to be reached with comprehensive inspections and analysis. The following further investigative study was recommended:

1. A more comprehensive review of the Archive is needed as the collection is so large. Further review of similar stainless steel-clad monuments should be part of this research.
2. Close-up access to the various faces of the Arch will be necessary. Close-up access would provide opportunities for visual and microscopic inspections, non-destructive sample removal of stains and discolorations, sample collection of soils or laboratory analysis, measurements for surface tolerances and deformations, and treatment mock ups. Types of close-up access methods were considered including cranes, scaffolding, rappelling, drones and helicopters. Each had shortcomings and limitations. Cranes will only rise about 300 feet. Scaffolding would be extremely expensive. Rappelling access would be confined to experienced climbers, and drones and helicopters violated FAA requirements and would not provide adequate closeness.
3. Laboratory analyses were proposed:
    a. Chemical analysis of the stainless steel.
    b. Metallurgical analysis of small stainless/weld samples.
    c. Moisture and chloride testing of concrete samples from between the two skins.
    d. Corrosion potential measurement of concrete reinforcing.
    e. Analysis of various stains and discoloration using X-Ray diffraction, Scanning Electron Microscope, Infra-Red, or Atomic Absorption.

4. A climatological monitoring system was proposed that would entail placing temperature and relative humidity measurement devices in the interior, in the space between the skins and on the interior sides of the skins of both legs at various heights from top to bottom.

5. Since the Arch is an important structure it was recommended that a Historic Structure Report be prepare to document the history and chronology of its development and to develop the appropriate treatment recommendation for the National Park Service to implement.

It was recommended that the Arch be cleaned within the next 10 years and that it be cleaned on a 50-year cycle thereafter.

National Expansion Memorial Gateway Arch Historic Structure Report (HSR)

Prior to proceeding with more intrusive investigative procedures, it is part of the NPS methodology to prepare a Historic Structure Report on its properties. Subsequently the same team was requested to prepare such a report. The team was led by BVH Architecture (BVH) with consultants Wiss, Janney, Elstner Associates, Inc. (WJE), Alvine and Associates (Alvine) and BAF Consulting (BAF).

The purpose of the HSR was to provide a compilation of the findings of research, investigation, analysis, and evaluation of the historic structure. The preservation objectives for the historic property were identified and treatment measures recommended for implementing and accomplishing these objectives.

The HSR addressed key issues specific to the Gateway Arch, including the construction chronology of the Arch; the existing physical condition of the exterior skin and structural systems; interior spaces and features; mechanical and electrical systems; code issues related to structural performance and public access to the Arch; and the historic significance and integrity of the structure.

METHODOLOGY

The following project methodology was used for this study.

1. Archival research was performed to gather information about the original construction and past modifications and repairs to the Arch for use in assessing existing conditions and developing treatment recommendations.

2. Formal oral history interviews were performed with project engineer for the Pittsburgh-Des Moines Steel Company on the construction of the Arch, and with an architect with Eero Saarinen and Associates who participated in the development of the construction documents and in site observation during construction of the Arch.

3. A condition survey of the Arch was performed, and observations documented with photographs, field notes, and annotation on baseline drawings. The condition assessment addressed the exterior and interior surfaces and features of the Arch and the adjacent tram load zones. In addition, the assessment addressed structural, mechanical and electrical systems.

FINDINGS

The Gateway Arch is significant under National Register Criterion C for its architectural and engineering design as well as for the role it played in the career of architect Eero Saarinen. The Gateway Arch is the focus of Gateway Arch National Park, for which the landscape was designed by Saarinen and noted landscape architect Dan Kiley. Saarinen and Kiley sculpted the surrounding landscape to

[40] National Park Service Jefferson National Expansion Memorial Gateway Arch Historic Structure Report, prepared by Bahr, Vermeeer & Haecker Architects. June 2010.

create special views of the Arch. Although some historians do not consider the Gateway Arch to be Saarinen's most influential design, others see it as his greatest contribution to American architecture.

The period of significance is dated to the official dedication of the Arch in May 1968. The most important character-defining features of the Arch are the weighted catenary based design, the stainless steel skin, the uniquely engineered tram by which visitors ascend and descend the legs; and the landscaping that focuses on the monument.

The Gateway Arch retains a high degree of integrity of location, design, setting, materials and workmanship, feeling and association.

Based on historical documentation and physical evidence gathered during the study, a context history, a detailed history of the Arch design and construction, and a chronology of construction were developed. An evaluation of the significance was also prepared, taking into consideration previous historical assessments including the National Historic Landmark (NHL) documentation and other reference documents, as well as guidelines provided *by National Register Bulletin 15: How to Apply the National Register Criteria for Evaluation*. This evaluation of history and significance provided the basis for the development of recommended treatment alternatives.

Based on the evaluation of historical and architectural significance of the structure, guidelines were prepared to assist in the selection of preservation treatments. The *Secretary of the Interior's Standards for the Treatment of Historic Properties* guided the development of treatment recommendations for the significant exterior and interior features of the Gateway Arch. Following the overall treatment approach of preservation, the specific recommendations addressed observed existing distress conditions as well as long-term preservation objectives.

Gateway Arch Corrosion Investigation - Part II

The Gateway Arch Corrosion Investigation—Part 2 addressed many of the recommended investigative procedures that were recommended in the Part 1 investigation. This investigation was implemented by Wiss, Janney, Elstner Associates Inc. (WJE) (Figure 2-26).

Figure 2-26—The Part II Corrosion Investigation Team. Source: S. Kelley

[41] Gateway Arch Corrosion Investigation Part 2 Jefferson National Expansion Memorial, prepared by Wiss, Janney, Elstner Associates, Inc., 7 September 2012.

METHODOLOGY

The Gateway Arch National Park Archives were surveyed and pertinent documents reviewed, and archival research was performed on other stainless steel clad structures that predate or are contemporary with the Gateway Arch. This research revealed that stainless steel on the other buildings and monuments have weathered well and have only required a mild cleaning. Some of the example buildings of a similar era included (Figure 2-27) the Chrysler Building (1929), Socony-Mobil Building (1954-1956), Inland Steel Building (1956-1958) and the Unisphere at the World's Fair (1964). Stainless steel is still extensively used architecturally in exposed environments. The Gateway Arch stands alone from other buildings and monuments researched in its extensive use of shop and field welds.

Figure 2-27—The Socony-Mobil Building being cleaned in 1995. Source: ATI Allegheny Ludlum

The exterior surfaces of the Arch intrados were visually inspected using telephoto photography, field microscopes, and a hand-held XRF device (Figure 2-28). Many of the discolorations of concern are caused by atmospheric pollutants or inadequate cleaning and polishing of the Arch after erection. Chromium depletion has been detected at some of the welds which can lead to intergranular corrosion. In addition, some carbon steel from the back-up plate may have been incorporated into the weld. If this material is exposed to water and air, corrosion can occur and stain the surface of the stainless steel. Near grade, crevice corrosion is the result of removal of the chromium oxide layer from the tools used to create incised graffiti, a result of surface metal deposits left from those tools, or a combination of the two.

Figure 2-28—The surface of the steel was evaluated using a handheld XRF in March 2011. Source: P. Krauss

Samples of carbon steel and concrete were removed from the legs of the Arch (Figure 2-29) for testing in the laboratory. Stainless steel from the archives was laboratory tested as well. The steels were found to meet requirements specified during construction. Review of the concrete mixture characteristics indicated that the concrete is not of concern.

Long-term monitoring instrumentation was installed within the legs of the Arch. and the space between the two skins (Figures 2-30 and 2-31). Climatic conditions between the skins were found to be influenced by the air conditioning on the interior more so than the outside. However, the dew point is similar in the Arch interior, the interstitial space and exterior. It was found that there were few time periods where the dew-point temperature was close to the steel-plate temperatures making a propensity for condensation.

A comprehensive study was carried out on access strategies to perform future close up inspection and testing on the upper reached of the Arch intrados. An industrial rope access technique utilizing choker hitched ropes was recommended for access to the upper reaches of the Arch.

PART II CONCLUSIONS & RECOMMENDATIONS

Further investigation and testing are needed to evaluate if there is chromium depletion and intergranular corrosion at the welds, contamination of carbon steel at the welds, and their effects on surface staining.

Close up inspection and testing of upper reaches of the Arch were recommended using industrial rope access (IRA) with choker hitched ropes. During this access, residue samples can be surveyed up close and removed for laboratory analysis, welds can be visually inspected, and cleaning can be performed on some of the discolorations.

At the base where the surface has incised graffiti, more aggressive cleaning treatments should be tested on a trial basis prior to removal of corrosion and polishing. Clear coatings might be considered after the surface has been passivated to protect against the effects of further incised graffiti.

The Gateway Arch should be cleaned to provide mitigation of potential intergranular corrosion occurring at the welds. Stains that emanate from the welds should be cleaned using the gentlest means possible possibly followed by a passivation treatment. Consideration should be given to removing rough portions of welds and dressing and polishing welds to reduce blowholes, slag, and weld splatter that are potential sites for corrosion and staining.

Figure 2-29—Coring extraction of 5 inch diameter concrete sample using a coring rig attached to the wall at North Station 71. Source: S. Kelley

Figure 2-30—Large hexagonal inspection opening at North Station 43 east face. Source: S. Kelley

Gateway Arch Corrosion Investigation - Part III

The Gateway Arch Corrosion Investigation—Part 3[42] addressed the remaining investigative procedures that were recommended in the Part 1 investigation. This investigation was implemented by Wiss, Janney, Elstner Associates Inc. (WJE) (Figure 2-32).

METHODOLOGY

The following approach was implemented on the north leg of the Arch:

1. Close inspection of the stainless steel from aerial lifts at the base (Figure 2-33).
2. Removal of weld samples for metallurgical analysis (Figure 2-34).
3. Cleaning trials of the stainless steel at the base and the intrados (Figure 2-35).
4. Close inspection of the stainless steel welds of the extrados of the north leg using Industrial Rope Access (IRA) (Figure 2-36).
5. Close inspection of discolorations at the upper reaches on the west intrados of the north leg and soil sample removal using IRA (Figure 2-37).
6. Chemical analysis of soils removed from the intrados.

CONCLUSIONS

The visual anomalies of the stainless steel skin were classified into three categories:

1. Blemishes: Blemishes are alterations to the surface texture which create a visual aberration under specific lighting and observation angles.
2. Deposits: Deposits refer to particles such as atmospheric pollutants on the stainless steel

Figure 2-31—Installation of a long-term temperature and relative humidity monitoring system at various heights of both legs of the arch. Source: S. Kelley

Figure 2-32—The Part III Corrosion Investigation team including Al O'Bright, Catherine Houska, Stephen Kelley and technicians from Zahner Metalabs. Source: S. Kelley

[42] Gateway Arch Corrosion Investigation Part 3, prepared by Wiss, Janney, Elstner Associates, Inc., 2 February 2015.

surface are not part of the stainless steel.

3. Discoloration: Discoloration refers to chemical alteration, such as corrosion, to the surface of the stainless steel surface.

Visual observations from close-up inspection revealed the following:

1. Blemishes in the stainless steel finish are a result of surface scratches that are shallower than the finish profile, and are visual in a variety of patterns, including vertical streaks and circles.
2. The panels appear darker or lighter, or have darker or lighter streaks based on the observation angle of the viewer.
3. Incised graffiti and impact damage blemish the surface at the lowest two panels. The depth of the damage ranged from superficial scratches to deep hammer indents.
4. Surface deposits are common at many horizontal weld lines and tended to be dark in color. Additionally the deposits appear to streak down the panels originating from the weld lines.
5. Heat tint is present at some weld lines.
6. General orange surface discoloration is observed at the lowest eight panels.
7. Welds along the extrados were in good condition.
8. At the lowest two panels, red corrosion staining is often associated with the incised blemishes, either by corrosion of the panel surface or due to corrosion of the residue left from the mild steel implements used to scratch the graffiti into the surface.
9. Above Station 45, the out-of-plane deformation of the stainless steel panels in between stiffeners, also referred to as “oil-canning”, was measured to be approximately 1/8 inch at several locations.

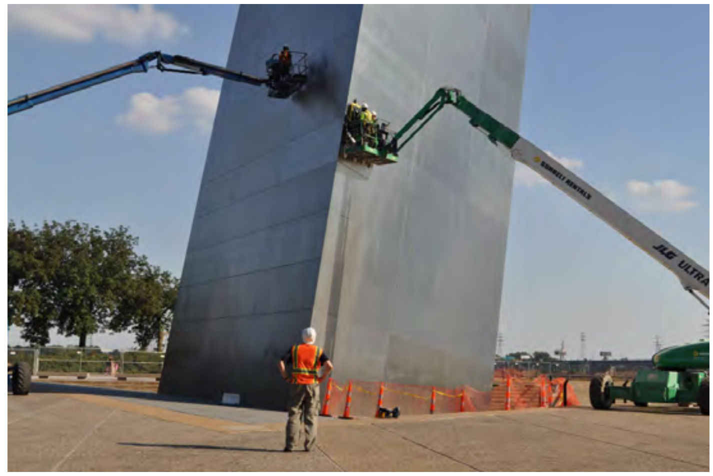

Figure 2-33—Inspection of the lower reaches of the north leg with personnel lifts. Source: S. Kelley

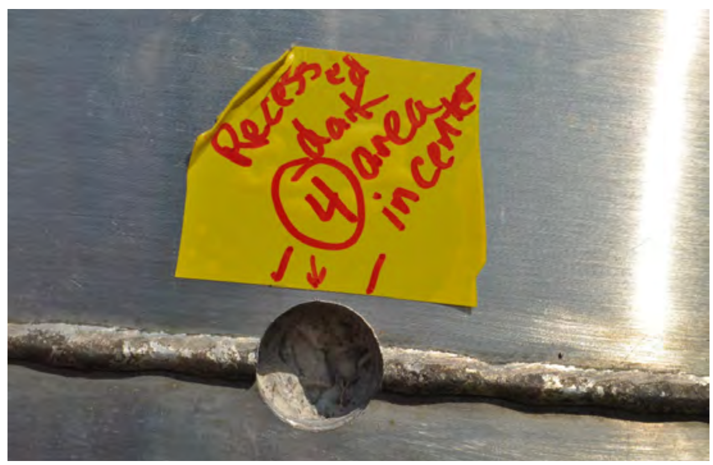

Figure 2-34—Removal of a field weld sample from the exterior skin of the arch. Source: S. Kelley

Laboratory studies consisted of an analysis of the deposit samples removed from the surface of the stainless steel and metallurgical analysis of weld samples and revealed the following:

1. Gunshot residue (GSR) sample kits were used to remove samples of the surface deposit from the stainless steel skin of the Arch. In the laboratory, the sample kits were analyzed using light

microscopy and scanning electron microscopy (SEM) with energy dispersive x-ray spectroscopy (EDS) for elemental analysis. The deposits at the vertical streaks consisted of fly ash, pollen, calcite, dolomite and other common atmospheric pollutants.

2. Five weld samples were analyzed using light microscopy and scanning electron microscopy (SEM) with energy dispersive x-ray spectroscopy (EDS) for elemental analysis. The chemical analysis of the plate material was consistent with the specified Type 304 stainless steel. The chemical analysis of the weld material was consistent with 300 series stainless steel. The welds in each sample appeared to be in serviceable condition with no surface corrosion associated with sensitization.

Cleaning trials only using gentle chemical methods were performed on the exterior stainless steel to evaluate the effectiveness of removing blemishes, deposits, and discoloration. Based on the trials, removal of the blemishes further creates visual anomalies. The surface deposits can easily be removed but does not create a significant improvement. Chemical cleaning is effective at removal some of the discoloration.

Figure 2-35—Cleaning samples performed by Catherin Houska. Source: S. Kelley

Figure 2-36—Inspection of the welds on the extrados of the north leg using DAT. Source: S. Kelley

PART III RECOMMENDATIONS

The exterior stainless steel of the Arch is in serviceable condition without significant structural distress or deterioration. The visual anomalies, including a variety of blemishes, deposits, and discoloration, are not causing significant corrosion or distress of the stainless steel currently, and many of the visual anomalies are from original construction. Over time, or with significant atmospheric changes, there is a possibility that the corrosion or deposits could become more aggressive. Long-term monitoring is recommended to document visual changes in the stainless steel that could become significant.

The cleaning trials were successful at reducing some of the discoloration and provided a wide range of passivation and refinishing options for the stainless steel. Based on the nature of refinishing stainless steel, it is likely that any attempt to globally refinish the stainless steel panels could result in a more noticeable uneven appearance in the finish. At the base of the Arch at locations of incised graffiti, a cleaning treatment could be implemented with a more precise method of refinishing the stainless steel and an acceptable treatment could be applied. To develop a cleaning treatment at the base, consideration should be given to the anticipated refinish appearance of the stainless steel, including graffiti, and long-term maintenance of the stainless steel at the base.

Rebranding as the Gateway Arch National Park

The United States Congress approved the Gateway Arch National Park Designation Act in early 2018 to re-designate Jefferson National Expansion Memorial as Gateway Arch National Park. U.S. President Donald Trump signed the act into law on February 22, 2018.[43]

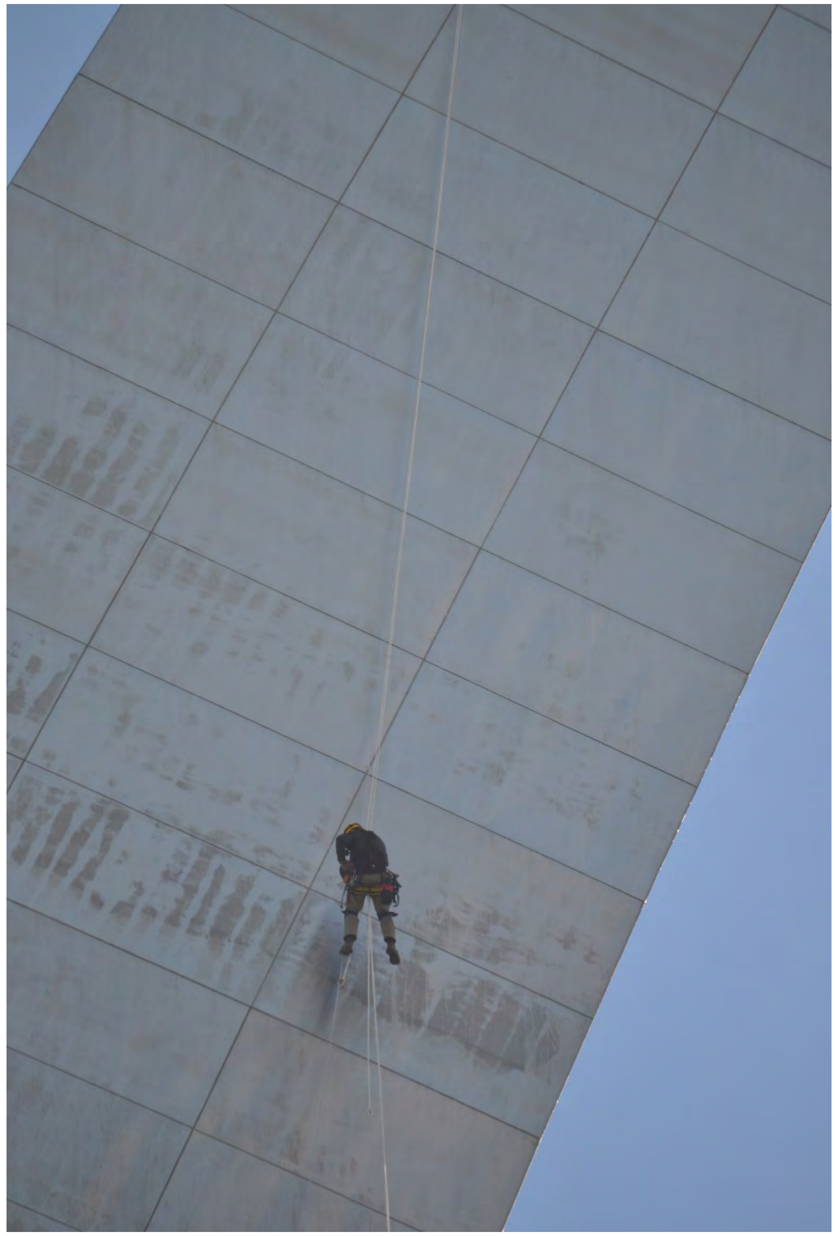

Figure 2-37—Inspection of severe staining on the west intrados of the north elg at 424 feet above grade. Source: S. Kelley

[43] "President Donald J. Trump Signs S. 1438 into Law." White House.

B. SUMMARY OF INVESTIGATIONS & ANALYSIS FROM 2005-2014

The following section contains a brief synopsis of previous studies and reports concerning the history and corrosion investigations performed on the Gateway Arch by the project team.

Gateway Arch Corrosion Investigation - Part I

MAY 2006

GOALS OF THE CORROSION INVESTIGATION - PART I

Over the previous decade, the National Park Service had observed discoloration and streaking at the stainless steel exterior and the corrosion of carbon steel elements at the interior. Due to the many changes in methods, design, and materials during construction of the Arch, some suspected that these revisions may be the source of the discoloration observed principally above the 300' level, at welds and at interior surfaces. The Gateway Arch Corrosion Investigation-Part I was meant to be a non-intrusive procedure that would guide the future scope of work that would be developed from the recommendations from this study that may include further detailed analyses, non-destructive evaluations, materials sampling, close up inspection and monitoring which will also aid in the development of final treatment recommendations.

The team was led by BVH Architecture (BVH) with consultants Wiss, Janney Elstner Associates, Inc. (WJE) and Vertical Access (VA). Specifically the following persons took part in this study:

- Al O'Bright – NPS, Contracting Officer's Technical Representative, Historical Architect
- Dan Worth – BVH Architecture, Historical Architect, Project Manager
- Stephen J. Kelley – WJE, Technical Lead Consultant,
- Paul Krauss – WJE, Corrosion Specialist
- Kent Diebolt – VA, Difficult Access Specialist

The following project goals were determined: identify suspected phenomena to help determine the causes of corrosion and discoloration to the stainless steel and carbon steel skins; analyze and prepare recommendations for further detailed investigations which will assist in developing long-term treatment recommendations for the preservation of the Monument; and determine how best to treat or protect the stainless steel base segments at grade from vandalism.

METHODOLOGY

The Part I investigation and report development consisted of on-site investigations, archival research, document research and review, and interviews with Gateway Arch National Park and NPS personnel. On-site investigations were conducted on October 5, 6, and 7, 2005. The following methodology was followed:

1. The Gateway Arch National Park Archives, located in the Old Courthouse, were visited and several important collections of materials were made available to the team. Original contract documents were reviewed including drawings, specifications, addenda, and change orders. Correspondence files from several different collections were reviewed which included design, bidding, construction, correspondence, memoranda, etc. A second visit to the archives occurred in January 2006. Copies of original shop drawings were examined and briefly reviewed. Submittals of stainless steel welds, carbon steel and various finishes were also viewed.
2. NPS staff was interviewed about maintenance procedures, observations of existing conditions, areas of corrosion that they have noticed or repaired, any previous reports or corrective measures that they have undertaken. Discussions were also held about the interior environmental conditions and seasonal behavior of the Arch.
3. Exterior surfaces were visually inspected from the ground and from the Old Courthouse dome using binoculars and spotting scopes. Copies of drawings obtained from the original contract documents were used to map areas of corrosion or discoloration. The interior of the north and

south legs of the Arch were accessed via stairways leading from the top to the base and visually inspected.

CONCLUSIONS

The stainless steel skin is discolored and stained to a different degree depending on the surface condition and represents a variety of phenomena. The well cleaned south to north surfaces (extrados), due to their direct exposure to rain, have minimum staining, while the other (intrados) faces have minor to moderate discoloration. Suspected corrosion of welds was observed as well as pitting at the base of the structure. The extent of possible corrosion is hard to determine at higher elevations due to difficulty of access. It is possible that corrosion at welds or at contaminated areas is taking place aggressively.

As the structure is subject to dynamic stress cycles and there is a possibility that welds have failed locally generating points of water leakage into the interstitial space. Corrosion products of carbon steel may then have stained the stainless steel surface.

For the carbon steel, the greatest threat is water from leakage, condensation, and deliquescence. Coring into the interstitial space and close inspection is needed to clarify such concern.

At the base of the Arch, grinding and polishing is necessary to remove most of the scratches and damage to the Arch skin at the base. However, extreme care will be needed because such work may change the appearance of the lower portion of the arch and reduce its thickness. Repeated grinding and polishing could result in an unacceptable loss of section.

A wax treatment may be beneficial to reduce the corrosion of stainless steel at the scratches in the surface. The wax will also fill surface voids and porosity further protecting the surface.

RECOMMENDATIONS

Since the Arch is a unique monument in typology and material, a more scientifically informed understanding of its behavior needs to be reached with comprehensive inspections and analysis. The following further investigative study was recommended:

1. A more comprehensive review of the Archive is needed as the collection is so large. Further review of similar stainless steel-clad monuments should be part of this research.
2. Close-up access to the various faces of the Arch will be necessary. Close-up access would provide opportunities for visual and microscopic inspections, non-destructive sample removal of stains and discolorations, sample collection of soils or laboratory analysis, measurements for surface tolerances and deformations, and treatment mock ups. Types of close-up access methods were considered including cranes, scaffolding, rappelling, drones and helicopters. Each had shortcomings and limitations. Cranes will only rise about 300 feet. Scaffolding would be extremely expensive. Rappelling access would be confined to experienced climbers, and drones and helicopters violated FAA requirements and would not provide adequate closeness.
3. Laboratory analyses were proposed:
   a. Chemical analysis of the stainless steel.
   b. Metallurgical analysis of small stainless/weld samples.
   c. Moisture and chloride testing of concrete samples from between the two skins.
   d. Corrosion potential measurement of concrete reinforcing.
   e. Analysis of various stains and discoloration using X-Ray diffraction, Scanning Electron Microscope, Infra-Red, or Atomic Absorption.
4. A climatological monitoring system was proposed that would entail placing temperature and relative humidity measurement devices in the interior, in the space between the skins and on the interior sides of the skins of both legs at various heights from top to bottom.

5. Since the Arch is an important structure it was recommended that a Historic Structure Report be prepare to document the history and chronology of its development and to develop the appropriate treatment recommendation for the National Park Service to implement.

It was recommended that the Arch be cleaned within the next 10 years and that it be cleaned on a 50-year cycle thereafter.

National Expansion Memorial Gateway Arch Historic Structure Report (HSR)

JUNE 2010

GOALS OF THE HSR

Prior to proceeding with more intrusive investigative procedures, it is part of the NPS methodology to prepare a Historic Structure Report on its properties. Subsequently the same team was requested to prepare such a report. The team was led by BVH Architecture (BVH) with Consultants Wiss, Janney, Elstner Associates, Inc. (WJE), Alvine and Associates (Alvine) and BAF Consulting (BAF). Specifically, the following persons took part in this study:

+ Al O'Bright – NPS, Contracting Officer's Technical Representative, Historical Architect
+ Dan Worth – BVH Architecture, Historical Architect, Project Manager
+ Stephen J. Kelley – WJE, Project Manager
+ Deborah Slaton – WJE, HSR Principal Investigator
+ Steve Alvine – AE, MEP Consultant
+ Bruce Fisher – BAF, Code Consultant

The purpose of the HSR was to provide a compilation of the findings of research, investigation, analysis, and evaluation of the historic structure. The preservation objectives for the historic property were identified and treatment measures recommended for implementing and accomplishing these objectives.

The HSR addressed key issues specific to the Gateway Arch, including the construction chronology of the Arch; the existing physical condition of the exterior skin and structural systems; interior spaces and features; mechanical and electrical systems; code issues related to structural performance and public access to the Arch; and the historic significance and integrity of the structure.

METHODOLOGY

The following project methodology was used for this study.

1. Archival research was performed to gather information about the original construction and past modifications and repairs to the Arch for use in assessing existing conditions and developing treatment recommendations.

2. Formal oral history interviews were performed with project engineer for the Pittsburgh-Des Moines Steel Company on the construction of the Arch, and with an architect with Eero Saarinen and Associates who participated in the development of the construction documents and in site observation during construction of the Arch.

3. A condition survey of the Arch was performed, and observations documented with photographs, field notes, and annotation on baseline drawings. The condition assessment addressed the exterior and interior surfaces and features of the Arch and the adjacent tram load zones. In addition, the assessment addressed structural, mechanical and electrical systems.

FINDINGS

The Gateway Arch is significant under National Register Criterion C for its architectural and engineering design as well as for the role it played in the career of architect Eero Saarinen. The Gateway Arch is the focus of Gateway Arch National Park, for which the landscape was designed by Saarinen and noted landscape architect Dan Kiley. Saarinen and Kiley sculpted the surrounding landscape to create special views of the Arch.

Although some historians do not consider the Gateway Arch to be Saarinen's most influential design, others see it as his greatest contribution to American architecture.

The period of significance is dated to the official dedication of the Arch in May 1968. The most important character-defining features of the Arch are the weighted catenary based design, the stainless steel skin, the uniquely engineered tram by which visitors ascend and descend the legs; and the landscaping that focuses on the monument.

The Gateway Arch retains a high degree of integrity of location, design, setting, materials and workmanship, feeling and association.

Based on historical documentation and physical evidence gathered during the study, a context history, a detailed history of the Arch design and construction, and a chronology of construction were developed. An evaluation of the significance was also prepared, taking into consideration previous historical assessments including the National Historic Landmark (NHL) documentation and other reference documents, as well as guidelines provided by *National Register Bulletin 15: How to Apply the National Register Criteria for Evaluation*. This evaluation of history and significance provided the basis for the development of recommended treatment alternatives.

Based on the evaluation of historical and architectural significance of the structure, guidelines were prepared to assist in the selection of preservation treatments. *The Secretary of the Interior's Standards for the Treatment of Historic Properties* guided the development of treatment recommendations for the significant exterior and interior features of the Gateway Arch. Following the overall treatment approach of preservation, the specific recommendations addressed observed existing distress conditions as well as long-term preservation objectives.

Gateway Arch Corrosion Investigation - Part II

7 SEPTEMBER 2012

The Gateway Arch Corrosion Investigation—Part 2 addressed many of the recommended investigative procedures that were recommended in the Part 1 investigation. This investigation was implemented by Wiss, Janney, Elstner Associates Inc. (WJE). Specifically, the following persons took part in this study:

+ Al O'Bright – NPS, Contracting Officer's Technical Representative, Historical Architect
+ Stephen J. Kelley – WJE, Project Manager and Lead Technical Consultant
+ Don Meinheit – WJE, Field Production Specialist
+ Paul Krauss – WJE, Corrosion Specialist
+ F. Dirk Heidbrink – WJE, Monitoring Specialist
+ Joshua Freedland – WJE, Architectural Conservator
+ David Megerle – WJE, Difficult Access Specialist

METHODOLOGY

The Gateway Arch National Park Archives were surveyed and pertinent documents reviewed, and archival research was performed on other stainless steel clad structures that predate or are contemporary with the Gateway Arch. This research revealed that stainless steel on the other buildings and monuments have weathered well and have only required a mild cleaning. In addition, stainless steel is still extensively used architecturally in exposed environments. The Gateway Arch stands alone from other buildings and monuments researched in its extensive use of shop and field welds.

The exterior surfaces of the Arch intrados were visually inspected using telephoto photography, field microscopes, and a hand held XRF device. Many of the discolorations of concern are caused by atmospheric pollutants or inadequate cleaning and polishing of the Arch after erection. Chromium depletion has been detected at some of the welds which can lead to intergranular corrosion. In addition, some carbon steel from the back-up plate may have been incorporated into the weld. If this material is exposed to water and air, corrosion can occur and stain the surface of the stainless steel. Near grade, crevice corrosion is the result of removal of the chromium oxide layer from the tools used to create incised graffiti, a result of surface metal deposits left from those tools, or a combination of the two.

A series of inspection openings were created through the interior carbon steel skin in order to view the space between the skins. The metal surfaces facing this space was observed to be in good condition, however there are signs of past moisture. As no moisture was present during the investigation it is not known whether the water streaks observed are from original construction or from condensation. The signs of moisture indicate that the amount of water is not substantial.

Samples of carbon steel and concrete were removed from the legs of the Arch for testing in the laboratory. Stainless steel from the archives was laboratory tested as well. The steels were found to meet requirements specified during construction. Review of the concrete mixture characteristics indicated that the concrete is not of concern.

Long-term monitoring instrumentation was installed within the legs of the Arch. and the space between the two skins. Climatic conditions between the skins were found to be influenced by the air conditioning on the interior more so than the outside. However, the dew point is similar in the Arch interior, the interstitial space and exterior. It was found that there were few time periods where the dew-point temperature was close to the steel-plate temperatures making a propensity for condensation.

A comprehensive study was carried out on access strategies to perform future close up inspection and testing on the upper reached of the Arch intrados. An industrial rope access technique utilizing choker hitched ropes was recommended for access to the upper reaches of the Arch.

CONCLUSIONS & RECOMMENDATIONS

Further investigation and testing is needed to evaluate if there is chromium depletion and intergranular corrosion at the welds, contamination of carbon steel at the welds, and their effects on surface staining.

Close up inspection and testing of upper reaches of the Arch were recommended using industrial rope access (IRA) with choker hitched ropes. During this access, residue samples can be surveyed up close and removed for laboratory analysis, welds can be visually inspected, and cleaning can be performed on some of the discolorations.

At the base where the surface has incised graffiti, more aggressive cleaning treatments should be tested on a trial basis prior to removal of corrosion and polishing. Clear coatings might be considered after the surface has been passivated to protect against the effects of further incised graffiti.

The Gateway Arch should be cleaned to provide mitigation of potential intergranular corrosion occurring at the welds. Stains that emanate from the welds should be cleaned using the gentlest means possible possibly followed by a passivation treatment. Consideration should be given to removing rough portions of welds and dressing and polishing welds to reduce blowholes, slag, and weld splatter that are potential sites for corrosion and staining.

Gateway Arch Corrosion Investigation—Part III

2 FEBRUARY 2015

The Gateway Arch Corrosion Investigation—Part 3 addressed the remaining investigative procedures that were recommended in the Part 1 investigation. This investigation was implemented by Wiss, Janney, Elstner Associates Inc. (WJE). Specifically, the following persons took part in this study:

+ Al O'Bright – NPS Contracting Officer's Technical Representative, Historical Architect
+ Chance Baragary – Bi-State Development Agency,

Project manager

+ Stephen J. Kelley – WJE, Technical Team Leader
+ Catherine Houska – Stainless Steel Specialist
+ William Zahner – Stainless Steel Specialist
+ Paul Krauss – WJE, Corrosion Specialist
+ Joshua Freedland – WJE, Architectural Conservator
+ David Megerle – WJE, Difficult Access Program Manager

METHODOLOGY

The following approach was implemented on the north leg of the Arch:

+ Close inspection of the stainless steel from aerial lifts at the base
+ Removal of weld samples for metallurgical analysis
+ Cleaning trials of the stainless steel at the base and the intrados
+ Close inspection of the stainless steel welds of the extrados of the north leg using Industrial Rope Access (IRA)
+ Close inspection of discolorations at the upper reaches on the west intrados of the north leg and soil sample removal using IRA
+ Chemical analysis of soils removed from the intrados

CONCLUSIONS

The visual anomalies of the stainless steel skin were classified into three categories:

1. Blemishes: Blemishes are alterations to the surface texture which create a visual aberration under specific lighting and observation angles.
2. Deposits: Deposits refer to particles such as atmospheric pollutants on the stainless steel surface are not part of the stainless steel.
3. Discoloration: Discoloration refers to chemical alteration, such as corrosion, to the surface of the stainless steel surface.

Visual observations from close-up inspection revealed the following:

1. Blemishes in the stainless steel finish are a result of surface scratches that are shallower than the finish profile, and are visual in a variety of patterns, including vertical streaks and circles.
2. The panels appear darker or lighter, or have darker or lighter streaks based on the observation angle of the viewer.
3. Incised graffiti and impact damage blemish the surface at the lowest two panels. The depth of the damage ranged from superficial scratches to deep hammer indents.
4. Surface deposits are common at many horizontal weld lines and tended to be dark in color. Additionally the deposits appear to streak down the panels originating from the weld lines.
5. Heat tint is present at some weld lines.
6. General orange surface discoloration is observed at the lowest eight panels.
7. Welds along the extrados were in good condition.
8. At the lowest two panels, red corrosion staining is often associated with the incised blemishes, either by corrosion of the panel surface or due to corrosion of the residue left from the mild steel implements used to scratch the graffiti into the surface.
9. Above Station 45, the out-of-plane deformation of the stainless steel panels in between stiffeners, also referred to as “oil-canning”, was measured to be approximately 1/8 inch at several locations.

Laboratory studies consisted of and analysis of the deposit samples removed from the surface of the stainless steel and metallurgical analysis of weld samples and revealed the following:

1. Gunshot residue (GSR) sample kits were used to remove samples of the surface deposit from the stainless steel skin of the Arch. In the laboratory, the sample kits were analyzed using light microscopy and scanning electron microscopy (SEM) with energy dispersive x-ray spectroscopy (EDS) for elemental analysis. The deposits at the vertical streaks consisted of fly ash, pollen, calcite, dolomite and other common atmospheric pollutants.
2. Five weld samples were analyzed using light microscopy and scanning electron microscopy (SEM) with energy dispersive x-ray spectroscopy (EDS) for elemental analysis. The chemical analysis of the plate material was consistent with the specified Type 304 stainless steel. The chemical analysis of the weld material was consistent with 300 series stainless steel. The welds in each sample appeared to be in serviceable condition with no surface corrosion associated with sensitization.

Cleaning trials only using gentle chemical methods were performed on the exterior stainless steel to evaluate the effectiveness of removing blemishes, deposits, and discoloration. Based on the trials, removal of the blemishes further creates visual anomalies. The surface deposits can easily be removed but does not create a significant improvement. Chemical cleaning is effective at removal some of the discoloration.

RECOMMENDATIONS

The exterior stainless steel of the Arch is in serviceable condition without significant structural distress or deterioration. The visual anomalies, including a variety of blemishes, deposits, and discoloration, are not causing significant corrosion or distress of the stainless steel currently, and many of the visual anomalies are from original construction. Over time, or with significant atmospheric changes, there is a possibility that the corrosion or deposits could become more aggressive.

Long-term monitoring is recommended to document visual changes in the stainless steel that could become significant.

The cleaning trials were successful at reducing some of the discoloration and provided a wide range of passivation and refinishing options for the stainless steel. Based on the nature of refinishing stainless steel, it is likely that any attempt to globally refinish the stainless steel panels could result in a more noticeable uneven appearance in the finish. At the base of the Arch at locations of incised graffiti, a cleaning treatment could be implemented with a more precise method of refinishing the stainless steel and an acceptable treatment could be applied. To develop a cleaning treatment at the base, consideration should be given to the anticipated refinish appearance of the stainless steel, including graffiti, and long-term maintenance of the stainless steel at the base.

Technical Description

III.

Description of Monument

This section was taken from the National Park Service Jefferson National Expansion Memorial Gateway Arch Historic Structure Report - Volume 1, June 2010—prepared by BVH Architecture, Wiss, Janney, Elstner Associates (WJE), and Alvine and Associates.

An inverted weighted catenary curve, rising 630 feet above grade with massive concrete foundations extending nearly 50 feet below grade, and with an overall width equal to its height, the Gateway Arch exemplifies the intricacy of structure within the confines of one of the simplest building forms, the arch. An orthotropic design, in which the inner and outer skins are attached together to form a composite structure, was utilized for the Arch; thus an internal structural skeleton does not exist.

Each leg of the Arch is constructed of double-walled equilateral triangular "tube" segments, with an outer dimension of each side of the triangular section measuring 54 feet at grade level and tapering to 17 feet at the top. To an elevation of 300 feet above grade, the interstitial space between the inner and outer walls or skins of the double-walled segments is filled solid with reinforced concrete, utilizing post-tensioning bars in the extrados corners to provide stiffness and dead weight to the arch to resist overturning, bending and torsional moments caused by wind, temperature change, and construction loading of the creeper derricks and to provide rigidity during construction.

The space between the inner and outer walls at the base is 3 feet 41/2 inches at the termination of the concrete fill and only 7-3/4 inches above the 400 foot level; this dimension remains consistent to the top of the Arch. The outer skin assembly consists of 1/4 inch thick A304 alloy austenitic stainless steel plates welded together, while the interior skin assembly consists of 3/8 inch thick type A-7 carbon steel plates, except at the corners where the plates are 1-3/4 inches thick.

The Gateway Arch was constructed in segments in much the same way as modern long-span cable stayed bridges are, with a completed segment of specified length and geometric shape brought to the construction site either partially or wholly assembled, ready to be fastened to the existing structure. The triangular tube segments ranged from 12 feet in height at the base to an 8 foot tall keystone segment at the top. Each of the segments was set into place with either conventional ground-supported cranes for the segments within the first 72 feet above grade or creeper derrick cranes attached to the legs of the constructed portion of the Arch when construction had surpassed 72 feet.

Each evening after a section of the Arch was placed; the section location was surveyed using a theodolite scope and triangulation of the readings. Upon completion of surveying, readings were reviewed and calculations completed to determine if any changes to the set of an Arch section were required prior to welding. Positions were surveyed at night when there were no movement

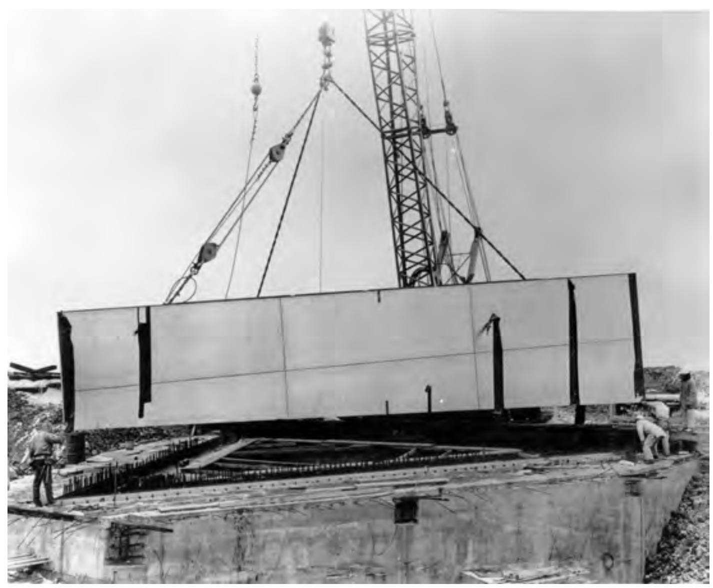

Figure 3-1—Initial placement of first segment, prior to field welding. Source: JNEM archive, image V106-396.

[1] Kenneth J. Kolkmeier, "Layout and Erection Control of the St. Louis Memorial Arch," presented at the ASCE Annual Meeting and Environmental Engineering Conference, October 12-22, 1965.

[2] George B. Hartzog, Jr., Director of the National Park Service, 1964–1972, "Will the Arch Stand?" in Moore, *Gateway Arch: An Architectural Dream.*

effects due to solar radiation and in order to assure that the legs would be in alignment when the top was reached.[1] The surveying was also completed at night because the temperature was more constant, thus limiting displacements caused by temperature differences (Figures 3-1 and 3-2).[2]

All the vertical and horizontal shop welds on the exterior between plates are uniform and were completed as single pass welds to create a smooth and uniform appearance. Mr. Kolkmeier provided insight about the welding process and stated that all welds were performed to American Society of Mechanical Engineers (ASME) standards and were X-rayed. Most stainless steel welds were performed in the shop, except as implemented for joining sections in the field. All exterior welds were argon gas/CO2 shielded. All interior welds were hand welded, while exterior welds were performed using a machine/jig.[3]

However, as completed the field welds are not as neatly done as the shop welds. Oftentimes, particularly at the base, the field welds were completed as multi-pass welds in order to accommodate for tolerances between the triangular tubular sections. The field welds on the exterior are multi-pass full penetration groove welds, with the reinforcement above the plate not ground smooth. The multi-pass welds vary in size as necessary to accommodate for tolerance of dimensional variances. Some of the horizontal field welds between successive sections appear to be discolored, which is most likely attributed to atmospheric soiling. Mr. Kolkmeier indicated that the field welds at the stainless steel plates on the exterior were not ground flush as an architectural decision,

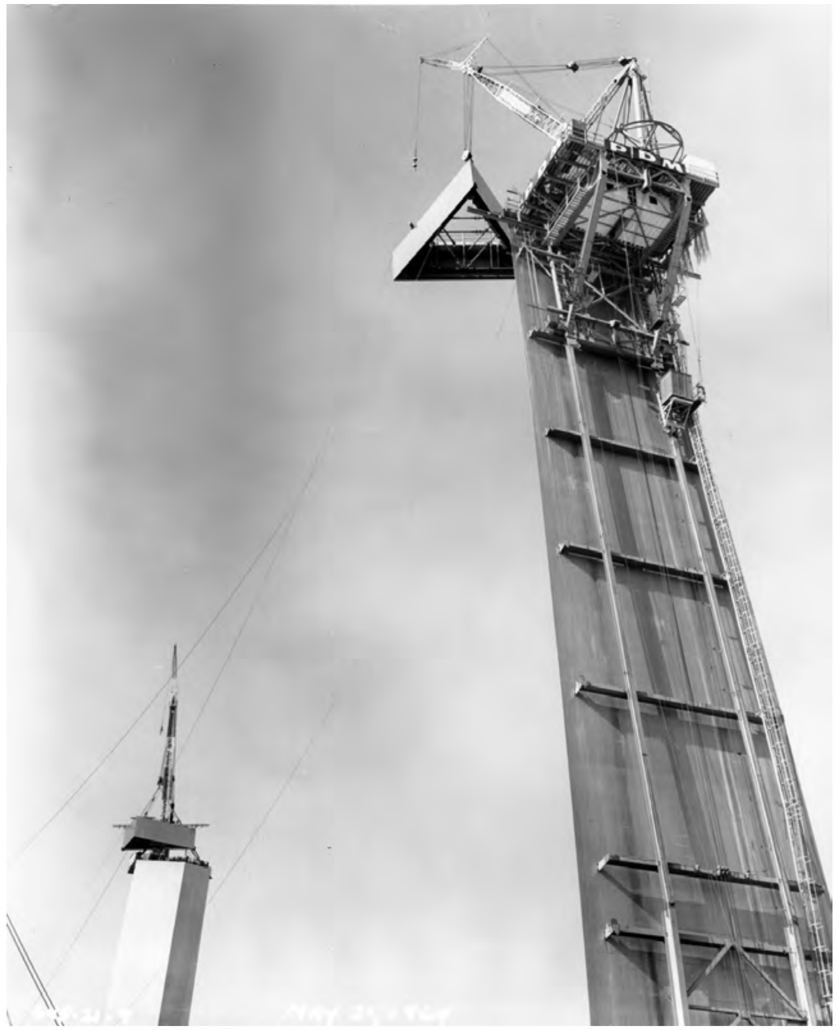

Figure 3-2—View of initial placement of a segment of the Arch completed from the creeper derrick crane. Source: JNEM archive, image V106-4048

and helped establish the pattern on the skin of the Arch that was desired by Saarinen.[4] The locations of the plug welds where the creeper derricks were attached have been ground flush and are thus undetectable from grade.

The lowest four tube segments (Stations 68, 69, 70 and 71) for both legs were entirely shop assembled as singular large triangular

[3] Worth and Kelley, interview with Kolkmeier, January 14, 2009.

[4] Ibid.

[5] Dan Worth, Stephen Kelley, and Robert Moore, interview with Kenneth Kolkmeier, Old Court House, JNEM, St. Louis, Missouri, January 14, 2009.

segments, shipped to the site, and installed. Thus, the only field welding required at these sections was between triangular sections at the horizontal station lines (Figure 3-3).[5] The remaining segments up to the 300 foot level (Station 45) were fabricated in the shop as three rectangular panels (one for each side of the triangular section).

As part of the on-site assembly, the corners were field welded together joining the three sections into one triangular tube section, and pick point plates were installed at the intrados corners for creeper crane lift cables. By welding pick points to the segments, the cables could be adjusted in length to make fine adjustments, assisting in fitting the section into place. When the final location was determined by the surveying process described above, the segments were field welded at the station joint between segments. The segments above the concrete fill (Station 44 to Station 0) were constructed as three L-sections, so the field welding occurred within the plates rather than at the corners (Figure 3-4). Again, these segments were assembled on site, hoisted into place, fitted, and welded to the segments below.

Figure 3-3—Shop assembly of the Arch segments, showing internal temporary framing for placement and installation. Source: JNEM archive, image V106-3946

The footing excavation for each leg of the Arch was 75 feet wide by 94 feet long, extending to a depth of nearly 50 feet at the southeast portion of the south leg corner in order to reach bedrock (Figure 3-5). The concrete footing has four steps, each approximately 10 feet deep (Figure 3-6). The initial concrete placement for the south leg foundation consisted of 2,400 cubic yards of concrete and took nearly twenty-three hours to place.[6]

Figure 3-4—Typical segment above concrete fill (Station 0 to Station 44) constructed as three L- sections. Source: Arteaga Photos, Ltd. (from Gateway Arch: An Architectural Dream, pg. 104)

Concrete was placed continuously in order to avoid a cold joint in the foundation pad that could later present structural inadequacies. Formwork was erected to create a triangular void within each foundation leg in order to provide the required space for the tram load zone and elevator pit. The remaining portion foundation pads of each leg were constructed in seven pours, with each pour having a depth of five feet. Each placement of concrete

[6] Ted Rennison, "Laying the Foundations," in Moore, *Gateway Arch: An Architectural Dream*

[7] Memorandum from B. A. Prichard of MacDonald Construction Company, St. Louis, Missouri, to Bruce Detmers of Eero Saarinen and Associates, June 4, 1962, Ref. Contract No. 14-10-0232-462.

Figure 3-5—View showing excavation for concrete footings of Arch. Source: JNEM archive, image V106-3865

Figure 3-6—View showing completed reinforced concrete footing, including reinforcing and post-tensioning bars. Source: Arteaga Photos, Ltd. (from Gateway Arch: An Architectural Dream, pg. 59)

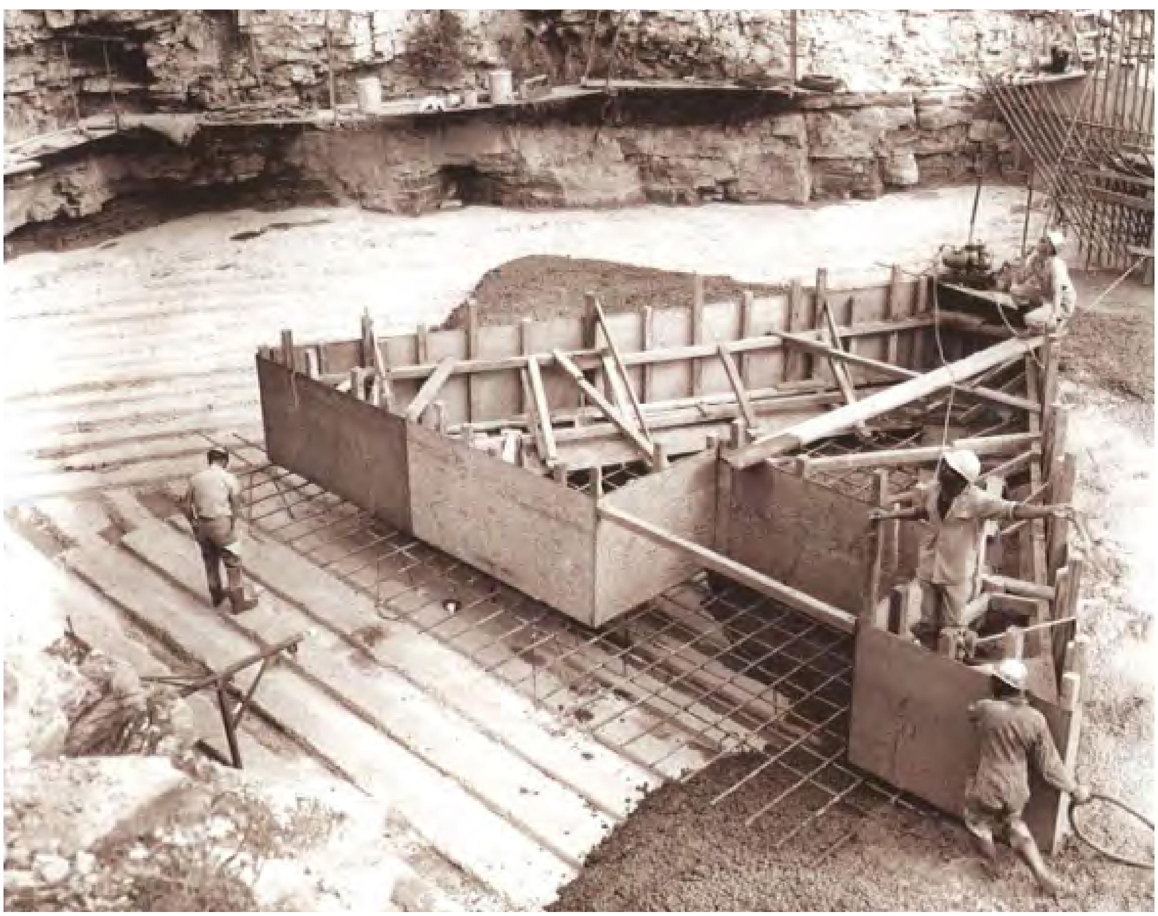

Figure 3-7—View of concrete foundation completed in seven pours with a series of grooves for keying the pours together.

Source: Arteaga Photos, Ltd. (from Gateway Arch: An Architectural Dream, pg. 58) consisted of two 2-1/2 foot lifts of concrete with retarders used in the first, lower mix to prevent a cold joint between the 2-1/2 foot lifts. The pours were keyed together with a series of grooves (Figure 3-7). A series of the post-tensioning bars (1-1/4 inch diameter) were installed and anchored at 34 feet and 24 feet below grade. These two levels of post-tensioning bars were offset to ensure that the entire tension load of the bars was not concentrated at one location within the footings. Two hundred and fifty-two post-tensioning bars were placed in each leg (126 bars in each of the two outside/extrados corners) and continued to the 300 foot level where the reinforced concrete fill terminates (Figures 3-8 and 3-9).

Figure 3-9—Overall view in archival photograph, showing concrete footing and post-tensioning bars in extrados corners. Source: JNEM archive, image V106-3877

Figure 3-8—Post-tensioning bars in extrados corners at the concrete footings.

Source: JNEM archive, image V106-3926

[8] Post-tensioned concrete is concrete reinforced with wire strands, which are post-tensioned within their elastic limit to give an active resistance to loads. (Source: Dictionary.com Unabridged. Based on the Random House Dictionary, Inc. 2010.

From foundation level to the 300-foot level (Station 45), the interstitial three foot space between the inner and outer plates of both Arch legs was filled with reinforced and post-tensioned concrete (Figure 3-10).[8] Steel stiffener angles are fastened to the interior plate of each section with 3/8 inch diameter stud bolts, to which are attached additional stiffener angles welded to the exterior plate. The stiffener angles, stud bolts and post-tensioning strands work with the prestressed concrete to create a composite section,[9] in which the concrete and the steel skin plates create a structural member that act as a single unit resulting system has greater load carrying capacities than the sum of its parts.

During the construction of the Arch, an inward thrusting force caused by the leaning of each leg was present, which would typically be carried by the keystone unit of an arch when in place. This inward thrusting causes significant tensile stresses within the individual segments of the arch legs, which are only experienced during construction, because the structure of an arch is not resolved until the keystone is place. A completed arch provides a structure that eliminates tensile stresses, as all the forces are resolved into compressive stresses. This is useful because concrete can strongly resist compression but is very weak when tension, shear or torsional stress is applied.

The challenge was to provide an alternative force mechanism to keep the sides of the arch from falling inward before the keystone was placed. Consequently, the Arch position needed to rely on either large tieback cables or another mechanism to hold the inward deflection of the Arch to within the specified engineering tolerances. A composite member consisting concrete fill reinforced with post-tensioning reinforcing bars along with the inner and outer skins was designed to resist the gravity loads causing inward deflection of the Arch legs and the overturning moment, thus eliminating the need for large tieback cables.

The post-tensioning bars and temperature reinforcing

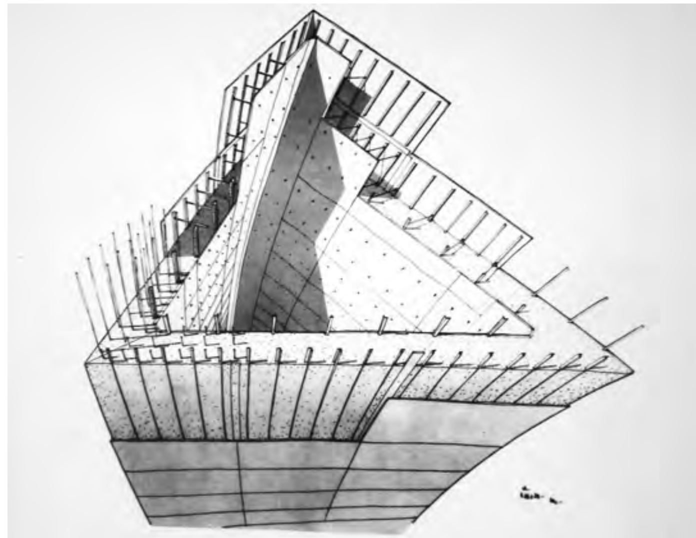

Figure 3-10—Schematic drawing, showing composite section of the Arch below the 300 foot elevation.

Figure 3-11—Overall view showing integration of the reinforcing bars at the concrete footing and concrete filled portion of the steel skins. Source: JNEM archive, image V106-3940

[9] Composite section: A structural member composed of two or more dissimilar materials joined together to act as a unit in which the resulting system is stronger than the sum of its parts.

steel were integrated within the concrete filled portion of the Arch to induce compressive forces in the concrete and increase strength by tensioning the steel bars, to effectively carry the design loads during construction (Figure 3-11). The 1-1/4 inch diameter post-tensioning steel bars and sleeves were held in place by steel positioning plates with holes drilled to the appropriate bar spacing. The bars needed to be inclined in two directions in order to follow the double curvature of the Arch. The fitting of the 126 bars in the cross section at the base became more congested as the size of the cross section decreased with the taper of the tubular leg sections. Each bar was tensioned to 142,000 lbs. (approximately 115 ksi bar stress), continuing to the top of the concrete fill. Post-tensioning occurred for each of the bars when the concrete fill reached a compressive strength of 4,000 psi. The required compressive strength was typically reached in seven to ten days after placement and was approximately 80 percent of the design strength. The concrete was placed in approximately five-foot lifts and terminated one foot short of the segment height, to permit installation of the steel positioning plates. The 142,000 lb. stressing for each bar was done by a hydraulic jack, with a total of 18,000 tons of prestress applied per leg. The design engineers specified tensioning the bars in sequence to balance the loading on the existing structure and so as not to over-stress the concrete fill. The full tension load was applied to each bar in one operation with a 100 ton capacity hydraulic jack, which reacted against a steel jacking plate embedded at the top of the concrete (Figures 3-12 and 3-13).[10]

Above Station 45 where the concrete pour was stopped, the inner and outer skins are connected together using a series of carbon

Figure 3-12—View of tensioning the reinforcing bars below the 300-foot level. Source: JNEM archive, image V106-3933

steel stiffener angles, diaphragms, 1/2 inch diameter bars, and bent steel plates in a cellular type of construction, similar to aircraft design. The steel stiffener angles were spaced based on a ratio of the panel and tube width. The stiffener angles (2 inch by 2 inch by 1/4 inch) are stitch welded to the back side of the exterior stainless plates with fillet welds. A welded built-up stiffener angle, fabricated from a 2-inch by 1/2-inch steel plate and a 1/4-inch steel plate of

[10] Joe Jensen, "Facts about the Construction," in Moore, *Gateway Arch: An Architectural Dream*.

width equal to the space between interior and exterior skins, is bolted to the interior carbon steel plates. The interior and exterior skins are further tied together with diagonal rod braces.

A secondary measure to provide stability against the inward acting bending moments on the cantilevered Arch legs was implemented near the top of the Arch. When the legs reached an elevation of 530 feet, about 100 feet from the top of the Arch, a large trussed strut was installed between the legs (Figures 3-14 and 3-15). This additional measure of construction stability was deemed necessary by the contractor to ensure the stability of the cantilever legs, while simultaneously limiting the stresses on the post-tensioned concrete (Figure 3-16).

Figure 3-14—Close up view of the trussed strut installed during construction to resist overturning and deflection of the cantilevered Arch legs. Source: JNEM archive, image V106-4111

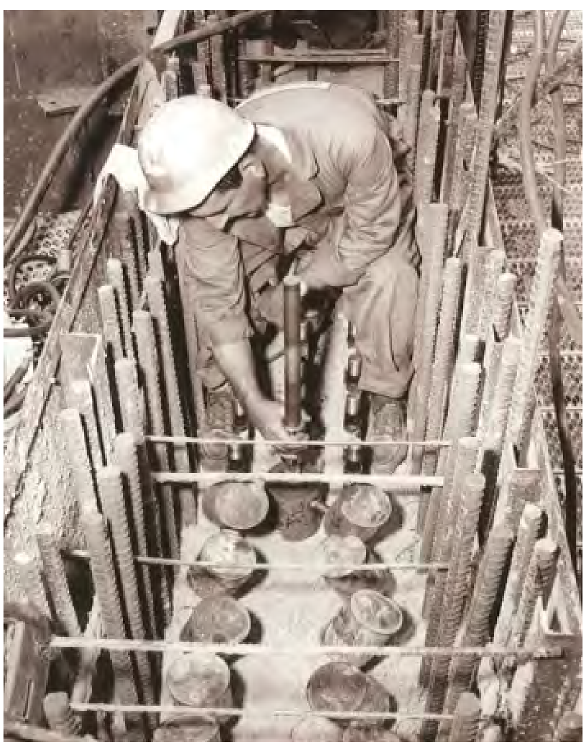

Figure 3-13—View of tensioning the reinforcing bars below the 300 foot level. Source: Arteaga Photos, Ltd. (Gateway Arch: An Architectural Dream, pg. 60)

Figure 3-15—View of the trussed strut installed during construction to resist overturning and deflection of the cantilevered Arch legs.

Source: JNEM archive, image V106-4119

Figure 3-16—Overall view of the strut installed during construction.

Source: JNEM archive, image V106-4124

Evaluation of Significance

IV.

SIGNIFICANCE CRITERIA

This section was taken from the National Park Service Jefferson National Expansion Memorial Gateway Arch Historic Structure Report - Volume 1, June 2010—prepared by BVH Architecture, Wiss, Janney, Elstner Associates (WJE), and Alvine and Associates.

The Criteria for Evaluation for listing on the National Register of Historic Places state:

> The quality of significance in American history, architecture, archeology, engineering, and culture is present in districts, sites, buildings, structures, and objects that possess integrity of location, design, setting, materials, workmanship, feeling, and association, and:
>
> A. That are associated with events that have made a significant contribution to the broad patterns of our history; or
>
> B. That are associated with the lives of persons significant in our past; or
>
> C. That embody the distinctive characteristics of a type, period, or method of construction, or that represent the work of a master, or that possess high artistic values, or that represent a significant and distinguishable entity whose components may lack individual distinction; or
>
> D. That have yielded, or may be likely to yield, information important in prehistory or history.

Criteria Considerations

Ordinarily cemeteries, birthplaces, graves of historical figures, properties owned by religious institutions or used for religious purposes, structures that have been moved from their original locations, reconstructed historic buildings, properties primarily commemorative in nature, and properties that have achieved significance within the past 50 years shall not be considered eligible for the National Register. However, such properties *will qualify* if they are integral parts of districts that do meet the criteria or if they fall within the following categories:

> A. A religious property deriving primary significance from architectural or artistic distinction or historical importance; or
>
> B. Building or structure removed from its original location but which is primarily significant for architectural value, or which is the surviving structure most importantly associated with a historic person or event; or
>
> C. A birthplace or grave of a historical figure of outstanding importance if there is no appropriate site or building associated with his or her productive life; or
>
> D. A cemetery that derives its primary importance from graves of persons of transcendent importance, from age, from distinctive design features, or from association with historic events; or
>
> E. A reconstructed building when accurately executed in a suitable environment and presented in a dignified manner as part of a restoration master plan, and when no other building or structure with the same association has survived; or
>
> F. A property primarily commemorative in intent if design, age, tradition, or symbolic value has invested it with its own exceptional significance; or
>
> G. A property achieving significance within the past 50 years if it is of exceptional importance.[1]

The Gateway Arch is significant under National Register Criterion C for its architectural and engineering design as well as for the role it played in the career of architect

[1] *Code of Federal Regulations, Title 36, Part 60,* "The National Register Criteria for Evaluation."

Eero Saarinen. The Gateway Arch is the focus of JNEM, for which the landscape was designed by Saarinen and noted landscape architect Dan Kiley. Saarinen and Kiley sculpted the surrounding landscape to create special views of the Arch.

Eero Saarinen was born in Finland in 1910 and immigrated to the United States with his family in 1923. His father, renowned architect Eliel Saarinen, was the first president of the Cranbrook Institute of Architecture and Design in Bloomfield Hills, Michigan. After studying sculpture in Paris and Architecture at Yale University, Eero Saarinen joined his father's firm in 1937. Eero took over the firm in 1950 after his father's death.[2]

In 1947, Eero Saarinen entered the architectural design competition for JNEM. His winning entry for what is now known as the Gateway Arch was one of the first major designs Saarinen completed on his own. Over the next thirteen years Saarinen designed several more influential projects, including the General Motors Technical Center outside of Detroit, the TWA Terminal at John F. Kennedy International Airport in New York City, and Dulles Airport outside of Washington, D.C. Saarinen died in 1961 at the age of 51, seven years before the Gateway Arch was formally dedicated.[3]

Although some historians do not consider the Gateway Arch to be Saarinen's most influential design, others see it as his greatest contribution to American architecture. Architect Robert Venturi called the Arch "one of the best things since World War II—it is a thing that is very difficult to do which is to do a non-functional, sculptural symbolic gesture of enormous scale."[4]

The design of the Gateway Arch is based on a weighted catenary; however, neither the extrados nor the intrados of the arch is a true catenary. The arch is constructed of prefabricated double-wall carbon steel and stainless steel triangular segments that reduce in size as they approach the apex. This stressed metal double skin carries the structural loads, eliminating the need for interior framing. The innovative structural engineering design of the Arch by Hannskarl Bandel and Fred Severud contributes to its significance. In addition, the inventive tram system within the legs of the Arch that lifts visitors to the top of the Arch is a significant feature.

While properties that are primarily commemorative in intent are often not considered eligible for the National Register, Criteria Consideration F states that such a structure can be listed if design, age, tradition, or symbolic value has invested it with its own exceptional significance.[5] Such is the case with the Gateway Arch, as its innovative design and symbolic value have made it an important icon of the built American landscape. Since the beginning of its construction in the 1960s, the Gateway Arch has been a symbol of the city of St. Louis and its role as the "gateway to the West."

Properties that have achieved significance within the past fifty years are also generally not considered eligible for inclusion on the National Register. However, Criteria Consideration G asserts that such properties can be listed if they are of exceptional importance. The groundbreaking design of the Gateway Arch allowed it to achieve significance almost immediately, as evidenced by its addition to the National Register in 1985, less than twenty years after its completion.[6]

Consideration of significance to the level of a National Historic Landmark is discussed in the National Register

[2] Laura Soullière Harrison, *National Register of Historic Places Nomination Form: Gateway Arch* (Washington, D.C.: NPS, 1985). This National Register nomination serves as documentation for the National Historic Landmark listing of the structure.

[3] Michael Capps, *Jefferson National Expansion Memorial, Architect Eero Saarinen, viewed* at http://www.nps.gov/jeff/planyourvisit/architect.htm, 2006.

[4] As quoted in Soullière Harrison, 7.

[5] CFR 36, "The National Register Criteria for Evaluation."

[6] Soullière Harrison, 8.

Bulletin, *How to Prepare National Historic Landmark Nominations:*

> By definition, the almost 2,300 properties designated as National Historic Landmarks are the most significant places in American history—they illustrate and commemorate our collective past and help us to understand our national identity. National Historic Landmarks outstandingly represent and interpret the best and brightest and the most tragic aspects of our history. Through these landmarks, all Americans can better understand and appreciate the broad trends and events, important persons, great ideas and ideals, and valuable accomplishments in the arts and sciences, and humanities, that are truly significant in our history.[7]

Potential National Historic Landmarks are evaluated for their national significance according to a set of criteria that is different from the more familiar National Register criteria. The Criteria for Evaluation for the designation of a National Historic Landmark (NHL) state:

> The quality of national significance is ascribed to districts, sites, buildings, structures, and objects that possess exceptional value or quality in illustrating or interpreting the heritage of the United States in history, architecture, archeology, engineering, and culture and that possess a high degree of integrity of location, design, setting, materials, workmanship, feeling, and association, and:
>
> A. That are associated with events that have made a significant contribution to, and are identified with, or that outstandingly represent, the broad national patterns of United States history and from which an understanding and appreciation of those patterns may be gained; or
>
> B. That are associated importantly with the lives of persons nationally significant in the history of the United States; or
>
> C. That represent some great idea or ideal of the American people; or
>
> D. That embody the distinguishing characteristics of an architectural type specimen exceptionally valuable for a study of a period, style or method of construction, or that represent a significant, distinctive and exceptional entity whose components may lack individual distinction; or
>
> E. That are composed of integral parts of the environment not sufficiently significant by reason of historical association or artistic merit to warrant individual recognition but collectively compose an entity of exceptional historical or artistic significance, or outstandingly commemorate or illustrate a way of life or culture; or
>
> F. That have yielded or may be likely to yield information of major scientific importance by revealing new cultures, or by shedding light upon periods of occupation over large areas of the United States. Such sites are those which have yielded, or which may reasonably be expected to yield, data affecting theories, concepts and ideas to a major degree.

National Historic Landmark Exclusions

Ordinarily, cemeteries, birthplaces, graves of historical figures, properties owned by religious institutions or used for religious purposes, structures that have been moved from their original locations, reconstructed historic buildings and properties that have achieved significance within the past fifty years are not eligible for designation. If such properties fall within the following categories they may, nevertheless, be found to qualify:

1. A religious property deriving its primary national significance from architectural or artistic distinction or historical importance; or

[7] National Register Bulletin, *How to Prepare National Historic Landmark Nominations* (Washington, D.C.: National Park Service, 1999).

2. A building or structure removed from its original location but which is nationally significant primarily for its architectural merit, or for association with persons or events of transcendent importance in the nation's history and the association consequential; or

3. A site of a building or structure no longer standing but the person or event associated with it is of transcendent importance in the nation's history and the association consequential; or

4. A birthplace, grave or burial if it is of a historical figure of transcendent national significance and no other appropriate site, building, or structure directly associated with the productive life of that person exists; or

5. A cemetery that derives its primary national significance from graves of persons of transcendent importance, or from an exceptionally distinctive design or an exceptionally significant event; or

6. A reconstructed building or ensemble of buildings of extraordinary national significance when accurately executed in a suitable environment and presented in a dignified manner as part of a restoration master plan, and when no other buildings or structures with the same association have survived; or

7. A property primarily commemorative in intent if design, age, tradition, or symbolic value has invested it with its own national historical significance; or

8. A property achieving national significance within the past 50 years if it is of extraordinary national importance.[8]

The Gateway Arch was designated as a National Historic Landmark on May 28, 1987, and was documented in the National Historic Landmark theme study, "Architecture in the Parks." The properties included in this thematic nomination are nationally significant for their architecture, are located within the boundaries of an area of the National Park system, and were constructed for visitor use or for interpretive or administrative purposes. JNEM was the first major national park development after World War II. The design of the Gateway Arch was a turning point in the shift from the rustic style of park architecture used for buildings throughout the 1920s and 1930s to a more modern style of architecture that characterized the Mission 66 period.[9]

Period of Significance

As a structure considered primarily significant for its architectural design, the period of significance for the Arch is associated with its initial design and construction. The relatively minor changes to the Arch since its completion in 1965 are not considered to be contributing alterations. Therefore, the period of significance is dated to the official dedication of the Arch in May 1968. Further consideration is needed regarding the period of significance for the museum, which was completed later. The museum was excluded from the scope of study of this report.

Character-Defining Features

The historic nature of significant buildings and structures

[8] *National Register Bulletin 16a: How to Complete the National Register Registration Form* (Washington, D.C.: NPS, National Register of Historic Places, 1977, revised 1997).

[9] Soullière Harrison, *National Park Service: Architecture in the Parks,* <www.nps.gov/history/history/online_books/harrison/harrison0.htm>, 1986. Refer also to Ethan Carr, *Mission 66: Modernism and the National Park* (Amherst: University of Massachusetts Press, 2007). According to Carr, the proposed design of the Gateway Arch was the turning point in NPS architecture. It influenced the decision to use modern architecture for the Mission 66 program, as it proved that a modern design could be successful at "interpreting" the park to contemporary visitors, compared to earlier rustic-style park buildings which sought to blend with the natural and vernacular character of the park.

is defined as their character, which is embodied in their identifying physical features. Character-defining features can include the shape of a building; its materials, craftsmanship, interior spaces, and features; and the different components of its surroundings.[10]

The most important character-defining feature of the Arch, whose design is based upon a weighted catenary, is the simple arch shape itself. The modulation of the shape, which tapers in cross section from grade to the apex of the Arch, as well as the overall height and breadth of the shape, were carefully studied and repeatedly refined by Saarinen as the design evolved. The overall shape of the Arch gives the structure its visual identity. The arch shape is also a key component of the symbolic intent of the memorial design, which is to commemorate the "Gateway to the West." The overall shape is defined by the metal skin of the Arch, which is the load-bearing element of the structure. The stressed metal skin allows the interior of the Arch to be free of large-scale framing or reinforcement. Since the exterior skin is also the primary structure of the Arch, the overall shape of the exposed exterior surface gains added importance as a character-defining feature.

While difficult to see from afar, the thirty-two small openings at the top of the structure are an important aspect of the Arch. Saarinen envisioned a space at the apex of the Arch from which visitors could view the surrounding area; thus these openings are important to the function of the arch.

The stainless steel material that covers the exterior of the Arch contributes to the overall character of the structure. The reflectivity of the material is an important aspect of the Arch's design. At close range, the craftsmanship of the machined finishes of the stainless steel further adds to the overall character of the Arch.

Although much of the interior volume of the Arch itself has a utilitarian character, there are some individual spaces that are important to visitors' experience of the Gateway Arch. The observation level at the apex of the Arch was an important part of Saarinen's initial concept for the memorial. Other important spaces include the north and south tram load zones at the base of the Arch. The spatial volume of these underground areas as designed by Saarinen and Associates is a notable character-defining feature of the Arch interior. Although not generally accessible to the public, the egress stairs positioned within each leg of the Arch are a structurally distinctive element that can be viewed through the windows of the tram.

The tram by which visitors ascend and descend the Arch is also a character-defining element of the structure, as well as a unique engineering invention. The custom-built tram system was specifically designed to allow visitation to the top of the uniquely shaped Arch structure, and therefore it is a critical part of the intended function of the memorial. The tram ride is a key component of the visitor's experience in the Arch.

Several aspects of the setting of the Gateway Arch are important to the visual character. The surrounding landscape designed by Saarinen and Dan Kiley adds significantly to the Arch's overall character. The Arch's proximity to the river as well as its placement on axis with the Old Courthouse are also important to the visual character of the Arch and underscore its historical/commemorative function.

Another important aspect of the Gateway Arch is the sequence of approach to the memorial. Eero Saarinen and Dan Kiley envisioned the Arch as emerging from a forest-like green space juxtaposed with the surrounding urban landscape. The surrounding landscape was designed with views of the Arch in mind. These views as well as the sequence of approach experienced by the visitor add significantly to the character of the Gateway Arch itself

Assessment of Integrity

Assessment of integrity is based on an evaluation of the existence and condition of the physical features which date to a property's period of significance, taking into

[10] Lee H. Nelson, FAIA, *Preservation Brief 17: Architectural Character: Identifying the Visual Aspects of Historic Buildings as an Aid to Preserving Their Character* (Washington, D.C.: NPS, Technical Preservation Services, 1988).

consideration the degree to which the individual qualities of integrity are present. The seven aspects of integrity as defined in the National Register Criteria for Evaluation are location, design, setting, materials, workmanship, feeling, and association. As noted in *National Register Bulletin 15: How to Apply the National Register Criteria for Evaluation:*

> Location is the place where the historic property was constructed or the place where the historic event occurred… Design is the combination of elements that create the form, plan, space, structure, and style of a property… Setting is the physical environment of a historic property… Materials are the physical elements that were combined or deposited during a particular period of time and in a particular pattern or configuration to form a historic property… Workmanship is the physical evidence of the crafts of a particular culture or people during any given period in history or prehistory… Feeling is a property's expression of the aesthetic or historic sense of a particular period of time… Association is the direct link between an important historic event or person and a historic property.[11]

For NHL designation, a property should possess these aspects to a high degree. The property must retain the essential physical features that enable it to convey its historical significance. The essential physical features are those features that define both why a property is significant (NHL criteria and themes) and when it was significant (period of significance). National Register Bulletin 15 defines integrity as "the ability of a property to convey its significance."[12] As noted in the National Register Bulletin, *How to Prepare National Historic Landmark Nominations,*

> Integrity is the ability of a property to convey its historical associations or attributes. The evaluation of integrity is somewhat of a subjective judgment, but it must always be grounded in an understanding of a property's physical features and how they relate to its historical associations or attributes. The NHL survey recognizes the same seven aspects or qualities of integrity as the National Register.[13]

The primary historical significance of the Gateway Arch is related to the innovative design of the structure. The integrity of the Arch itself as well as the integrity of other original features of Saarinen's concept, such as the connection between the site and the Arch, are the most important physical aspects that convey this significance. The discussion below considers each of the seven aspects of integrity as they relate to the Gateway Arch.

Integrity of Location. The Gateway Arch retains a high degree of integrity of location in relationship to its site. The building location and the boundaries of the site are unchanged since the Arch was dedicated in 1968.

Integrity of Design. The Gateway Arch retains a high degree of integrity of design, as few alterations to the structure have been implemented since its original construction. While minor alterations have been made to the interior of the Arch, including flooring infill of portions of the two-story tram load zones, the initial design concept by Kevin Roche of Saarinen and Associates is still evident.

Integrity of Setting. The Gateway Arch retains a high degree of integrity of setting. The adjacent parkland also retains a high integrity of setting as the surrounding environment reflects the environment as it existed when the park was completed. By 1968, the broader urban context around the memorial already included the characteristic elements of the city today, including high rise commercial buildings, the Mississippi River bridges, and the nearby railroads and interstate highways. Saarinen's initial concept of having the arch emerge from an open green space within an urban setting is still present today.[14]

Integrity of Materials and Workmanship. The Gateway Arch retains a high degree of integrity of materials and

[11] *National Register Bulletin 15: How to Apply the National Register Criteria for Evaluation*, 44–45.

[12] Ibid.

[13] National Register Bulletin, *How to Prepare National Historic Landmark Nominations* (Washington, D.C.: National Park Service, 1999).

workmanship. The exterior retains its original materials, and the majority of the exterior surface has been left untouched since the initial construction of the Arch. Some of the interior materials have been changed. This has included replacement of worn flooring materials in public areas, to match the original materials. Although the original materials have been replaced, the replica materials installed are similar mass-manufactured materials. In other areas such as the tram load zones, new wall cladding and interpretive displays have been added over the original wall surfaces, which remain intact although concealed. These interior changes have a minor impact on the integrity of the Arch.

Integrity of Feeling. The Gateway Arch retains a high degree of integrity of feeling. The structure still conveys the historic and aesthetic feeling of a symbolic gateway and a public memorial as was the original design intent.

Integrity of Association. The Gateway Arch retains a high integrity of association. The Arch and JNEM as a whole continue the commemoration of the westward expansion of the United States in the nineteenth century. The Arch also retains its association with Eero Saarinen as his original design intent is still evident today.

[14] Regina M. Bellavia and Gregg Bleam, *Cultural Landscape Report* (Omaha, Nebraska: NPS, 1996), 188–190.

Cleaning & Refinishing Studies

V.

INTRODUCTION

After the three-part corrosion investigation that was competed in 2014, two distinctly different finish conditions were found at the base and at the upper areas of the stainless steel skin of the Gateway Arch. The upper areas had the original finish which was relatively consistent in gloss and surface roughness but discolored. The discolorations on the upper reaches were not corrosion of the stainless steel skin but were oxidizing (i.e. corroding) iron and steel particle deposits from historic industrial sources along with minor amounts of deicing salts. Therefore, they are not the result of an incipient structural problem.

Five samples representative of both the field and shop welds that were removed from the lower north leg in 2014 were found to be sensitized due to re-welding and excessive heat input, but no instances of corrosion were found indicating that the environment has not been corrosive enough for the sensitization to cause a problem. Both field and shop welds were found not to be full penetration in field x-ray analysis and some sections at and near the base were welded two or three times based on archival documentation. The surrounding environment today is less corrosive than it had been historically due to the dramatic reduction in pollutants from heavy industry.

The base of the Arch had clearly been refinished in one area, with distinctly different surface roughness and gloss measurements than the elevated panels. There are superficial deicing salts staining, deep scratches and impact damage. Some of the scratches contain embedded iron particles from carbon or alloy steel. The TMR Stainless report in the 2014 Appendix identified this as the primary corrosion concern and recommended removal.

For the cleaning of the stainless steel skin, an effective cleaning method that is the gentlest should be selected, in keeping with the *Secretary of Interior's Standards for the Treatment of Historic Buildings.* The cleaning system or systems to be used must be appropriate for the substrate and conditions to be addressed. Improper cleaning can damage materials by causing discoloration, etching, or superficial corrosion staining. The team has developed a methodology to quantify the measurement criteria of effectiveness, gentleness and economic feasibility relative to a wide range of cleaning methods including chemical, water, laser ablation plus the mild abrasive/chemical methods that were implemented on a trial basis in 2014.

A visual inspection was performed of the stainless steel surfaces of the south leg from grade to the second horizontal weld line to determine the appropriate abrasive grit that might be used to refinish the blemished stainless steel at the base of the Monument.

An expert workshop was held at the Gateway Arch with invited participants to see the Monument and its challenges, discuss conservation treatment philosophy, consider cleaning and refinishing treatments are available and to chart a course of action for future mock ups.

Small-scale cleaning and refinishing samples were performed at the Zahner Metalab in Kansas City, Missouri on March 25-27, 2019. Present from the team for this testing included Bill Zahner and Dan Gierer from Zahner Metalabs; Catherine Houska of Houska Consulting; and Stephen Kelley, Dan Worth, and Julie Cawby from BVH Architecture.

SKIN ANOMALIES BY TYPE

As reported in the Part 3 Corrosion report completed by Wiss, Janney, Elstner Associates, Inc. in 2015 report, visual anomalies on the stainless steel skin of the Gateway Arch can generally be classified into the following types:

1. Discoloration: Discoloration includes chemical alteration, such as superficial corrosion staining, to the surface of the stainless steel surface (Figure 5-1). Brownish-orange superficial surface corrosion staining was observed at the lowest eight panels. At the lowest two panels, red-orange corrosion staining (Figure 5-2) is often associated with the incised blemishes and appeared to be the result of corrosion of iron particles embedded in the surface from the implements used to scratch the graffiti.

2. Deposits: Deposits include particles, such as atmospheric pollutants, on the stainless steel surface that are not part of the stainless steel (Figures 5-3 and 5-4). Surface deposits are common at many horizontal welds and tend to be dark in color. The deposits streak down the panels, originating from the horizontal welds. Deposits removed from the Monument in 2014 (Appendix A) include industrial particulates (i.e. fly ash, small ferrochrome oxide, iron and steel slag, iron, copper zinc, lead, and titanium), carbon rich material (i.e. spores, pollens), clay materials, silica (sand), dolomite, mineral wool, paint particles, and calcite and magnesia alumina silicates. Most of the deposits are most likely from current and past heavy industrial activities in the area. Deposits are particularly thick at the base of the Monument where oils are present on the surface from visitors touching the stainless steel skin (Figure 5-5). Deicing chlorides (salts), which are not visible but troubling, are at the lower reaches and most likely from salting the plaza and nearby highways to mitigate snow accumulation.

3. Blemishes: Blemishes include alterations to the surface texture that create a visual anomaly under specific lighting conditions and at certain observation angles. Blemishes were caused during original fabrication (Figure 5-6); damage during shipping such as minor scratches caused by shipping straps (Figure 5-7); refinishing in the field during construction at areas such as the creeper crane track attachments on the extrados (Figure 5-8); general oil canning of the skin above the concrete pour (Figure 5-9); blemishes associates with the trussed strut (Figure 5-10); graffiti (Figures 5-11 and 5-12); and previous attempts to remove the graffiti (Figure 5-13).

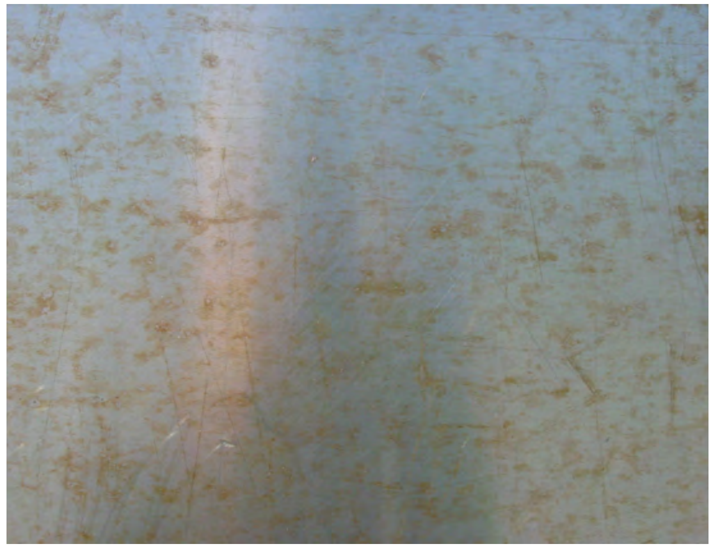

Figure 5-1—Discoloration in the form of superficial corrosion staining to the stainless steel surface. This is a typical condition at the base and lower reaches of the monument. Source: S. Kelley

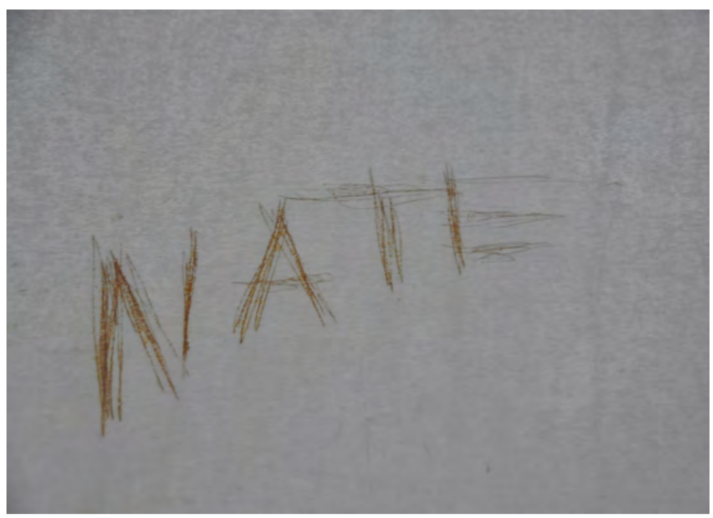

Figure 5-2—Corrosion associated with incised graffiti is the result of corrosion of iron particles from the implements used to scratch the graffiti. Source: S. Kelley

Figure 5-3—Deposits composed of atmospheric pollutants that cause vertical streaking emanating from field welds and shop welds. Source: S. Kelley

Figure 5-4—Deposits on the upper reaches of the monument that collect on the indented "oil canning" of the panels that occurs between interior stiffeners.

Source: S. Kelley

Figure 5-5—Oil deposits at the base of the monument from visitors touching the stainless steel surface.

Source: S. Kelley

Figure 5-6—Faint circular blemish caused by suction cups that were used to handle the stainless steel panels during fabrication. Source: 2015 Gateway Arch Corrosion Investigation Part III, WJE

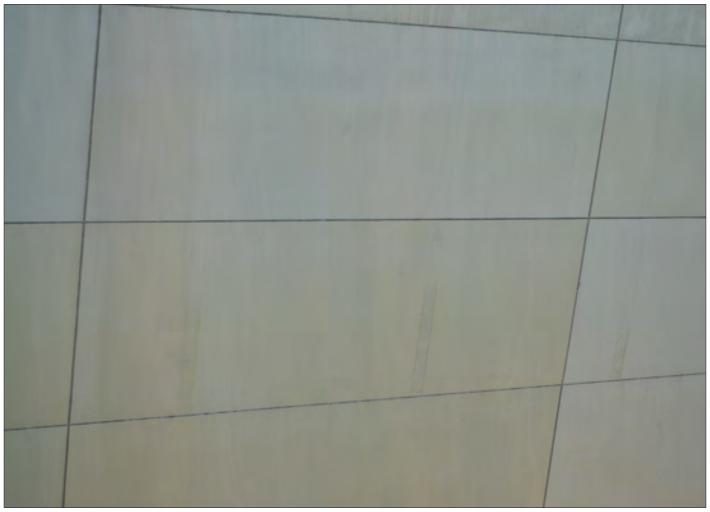

Figure 5-7—Blemishes in the form of darkened vertical lines caused by straps that were used to handle the segment of the monument during shipping. Source: S. Kelley

SKIN ANOMALIES BY LOCATION

Anomalies on the stainless steel skin of the Arch can also be categorized by their location relative to the ground. This is important to understand because of the significant cost for access to the upper reaches of the Arch. For this report we will divide them into anomalies within the first two panels above grade, within the first eight panels above grade, and throughout the Monument:

1. Within the lowest two panels: incised graffiti, red-orange corrosion staining associated with incised graffiti, and surface deposits mixed with oil from the hands of visitors touching the Monument. Of these anomalies, removal of the red orange corrosion staining is high priority as this phenomenon will worsen if not addressed. The mitigation of graffiti is also of concern because its presence invites further graffiti.

2. Within the lowest eight segments: superficial corrosion staining and deicing chlorides. It is a high priority to remove these anomalies as deicing chlorides will promote further corrosion and the present corrosion will worsen if not addressed.

3. Throughout the Monument: Atmospheric pollutants and blemishes created during fabrication, shipping and erection are also found at all levels of the Arch. These discolorations are of aesthetic concern but are not considered to be high priority.

Atmospheric pollutants in the lower reaches where essential cleaning takes place will be removed. There has been discussion regarding whether the visible soil deposits in the form of streaking that mimic water runoff patterns represent a “patina” that may be left in place. In removal of embedded ferrous particles and superficial corrosion, all soil deposits would automatically be removed from the lower eight panels as part of this process. This would make the removal of soil deposits above this area desirable in order to match the appearance above and below the eighth panel line.

Blemishes in the lower areas that were caused by fabrication, shipping and erection will remain unaffected by cleaning. The blemishes are not causing damage but tell a story of the original construction of the Arch. These anomalies include blemishes from handling the stainless steel panels, such as circular scratch patterns from suction cups used to move the panels, and vertical scratch patterns from tie-downs used during shipping; weld splatter; and out-of-plane deformation of the stainless steel panels of approximately 1/8 inch between stiffeners above station 45 where the concrete pour stopped.

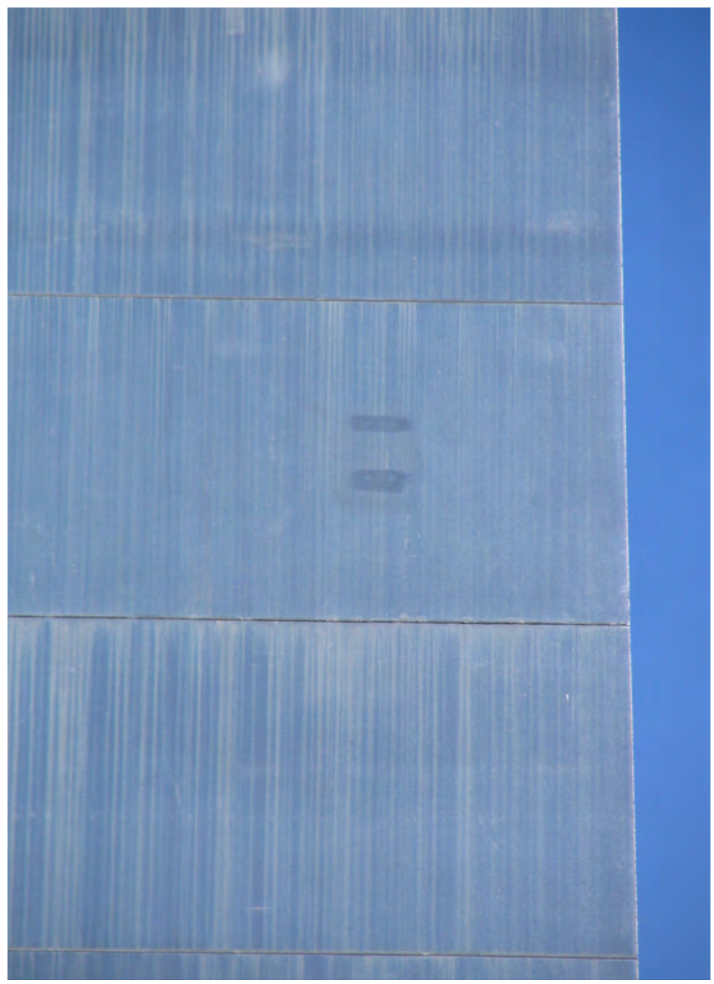

Figure 5-8—Blemishes on the extrados where the creeper crane was attached to the leg during erection. Source: S. Kelley

Cleaning & Refinishing Studies

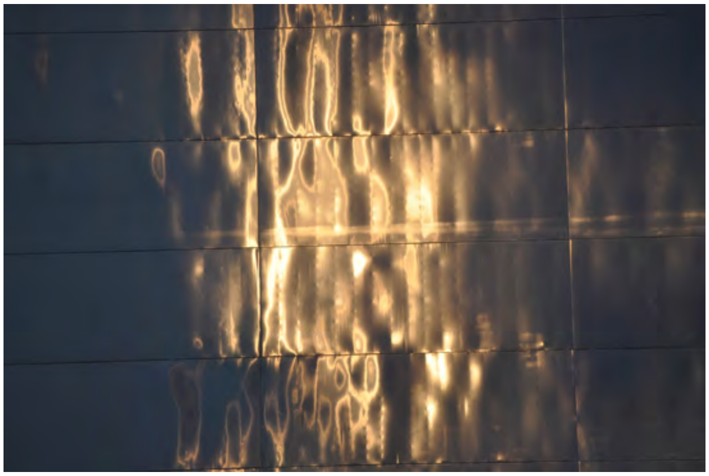

Figure 5-9—Oil canning of the stainless steel surface at the upper reaches of the Monument can easily be seen during some lighting conditions. Source: S. Kelley

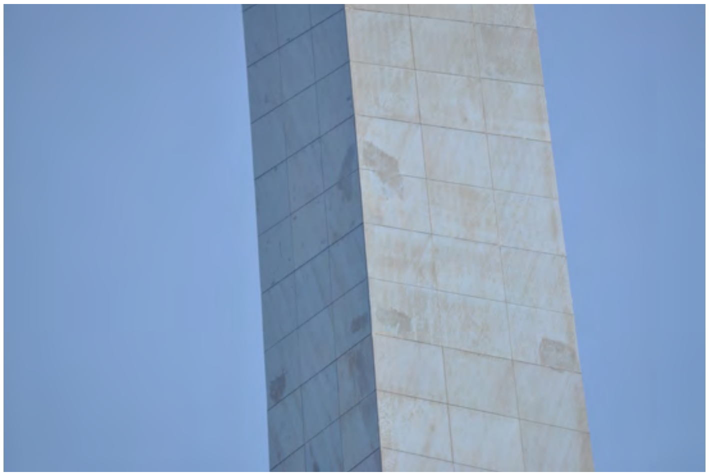

Figure 5-10—Blemishes on the intrados of the south leg where the trussed strut was temporarily installed to stabilize the two legs during construction. Source: S. Kelley

Figure 5-11—Incised graffiti at the base of the Monument. Source: S. Kelley

Figure 5-12—Damage to the surface of the Monument caused by striking with the claw of a hammer. Source: S. Kelley

Figure 5-13—Unsuccessful refinishing of the east face of the south leg, date of refinishing unknown.

Source: S. Kelley

INITIAL SKIN ANALYSIS

A visual inspection was performed of the stainless steel surfaces of the north and south legs from grade to the second horizontal weld line (Figures 5-14 and 5-15). This inspection took place on August 3, 2018 by Al O'Bright representing the National Park Service; Paul Kuensner of the Association for Preservation Technology; Dan Gierer and William Zahner of Metalabs; and Dan Worth, Julie Cawby, and Steve Kelley of BVH Architecture. The purpose of this study was to determine parameters for potentially refinishing the base of the Monument where there are extensive blemishes from incised graffiti. A detailed record of the visit is found in Appendix B.

The Arch skin is made up of stainless steel plate elements, approximately 60 inches wide by 144 inches in length. The plate elements are continuously welded along horizontal and vertical seams. The vertical welds and horizontal welds alternate from field to shop weld. The field welds are visibly coarser than the shop welds. The stainless steel has a matte, satin, directional finish running the long (horizontal) direction of the plate elements. This is a common stainless steel finish applied in a factory setting by passing the plate below a polishing belt containing specific grit. These belts are changed out frequently to keep the finish consistent.

Visual Examination

The visual examination was performed with the naked eye and with a digital microscope (Figure 5-16). A glossmeter was also used to measure gloss perpendicular and parallel to the directional finish (Figure 5-17).

The surface has levels of visual undulation across it. These are induced on the stainless steel by thermal changes in the welded plate. The undulations correlate to the position of the vertical stiffeners on the inward side of the plate. The extent of the undulations from a theoretical plane was not measured. These smooth waves are apparent on all faces and up the vertical surface of the Arch. In particular, they are visible at night with a grazing light across the surface.

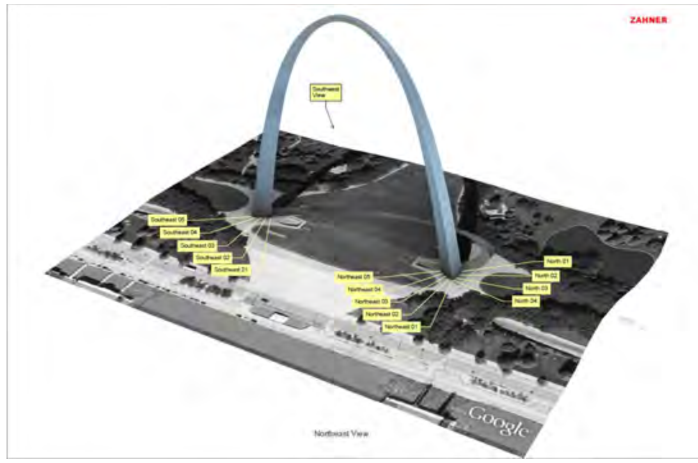

Figure 5-14—Schematic view of the areas tested during the initial skin analysis, view from the northeast. Source: Zahner Metalab report

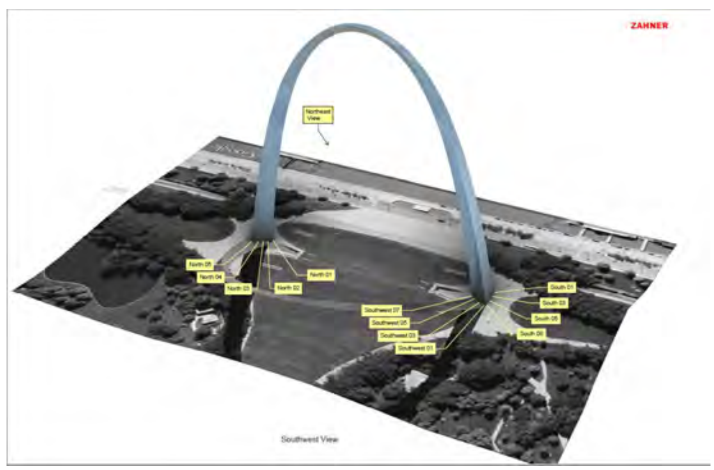

Figure 5-15—Schematic view of the areas tested during the initial skin analysis, view from the southwest. Source: Zahner Metalab report

Cleaning & Refinishing Studies

North Leg

There was an abundance of blemishes in the form of incised graffiti from ground to 3 meters above ground on all three faces. On the north face and some of the east face, hammer marks were visible on the surface. The scratches are haphazard across the finish making them more apparent. They are approximately 2/10s of a millimeter in depth. Half-moon-shaped hammer marks are deeper, they are as much as 1 mm in depth. Some scratches have ferrous corrosion present. This is transfer corrosion from steel used to produce the scratch. No pitting corrosion or stress corrosion cracking was observed.

On the east side of the north leg there is apparent 'tea stain' from de-icing salts. There is a significant amount of weld splatter around the field welds and the welds were blackish in some areas. Under a microscope, green deposits were apparent. This is most likely organic matter living in the coarse surface of the weld.

Figure 5-16—Examination of the stainless steel skin utilizing digital microscopy. Source: S. Kelley

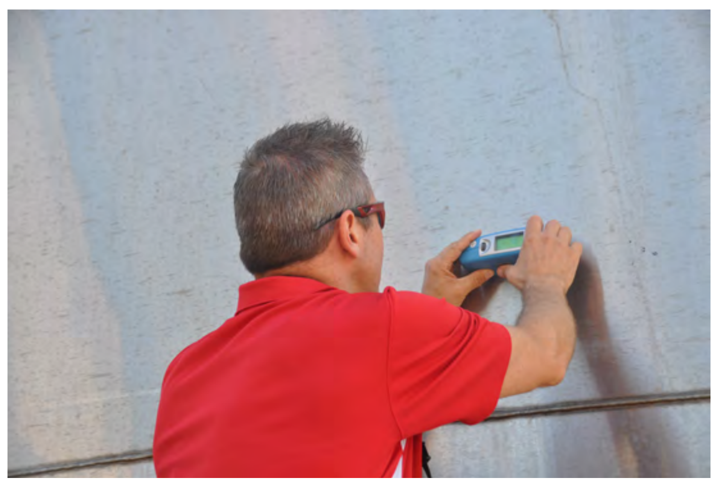

Figure 5-17—Examination of the stainless steel skin utilizing a glossmeter. Source: S. Kelley

South Leg

Like the north leg, there was an abundance of blemishes in the form of incised graffiti from ground to three meters above ground on all three faces. There were also round dents from what appeared to be the striking of a peening hammer. Some scratches have ferrous corrosion present. No pitting corrosion or stress corrosion cracking was observed.

GATEWAY ARCH EXPERT WORKSHOP

The Expert Workshop was held on October 2-4, 2018 at the Gateway Arch National Monument (Figures 5-18, 5-19 and 5-20). The leaders were Al O'Bright, Dan Worth and Stephen Kelley. Those who participated included Michael Ward, Frank Mares and Bob Moore of the NPS; Chance Baragary of Bi-State Development; Dean Koga of the Association for Preservation Technology; Julie Cawby of BVH Architecture; L. William Zahner and Dan Gierer of A. Zahner Company; Catherine Houska of Catherine Houska Consulting LLC; Rich Barry and Thorsten Moewes of Kärcher U.S. Projects; Marshal Jones of GE Global

Figure 5-18—Expert Workshop participants examining the base of the Gateway Arch. Source: S. Kelley

Figure 5-19—Expert Workshop participants sharing their experience. Source: S. Kelley

Figure 5-20—Group photo of Expert Workshop participants.

Source: S. Kelley

Research Manufacturing Technologies; Daryl Roll, Jordan Schaecher and Timothy Velaquez of AstroPak; Richard Pieper formerly of Jan Hird Pokorny Associates; and Joe Sembrat of Evergreene Architectural Arts. A detailed record of this workshop is provided in Appendix C.

The Workshop leaders gave an overview of the three-day Workshop agenda and project timeline and thanked the Getty Conservation Institute (Getty), the Association of Preservation Technology (APT), The National Park Service (NPS) and Bi-State Corporation (Bi-State) for financial support and assistance in developing the Keeping it Modern Grant application.

The NPS described the orthotropic structural design (meaning that the skin is also the structural system) composed of a three-sided "tube" with inner skin of carbon steel and an exterior skin of stainless steel. The uniqueness of the Monument is that the skin serves three functions: it is structural; it is the primary protection against the weather; and it is the primary aesthetic for the Monument. Houska noted that this project was the first structural stainless steel project in the world and lead to the initial development the ASCE-8 standards.

In 1996 the NPS first noticed areas of concern including: streaks and stains on exterior surface; streaks emanating from the welds; and stiffener plates could be seen by oil canning of the skin. Moisture in the concrete was suspected as playing a role and other potential causes were suspected including air pollution from numerous industrial plants close to the Arch, most of which have since closed. Consequently, the NPS commissioned the BVH Team to perform a Phase 1 Corrosion Study in 2006 followed by a Historic Structure Report in 2010. Phases 2 and 3 Corrosion Studies were completed in 2014.

The workshop leaders presented the issues of this current project scope relative to the skin of the Monument: incised graffiti with embedded ferrous staining; oils from touching by humans; scratches from snow removal equipment; damage from other cleaning attempts; surface corrosion; and atmospheric pollutants deposits.

1. ***Water Cleaning (Moewes and Barry of Kärcher)***
   Kärcher described their Cultural Sponsoring Program which is part of their philanthropic philosophy. The program encompasses cleaning of historic monuments at little to no cost. Some key elements of their cleaning philosophy were:

   a. Understanding the four ways soils stick to surface: electrostatic; adhesive; mechanical; and chemical.
   b. The Sinner's Circle: temperature, mechanical (scrubbing), chemical, and time. If you take away one you must make it up with one or more of the other three.
   c. They stated that the cleaning method and access to the area to be cleaned go hand in hand.

2. ***Chemical Cleaning (Roll of AstroPak)***
   AstroPak presented various chemical approaches to cleaning the stainless steel skin including:

   a. **Passivation:** Removal of free iron which will enhance surface corrosion. The passive layer that is created can be compromised by welding, soiling, grinding, sanding, polishing and/or corrosion. Gun shot residue analysis and Scanning Electron Microscopy (SEM) are ways that passivation may be measured non-destructively.
   b. **Pickling**: Removal of material from the surface including ferrous inclusions, which would prepare the surface for passivation.
   c. Remove the passive layer which need to be re-formed. Both iron and chrome are removed which prepares surface for passivation.

   Profilometer measurements on their own are not valid to measure surface elements.

3. ***Laser Ablation Cleaning (Jones)***
   Dr. Jones opened his presentation with some ideas from his experience the industry based on

his understanding of the Arch.

a. CO_2 laser glazing with robot is possible to remove the scratches.

b. Arch indentations and deep graffiti incisions can be infilled using supersonic (velocity) laser deposition combining cold spray with lasers. With supersonic laser deposition one can apply coatings and fill in voids. These techniques do not create heat so there would be no melting.

4. ***Refinishing the Skin (Zahner)***
The refinishing of the incised damage to the skin was discussed. It was noted that in refinishing, some of metal will be removed from surface. This could cause a change of appearance. Some graffiti is too deep to remove without removing a significant amount of metal. Corrosion and embedded ferrous metals would need to be removed prior to refinishing.

5. ***Architectural Conservator Perspective (Pieper, Koga and Sembrat)***
It was discussed how lighting and the time of day present a dramatic visual change of the Arch skin. Some guiding Principles were discussed including:

a. First, do no harm—*Primum non nocere*

b. The need to address root causes rather than symptoms.

c. Patina is "the dirt that you like." Perhaps cleaning the Arch does not mean to remove all deposits and blemishes but perhaps leave in place those effects that have become part of the Monument.

d. Until the NPS initiates measures to prevent further graffiti attacks, graffiti will continue and refinishing of the base will be a lost effort.

e. Treatment philosophies that are implemented now will set methodologies in the future.

f. Choose interventions that are reversible or re-treatable. Do not limit future cleaning options by methods chosen today.

f. We are part of a continuum of this Monument. Do as little as possible and as much as necessary.

6. ***Team Discussion***

GENERAL

It was agreed by the participants that the Expert Workshop was a meaningful process and very successful. It was also a consensus that further cleaning and refinishing studies should not be performed on the Monument, but on stainless steel samples in a laboratory situation. The participants developed a pros and cons matrix for the various cleaning techniques that were discussed (Figure 5-21).

The areas that could be treated were identified: graffiti at the base, superficial corrosion near the base, chloride contaminants near the base, and the entire Monument where there is atmospheric deposition. The easiest to clean (atmospheric deposition) is the most difficult to re-create on a mock-up sample.

Houska and Zahner agreed to work together to locate and procure appropriate stainless steel plate for cleaning and refinishing at Zahner Metalabs in Kansas City, Missouri. Kärcher and AstroPak agreed to perform water and chemical cleaning tests respectively at Zahner Metalab. Joe Sembrat of EverGreene agreed to perform laser cleaning. Zahner will re-create graffiti and superficial corrosion on selected samples that will be cleaned.

GRAFFITI

The graffiti was discussed at length and two approaches were discussed: leave the graffiti in place, or remove it. Is graffiti a palimpsest and should it be conserved as is because in 100 years it may be considered historic?

Cleaning & Refinishing Studies

Gateway Arch - Potential stainless steel skin surface treatments - 4 October 2018							
Media Types		Uses	Pros	Cons	Safety Concern	Aesthetics (Appearance Change)	Gentleness (Material Loss)
Water - cleaning	**Water** pressure and temperature dependant	removal of atmospheric pollutants, chlorides, embedded iron. Hot water including a Chloride wash (Chlor-Rid)	equipment not needed near application (subject to air temperature), minimal containment needed; hot water effective for removal of oil/grease deposits	protection needed for applicator only	no	tbd	tbd
	Steam pressure dependent	removal of atmospheric pollutants, hydrocarbon, grease	steam effective for removal of o	protection needed for applicator only	yes	tbd	tbd
Chemical - cleaning (as per ASTM A380 and A967)	**Cleaning** De greasing, Rinsing, Surfactants	removal of atmospheric pollutants, chlorides, hydrocarbons	Large equipment not required	containment and protection needed	yes	tbd	tbd
	Pickling	removal on embedded iron, surface corrosion	Large equipment not required	containment and protection needed	yes	tbd	tbd
	Chemical passivation	passivation, removal of sulfides, some cleaning	Large equipment not required	containment and protection needed	yes	tbd	tbd
Laser - cleaning and refinishing	**Lasers** 1064 laser ablation, glazing, supersonic	need a vented system to capture the vapor with HEPA filter to test vapor effluent; Remove iron oxides, embedded iron, corrosion, atmospheric depositions, hydrocarbons, chlorides. Scratch treatment.; can "heal" surface at grafitti; Can fill areas of material alteration (dents) when combined with cold spray	Application can be feathered	Equipment needed near application, laser curtains for protection; need to polish afterward	yes	tbd	tbd
Mechanical - cleaning	**Sponge jet**	graffitti coatings, atmospheric pollutants, corrosion		equipment needed near application, noisy, containment needed, recapture of material	yes	no	tbd
	Dry Ice	removes atmospheric pollutants and corrosion with no surface damage, removal of grease, hydrocarbon, organics		equipment needed near application, noisy, limited by air temperature	yes	yes	tbd
Mechanical - refinishing	**Abrasion**	Scratch treatment				yes	tbd
	Electro-polishing	Removal of embedded iron, chlorides, passivation (debate on this). Scratch treatment			yes	yes	tbd

Figure 5-21—Matrix developed by the Expert Workshop participants considering the pros and cons of various cleaning techniques.

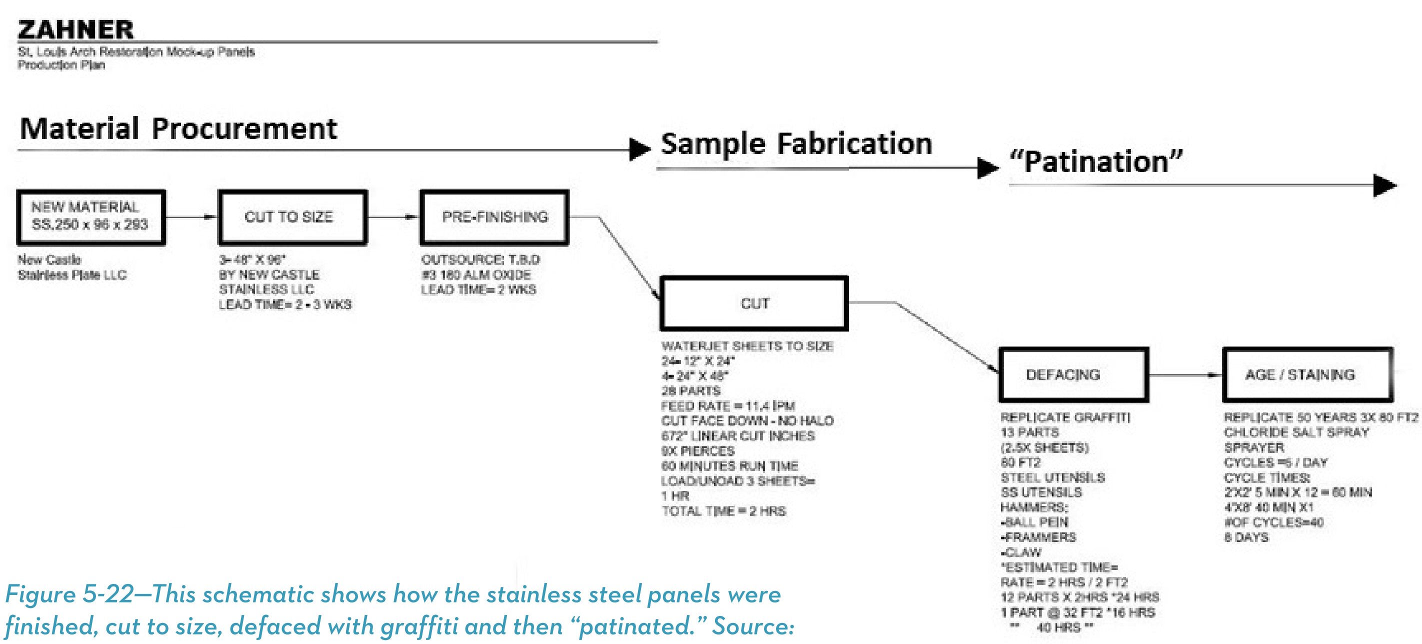

Figure 5-22—This schematic shows how the stainless steel panels were finished, cut to size, defaced with graffiti and then "patinated." Source: Zahner Metalabs

If the graffiti is removed it will only reoccur if measures are not taken to hinder graffiti. The NPS is hesitant to place signage discouraging graffiti or taking punitive action against tourists to cause graffiti. The NPS also does not want to hinder tourists from touching the skin as this was always a part of the original design intent of the Monument.

Finally, it was discussed whether a patch of graffiti could be left in place on one of the legs as an example of damage that was done in the past to discourage future graffiti. Other graffiti would be removed by refinishing. Signage could be provided at the graffiti patch to interpret and provide an example of past damage to be avoided. Refinishing would not be so intrusive so that deep incisions and indentations may be obscured but otherwise left in place.

A simple handrail was also discussed that could be placed around both legs to discourage visitors from accessing the skin at any of the three sides of each leg. The handrail could have a movable and removable gate that could be opened at different locations to control areas where visitors can touch the Monument.

CLEANING

It was agreed the highest priority is to remove chlorides at the base, restore the passive layer and arrest superficial corrosion in this area. Chloride cleaning should be performed yearly with de-ionized water spray and is very easy and effective.

A palette of techniques could be used for the cleaning of the Arch. The technique should be seen as a tool kit where the appropriate tool is chosen for the appropriate task to be performed.

There was an active discussion regarding limitations on cleaning heights. During the Expert Workshop limits were set to the lower 80 feet. It was agreed that there should be no limitations set, and that it should be assumed that the entire Monument would be cleaned.

REFINISHING

The idea of refinishing will be explored further even if it is not implemented. The concern was expressed that continual refinishing over time would lead to significant metal removal. Also, the participants entertained the idea of finishing the base level with the finish that would be knowingly different from the rest of the Monument.

MONITORING

The idea was discussed that the present graffiti should be photo documented so the changes in graffiti can be monitored. At present it is not known how often the graffiti occurs because of the amount of graffiti that presently exists.

MOCK UP WORKSHOP - TESTING SAMPLE PREPARATION

Stainless Steel Panels

The outer skin of the Gateway Arch consists of 1/4-inch-thick A304 alloy austenitic stainless steel panels that are welded together. The plates were specified to have a No. 3 brushed finish. Metallurgical testing performed in 2014 revealed at the stainless steel also had a high sulfur content. The Arch was constructed prior to the introduction of the Argon Oxygen Deoxidation (AOD) furnace into the United States so the stainless steel used would have been high in both carbon and sulfur. Higher sulfur levels cause inclusions (i.e. surface sulfides), which make stainless steel more susceptible to corrosion unless it is chemically passivated, which is why the final step in the Arch construction was chemical passivaton. This made use of a higher sulfur plate preferable for the trials.

It was decided that small-scale cleaning and refinishing samples would not occur on the skin of the Monument but rather on small scale laboratory samples. For the small-scale cleaning samples, we procured a 4 ft x 12 ft x 1/4-inch-thick A304 alloy austenitic stainless steel panel with a high sulfur content. This panel had a No. 3brushed finish. This panel was cut into 2 foot square and 6 inch square sections for the small-scale cleaning testing.

Recreating Visual Anomalies

In order to perform cleaning treatments on the sample panels they needed to be soiled and discolored in some manner. It was agreed there was virtually no way to introduce more than 40 years' worth of industrial pollutant soil deposits on the surface of the sample plates. However, the plates could be discolored with superficial corrosion staining by introducing chemical salts and incised graffiti could be introduced using ferrous metal tools. The following steps were implemented (Figure 5-22):

a. The panels were cleaned with acetone to remove any residual oils or dirt;
b. Ferrous metal objects (steel bars, angles, nails, ball peen hammer, and steel saw filings) were used to scratch into the stainless surface and embed iron oxides into the stainless surface;
c. Panels were laid flat and deicing salts (active ingredients: sodium chloride, magnesium chloride, calcium chloride and potassium chloride) dissolved in tap water were spray applied in several cycles so that the panels would stay wet;
d. Steel filings were sprinkled on to the panels and wet cycled to induce staining. This process was repeated 6 to 8 times per day for 2 weeks;
e. The panels were moved outside for 2 weeks and exposed to the weather in a near vertical position to allow moisture and rain to drain off the panels, and;
f. Prior to cleaning testing, the panels were rinsed with de-ionized water.

These steps were implemented on all plates except for one plate that was left untouched as the control sample (Figure 5-23). After these steps were implemented a second panel was placed aside as a visually compromised control sample (Figure 5-23). It is reasonable to conclude that if acceptable techniques are found to remove surface corrosion, then those techniques and quite possibly much less aggressive techniques can be utilized to remove surface deposits.

There has been discussion regarding whether the incised graffiti should also be removed by refinishing the plates on the base segment of each leg. It was noted that the east face of the south leg had been refinished in the past using the circular grinder and unsuccessful attempt to mitigate the graffiti. This treatment has strikingly changed the appearance of the east face of the leg and is arguably more unsightly than the incised graffiti when viewed from a distance. Consequently, we also performed a cursory study on refinishing as removal of the graffiti is not possible using any of the cleaning methods that were tested.

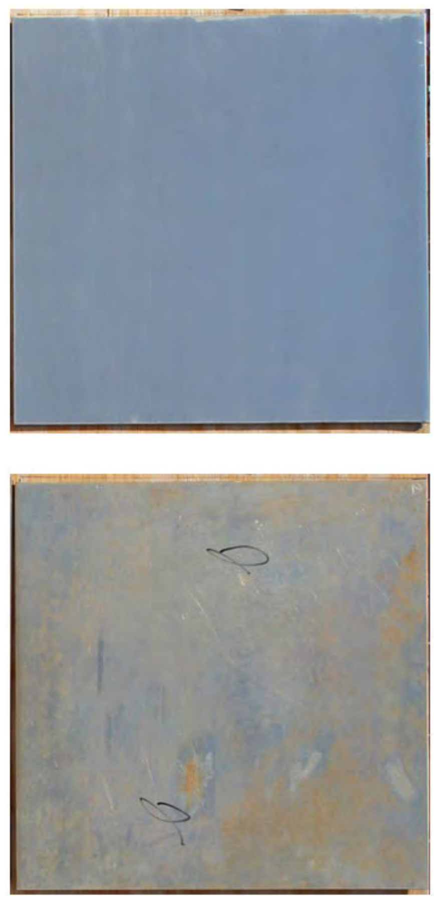

Figure 5-23—The control panels for the study: the clean control panel on the top; and the incised and "patinated" control panel on the bottom. These control panels were kept for comparison with the other panels upon which cleaning testing would be implemented.

Source: S. Kelley

MOCK UP WORKSHOP - CLEANING SAMPLE INSTALLATION

Three entities were invited to implement cleaning procedures using variations of the following techniques: water under pressure; chemical with scrubbing; and laser ablation. These procedures were graded regarding their effectiveness and gentleness. It is important to note that these 2 criteria are not necessarily in harmony with each other so that value judgments were made. The test results were compared with the testing procedures that were implemented in 2014.

1. ***Water and Dry Ice Cleaning Techniques (Kärcher)*** Kärcher performed cleaning testing on plate samples 3 and 4 on March 26, 2019 at Zahner Metalabs in Kansas City Missouri. They performed cleaning testing on plate sample 5 on May 17 and July 9, 2019 at their facility in Winnenden, Germany. Testing in the German facility was carried out because of the availability of equipment that could not be found in the United States and could achieve very high pressures and velocities. The tests are described in detail in Appendix D. Following is a list of their tests:

Test 3A: High pressure water cleaning using a 1% solution of ChlorRid mixed in potable water. The working pressure of the water in the hose was 180 bar (2600 psi). Temperature of the water in the hose was 87°C (189°F). The spray shape from the nozzle was that of a fan with a spread of 25°. The nozzle was held approximately 15 cm (6 in) from and oriented perpendicular to the surface. The impact pressure was estimated to be between 1 to 2 bar (15 and 30 psi) (Figure 5-24).

Test 3B: Steam cleaning using a 1% solution of ChlorRid mixed in potable water. The working pressure of the steam in the hose was 55 bar (800 psi). The temperature of the steam in the hose was 135°C (275°F). The spray shape from the nozzle was that of a fan with the spread of 50°. The nozzle was held 10 to 15 cm (4 to 6 in) from and oriented perpendicular to the surface (Figure 5-25).

Figure 5-24—Test 3A high pressure water cleaning by Kärcher. Source: S. Kelley

Figure 5-25—Test 3B steam cleaning by Kärcher. Source: S. Kelley

Test 4A: Ultra-high pressure water cleaning using 1% solution of ChlorRid mixed in potable water. The working pressure of the water in the hose was 500 bar (7250 psi). The temperature of the water was 15°C (60°F). The spray shape from the nozzle was that of a fan with the spread of 15°F. The nozzle was held 5 to 10 cm (2 to 4 in) from and oriented perpendicular to the surface (Figure 5-26).

Test 4B-1: Dry ice (a solid form of carbon dioxide) cleaning. The working pressure was 3 bar (43 psi). The temperature of the dry ice was -79°C (-110°F). The spray shape from the nozzle was round. The nozzle was held 10 to 15 cm (4 to 6 in) from and oriented perpendicular to the surface (Figure 5-27).

Figure 5-26—Test 4A ultrahigh pressure (500 bar) water cleaning by Kärcher. Source: S. Kelley

Figure 5-27—Test 4B – 2 dry ice cleaning by Kärcher. Source: S. Kelley

Figure 5-28—Test 6A ultrahigh pressure (1000 bar) water cleaning by Kärcher at their facility in Germany. Source: Kärcher

Test 4B-2: Dry ice (a solid form of carbon dioxide) cleaning. The working pressure was 6 bar (87 psi). The temperature of the dry ice was -79°C (-110°F). The spray shape from the nozzle was round. The nozzle was held 10 to 15 cm (4 to 6 in) from and oriented perpendicular to the surface.

Test 4B-3: Dry ice (a solid form of carbon dioxide) cleaning. The working pressure was 8.5 bar (123 psi). The temperature of the dry ice was -79°C (-110°F). The spray shape from the nozzle was round. The nozzle was held 10 to 15 cm (4 to 6 in) from and oriented perpendicular to the surface.

Test 6A: Ultra-high pressure water cleaning using potable water. Working pressure of the water in the hose was 1,000 bar (14,504 psi). Water temperature is not provided. The spray shape from the nozzle was that of a fan with the spread of 20°. The nozzle was held 2.5 to 5 cm (1 to 2 in) from and oriented perpendicular to the surface (Figure 5-28).

Figure 5-29—Test 6B-1 ultrahigh pressure (1500) water cleaning by Kärcher and their facility in Germany. Source: Kärcher

Test 6B-1: Ultra-high pressure water cleaning using potable water. Working pressure of the water in the hose was 1,500 bar (21,756 psi). The temperature of the water was 150°F. The spray shape from the nozzle was that of a fan with the spread of 10°. The nozzle was held 2.5 to 5 cm (1 to 2 in) from and oriented perpendicular to the surface (Figure 5-29).

Test 6B-2: Ultra-high pressure water cleaning using potable water. Working pressure of the water in the hose was 2,200 bar (31,908 psi). The temperature of the water was 65°C (150°F). The spray shape from the nozzle was that of a fan with the spread of 10°. The nozzle was held 2.5 to 5 cm (1 to 2 in) from and oriented perpendicular to the surface (Figure 5-30).

Test 6B-3: Ultra-high-pressure water cleaning using potable water. Working pressure of the water in the hose was 3,000 bar (43,511 psi). The temperature of the water was 65°C (150°F). The spray shape from the nozzle was that of a fan with the spread of 10°. The nozzle was held 2.5 to 5 cm (1 to 2 in) from and oriented perpendicular to the surface (Figure 5-31).

Test 6B-4: Ultra-high pressure water cleaning using potable water. Working pressure of the water in the hose was 3,000 bar (43,511 psi). The temperature of the water was 65°C (150°F). The spray shape from the nozzle was round. The nozzle was held 2.5 to 5 cm (1 to 2 inch) from and oriented perpendicular to the surface (Figure 5-32).

The results of the cleaning of these three panels using water techniques shown in Figure 5–33.

Figure 5-30—Test 6B-2 ultrahigh pressure (2200) water cleaning by Kärcher and their facility in Germany. Source: Kärcher

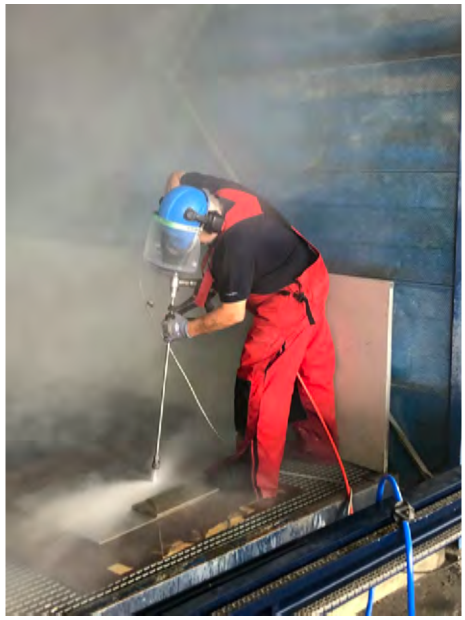

Figure 5-31—Test 6B-3 ultrahigh pressure (3000) water cleaning by Kärcher and their facility in Germany. Source: Kärcher

Figure 5-32—ultrahigh pressure (1500) water cleaning using a round nozzle by Kärcher and their facility in Germany. Source: Kärcher

Figure 5-33—Result from testing, shown from left to right, on panels 3, 4 and 6. Source: S. Kelley

2. *Chemical Cleaning Techniques (Astro Pak)*

Astro Pak, incorporated in Costa Mesa, CA, performed cleaning testing on plate samples 7, 8 and 9 on March 25-27, 2019 at Zahner Metalabs in Kansas City Missouri. Generally, the Astro Pak processes were multistage and were designed to remove organic material, debris, free iron, de-rouge and passivate stainless steel surfaces. Chemicals used included degreasing agents, phosphoric and citric acids, multiple chelants and surface-active agents for the removal of organic material, metal oxides and other corrosion promoting impurities. The tests are described in detail in Appendix E. The significant tests listed below are those performed on panels 7 and 9. Testing on panel 8 was a pre-testing procedure (Figures 5-34 and 5-35) in order to fine-tune the tests on panels 7 and 9. Following is a list of their tests:

Figure 5-34—Pretesting performed on panel 8 prior to testing on panels 7 and 9. In this image panel 8 is shown prior to pretesting. Source: S. Kelley

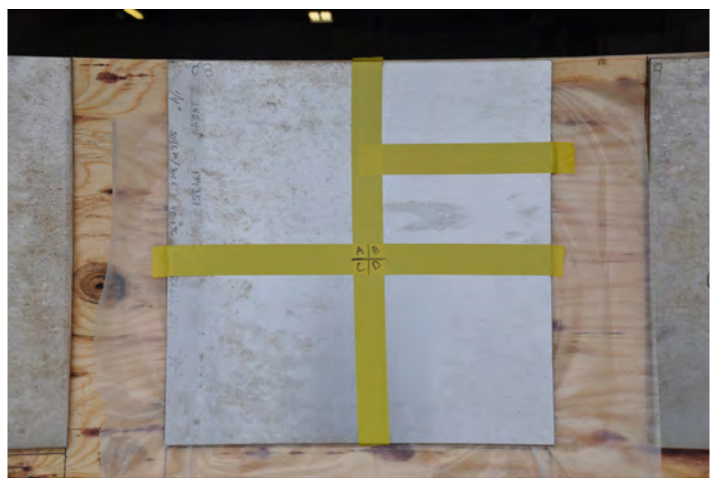

Figure 5-35—Pretesting performed on panel 8 prior to testing on panels 7 and 9. In this image panel 8 is shown after pretesting. Source: S. Kelley

Test 7A

- Isopropyl alcohol cleaner, a mild alkaline, was uniformly applied to the surface at a minimum surface temperature of 15°C (60°F), and the surface was then wiped to remove film or other debris (Figure 5-36).
- Next a uniform layer of AP 401 gel, a de-rouging compound, was applied to the surface and allowed to dwell for 30 to 120 minutes, or until the surface was visually free of surface corrosion and stains (Figure 5-37). The AP 401 gel was then applied to a white Scotch Brite (WSB) pad and the surface was lightly but vigorously scrubbed by hand (Figure 5-38). After completion of the de-rouging in process, the surface was rinsed with deionized water and wiped with an isopropyl alcohol saturated (IPA) clean wipe to remove all residue.
- Next a uniform layer of UltraPass gel passivation solution was applied to the surface and allowed to dwell for 30 to 120 minutes. After completion of the passivation process, the surface was rinsed with deionized water and wiped with an isopropyl alcohol saturated (IPA) clean wipe to remove all residue.
- Finally, the surface was wiped with isopropyl alcohol saturated (IPA) cleaning wipes to ensure cleanliness and allow to air dry.

Figure 5-36—Wiping of the surface of the panel with isopropyl alcohol and a cotton cloth to remove film and other debris.

Source: S. Kelley

Figure 5-37—Application of the rouging compound with a paintbrush. Source: S. Kelley

Figure 5-38—Vigorous scrubbing of the surface by hand using a Scotch Brite pad. Source: S. Kelley

Test 7B

- Isopropyl alcohol cleaner, a mild alkaline, was uniformly applied to the surface at a minimum surface temperature of 15°C (60°F), and the surface was then wiped to remove film or other debris.
- Next a uniform layer of AP 401 gel, a de-rouging compound, was applied to the surface and allowed to dwell for 30 to 120 minutes, or until the surface was visually free of surface corrosion and stains. The AP 401 gel was then applied to a white Scotch Brite (WSB) pad and the surface was lightly but vigorously scrubbed aided by an orbital sander/polisher (Figure 5-39). After completion of the de-rouging in process, the surface was rinsed with deionized water and wiped with an isopropyl alcohol saturated (IPA) clean wipe to remove all residue.
- Next a uniform layer of UltraPass gel passivation solution was applied to the surface and allowed to dwell for 30 to 120 minutes. After completion of the passivation process, the surface was rinsed with deionized water and wiped with an isopropyl alcohol saturated (IPA) clean wipe to remove all residue.
- Finally, the surface was wiped with isopropyl alcohol saturated (IPA) cleaning wipes to ensure cleanliness and allow to air dry.

Test 8A

- Isopropyl alcohol cleaner, a mild alkaline, was uniformly applied to the surface at a minimum surface temperature of 15°C (60°F), and the surface was then wiped to remove film or other debris.
- Next a uniform layer of AP 401 gel, a de-rouging compound, was spray and brush applied to the surface and allowed to dwell for 30 minutes or less.
- AP 401 gel was reapplied every 10 to 15 minutes and scrubbed with WSB pad.

Figure 5-39—Vigorous scrubbing of the surface using an orbital sander and a Scotch Brite pad. Source: S. Kelley

- The surface was rinsed with deionized water and wiped with an isopropyl alcohol saturated (IPA) clean wipe to remove all residue.
- Finally, the surface was wiped with isopropyl alcohol saturated (IPA) cleaning wipes to ensure cleanliness and allow to air dry.

Test 8B-1

- Isopropyl alcohol cleaner, a mild alkaline, was uniformly applied to the surface at a minimum surface temperature of 15°C (60°F), and the surface was then wiped to remove film or other debris.
- Next a uniform layer of AP 410, a de-rouging compound, was spray and brush applied to the surface and allowed to dwell for 30 minutes or less.
- A layer of AP 401 gel was then spray and brush applied.
- AP 401 gel was reapplied every 10 to 15 minutes and scrubbed with WSB pad.
- The surface was rinsed with deionized water and wiped with an isopropyl alcohol saturated (IPA) clean wipe to remove all residue.

- Finally, the surface was wiped with isopropyl alcohol saturated (IPA) cleaning wipes to ensure cleanliness and allow to air dry.

Test 8B-2

- Isopropyl alcohol cleaner, a mild alkaline, was uniformly applied to the surface at a minimum surface temperature of 15°C (60°F), and the surface was then wiped to remove film or other debris.
- Next a uniform layer of AP 410, a de-rouging compound, was spray and brush applied to the surface and allowed to dwell for 30 minutes or less.
- Another layer of AP 401 gel was then spray and brush applied.
- AP 401 gel was reapplied every 10 to 15 minutes and scrubbed with WSB pad.
- The surface was rinsed with deionized water and wiped with an isopropyl alcohol saturated (IPA) clean wipe to remove all residue.
- Finally, the surface was wiped with isopropyl alcohol saturated (IPA) cleaning wipes to ensure cleanliness and allow to air dry.

Test 8C

- Isopropyl alcohol cleaner, a mild alkaline, was uniformly applied to the surface at a minimum surface temperature of 15°C (60°F), and the surface was then wiped to remove film or other debris.
- Next a uniform layer of AP 401 gel, a de-rouging compound, was spray and brush applied to the surface and allowed to dwell for 30 minutes or less.
- AP 401 gel was reapplied every 10 to 15 minutes and scrubbed with WSB pad.
- The surface was rinsed with deionized water and wiped with an isopropyl alcohol saturated (IPA) clean wipe to remove all residue.
- Finally, the surface was wiped with isopropyl alcohol saturated (IPA) cleaning wipes to ensure cleanliness and allow to air dry.

Test 8D

- Isopropyl alcohol cleaner, a mild alkaline, was uniformly applied to the surface at a minimum surface temperature of 15°C (60°F), and the surface was then wiped to remove film or other debris.
- Next a uniform layer of AP 401 gel, a de-rouging compound, was spray applied to the surface, scrubbed with a WSB pad and allowed to dwell for 30 minutes or less.
- Another layer of AP 401 gel was then reapplied by spray and scrubbed with a WSB pad.
- AP 401 gel was reapplied every 10 to 15 minutes and scrubbed with WSB pad.
- The surface was rinsed with deionized water and wiped with an isopropyl alcohol saturated (IPA) clean wipe to remove all residue.
- Finally, the surface was wiped with isopropyl alcohol saturated (IPA) cleaning wipes to ensure cleanliness and allow to air dry.

Test 9A

- Isopropyl alcohol cleaner, a mild alkaline, was uniformly applied to the surface at a minimum surface temperature of 15°C (60°F), and the surface was then wiped to remove film or other debris.
- Next a uniform layer of the NeutraRouge solution, a de-rouging compound, was applied to the surface and allowed to dwell for 30 to 120 minutes, or until the surface was visually free of surface corrosion and stains. The NeutraRouge was then applied to a white Scotch Brite (WSB) pad and the surface was lightly but vigorously scrubbed by hand. After completion of the de-rouging in process, the surface was rinsed with deionized water and wiped with an isopropyl alcohol saturated (IPA) clean wipe to remove all residue.

- Next a uniform layer of UltraPass gel passivation solution was applied to the surface and allowed to dwell for 30 to 120 minutes. After completion of the passivation process, the surface was rinsed with deionized water and wiped with an isopropyl alcohol saturated (IPA) clean wipe to remove all residue.
- Finally, the surface was wiped with isopropyl alcohol saturated (IPA) cleaning wipes to ensure cleanliness and allow to air dry (Figure 5-40).

Test 9B

- Isopropyl alcohol cleaner, a mild alkaline, was uniformly applied to the surface at a minimum surface temperature of 15°C (60°F), and the surface was then wiped to remove film or other debris.
- Next a uniform layer of the NeutraRouge solution, a de-rouging compound, was applied to the surface and allowed to dwell for 30 to 120 minutes, or until the surface was visually free of surface corrosion and stains. The NeutraRouge was then applied to a white Scotch Brite (WSB) pad and the surface was lightly but vigorously scrubbed aided by an orbital sander/polisher. After completion of the de-rouging in process, the surface was rinsed with deionized water and wiped with an isopropyl alcohol saturated (IPA) clean wipe to remove all residue.

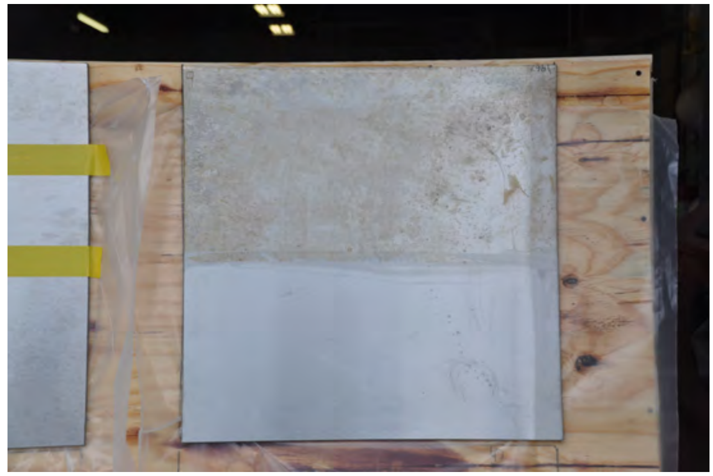

Figure 5-40—Panel 9 with the lower half cleaned.
Source: S. Kelley

- Next a uniform layer of UltraPass gel passivation solution was applied to the surface and allowed to dwell for 30 to 120 minutes. After completion of the passivation process, the surface was rinsed with deionized water and wiped with an isopropyl alcohol saturated (IPA) clean wipe to remove all residue.
- Finally, the surface was wiped with isopropyl alcohol saturated (IPA) cleaning wipes to ensure cleanliness and allow to air dry.

The results of the cleaning of these three panels using water techniques shown below in Figure 5–41.

Figure 5-41—Result from testing, shown from left to right, on panels 7, 8 and 9.

Source: S. Kelley

3. Laser Cleaning Techniques (Evergreene/Adapt)

Evergreene Architectural Arts, incorporated in New York, NY, in conjunction with Adapt Laser Systems of Kansas City MO, performed cleaning testing on panel samples 1 1, 12 and 13 on March 27, 2019 at the Adapt Laser Facility on 1218 Guinotte Avenue in Kansas City. The variables in the testing procedures using lasers were power output in pulse frequency, mark speed, and sweep speed. In addition, the direction of the laser was run perpendicular (Figure 5-42), parallel (Figure 5-43) and diagonal (Figure 5-44) to the brushed finish grain on the surface of the panel. The result was immediate (Figure 5–45). By changing these variables, there are countless further tests that could be implemented beyond what was done in March 27, as can be seen on panel 13. The tests are described in detail in (Appendix F). The significant tests listed below are those performed on panels 11 and 12. Testing on panel 13 was a pre-testing and more experimental procedure. Following is a list of their tests:

Test 11A: The width of the laser scan was 100 mm. The pulse intensity was 12 MW/cm2. The sweep speed was 13.19 mm/sec. The laser was run diagonal to the brushed finish grain.

Test 11B: The width of the laser scan was 100 mm. The pulse intensity was 12 MW/cm2. The sweep speed was 6.73 mm/sec. The laser was run parallel to the brushed finish grain.

Test 11C: The width of the laser scan was 100 mm. The pulse intensity was 12 MW/cm2. The sweep speed was 2.42 mm/sec. The laser was run parallel to the brushed finish grain.

Test 11D: The width of the laser scan was 100 mm. The pulse intensity was 24 MW/cm2. The sweep speed was 29.33 mm/sec. The laser was run parallel to the brushed finish grain.

Test 12A: The width of the laser scan was 100 mm. The pulse intensity was 12 MW/cm2. The sweep speed was 13.19 mm/sec. The laser was run perpendicular to the brushed finish grain.

Test 12B: The width of the laser scan was 100 mm. The pulse intensity was 12 MW/cm2. The sweep speed was 13.19 mm/sec. The laser was run parallel to the brushed finish grain.

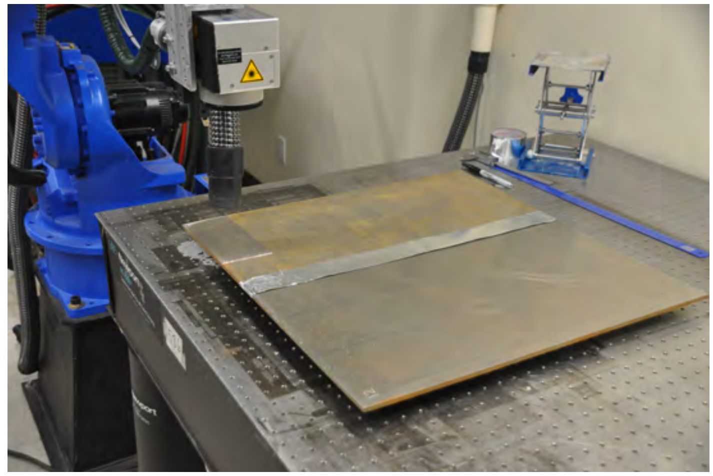

Figure 5-42—Laser cleaning with the laser running perpendicular to the brushed finish. Source: S. Kelley

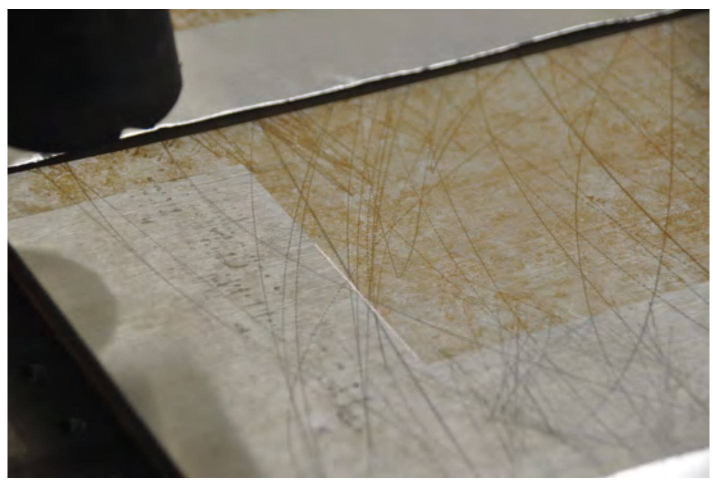

Figure 5-43—Laser cleaning with the laser running parallel to the brushed finish. Source: S. Kelley

Test 13B: The width of the laser scan was 100 mm. The pulse intensity was 24 MW/cm2. The sweep speed was 29.33 mm/sec. The laser was run parallel to the brushed finish grain.

The results of the cleaning of these three panels using laser cleaning techniques shown in Figure 5–46.

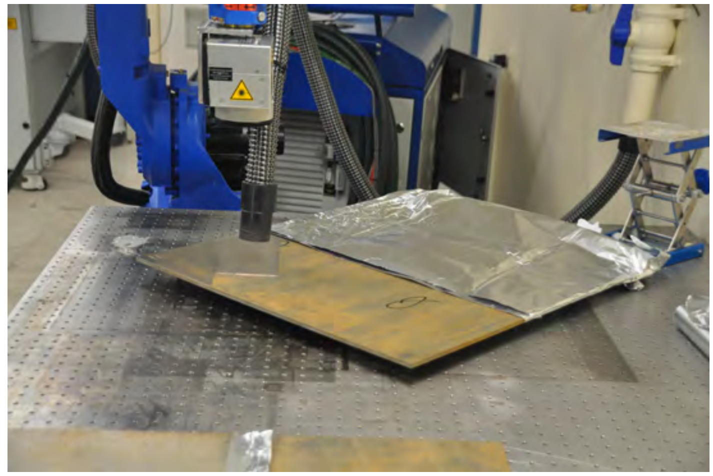

Figure 5-44—Laser cleaning with a laser running diagonal to the brushed finish. Source: S. Kelley

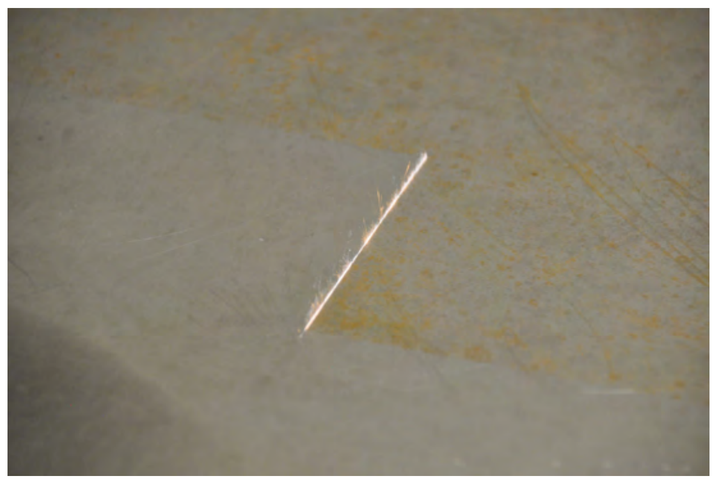

Figure 5-45—Close up view of the laser cleaning showing the immediate results. Source: S. Kelley

Figure 5-46—Result from testing, shown from left to right, on panels 11, 12 and 13.

Source: S. Kelley

4. ***Cleaning Techniques Performed in 2014 (WJE)***
Cleaning trials were performed on the exterior stainless steel to evaluate the effectiveness of various cleaning systems to remove blemishes, deposits, and discoloration by a team led by Wiss, Janney, Elstner Associates, Inc. (WJE). The cleaning studies were completed on the east face, on the center panel at the base of the north leg (Figure 5-47), and at the intrados (Figure 5-48), which was accessed using Industrial Rope Access techniques. Cleaning systems tested included solvents, detergents, degreasers, weak acids, and abrasive techniques. Following is a list of their successful tests:

Test A

- The surface was first wiped with a clean cotton cloth dipped in xylene followed by a clean cotton cloth dipped in ethanol to remove organic residue such as oils, waxes, lotions and the like.
- The surface was then rinsed with water and wiped with ethanol and a clean cotton rag. Bar Keeper's Friend (5 to 10% oxalic acid, pH 1.5 to 2.5, mixed with powdered feldspar) was mixed with water and applied as a paste slurry.
- The surface was then vigorously scrubbed by hand with a mildly abrasive nonmetallic pad.
- The surface was finally rinsed with deionized water and cotton towel dried.

Test A2

- The surface was first wiped with a clean cotton cloth dipped in xylene followed by a clean cotton cloth dipped in ethanol to remove organic residues such as oils, waxes, lotions and the like.
- The surface was then rinsed with water and wiped with ethanol and a clean cotton rag. Bar Keeper's Friend (5 to 10% oxalic acid, pH 1.5 to 2.5, mixed with powdered feldspar) was mixed with water and applied as a paste slurry.
- The surface was then vigorously scrubbed by hand with a mildly abrasive nonmetallic pad.

Figure 5-47—Testing being performed using mild chemical/ abrasive methods on the east face of the north leg of the monument in 2014. The technician is Catherine Houska. Source: S. Kelley

Figure 5-48—Testing being performed at approximately 425 feet above grade on atmospheric pollutant deposits. This is the only cleaning testing done only on deposits. Source: S. Kelley

- After removal of the paste, the surface was treated with Avesta 630 passivate or (2 to 4.5% hydrogen peroxide, pH 7).
- The surface was finally rinsed with deionized water and cotton towel dried.

Test C

- The surface was first wiped with a clean cotton cloth dipped in xylene followed by a clean cotton cloth dipped in ethanol to remove organic residues such as oils, waxes, lotions and the like.
- The surface was then rinsed with water and wiped with ethanol and a clean cotton rag.
- The surface was vigorously scrubbed by hand with a Norton woven abrasive ultra-fine sanding pad.
- The surface was finally rinsed with deionized water and cotton towel dried.

Test C2

- The surface was first wiped with a clean cotton cloth dipped in xylene followed by a clean cotton cloth dipped in ethanol to remove organic residues such as oils, waxes, lotions and the like.
- The surface was then rinsed with water and wiped with ethanol and a clean cotton rag.
- The surface was vigorously scrubbed by hand with a Norton woven abrasive ultra-fine sanding pad.
- The surface was then treated with Avesta 630 passivate or (2 to 4.5% hydrogen peroxide, pH 7).
- The surface was finally rinsed with deionized water and cotton towel dried.

Test F

- The surface was first wiped with a clean cotton cloth dipped in xylene followed by a clean cotton cloth dipped in ethanol to remove organic residues such as oils, waxes, lotions and the like.
- The surface was then rinsed with water and wiped with ethanol and a clean cotton rag.
- Avesta cleaner 401 (10 to 20% phosphoric acid, 0.1 to 0.9% hexafluorosilicic acid, 3 to 5% alcohol, pH .6).
- The surface was then treated with Avesta 630 passivate or (2 to 4.5% hydrogen peroxide, pH 7).
- The surface was finally rinsed with deionized water and cotton towel dried.

Test H

- The surface was first wiped with a clean cotton cloth dipped in xylene followed by a clean cotton cloth dipped in ethanol to remove organic residues such as oils, waxes, lotions and the like.
- The surface was then rinsed with water and wiped with ethanol and a clean cotton rag. Bar Keeper's Friend (5 to 10% oxalic acid, pH 1.5 to 2.5, mixed with powdered feldspar) was mixed with water and applied as a paste slurry.
- The surface was vigorously scrubbed by hand with a Norton woven abrasive ultra-fine sanding pad.
- The surface was finally rinsed with deionized water and cotton towel dried.

The results of the cleaning of the WJE testing are shown in Figure 5-49.

Figure 5-49—The labeled areas of the testing on the east face of the north leg of the monument in 2014. The successful tests were found to be A, C, F and H. Source: 2015 Gateway Arch Corrosion Investigation Part III, WJE

MOCK UP WORKSHOP - RESULTS OF SAMPLE CLEANING

1. ***Effectiveness (Aesthetic) Assessment***
   The visual or aesthetic assessment, the most important aspect of the selection of cleaning systems, was performed by observing the mock up panels relative to the control panel. This was easily done for the water and dry ice cleaning trials, chemical cleaning trials and laser cleaning trials as a test panels were altogether with the control panel. Observing these panels in different interior and exterior light applications it was found that indirect lighting outside during a sunny day was the optimal condition (Figure 5-50). Attributes which play a role in this visual assessment are surface texture, surface roughness, gloss and luster. The goal in the visual assessment was to find those cleaning methods which provide an appearance which deviates the last from the control panel. A visual comparison of these techniques, excluding those implemented in 2014, are presented in Figure 5 – 51.

   WATER & DRY ICE CLEANING

   The techniques tested by Kärcher—which included pressurized water, steam and dry ice—may be acceptable to remove surface deposits on the upper reaches of the Monument. However, they left discolorations on the surface and were not found to be suitable for the removal of surface

Figure 5-50—The test panels showing water, dry ice, chemical and laser cleaning techniques located outside during a sunny day for visual (aesthetic) assessment. Source: J. Cawby

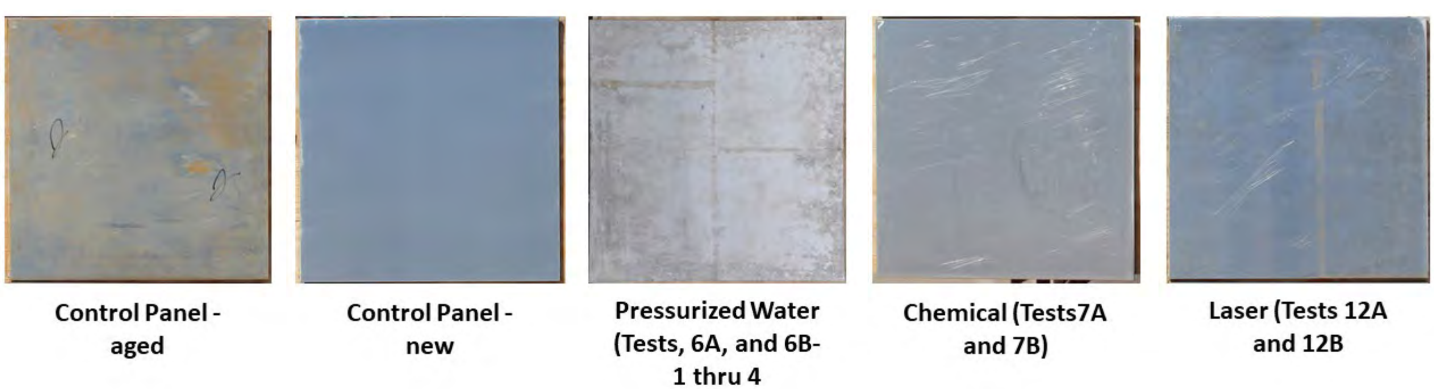

Figure 5-51—The most successful cleaning samples using water, chemical and laser are shown on the right with the control panels shown on the left. Source: S. Kelley

corrosion or the corrosion from iron deposits within the graffiti.

CHEMICAL CLEANING

The AstroPak chemical cleaning was found to be successful in removing surface corrosion and embedded metal oxides within the graffiti. The chemical techniques that they utilized produced the appearance of the test panels closest to the control panel.

LASER CLEANING

The techniques tested by Adapt Laser may be acceptable to remove surface deposits on the upper reaches of the Monument. The laser cleaning was found to be only moderately successful in removing surface corrosion and embedded metal oxides within the graffiti. Overlap lines were visible on the sample panels (Figure 5-52).

Discussions with the use of this technique were focused upon a robotic delivery system rather than scaffolding, and concern has been expressed about leaving streaks on the Monument from the climbing robot wheels. This is a relatively new technology for this application, and further testing is required.

CHEMICAL/ABRASIVE CLEANING (2014)

Based on the chemical/abrasive trials that were implemented in 2014 it was found that the surface deposits could easily be removed. Some of these were the only testing performed high above the base, and results would indicate the surface deposits may be easily removed using any variety of techniques. However, this testing was effective at removing only some of the superficial corrosion staining.

2. *Gentleness Assessment*

In addition to the visual evaluation of the samples after the cleaning trials, a metallurgical assessment was conducted by Catherine Houska Consulting LLC and included specular gloss (reflectivity), surface roughness and microscopic surface evaluation. The study was limited to two primary goals: removal of deicing salt related corrosion staining, and removal of embedded iron. The limitation was the lack of recreating surface deposits on the upper reached of the monument in a laboratory setting. The gentleness assessment provides a metric to determine those cleaning methods that deviate the least from that of the unblemished control panel.

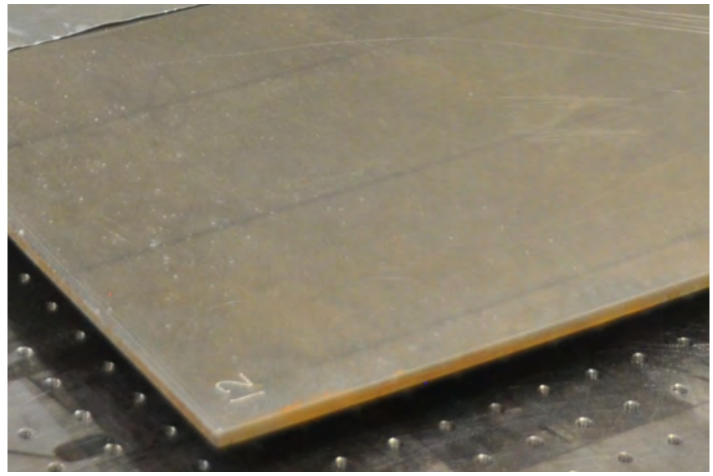

Figure 5-52—Close up view of panel 12 after laser cleaning showing lines where the passes with the laser overlapped. Source: S. Kelley

The tools used are quality control measures and are well known in the metal finishes industry. These tools would need to be further developed for this unique use and should be used in tandem and not apart from the visual assessment visual assessments described above.

SPECULAR GLOSS

A glossmeter was used to measure the specular, or mirror-like, reflection gloss of the surface of cleaned samples (Figure 5-53). Gloss is determined by projecting a beam of light at a fixed intensity and angle onto a surface and measuring the amount of reflected light at an equal but opposite angle. Specular gloss is probably the most often used parameter when the surface optical quality of a product needs to be evaluated.

The specular gloss values for the water cleaning samples were all in the very low-range, i.e. furthest from the control sample. The values for chemical cleaning sample #9 for the 410, handbuffed/bottom and neutral rouge/top were in the high-range, i.e. closest to the control sample with the neutral rouge having a substantially smaller standard deviation. The laser cleaning measurements were in the mid-range compared with the Control Sample with the best results on Sample 12A.

Figure 5-53—Using a MeterTo 3nh Tri Gloss meter to measure spectral gloss. Source: D. Worth

SURFACE ROUGHNESS

A profilometer is a measuring instrument used to measure a surface's profile, to quantify its roughness (Figure 5-54). The profilometer used for this assessment automatically measured numerous characteristics. The average values for the following three primary measurements were used for comparison: Ra (Average Roughness) is the average deviation of the profile from the mean line; Rz is the average of the 5 peak-to-valley heights; and Rmax is the maximum peak-to-valley height within one cut-off (Figure 5-55).

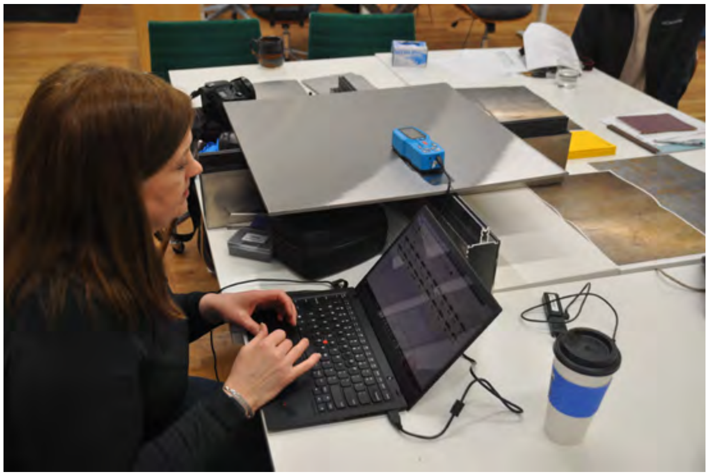

Figure 5-54—Using a VTSYIQI Surftest KR200 Portable Profilometer to measure surface roughness. Source: S. Kelley

When all three surface roughness parameters were considered, the chemical cleaning samples were more similar in surface roughness to the control samples. The laser cleaning samples were in the mid-range with Sample 12A yielding the best results. The surface roughness of the water cleaning samples and some of the laser samples were not tested because the remaining corrosion product on the surface would have damaged the profilometer.

MICROSCOPIC EVALUATION

A digital microscope (Figure 5-56) was utilized to compare the water, chemical and laser cleaning samples with the control sample (Figure 5-57) on a micro-scale. With the water cleaning samples staining around areas with embedded iron in the incisions can be seen indicating that the embedded iron had not been removed (Figure 5-58). This cleaning method was not considered effective.

The chemical cleaning Sample 9 met with the greatest success (Figure 5-59). Deicing salts staining was removed. No embedded iron particles were observed but some residual staining was still present on the surface. This method was considered effective.

Laser cleaning provided varying results, many of them unsatisfactory. The most successful Sample was 12A. The embedded carbon steel and corrosion staining were removed other than very small particles (Figure 5-60). However, on this same sample there was what is hypothesized as heat-related surface damage which appeared as darkened areas that were not visible to the naked eye (Figure 5-61). On Sample 13 the brushed finish of the stainless steel appeared to be melted by the laser (Figure 5-62). There was significant heat related surface damage (dark areas) over the entire surface. Of the cleaning methods evaluated, the one with the most flexibility in the least amount of research is lasers. The gentleness evaluation of lasers reveals that more research is required to determine those parameters will not cause damage to the surface of the monument.

3. ***Economic Feasibility Assessment***
The feasibility assessment (cost aspects) includes several factors primary of which are access to the work, availability of technology, physical work required and disposal of potentially harmful wastes. Of these factors the one with the greatest impact is access when considering cleaning above the lowest 8 segments. Access to the upper reaches of the Monument is nothing less than daunting. Providing scaffolding to completely cover the Monument, if possible, may cost tens of millions of dollars. It is the single most important factor in the feasibility assessment.

WATER & DRY ICE CLEANING

The greatest challenges access to the upper reaches of the Monument. As previously described scaffolding access, if at all possible, would be extremely expensive. Materials would need to be moved to areas of the Monument to be clean from the ground and would include heavy equipment which would be required to pressurize water being used.

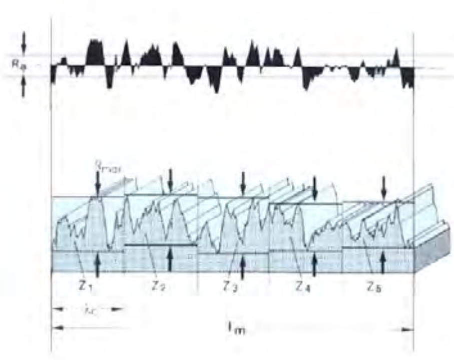

Figure 5-55—Graphic depiction of Ra surface measurement at top and the derivations of Rz and Rmax at the bottom. Source: Appendix G

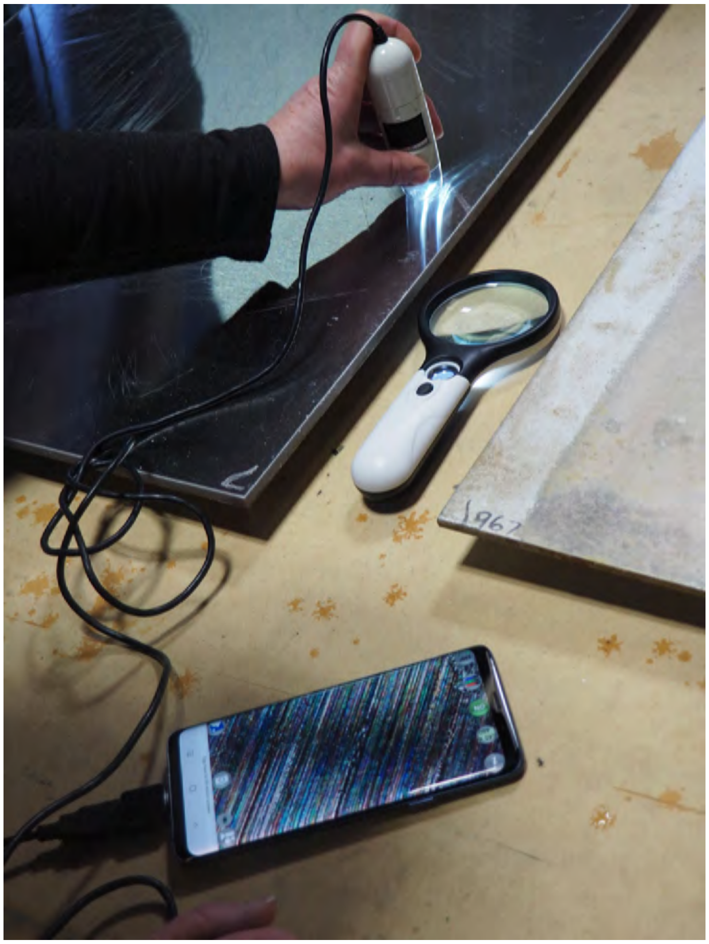

Figure 5-56—Using a Dino-Lite USB Digital Microscope with 10x-230x optical magnification to photograph the surface on a micro-scale. Source: D. Worth

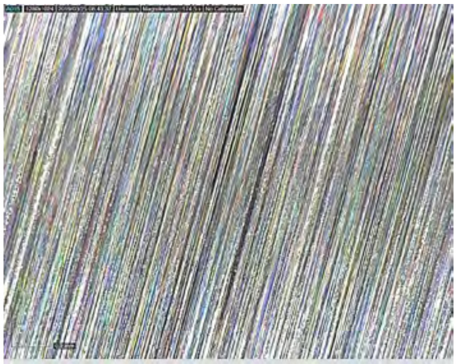

Figure 5-57—Micrograph of the unblemished control panel. Source: C. Houska

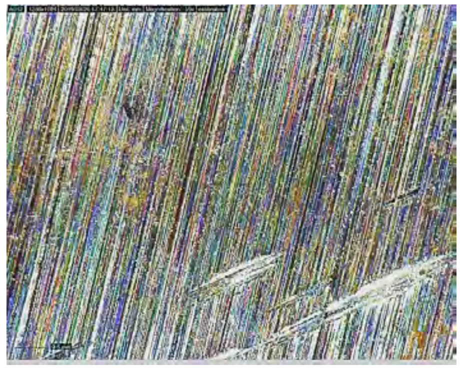

Figure 5-58—Water cleaning Sample 4A shows significant remaining staining associated with deicing salts pitting. 58.9x. Source: C. Houska

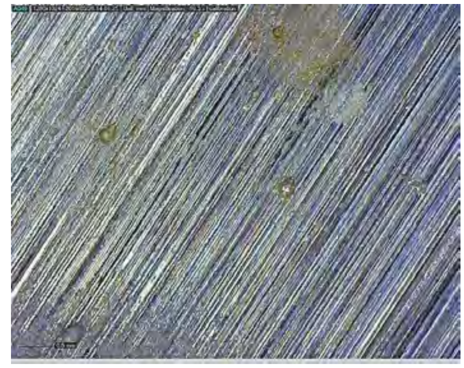

Figure 5-59—Chemical cleaning Sample 9. No embedded iron particles were observed but some residual staining was still present on the surface. 59.3x. Source: C. Houska

Figure 5-60—Laser cleaning Sample 12A. There is residual surface contamination from corrosion staining and embedded iron. 50.9x. Source: C. Houska

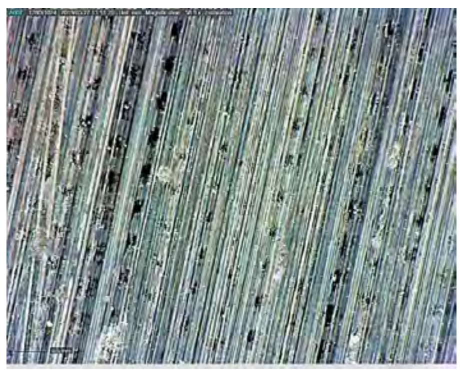

Figure 5-61—Laser cleaning Sample 12A. In this area there are what is believed to be significant heat-related surface damage (dark spots). 58.9x. Source: C. Houska

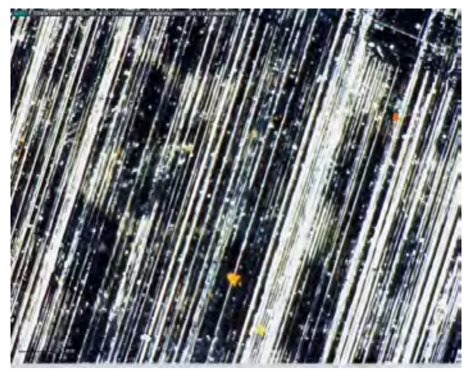

Figure 5-62—Laser cleaning Sample 13. There is significant heat-related surface damage (dark areas) over the entire surface and some areas had melted (polished grain line was gone). 59.3x. Source: C. Houska

CHEMICAL CLEANING

The greatest challenge is access to the upper reaches of the Monument. As previously described scaffolding access, if at all possible, would be extremely expensive. Materials would need to be moved to areas of the Monument to be clean from the ground. Control, collection and disposal of potentially hazardous chemicals would need to be carefully planned out to protect visitors below.

LASER CLEANING

Of the technologies considered, cleaning using lasers is the most prescient, and needs further research and development. The variables for use of this technology would need to be narrowed down by further testing to limit parameters such as the following:

- Temperature rise on the skin surface which could be damaging to the welds that have already been mildly sensitized.
- Forcing carbon deposits into the grain boundaries of the welds.
- Alteration of the original brushed finish by the laser process.
- Testing of delivery systems that will not mar the skin of the Monument.

Figure 5-63: Image of a climbing robot using a vacuum to secure to the surface of the structure being climbed. Source: International Climbing Machines

The delivery of laser cleaning equipment to the upper reaches of the Monument can potentially be performed using robotic techniques (Figure 5-63). However, robots would require tethers: one for electricity; and a second for fiber-optic delivery of the laser light. These tethers could not be very long without the robotic assembly becoming too heavy, therefore, access would be required on the extrados of both north and south legs. This would be a task that could only be accomplished by technicians skilled in industrial rope access (IRA), laser cleaning and robotic technology. Electricity could be fed from the top of the Monument, but the equipment to create and feed the laser through the fiber-optic cable would need to be on the outside of the Monument with the technician. It is assumed that such an approach would be much less expensive than scaffolding, but the costs would still be significant.

CHEMICAL/ABRASIVE CLEANING (2014)

The greatest challenge is access to the upper reaches of the Monument. As previously described scaffolding access, if possible, would be extremely expensive. Materials would need to be moved to areas of the Monument to be clean from the ground. Of the methods being considered this method would require the most “elbow grease” as vigorous scrubbing is part of all the techniques that were considered, and the techniques utilizing mild abrasives have been ruled out.

Cleaning & Refinishing Studies

SUMMARY EFFECTIVENESS, GENTLENESS & FEASIBILITY ASSESSMENTS

To compare the effectiveness, gentleness and economic feasibility of the cleaning techniques utilized at metal labs plus the techniques that were utilized in 2014 a comparative matrix has been developed. This is a qualitative value assessment and is based upon experience of the team. Gradation for the matrix below is given on a 1 to 10 scale, 10 being the best score.

Though the laser cleaning techniques appear to be moderately successful by this matrix must be noted that the testing that was done revealed some damage to the surface that was only apparent through microscopy. Laser cleaning has obvious benefits if a gentler method is found that addresses concerns that have been raised. This can only be accomplished through more research and development. This research should include, but not be limited to, review of published research papers, testing to assure that corrosion

Gateway Arch stainless steel skin cleaning evaluation matrix

Cleaning Techniques (applicator)	Effectiveness	Gentleness	Economic Feasibility	
	Visual aesthetics	Surface Roughness/Gloss/ Microscopic	lower 8 segments	upper segments
Chemical (Astropak)				
7 - 401 and buffer	10	8	8	3
7 - 401 and hand buffed	10	8	8	3
9 - 410 handbuffed	10	9	8	3
9 - Neutra rouge	10	>9	8	3
Water and Dry Ice (Karcher)				
3A	2	<1	8	4
3B	2	<2	8	4
4A - water clean	2	2	8	4
4B1 - dry ice	2	<4	8	4
4B2 - dry ice	2	<4	8	4
4B3 - dry ice	2	<4	8	4
6A - water clean at 1000 Bar	4	not measured	8	4
6B-1 - water clean at 1500 Bar	4	not measured	8	4
6B-2 - water clean at 2200 Bar	4	not measured	8	4
6b-3 - water clean at 3000 Bar	4	not measured	8	4
6B-4 - water clean at 3000 Bar, round nozzle	4	not measured	8	4
Laser Cleaning (Adapt/Evergreene				
11A - 12 MW/cm2, spd. 13.19, diagonal	10	<6	8	6
11C - 12 MW/cm2, spd 2.42, parallel	8	>5	8	6
11D - 24 MW/cm2, spd 29.33, parallel	8	<3	8	6
12A -12 MW/cm2, spd 13.19, perpendicular	8	7	8	6
12B -12 MW/cm2, spd 13.19, parallel	8	6	8	6
13B - 24 MW/cm2, spd 29.33, parallel	8	>6	8	6
Mild Abrasive/Chemical (2014 WJE testing)				
A - Bar Keeper's Friend	9	10	8	4
A2 - Bar Keeper's Friend/Avesta 630	9	10	8	4
C - Norton Woven Clean/Ultra Fine Pad	8	8	8	4
C2 - Norton/Ultra Fine Pad/Avesta 630	8	8	8	4
F - Avesta Cleaner 401/Passivator 630	8	10	8	4
H - Bar Keeper's Friend/Ultra Fine Pad	9	8	8	4

Evaluation grading from 1 to 10, higher score is better

Gateway Arch stainless steel skin cleaning evaluation matrix.

resistance has not been compromised by the treatment, and assurance that the welds are not further sensitized or carburized as the result of excessive heat.

REFINISHING

The ASTM A484/A484M No. 3 brushed finish on the stainless steel skin of the Gateway Arch was originally applied in a factory environment, but archival documentation shows that many sections were refinished on site due to finish damage during transit, installation and in areas where iron was embedded by the crane crawler. Surface roughness measurements parallel to and perpendicular with the grain and gloss measurements were taken at elevations in the fourth and twelfth panels from the Arch's north leg base in 2014. The typical horizontal profile averaged an Ra of 13 micro-inches, and the typical vertical profile averaged an Ra of 30 micro-inches, revealing that the surface profile in each direction is significantly different. The finish above the base is distinctly different from the base, which had clearly been refinished.

To re-create the original finish on site one would require the use of robotic techniques that would be installed at the base of the Monument legs. Using robotic techniques at the Zahner Metalab was not feasible during this study.

We decided to approximate such a finish using hand techniques that were installed by a trained Zahner technician. The refinishing was performed with a cylindrical sander using various sanding heads until a suitable sanding head was found (Figure 5–64). The refinishing was performed over several passes trying to keep the brushed finish straight and linear (Figure 5–65). The difference in the thickness of the plate from before and after the refinishing was measured with a digital caliper to 100th of a millimeter and the change could not be measured.

The results can be seen in Figures 5-66 and 5–67. Results of the refinishing were not perfect but show promise. The refinishing technique but must be further developed in trials to achieve a specular gloss that is closer to the original on the Monument.

Figure 5-64: Using a cylindrical sander to refinish one of the panels with incised graffiti. Source: S. Kelley

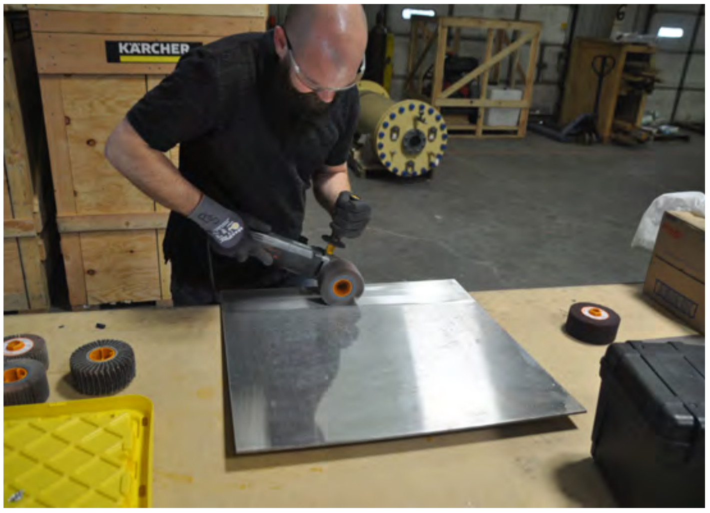

Figure 5-65: A second pass with the cylindrical sander to refinish the panel. Source: S. Kelley

Figure 5-66: A comparison of the control panel (left) and refinished panel (right) showing similar reflectance characteristics.

Source: S. Kelley

Figure 5-67: Partially refinished panel as viewed outside on a sunny day.

Source: S. Kelley

Conservation Policies

VI.

NPS POLICIES, SPECIAL MANDATES, AND ADMINISTRATIVE COMMITMENTS

The Department of the Interior, National Park Service (NPS) and the units that operate under its governance, abide by a number of federal laws and policies designed to protect, conserve and interpret the resources and values related to the designated purpose of each park. NPS also has a sophisticated compliance system from which many important documents are adopted for each park unit that provide additional guidance, several which have been cited previously including the recent *2009 General Management Plan/Environmental Analysis (GMP)* and the *National Park Service Jefferson National Expansion Memorial Gateway Arch Historic Structure Report - Volume 1, June 2010 (HSR).*

There are also in place special mandates and administrative commitments specific to the Gateway National Park. One of the most important of which is the National Historic Landmark (NHL) designation by The Secretary of the Interior for the Gateway Arch which places the monument as worthy of special protection under the National Historic Sites Act of 1935 and Section 110 (f) of the National Historic Preservation Act (NHPA) of 1966, as amended. Pursuant to Section 106 of the NHPA federal agencies are required to consider the effects of a proposed project on properties listed on the National Register of Historic Places.

In the event that a project may adversely affect a historic property the lead agency must enter into a consultation with the State Historic Preservation Officer, the Advisory Council on Historic Preservation and other interested agencies and individuals to identify and assess adverse effects, and resolve these effects through mutually agreed upon mitigation measures. National Historic Landmarks under the Historic Sites Act of 1935 are afforded a higher level of protection, requiring the agencies "to the maximum extent possible, undertake such planning and actions as may be necessary to minimize harm to such landmark." Where the alternatives require undo cost or compromise to the agencies goals, the agency should consider: the magnitude of the undertaking's harm to the historical, archaeological, and cultural qualities of the NHL; the public interest in the NHL; and the effect the mitigation action would have on meeting the goals and objectives of the undertaking.

GMP BUILDING AND SITE VALUES AND THEMES

The *2009 General Management Plan* includes fundamental values and primary interpretive themes of the Gateway National Park that must be respected as any planning and management of the resources are considered. These include several very important fundamental values and themes including:

- The iconic, inspirational and transcendent nature of the Gateway Arch as one of the unique and enduring symbols of national identity.
- The design and scale of the Gateway Arch integrated with its setting elevates the timeless form of an arch into as structure that is among the world's architectural, artistic and engineering marvels.

The GMP also identifies several key planning issues and concerns that are integral to the continual protection the monument including:

- **Design Integrity —** Protection of the Gateway Arch and site/landscape around the monument;
- **Programs/Visitors Services —** Balance of tranquility and open space around the monument with the increased programming and activities due to the expanded museum;
- **Access/Security —** Improve appropriate barrier free visitor entry / exiting sequencing and enabling effective security management and operation;
- **Operations —** Consider existing and future maintenance needs as well as accommodate visitor movement through the monument.

Conservation Policies

HSR TREATMENT RECOMMENDATIONS AND GUIDELINES

The U.S. National Park Service has developed definitions for the four major treatments that may be applied to historic structures: preservation, rehabilitation, restoration, and reconstruction. The approved 2010 Historic Structure Report recommended that ***Preservation*** is the appropriate treatment policy for the Monument.

When the property's distinctive materials, features, and spaces are essentially intact and thus convey the historic significance without extensive repair or replacement; when depiction at a particular period of time is not appropriate; and when a continuing or new use does not require additions or extensive alterations, ***Preservation*** is considered as the appropriate treatment.

Preservation is defined as the act or process of applying measures necessary to sustain the existing form, integrity, and materials of a historic property. Work, including preliminary measures to protect and stabilize the property, generally focuses upon the ongoing maintenance and repair of historic materials and features rather than extensive replacement and new construction. New exterior additions are not within the scope of this treatment; however, the limited and sensitive upgrading of mechanical, electrical, and plumbing systems and other code-required work to make properties functional is appropriate within a preservation project. Guidelines and requirements for Preservation as defined by the Secretary of Interior's Standards include:

1. *A property will be used as it was historically, or be given a new use that maximizes the retention of distinctive materials, features, spaces, and spatial relationships. Where a treatment and use have not been identified, a property will be protected and, if necessary, stabilized until additional work may be undertaken.*
2. *The historic character of a property will be retained and preserved. The replacement of intact or repairable historic materials or alteration of features, spaces, and spatial relationships that characterize a property will be avoided.*
3. *Each property will be recognized as a physical record of its time, place, and use. Work needed to stabilize, consolidate, and conserve existing historic materials and features will be physically and visually compatible, identifiable upon close inspection, and properly documented for future research.*
4. *Changes to a property that have acquired historic significance in their own right will be retained and preserved.*
5. *Distinctive materials, features, finishes, and construction techniques or examples of craftsmanship that characterize a property will be preserved.*
6. *The existing condition of historic features will be evaluated to determine the appropriate level of intervention needed. Where the severity of deterioration requires repair or limited replacement of a distinctive feature, the new material will match the old in composition, design, color, and texture.*
7. *Chemical or physical treatments, if appropriate, will be undertaken using the gentlest means possible. Treatments that cause damage to historic materials will not be used.*
8. *Archaeological resources will be protected and preserved in place. If such resources must be disturbed, mitigation measures will be undertaken.*[1]

Additionally the HSR noted that preservation efforts for the Arch would likely be performed as part of ongoing maintenance efforts rather than as a single comprehensive project, and therefore established prioritization or phasing of specific recommendations, including:

1. *Protection of Primary Structural Elements. Studies and recommended investigation and repair, as related to protection of the primary Arch structure from deterioration, should be undertaken.*
2. *Life Safety and Functionality Upgrades. Designs for appropriate life safety and functionality upgrades to the Arch should be studied and developed, with due consideration of the effect of any changes on the historic character-defining features of the Arch.*
3. *Restoration. Where altered, original interior finish materials and surfaces should be restored to a condition closer to the original design intent, including materials, textures, and color.*
4. *Cyclical Inspection and Maintenance. In addition to the specific repairs recommended, cyclical maintenance tasks such as inspection, painting of exposed steel elements, cleaning, repair, and/or replacement of finishes in the primary public areas of the arch, and other ongoing maintenance tasks should be continually implemented to avoid damage to the historic building fabric and to reduce the need for large-scale repair projects in future.*

Finally, the HSR recommended that all work performed on the Gateway Arch should be documented through notes, photographs, and measured drawings and/or sketches, and by as-built annotations to construction documents at project completion. These records should be permanently archived as a record of the work, for future reference, and to provide information for future maintenance of the Arch. These records will allow future observers to identify which materials and system components are original and to understand the chronology of repairs and other changes that have occurred to the structure over time. The HSR also recommended that these records be archived at Gateway Arch National Park and also included in another collection, such as the NPS Denver TIC, for reference.

ADDITIONAL POLICY CONSIDERATIONS

The conservation policies presented below are not meant to replace those already established and cited previously; they are presented for NPS consideration and to supplement the evaluation process prior to the implementation of any treatments presented in the following chapter.

INTERPRETATION/ACCESS AND VANDALISM/SITE MANAGEMENT

One of the primary interpretive themes of the park is allowing access to the Monument—both the interior and exterior. One element of that interpretive experience is where Arch touches ground. Visitors are drawn to the base of the Monument in awe due to the incredible scale and design simplicity; they want to touch its surface and look up to sky; they and are filled with an unforgettable experience of light, shape, material and sheer scale of the Monument.

But allowing access to the bases of the Arch has its drawbacks. The north and south leg base sections of the Arch have experienced an excessive amount of vandalism and incised graffiti, some severe. Graffiti is sometimes associated with a form of artistic expression, made without permission within public view, and in the last decade has become a rapidly developing art form. In the case of the Arch, the markings are typically not artistic but more of a desire by individuals to leave a mark, sometimes destroying the surface by drilling and hammering. This type of vandalism is a deliberate defacing and damaging to the historic resource.

Park staff and consultants have noticed increased level of vandalism but the rate of new incised markings is unknown. Circulation patterns have recently changed around the base of the Arch due to relocating the entrance to the Museum to the new addition west of Arch. The original entrances at the base of the Arch now are for exiting only. The impact upon vandalism of this modification to circulation is not fully understood yet, as the new addition and entrance just opened in July 2019.

Conservation Policies

It is obvious that the material and design integrity at the base of the Arch is being impacted by continued vandalism and incised graffiti. As previously noted in previous studies and the HSR, the embedded iron from vandalism is a great concern and some level of intervention is needed to halt these actions to allow conservation and reverse adverse effects.

An educational policy specifically directed towards the impacts of vandalism could be a first step. This may entail use of interpretive displays or messaging to educate and raise awareness that vandalism threatens the integrity of the world class monument. Harmful markings can cause corrosion and impact the purity of the design and material finish for current and future generations of visitors.

If educational programs and interpretive elements or messaging fail to stop vandalism, and damage to the stainless steel surfaces continues to escalate, then a policy that includes some form of enhanced security or limiting access, whether temporary or permanent, may be needed to restrict visitor access to the base sections of the Arch.

An enhanced level of security around the base of the Arch could be approached on several different levels. Monitoring visitor activities at all times of day could be undertaken with use of additional security cameras focused at bases of north and south Arch legs. Monitoring activity could yield clues as to when vandalism is most likely to occur. Then, if it is feasible, adding park or security staff at key times of the day around the Arch base legs may help deter vandalism. If additional security personal is not feasibly, limiting visitor access to the Arch bases via a site barrier may be warranted. This action would take careful investigation of an appropriately design barrier that is modern and minimalistic in keeping with design of monument. Options discussed during this CMP effort have included a very simple removable railing. Other options identified but not yet explored include a change of paving materials directly round the base sections that would signal or prevent ready access to the face of the Arch. Before implementing any barriers they must be vetted thoroughly including costs/benefits of each as well as any adverse impacts.

AIR AND WATER QUALITY

As treatments are identified and implemented for cleaning and preserving the Arch, actions resulting in the degradation or improvement of air and water quality must be considered. Emissions from construction activities could have impacts on both local air and water quality. Mitigation policies and requirements must be included in the design and permitting process. The use of low sulfur fuels for example should be promoted, and the management of construction operations should be in compliance with state and local air and water quality requirements. The park does have several policies in the Superintendent's Compendium that should be adhered to, including idling of vehicles. All construction activities must also conform to EPA regulations and the Clean Water Act to prevent pollutant introduction into ground water and adjacent water bodies.

ASSET MANAGEMENT-MONUMENT MAINTENANCE AND CLEANING

As the treatment recommendations for the cleaning and conservation of the Arch are accepted and implemented, the Park should consider/update their Asset Management Plan to include and identify the activities pertaining to the inspection, maintenance, cleaning and conserving of the Arch exterior.

Management activities should include routine daily, monthly and annual inspections needed for the Arch base, lower sections and upper sections. If damage is identified and/or some intervention is required, guidance on the levels of intervention could be identified.

RECORDS AND ARTIFACTS

Vandalism and incised graffiti documentation and monitoring is needed to establish baseline data of the extent present before and after restoration and cleaning. This will help determine rate of vandalism, the kind of vandalism occurring and provide valuable information for the analysis and justification of the restoration of portions of the base sections are warranted. High definition photography/laser scanning and other methods of documentation should be investigated that will establish a long range data base on the base sections conditions.

STRATEGIC PARTNERSHIPS

The impact and value of several successful partnerships with entities including the Gateway Arch Foundation and Metro have been extremely beneficial to the conservation of the Monument, including the assistance with continued research into the best methods for the cleaning and preserving the stainless steel skin. It is important that these partnerships be sustained and strengthened to help enhance and implement many of the policies noted above.

Implementation

VII.

ACTION PLAN & PRIORITIES

Based upon our analysis and upon previous work done by others we propose the following technical recommendations to clean and refinish the Gateway Arch. The recommendations listed below are in order of chronology and priority.

Priority 1
Use low pressure deionized water mixed with ChlorRid to remove invisible chloride surface deposits from the lower eight segments of both legs of the Monument. Parameters such as water pressure and temperature, ChlorRid to water ratio, nozzle type and size, spray angle in shape, and distance of nozzle to the skin would all be fine tuned on site by the historic preservation professional working in tandem with the applicator. It is not anticipated that the water runoff will need to be captured at the base, but some simple tests can determine if the runoff poses a threat to the granite paving.

Priority 1A
Develop a cyclical maintenance plan for the care of the stainless steel skin of the Monument which includes the following elements:

- Monitor chloride buildups at the base of the Monument and continue to wash the Monument to remove any chloride contaminants which may be identified. Testing for chlorides should initially be performed by a professional but can thereafter be performed in-house by the National Park Service.
- Identify a collection of soft tools and chemicals which will not mar the surface of the Monument and can be used to remove stickers, chewing gum, welds, and other visible contaminants which become adhered to the surface.
- Record and catalog all present graffiti and surface incisions so that the progression (or lack of progression) of these surface scratches can be quantified. Cataloging the present graffiti is a challenge because the damages are superficial and offer no topography. However, it can be successfully captured photographically in the appropriate natural light or at nighttime with a raking artificial light. In addition, photogrammetry techniques can be explored as a method for cataloging incised graffiti.

Priority 2
Install large scale cleaning samples on the Monument skin using the recommended chemical cleaning technique. The end goal would be to utilize the technique to remove embedded iron from the incised graffiti at the base of the Monument and superficial corrosion from the stainless steel skin at the lowest eight segments of the Monument.

Priority 3
Continue experimentation on re-creating the original brushed finish on the skin. It is recommended that this testing be performed on a mockup that is outside and in the vicinity of one of the legs of the Monument. The end goal would be to refinish the incised graffiti damaged skin at the base of the Monument so that it closely matches the original and undamaged surface.

Priority 4
Continue experimentation on laser cleaning techniques to minimize heat output to assure that there is no surface alteration, further sensitization of the welds, or carburization at the welds.

Priority 4A
Run a climbing robot carrying intended loads on the skin of the Monument from the base to determine how high it can climb and how easy it is to control—and to determine whether it leaves marks on the skin from the suction cups. Marking, if it occurs, may be different on the upper reaches of the Monument where there is no concrete behind the stainless steel skin. There may be other technologies developed in the not-too-distant future other than suction cups that can also be used by robots to clean the outer skin.

Priority 4B
Develop cost estimates for gaining access to all elevations of the Monument using traditional scaffolding and using industrial rope access from the extrados to compare with robotic cleaning.

Priority 5
Clean the upper reaches of the Monument using either chemical (from 2014 or 2019 studies), laser, or a mixture of the two cleaning techniques.

SOURCE: D. WORTH

Appendices

IX.

Appendix A - Houska 2014

Gateway Arch, St. Louis, Missouri

Metallurgical Assessment of the Stainless Steel Exterior Including: Weld Condition, Overall Performance, Site, Surface Discoloration and Deposit Evaluation

Prepared for:

Wiss, Janney, Elstner Associates, Inc.
10 South LaSalle Street, Suite 2600
Chicago, Illinois 60603

Prepared by:

TMR Consulting
3209 McKnight East Drive
Pittsburgh, Pennsylvania 15237
412.369.0377

14-944 (CMH)
February 27, 2015

Gateway Arch, St. Louis, Missouri

Metallurgical Assessment of the Stainless Steel Exterior Including: Weld Condition, Overall Performance, Site, Surface Discoloration and Deposit Evaluation

Report prepared by Catherine Houska with assistance from William Pratt

A - Investigation Goals

The goals of this investigation were to examine and evaluate the condition and structural integrity of the stainless steel plate exterior of the Gateway Arch, including the welds and surface discoloration, and suggest corrective action(s) if necessary as well as comment on expected performance based on those findings and a site assessment. Assistance was also provided during the cleaning trials and assessment of finish appearance variations, and that has been summarized by Wiss, Janney, Elstner in their report.

The investigation was based on multiple phone calls; visual assessment of the surface during two site visits; a corrosion site assessment based on current conditions and those that existed during the previous fifty years; collection of representative surface samples using gun shot residue (GSR) kits; laboratory evaluation of weld samples; review of available project, archive and technical documents; surface chloride testing; and SEM/EDS (Scanning Electron Microscopy and Energy Dispersive Spectroscopy) of both the GSR kits and weld samples.

B - Conclusions

Overall the Gateway Arch is in very good condition. Although at least some welds are sensitized due to re-welding and excessive heat input, no corrosion was found adjoining the welds on the North leg indicating that the environment has not been corrosive enough for the sensitization to cause corrosion. The service environment is less corrosive now then it has been historically due to the dramatic reduction in pollutants from heavy industry. Weld imperfections were found within the five samples collected but none were of concern. The stainless steel appears to be the specified Type 304 with matching chemistry filler metal.

The base had light surface staining due to microscopic superficial shallow deicing salt corrosion pitting but it is a purely aesthetic issue. Very low concentrations of chlorides that are consistent in chemistry with deicing products were found in most of the surface samples and were probably from nearby roadways. The samples were collected in the autumn and the monument is well rain-washed during the summer, so this should be representative of the lowest chloride concentrations during the year.

The pavement at the base is heated and deicing products are reportedly not used. If the National Park Service were to consider using a deicing product in the future, then calcium magnesium acetate (CMA) should be used. Unlike chloride containing products (e.g. sodium chloride, magnesium chloride, calcium chloride, potassium, chloride, etc.) or urea, CMA is not corrosive to stainless steel or other construction materials.

The chloride related light staining at the base maybe the result of graffiti scratching creating a rougher surface or differences in rain washing. Hot water power washing in the spring with a chloride releaser additive such as Chlor-Wash or Chlor-Rid could minimize further staining and help to remove other surface accumulations.

Several long deep scratches along the base, which contained embedded iron, are a potential long-term concern. Even if the rest of the base is not cleaned, this embedded iron should be removed because the stainless steel underneath it will continue to corrode under the corrosion deposit. This area should be monitored if no cleaning is done.

Higher on the North leg most of the discoloration was grey, black or brown in color with some scattered small areas of superficial red toned staining. The deposits found on the surface correlate with the industries that are currently present or were in the area during the past 50 years and were mainly soil, fly ash, iron and steel slag, and iron particles. In a few locations there were also copper, copper zinc, lead, and titanium particles. The very localized scattered red toned surface staining above the base is associated with oxidation of the iron particles from nearby industry. These are assumed to be old deposits since emissions of this type are no longer permitted and the industries from which many of these particles were probably emitted have shut down. Small amounts of chlorides (deicing salt) were found on most of these samples from the highways surrounding the site.

Unless there is a dramatic change in the environment, such as much higher chloride salt levels, there is no concern about the continued good performance of the Gateway Arch.

C – Executive Summary

1. **1960's Metal Production Technology** - This stainless steel was produced prior to the introduction of AOD (Argon Oxygen Decarburization) furnace technology into the US stainless steel industry. Both higher carbon and sulfur levels must be assumed because of the technology that was used at that time and they can affect corrosion resistance.

2. **Stainless Steel Plate and Weld Filler Metal Chemistry** – Neither of the stainless steel plate producers (Outokumpu and ATI) nor the Gateway Arch archive had retained the original chemistry certifications. The weld filler metal supplier(s) are unknown and no certifications had been retained in the archives. The weld sample size agreed by the NPS and WJE was quite small and it was necessary to retain the samples. This made it impossible to do a full laboratory chemistry evaluation. Alloy verification was done using Scanning Electron Microscopy and Energy Dispersive Spectroscopy (SEM/EDS). This technique is not exact and is only permissible for general alloy verification. The plate appears to be the specified Type 304 with an appropriate matching chemistry filler metal.

3. **Site Corrosiveness Assessment** – Deicing chlorides (salts) are used on highways surrounding the site and that use has increased during the past fifty years. They are far enough away to make likely deicing salt exposure low based on the IL DOT/Argonne National Lab/NADP research in the Chicago area. Only very small amounts of chlorides were found on the surface using sensitive GSR lifts during the September and October 2014 inspections.

   Although there are still some industrial plants in the area, their emissions are minimal relative to the high levels of heavy industrial pollution that were once found in the city due metal production, coal burning power, chemical and other plants. The surface deposits are described in item 7. Environmental emission regulations and changes in local industry have significantly reduced exposure to potentially corrosive pollution. This site is less corrosive then it was over most of the monument's life.

4. **Appearance, Cleaning & Remedial Action** – The cleaning and surface restoration trials are discussed in the WJE report. Further corrosion of the base could be limited by removal of the embedded iron from scratched areas, cleaning to remove corrosion staining and surface deposits, and chemical passivation in accordance with ASTM A967 to remove surface sulfides exposed by accidental and deliberate surface abrasion. The technical reasons for this are described in this report. Chemical passivation is most commonly done with nitric acid but other acids (e.g. phosphoric, oxalic, etc.) are acceptable if applied in accordance with A967.

   If the base were power washed annually, additional staining should be minimal unless more iron is embedded in the surface. No coating or cleaning method should be used without the review and approval of a stainless steel metallurgist that specializes in atmospheric corrosion and aesthetic finishes. It is assumed that these options will be discussed in the WJE report.

5. **Weld Sensitization–** All five of the weld samples came from the lower sections of the North leg. Based on a review of the archives, these areas had been welded at least twice and some areas may have been welded three times, which explains their large size relative to the plate thickness. Even with today's low-carbon levels, the high levels of heat input associated with repeated welding of plate could cause sensitization (precipitation of carbides at grain boundaries), which decreases the corrosion resistance of the stainless steel plate adjoining the weld. Sensitization was found in the microstructures of all the samples, but neither they nor any area that was inspected exhibited the characteristic corrosion pattern associated with sensitization related corrosion. After 50 years of service, that indicates that even sensitized Type 304 is corrosion resistant enough for the current environment.

6. **Weld Imperfections** – Numerous weld imperfections were documented during visual examination and microscopic evaluation of the weld samples, including small areas of porosity, weld spatter, and weld slag. No cracking or significant corrosion was found at these imperfections after 50 years of service.

7. **Chloride and Surface Deposit Evaluation** – Minor amounts of deicing chlorides (salts) were found on the surface along with industrial particulates (i.e. fly ash, small ferrochrome oxide, iron and steel slag, iron, copper, copper zinc, lead, and titanium), carbon rich material (i.e. spores, pollens), clay materials, silica (sand), dolomite, mineral wool, paint particles, and calcite and magnesia alumina silicates.

   With the exception of the clay, sand, pollen and other characteristic constituents of normal surface "dust", the other accumulations can be explained by current and past heavy industrial activities in the area and nearby highways. The industrial pollutants could have been from plant emissions, dust generated as buildings were torn down or brown field site soil disturbed during reclamation or redevelopment. The iron particles that were not obviously from steel mills (i.e. iron without other elements) are typical of carbon steel particulate from construction sites.

The environment is not corrosive enough for these deposits to present a concern other then minor surface discoloration so their presence on the surface is a purely aesthetic issue. The iron particles found throughout these deposits could cause more red toned staining as they oxidize (i.e. corrode).

8 **Embedded Iron** - There were scratches on the surface of the base with embedded iron particles from carbon or alloy steel. The largest of these extend along the base, are relatively deep and may have been from a snowplow. This surface contamination should be removed because the deposit creates a crevice and corrosion does not stop when the iron has corroded away. The exposure of these areas to deicing salt increases the corrosion rate. Over time, linear, concentrated thickness loss due to corrosion could make weld repair necessary. Removal of the contamination should be with either a handheld electro-polishing wand or stainless steel pickling paste painted on to these localized areas with a small brush in accordance with ASTM A380 followed by chemical passivation to improve the corrosion resistance. Pickling is the most common chemical procedure used by the industry to remove oxides and heavily embedded iron contamination and consists of an acid mixture containing 8 to 20% (by volume) nitric acid (HNO_3) and 0.5 to 5% (by volume) hydrofluoric acid (HF). Pickling will dull the finish locally but careful limited application should mean that it is not noticeable.

D- Equipment List

Cameras: Panasonic DMC-FZ28 and Nikon Coolpix 4500
Sectioning: Buehler Samplmet Abrasive Cutter
Sanding: 4x36" and 1x30" belt sanders, 5" rotary disc sander
Mounting Compound: Buehler Varidur System
Abrasives: Aluminum Oxide-80, 120, 240 grit /Silicon Carbide-400, 600 grit
Polishing Abrasives: Buehler 6 micron and 1 micron diamond paste
Polishing Lubricant: Buehler Metadi Fluid
Polishing Pads: Buehler Microcloth PSA
Etchant: 10g oxalic acid dissolved in 90 mL of distilled water
Etching Mask: 3M 470 Electroplater's Tape
DC Power Supply: BK Precision Model 1710
Microscope: Nikon Optiphot
Stereoscope: Leica MZ6
SEM/EDS Gunshot residue SEM/EDS sampling kits (small and large area)
Scanning Electron Microscope with Energy Dispersive Spectroscopy capability

E - 1960's Stainless Steel Production and Chemistry

We were unable to locate the original mill or weld filler metal chemical certifications in the Gateway Arch archives. There has been considerable industry consolidation since the 1960's and the mills that produced the plate are now part of the corporate history of ATI Allegheny Ludlum and Outokumpu. The Eastern Stainless mill (Outokumpu) has been closed for over 20 years. Neither firm had retained the 50-year old mill certificates but both provided information about the technology and testing capability of that time period. The archive records did not identify the source of the filler metal.

The stainless steel used for this project predates the installation of the first AOD furnace in the United States. Eastern Stainless, which supplied half of the plate for this project, became the first US stainless steel mill to use an AOD in 1974. ATI began using AOD furnaces not long afterwards. AOD furnaces very efficiently remove impurities, including carbon and sulfur, and make overall chemistry control easier. So metal produced prior to their widespread use typically has higher levels of both elements and would not meet the requirements of the "low carbon" Type 304L austenitic stainless steels typically specified when welding sections that are 0.125 inches in thickness or greater today.[1]

Additionally, it typically took about three days to obtain heat chemistry during that time period so melt shops had higher target levels of alloying elements like chromium and nickel to ensure the desired properties. During the 1960's, the Type 304 plate specified for this project would have been ordered to ASTM A167. Type 304 and other common stainless steels were moved to ASTM A240 many years ago and A167 was recently withdrawn.

F – Weld Procedures

Welding procedure qualification records were found for the vertical and horizontal stainless steel butt joints in the archives dated January 7, 1964 (vertical) and May 18, 1963 (inclined horizontal).[2] It was not clear whether either was a final procedure and it appears that there were procedures for other joint configurations based on the correspondence in the file.

Both indicated that MIG welding was to be used, but there were different argon-CO_2 helium cover mixtures for each joint orientation. Both indicated that weld clean up was to be with a wire brush, there were to be two weld passes and a grooved back up root treatment. A Pittsburgh-Des Moines Steel Company letter dated December 5, 1963 mentioned removal of "weld haloes" (heat tint) using electrolytic methods.[3] Electrolytic cleaning wands are commonly used to remove heat tint today and it is an old technology, which probably has not changed much during the past 50 years. Presumably it was used in combination with brushing to restore corrosion resistance. Oakite 33, which is still sold today, was used to clean and degrease the surface prior to welding.[4] Both AWS Code and ASME code Section IX were referenced in the weld procedures.

G - Weld Sample Collection and Analysis

Five sample areas were selected on the North leg of the Arch after examination of the welds using a lift. Initially samples were only to be collected from the West face of the intrados but much higher levels of weld spatter and larger dark colored deposits were observed on the extrados welds making it desirable to see if there were other differences. Permission was obtained to obtain one sample from the extrados. The samples, which were approximately 0.75 inches in diameter, were removed by A. Zahner Company using a hole-saw with guides to prevent movement and the holes were filled with plugs welded in place followed by hand held electro polishing to remove heat tint and restore corrosion resistance.

The samples were centered on the welds and included small areas of both plates. We deliberately selected sample areas with larger weld beads, obvious weld repair or the other visual cues that might indicate a possible imperfection, since assessment of any problems would be the best indicator of any performance concerns. All of the samples came from the

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[1] Telephone and email conversations during 2014 with multiple current and retired employees of
[2] JEFF Archives, McDonald, Box 11, Folder 4 and Box 17, Folder 26
[3] JEFF Archives, McDonald, Box 10, Folder 5
[4] JEFF Archives, Same letter as 3, McDonald, Box 10, Folder 5

lower sections of the North leg. A mixture of “field” and “shop” welds were selected under the assumption that they had been exposed to the two different welding conditions.

However, during the second site visit, the daily reports were found and reviewed in the archives’ Eero Saarinen files. The report dated September 4, 1963 indicated that the carbon and stainless steel shop welds had not been X-rayed properly prior to shipment. Extensive lack of penetration was found during a field X-ray. Problems with the field welding equipment were also identified around that time period. Subsequent reports included approvals for 100% X-ray inspection of all of the welds below N63 and S63. (See WJE report for architects weld designations.) Only spot X-ray checks had been done previously. All of the welds above this level were subsequently 100% inspected as they were installed.[5]

These records implied that most if not all of the carbon and stainless steel below these levels was re-welded due to incomplete penetration and some areas needed further repair after re-inspection. Therefore, all of the sample welds were probably welded at least twice with the second of those welds being a field weld. This explains the large weld beads observed relative to the thickness of the plate. Initially, weld beads that were larger in overall size (wide, a greater protrusion from the surface and uneven in appearance) were selected for samples W1 and W2, since they represented a probable worse case scenario. Unfortunately, it was not possible to keep the hole-saw guide in position to remove them and alternative welds were selected. Only relatively flat weld beads could be removed using the fixturing.

Each sample was documented and sectioned using a water-cooled abrasive cutting wheel. The metallographic sections were mounted and polished using progressively finer abrasives. A portion of the polished surface was then masked to expose a limited area for electrolytic etching. Etching was performed using an oxalic acid solution and a current density of approximately 1 amp per square centimeter for a period of 90 seconds. Using optical light microscopy each section was examined in the etched condition. Sections 1, 3, and 5 were also examined in the as-polished condition. Prior to etching, sections 1 and 5 were examined using SEM/EDS.

Appendix A includes Figures A1 through A39. These are images of each weld prior to removal, the as-received sample appearance, photo macro and micrographs of etched and un-etched weld cross-sections, and representative SEM /EDS evaluations of samples W1 and W5. Optical light microscopy of the sections revealed the following:

1. Varying degrees of sensitized were found in the grain boundaries in the heat affected zone (HAZ) of all five samples when they were examined in the etched condition. The band of sensitized grains on sample W2 was located approximately 0.045” from the edge of the weld. There was no surface corrosion associated with this sensitization on any sample examined. None of the inspectors found the classic pattern of sensitization related corrosion at any location on the Arch. This indicates that the environment has not been severe enough to present a corrosion problem to sensitized welds.

2. Varying amounts of weld porosity were noted in all of the sectioned welds. The largest weld metal void was noted in sample W4 with a diameter of approximately 0.04”. Sample W5 contained a void with an approximate diameter of 0.024”.

[5] JEFF Archives, Saarinen files, daily reports

3. Subsurface contamination was noted in the weld metal near the weld crown of sample W5. The composition of the contaminant was analyzed using SEM/EDS and it was identified as weld slag. Some surface slag was found on both samples W1 and W5. No corrosion was observed.

4. All of the welds in these samples appeared to be full penetration.

5. SEM/EDS confirmed the presence of manganese sulfides in the base metal of sample W1. Sulfides were seen in other samples that were not sent to the SEM for confirmation.

6. A shallow weld undercut was noted at the inside surface of the plate in sample W3. No cracking had occurred after 50 years and there was no corrosion associated with it.

Even with today's low carbon levels, the high levels of heat input associated with repeated re-welding of plate could cause sensitization (precipitation of carbides at grain boundaries), which decreases the corrosion resistance of the plate in bands adjoining the weld. Given the high carbon levels typical of stainless steel produced prior to the introduction of the AOD, the sensitization observed during weld cross sectioning is not surprising. Since the welds that were sampled were in an area known to have had weld repair, we cannot be certain that welds higher on the structure were also sensitized. None of the inspectors saw any location with the classic banded corrosion pattern that is typically associated with sensitization related corrosion. If it has not occurred after 50 years, the environment does not appear to be corrosive enough for this to be a concern.

Table 1 summarizes the weld sample locations, weld appearance, and the imperfections that were documented. The specific Appendix A figures, which document each imperfection, are noted using the letter "A" and image number. Appendix B explains these common weld imperfections.

Table 1: Weld core sample locations, observations and imperfections

Sample No.	Face	Row	Panel	Location	Observations during sample selection	Imperfections
W1	West	9	North	12 ft. from north edge of panel	Very wide rounded weld bead with possible weld slag on the surface. Identified as a field weld.	Plate: Sensitized (A4, A5), small inclusions (A6), manganese sulfide stringers (A7, A8) Weld: Surface weld slag confirmed (A9)
W2	West	10	Center	4 ft. from south edge of panel	Somewhat larger section of an otherwise smaller shop weld	Plate: Sensitized (A14, A15), a small surface void that may either be pitting corrosion or an inclusion pulled from the surface during polishing (A16) Weld: Weld porosity (A13)
W3	West	6	North	2 ft. from north edge of panel	Weld repair area, shop weld	Plate: sensitized (A20, A21, plate inclusion (A24) Weld: Outside notch on weld surface (A22), undercut (A23), weld void (A25)
W4	West	6	North	6 ft. from north edge of panel	Somewhat recessed area shop weld with possible weld slag	Plate: sensitized (A29) Weld: Numerous small voids (A28)
W5	North - extrados	8	West	1 ft. from east edge of panel	Somewhat larger weld with possible weld slag	Plate: sensitized (A34) Weld: small void (A32, A33), surface and subsurface weld slag (A35 – A39)

H - Plate and Weld Chemistry

The removal of weld samples provided the ability to determine the approximate chemistry using SEM/EDS, which provides chemical analysis of the field of view or spot analyses of minute particles. SEM/EDS analyses were done at WJE (all 5 samples) and RJ Lee (samples 1 and 5). Neither of the stainless steel plate producers (Outokumpu and ATI) nor the Gateway Arch archive had retained the original chemistry certifications. The weld filler metal supplier(s) are unknown and no certifications had been retained in the archives. The small size of the plate in the weld samples and need to retain them made it impossible to do a full laboratory chemistry evaluation, which would also have destroyed the samples. Additionally, the weld area was not large enough for a full chemical analysis.

SEM/EDS chemistry is not exact and is only permissible for general alloy verification. It simply provides guidance about the relative concentration of each alloying element in a specific area. Neither carbon nor sulfur levels can be accurately measured so neither element was included in Table 2. The SEM/EDS values were rounded to one digit. Carbon levels measurements reported are typically much higher than what is physically possible in a stainless steel alloy due to surface contamination, and this can change the relative percentages of deliberate alloying elements making them look artificially lower. Unless carbon is specifically excluded from the analysis calculations, which was not done by either lab, the concentrations of deliberate alloying element additions will appear lower then they actually are. The plate appears to be the specified Type 304 with an appropriate matching chemistry filler metal.

Table 2: SEM/EDS chemistry evaluation

		SEM/EDS Data for Primary Elements (Mass %)				
Sample	**Description**	**Si**	**Cr**	**Mn**	**Fe**	**Ni**
ASTM A167-1963	Type 304	1	18.00-20.00	2	Rem	8.0-12
A240/A240M- 2015	Type 304	0.8	17.5-19.5	2.0	Rem	8.0-10.5
W1	Stainless plate	0.4	17.2	1.8	65.7	8.8
W1	Weld	0.4	17.6	1.8	61.9	8.4
W2	Stainless plate	0.4	17.8	2.0	65.3	8.4
W2	Weld	0.5	17.8	2.0	62.9	8.3
W3	Stainless plate	0.6	18.1	2.3	64.5	8.5
W3	Weld	0.4	17.2	2.1	59.8	8.0
W4	Stainless plate	0.4	17.8	1.7	65.1	8.7
W4	Weld #1	0.4	16.8	1.5	56.5	7.6
W4	Weld #2	0.4	16.6	1.5	55.7	7.6
W4	Weld #3	0.4	17.4	1.5	60.7	8.0
W5	Stainless plate	0.4	17.5	1.6	65.8	8.5
W5	Weld	0.4	17.8	1.7	61.3	8.3

Note: ASTM values are maximums unless a range is listed.

ASTM specifically permits chemistry variation outside the allowed range when single location higher accuracy full chemistry analyses are done (See ASTM A480/A480M-13b, Table A1.1). In a high accuracy single or limited sample analysis post-production, the following chemistry variations are allowed above or below the published ASTM A240 limits without being considered out of tolerance: chromium levels of up to 0.20%, nickel up to 0.10%, and manganese of up to

0.04%. As was noted, SEM/EDS is less accurate and the carbon levels can make alloying element additions appear lower then they actually are.

Most of the samples are within the current chemistry range for Type 304. If the carbon had been eliminated from the analysis, they should meet 1963 requirements. A few scans were below ASTM requirements but a full chemistry of larger samples, as required to confirm chemistry, and they may have been within compliance. It is likely that the plate and filler metal used on the Arch meet the specification requirements. Even if some plates or filler metal was outside of the required chemistry range, there has been no corrosion problem after 50 years of service and remedial action, such as plate identification and replacement, is not reasonable.

I - Gun Shot Residue SEM Lifts

TMR Consulting has been using the gunshot residue kits, which were developed for law enforcement use, from a highly rated forensic lab (R. J. Lee, Pittsburgh) in our metallurgical surface evaluations for many years. These specialized SEM/EDS sample collection tapes can pull finer particles from the surface for analysis then any other non-destructive means of surface assessment. Per agreement with R. J. Lee, they run the scans for TMR Consulting. The full analysis of that data, identification of the specific compounds like mill slag and their source based on a review of current and local industry using multiple sources was done by TMR Consulting. Figure 3 in the main WJE report contains a diagram showing the location of each station.

The samples are broken into two groups based on the inspection visit on which they were collected. The first group of samples include a number followed by the letter “B” and were collected between September 29 and October 1, 2014 from the lower areas of the North leg which were reachable by foot or lift. The areas that had more weld spatter or a coarser polished appearance, which increases surface roughness and tension making rain cleaning less effective, generally had larger surface deposit accumulations.

The samples identified with a number followed by the letter “C” were collected by the inspectors which climbed down the North leg between October 14 and 21, 2014. The samples had to be pre-numbered since that could not be done during sample collection. Due to the limitations associated with this type of inspection, the numbers are not continuous or in a specific order. The inspectors verbally reported the sample number as they worked. A mixture of small and large sample area kits were used, but the collection surface material is identical so size was not relevant. Smaller surface area kits make collection in narrower areas possible and are sometimes more convenient to handle. The findings and sample locations are summarized in Table 4 and documentation can be found in Appendix C. Images C1 through C52 in this Appendix document some of the typical particles on each sample. Fly ash and soil were found on most samples and, in most cases, not specifically documented due to their constant presence unless combined with other elements.

The particles found on surfaces varied. Most were iron rich, often in combination with oxygen (FeO) indicating corrosion of the iron. These iron-rich particles were found in combination with fly ash and soil components (e.g. carbon rich material (spores and pollens), clay materials, silica (sand), dolomite, calcite and magnesia alumina silicates). Chlorides (probably deicing salts) in very small concentrations were found on many of the samples at all heights on the Arch. Stainless steel (iron (Fe), chromium (Cr) and nickel (Ni)), mineral wool, paint particles, copper zinc alloy, and lead particles were also found in one or a few samples but were unusual.

With the exception of the clay, sand, pollen and other characteristic constituents of normal soil, the other accumulations can be explained by current and past industrial activities in the area, particularly the steel production (iron and ferrochrome (FeCr)), a coke plant, coal fired power plants and nearby highways. Isolated iron particles are probably carbon steel from nearby carbon steel fabrication (buildings, roadways) and are common on surfaces near construction sites.[6] The environment is not corrosive enough for these deposits to have caused more then superficial dark discoloration and some light scattered small areas of red toned superficial corrosion staining, so their presence on the surface is a purely aesthetic issue. With the exception of the base, the red toned staining was mainly from iron rich particles from nearby industry. The emissions of fly ash and other industrial particulate have been dramatically reduced in recent decades, but, if the surface was cleaned, some soil that contains these elements might still continue to deposit on the exterior surface.

Soil is composed or organic matter in combination with clay, sand, and silt. Sand and silt are just small particles of rock (i.e. silica (SiO_2), dolomite ($CaMg(CO_3)_2$), magnesia alumina silicates). Most clays are phyllosilicates, which have a visibly sheet-like structure like mica when examined under an SEM. Chemically clay is aluminum silicate, which may have significant amounts of iron, alkali metals, or alkaline earths.

Ferrochrome (FeCr) is an alloy of chromium and iron containing between 50% and 70% chromium. Individual particle chemistry can vary and may have higher iron levels. The production of steel is the largest consumer of ferrochrome, especially the production of stainless steel. All particles that contained iron and chromium but no nickel, so they have been categorized as ferrochrome indicating that they do not appear to be Type 304 stainless steel from the Gateway Arch.

The typical composition of iron and steel slag is shown in Table 3. Blast furnace slag is similar to fly ash in composition but other stages in the process contain iron and other elements. The iron particles found on the surface could also have been from manufacturing operations that generate fine particulates prior to the environmental regulations that limited plant emissions or nearby construction.

Table 3: Iron and steel slag composition[7]

Type	Blast furnace slag	Converter slag	Electric arc furnace slag	
Component			Oxidizing slag	Reducing slag
CaO	41.7	45.8	22.8	55.1
SiO_2	33.8	11.0	12.1	18.8
T-Fe	0.4	17.4	29.5	0.3
MgO	7.4	6.5	4.8	7.3
Al_2O_3	13.4	1.9	6.8	16.5
S	0.8	0.06	0.2	0.4
P_2O_5	<0.1	1.7	0.3	0.1
MnO	0.3	5.3	7.9	1.0

Fly ash (SiO_2, and CaO) is also known as flue-ash, and is one of the residues generated in combustion and consists of the fine particles that rise with the flue gases. In an industrial

6 See current and historic EPA records, https://www.stlouis-mo.gov/visit-play/stlouis-history.cfm, http://builtstlouis.net/, St. Louis' city website and other internet based information on current and historic industry.

7 Available from the US Geological Survey and numerous steel industry resources

context, fly ash most commonly refers to ash produced during combustion of coal (coal fired power plants, coke plants, steel mills and other coal burning industry). The chemistry of fly ash varies with the coal source(s), but all fly ash includes substantial amounts of silicon dioxide (SiO_2) and calcium oxide (CaO). Other constituents will be dependent on the coal source and can include trace quantities of arsenic, beryllium, boron, cadmium, chromium, hexavalent chromium, cobalt, lead, manganese, mercury, molybdenum, selenium, strontium, thallium, and vanadium, along with dioxins and PAH compounds. Fly ash used to be released into the environment and would have been in the environment for much of the Gateway Arch's service life since there were multiple coal burning power plants in the area, a coke plant and steel mills. In recent decades, scrubber systems have been mandated and fly ash is captured prior to release into the environment. It typically either goes to land fills or is used in concrete.

Table 4: SEM/EDS sample locations, descriptions and deposit chemistry

Sample	Description	Location	Chemistry
Group 1, base of North leg, arranged from lowest to highest elevation from the ground			
8B	Small dark surface area, possible adhesive	Above 2nd weld from base, extrados	Soil, fly ash, ferrochrome, chlorides, carbon rich materials (i.e. pollens), mineral wool, and other particles including iron (C23 – C27)
1B	Grey and black particles concentrated on weld spatter	3rd weld from bottom, 1st section from right, extrados	Steel or iron slag, carbon rich material (i.e. spores, pollens etc.) and iron particles entrapped or near fly ash and soil (C1-C12)
2B	Grey, brown and black particles concentrated on weld spatter	5th weld from bottom, extrados, west side central panel	Steel or iron slag, carbon rich material (i.e. spores, pollens etc.) entrapped or near fly ash, soil and a possible paint particle (C1-C12)
3B	Dark and white surface discoloration areas and a rainbow effect in areas.	8th row from base, extrados, across weld with dark area above and streaking below, west panel	Soil, fly ash, chlorides and trace amounts iron (Fe) rich and a possible stainless steel particle (C13 – 18)
4B	Dark and white surface discoloration areas and a rainbow effect in area	Same area as 3B but below weld	Predominantly soils, chlorides, iron rich and silica particles (C13 – 18)
5B	Red toned drip area coming down from weld area	8th weld from base, river side of intrados, north panel	Predominantly ferrochrome oxide with other particles in trace amounts like chlorides, fly ash, and organics (C19 – C22)
6B	Red toned area	Unknown, taken while on lift	Ferrochrome oxides with sulfur, chlorides and phosphorous combined with mixed clay, calcite, silica, pollens and spores (C19 – C22)
7B	Dark parallel vertical drip channeling marks	Station 69, extrados	Soil, fly ash, ferrochrome, chlorides, carbon rich materials (i.e. pollens), mineral wool, and other particles including iron (C23 – C27)
Group 2, Elevated Levels North Leg, arranged from lowest to highest elevation from the ground			
15C	Black deposit	Weld 97/station 49 extrados	Ferrochrome, iron and iron or steel slag particles and soil (C51 – C52)
5C	Dark residue	Station 35, Intrados	Iron with oxygen (corrosion product), steel or iron slag, ferrochrome, chlorides, copper zinc alloy particles, and soil (C36 – C40)
6C	No visible deposits	Station 35, intrados	Ferrochrome, carbon rich organics, chlorides (some were obviously sodium chloride), iron particles, soil (C41 – C43)
1C	Dark residue	Station 34, intrados	Tape surface stuck to collection box and could not be analyzed
3C	Black residue	Same area as 1 but to right	Tape surface stuck to collection box and could not be analyzed
4C	Dark residue	Weld 52/Station 31, extrados, central panel	Iron with oxygen (corroding iron), ferrochrome, lead, titanium, copper, chlorides, iron or steel slag, and a stainless particle with no oxygen (no corrosion) (C28 - C35)
13C	Red toned deposit	Exhaust grating, between slates, station 12/weld 6,	Copper zinc (Cu Zn), ferrochrome, iron or steel slag combined with oxygen, silica (sand),

		extrados	magnesium chlorides (deicing salt), and some titanium (C44 – C48)
14C	Black deposit	Exhaust grating, Station 12/weld 6, extrados	Silica (probably sand) and iron (probably from the steel mill) (C49 – C50)

Note: At least trace amounts of fly ash and soil components were found on all the samples and were not documented unless it was the primary constituent. See Figure 3 in the WJE report for a diagram showing the station locations.

J – Embedded Iron Contamination

There are scratches on the surface of the base with embedded iron particles from carbon or alloy steel. The deepest and largest of these extend along the base, are relatively deep and may have been from a snowplow. There are additional areas with small amounts of embedded iron in graffiti but these are less concerning because they are localized small areas and there is far less iron contamination.

This iron surface contamination should be removed, particularly from the long deep scratches, because the corrosion product from this deposit creates a crevice and does not allow oxygen to reach the surface. Corrosion of the stainless steel under the carbon steel corrosion product deposit will continue. Crevice corrosion can occur when the surrounding exposed stainless does not corrode and the rate of corrosion is higher. The exposure of these areas to deicing salt will increase the corrosion rate.

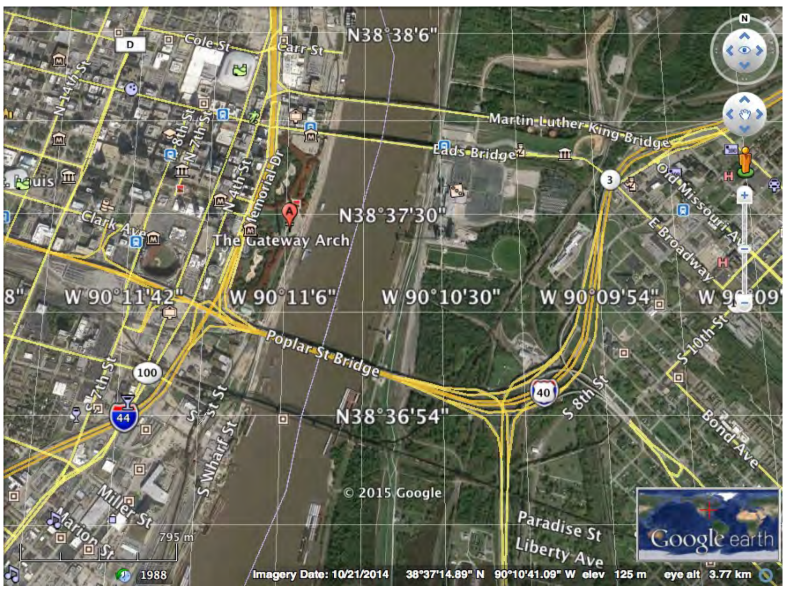
Over time, this linear, concentrated increased thickness loss due to corrosion could lead to thickness loss that presents a concern and weld repair might then become necessary. That is easily avoided. Removal of the contamination should be with stainless steel pickling paste painted on to these localized areas with a small artists brush in accordance with ASTM A380 followed by chemical passivation to improve the corrosion resistance within the scratch. Pickling will dull the finish locally but careful limited application should not make it noticeable since it is so close to the ground. These strong acids should only be used in compliance with manufacturers recommendations to ensure operator safety and to prevent damage to surrounding materials.

Figure 1: Embedded carbon steel, probably from a snow plow blade (Photo taken by authors in 2014)

K - Site Corrosion Assessment

Chlorides from deicing salt were found on the surfaces. Highways surround the site and they are within the documented distance that deicing salt can travel. Only very small amounts of chlorides were found on the surface during the September and October 2014 inspections. The high winds documented at the top and elevated sides indicate that most of the structure is probably well rain washed during storms.

Other then very small, localized areas, such as the elevated areas where iron and ferrochrome particles were found, the only corrosion observed on the surface was at the base. This area would not be as effectively washed by rain as elevated areas with higher wind levels. Light staining caused by microscopic deicing salt related pitting was observed at the base. Very little residue was found on the surface when a Chlor-Test was done, but that would not be unusual in the fall. This corrosion is superficial and could easily be removed.



Figures 2 and 3: Google Earth image (Left) showing the highways and bridges immediately around the site which are adding deicing salts (chlorides) to the environment and the superficial corrosion staining at the base caused by deicing salt exposure. (Right photo taken by authors in 2014)

Various sources were reviewed to determine the industrial pollution sources that have been in the area since the construction of the Gateway Arch. Many possible industrial plant sources have shut down or changed what they are producing during the past 50 years. The industries in the area, which could have contributed to the residue found in the surface deposits included several steel mills including Granite City Steel; companies that may have had steel foundries or manufacturing steps could put metallic particles in the air; St. Louis Army Ammunition Plant; Carondelet Coke Plant; three coal fired power plants Cahokia, Union Electric, and Venice; Sauget Industrial and Big River Zinc (zinc refinery); Cerro Copper (copper alloys); and chemical plants such as Monsanto and Pfizer.

L - Surface Cleaning, Restoration and Maintenance

The cleaning and refinishing trials at the base of the monument are discussed in the Wiss Janney Elstner report. In addition to the aesthetic considerations, there are technical reasons to consider some cleaning of the base of the monument. The primary concern is deeply embedded iron particles in scratches because corrosion of the stainless steel could continue under the crevice created by the iron corrosion product. This could be removed selectively with an electro polishing wand or with appropriate chemicals in accordance with ASTM A967. Some of the deeper scratches with heavily embedded iron may require careful removal of the iron with pickling paste, as described in A380, or an electro polishing wand.

The scratches in the surface of the base, including those not associated with iron contamination, increase the likelihood of corrosion in two ways. They roughen the surface, which increases corrosive deposit accumulation and corrosion, and open up the sulfide inclusions documented in the plate. Corrosion can initiate at sulfide inclusions when it would not occur otherwise. Surface sulfides can be removed by chemical passivation in accordance with ASTM A967 and manufacturers' recommendations about dwell time after the surface is cleaned to remove staining, dirt, oils and other deposits. Passivation that is done correctly by a firm that specializes in chemical cleaning of stainless steel will not change the appearance of the surface. No cleaning should be done unless a stainless steel metallurgist that specializes in finishes and atmospheric corrosion approves the procedures. Removing the shallower scratches is ideal from the standpoint of limiting corrosive deposit build up, but cleaning and passivation can be done without their removal.

Since the paving around the monument is heated, no deicing products are reportedly used. If the NPS should decide to use deicers at some future time, non-corrosive deicers that only work at somewhat higher temperatures (above 15 F) should be considered, such as calcium magnesium acetate (CMA). Hot water power washing of surfaces in early Spring, preferably with Chlor-Wash or Chlor-Rid which more effectively release chloride salts from surfaces, would also minimize staining.

Based on a review of the archive materials, the Arch was cleaned as the crane and supporting structure was removed. This included removal of carbon steel contamination, refinishing and cleaning. Use of pickling paste or chemical passivation products would be common today but we do not know what was used in this operation. Either would have removed surface sulfides and could be a factor in the essentially corrosion free performance of elevated areas.

Archive documentation makes it clear that the surface was not uniform in appearance upon completion. It is difficult to achieve finish consistency with polished bare metals in the field. Handling and installation damage was documented in the architect's daily reports and field refinishing was done. Field refinishing to eliminate damage never produces a completely uniform surface and it is always far less consistent then finishes applied under controlled factory conditions. Improving overall finish consistency in the field would be a highly labor intense process and perfection is not possible.

It is assumed that any work on elevated areas would be to remove the areas of dark discoloration from surface deposits. If abrasives that are capable of changing the finish morphology are used, they will change the appearance of those areas and that could result in visible areas of inconsistency. Either chemicals capable of removing the deposits without affecting the stainless steel or very fine abrasives that are not capable of changing the stainless steel surface would be needed.

Appendix A: Weld Sample Evaluation

Figure A1: W1, prior to removal (Photo taken by authors in 2014)

Figure A2: W 1 as-received condition. (Scale=1/32”) (Photo taken by authors in 2014)

Figure A3: Macrograph cross of section W1 in the etched condition (Photo taken by authors in 2014)

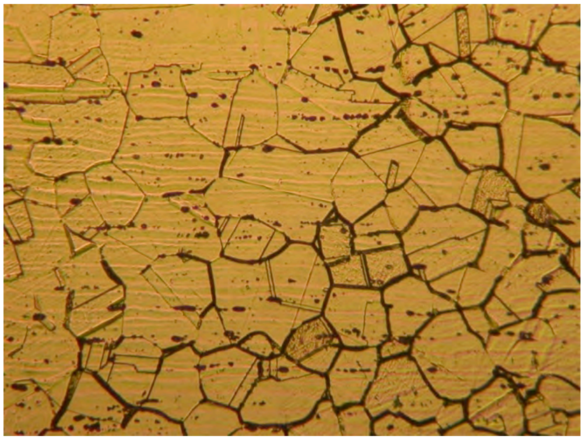


Figure A4: Micrograph of W1 in the etched condition showing sensitized grains (right) and grains that are not sensitized (left). (256x) (Photo taken by authors in 2014)

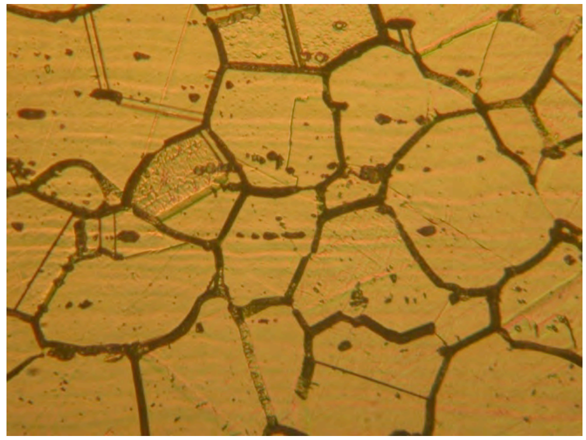


Figure A5: Micrograph of W1 in the etched condition showing sensitized grains in the plate. (517x)(Photo taken by authors in 2014)

Figure A6: Micrograph of a plate inclusion, W1, as-polished condition. (517x) (Photo taken by authors in 2014)

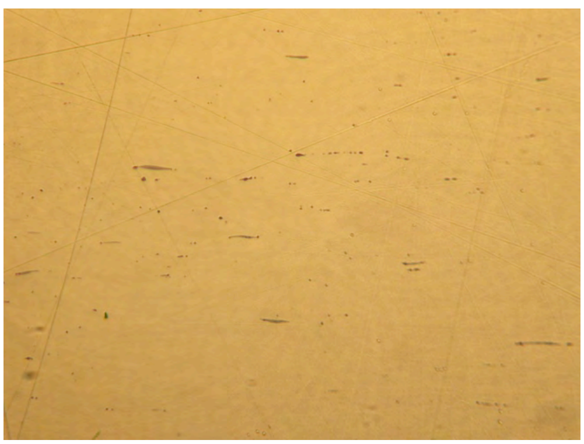


Figure A7: Micrograph of manganese sulfide stringers in the plate, W1, as-polished condition. (256x) (Photo taken by authors in 2014)

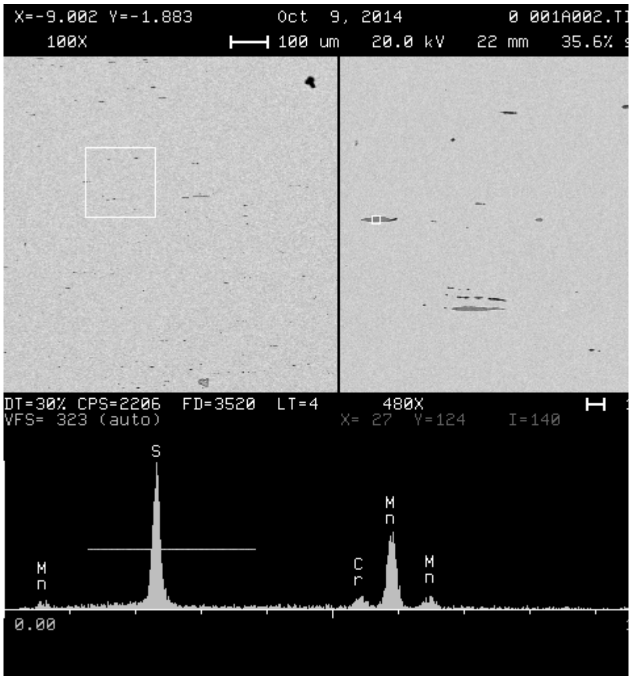


Figure A8: SEM/EDS confirming the presence of manganese sulfide stringers (RJ Lee SEM sample scan 2014)

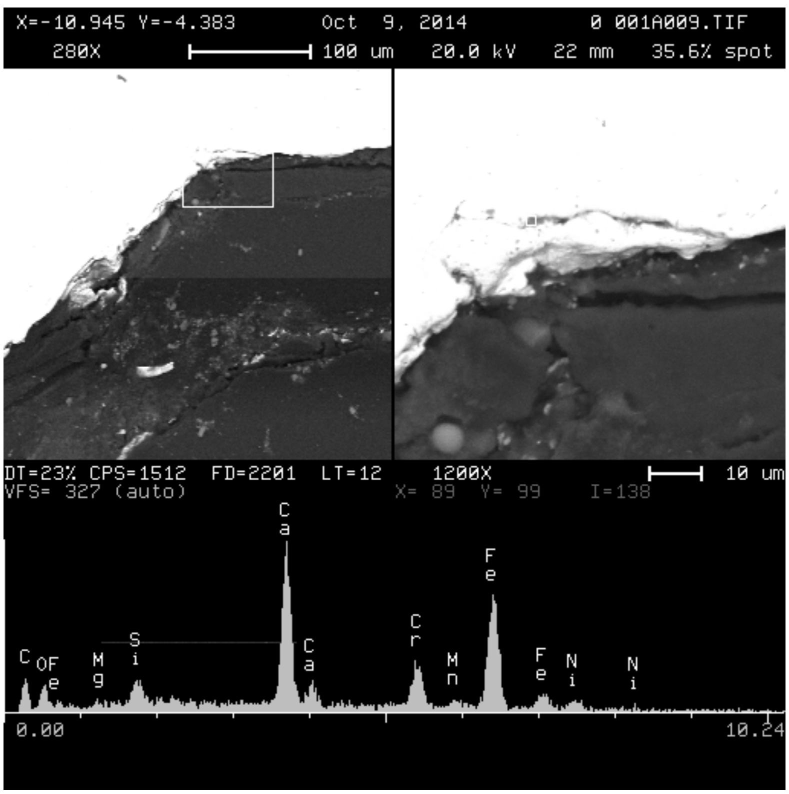


Figure A9: SEM/EDS showing some W1 surface weld slag (Ca and Si) (RJ Lee SEM sample scan 2014)

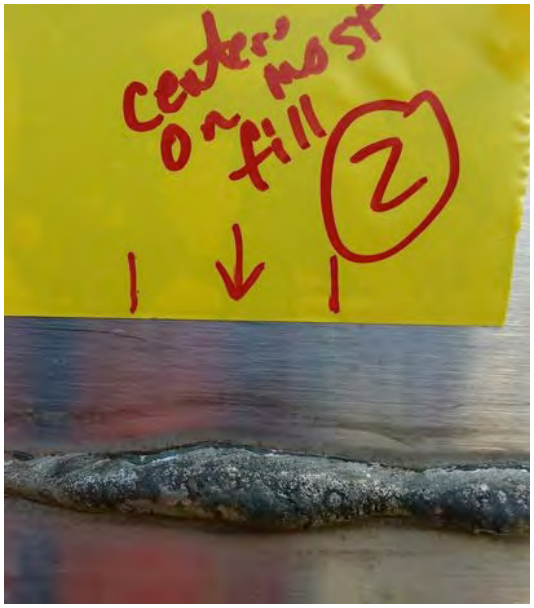


Figure A10: W2 prior to removal (Photo taken by authors in 2014)

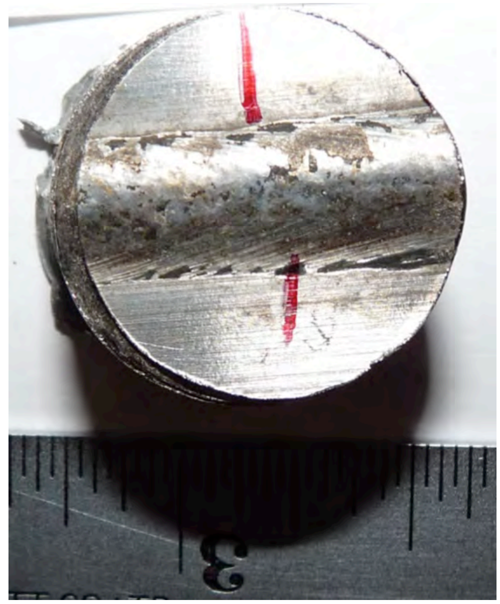


Figure A11: W2 as-received condition. (Scale=1/32”) (Photo taken by authors in 2014)

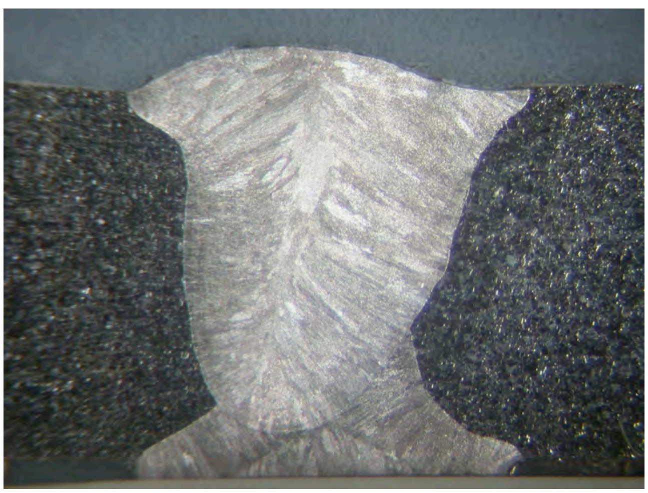


Figure A12: Macrograph of W2, etched condition (Photo taken by authors in 2014)

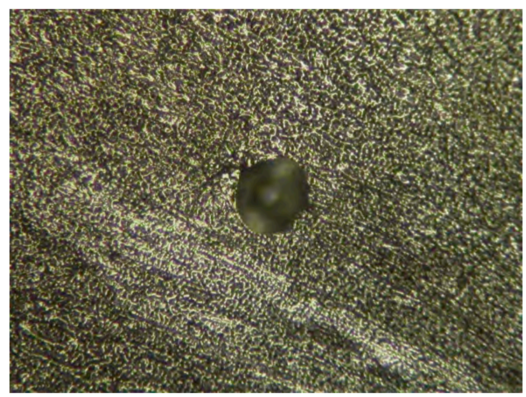


Figure A13: Micrograph of W2, etched condition, weld porosity, approximate diameter 0.004” (Photo taken by authors in 2014)

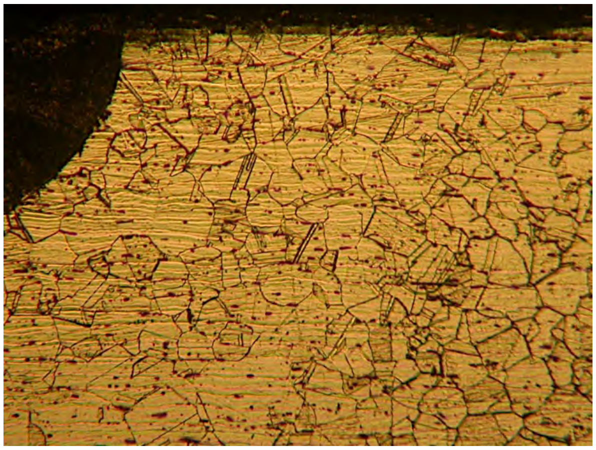


Figure A14: Micrograph W2 etched condition showing weld metal (top left corner), a band of grains that are not sensitized (center) and a band of sensitized grains (right). (122x) (Photo taken by authors in 2014)

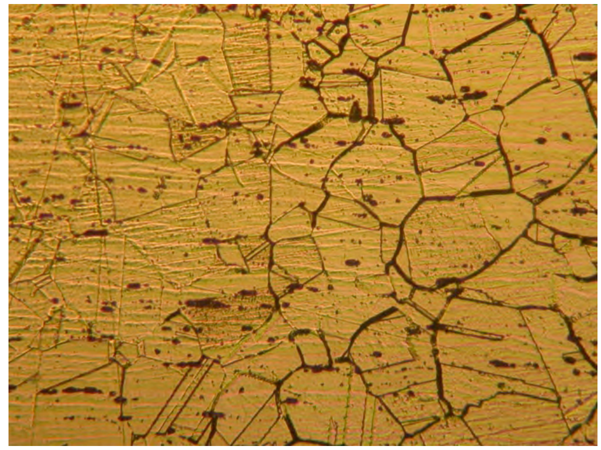


Figure A15: Micrograph W2, etched condition showing sensitized grains (right) and grains that are not sensitized (left). (256x) (Photo taken by authors in 2014)

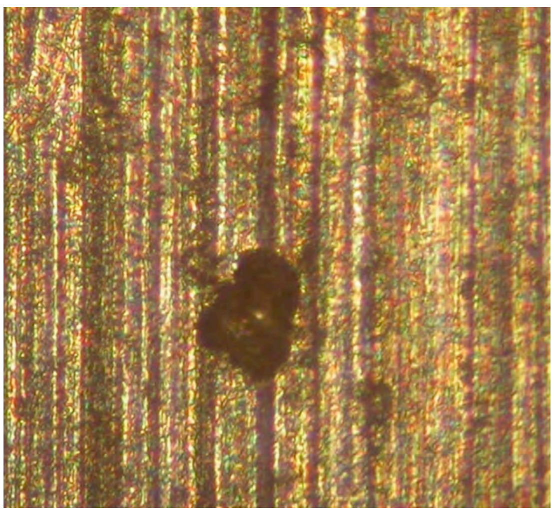


Figure A16: Cut, un-mounted section of the surface of the W2 sample with a small void of approximately 0.002” diameter located approximately 0.045” from the edge of the weld. This may have been very minor corrosion pitting of the surface since there are similar very small pit like shapes on the surface around it, but there was no visible staining when we examined it. Alternatively, an inclusion could have been pulled out of the surface during polishing. (Photo taken by authors in 2014)

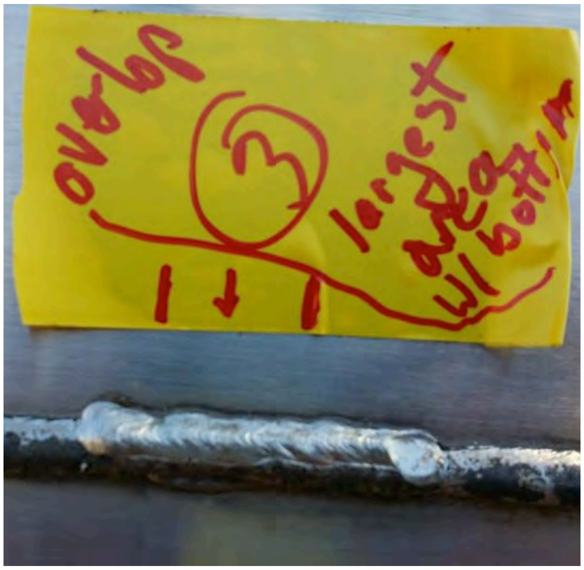


Figure A17: W3 prior to removal (Photo taken by authors in 2014)


Figure A18: W3 as-received condition. (Scale=1/32”)(Photo taken by authors in 2014)


Figure A19: Macrograph of W3, etched condition. (Photo taken by authors in 2014)

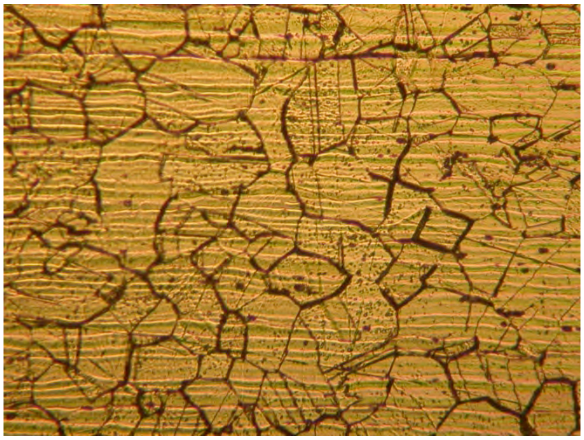


Figure A20: Micrograph W3, etched condition showing sensitized grains in the plate. (256x) (Photo taken by authors in 2014)

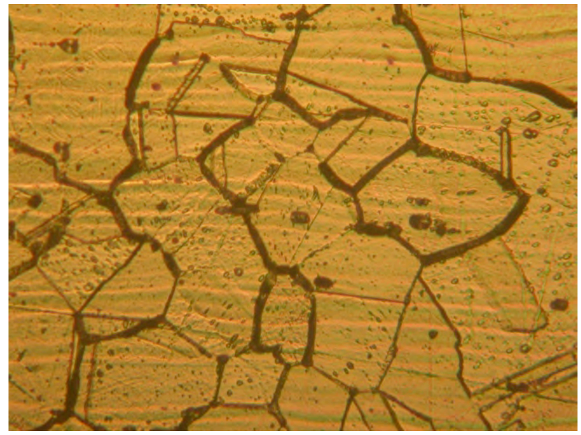


Figure A21: Micrograph W3, etched condition close up of sensitized grains in the plate. (517x) (Photo taken by authors in 2014)

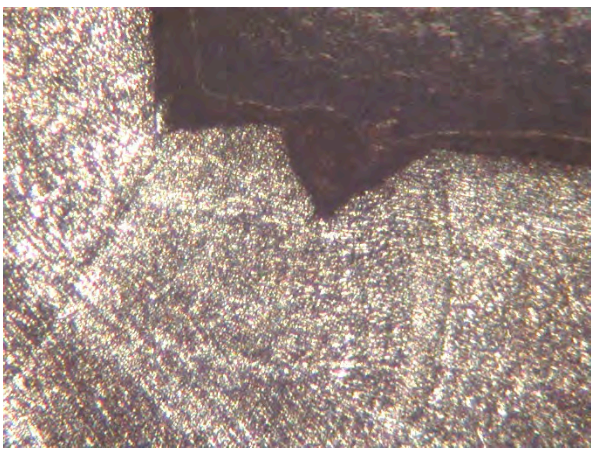


Figure A22: Micrograph W3, etched condition showing a notch in the outside weld surface. (122x) (Photo taken by authors in 2014)

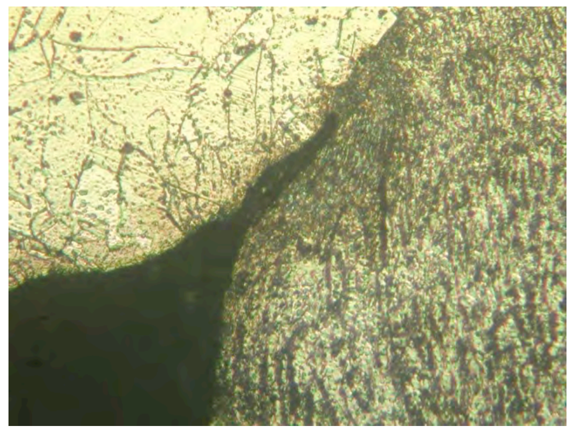


Figure A23: Micrograph W3, etched condition showing shallow undercut where the weld metal and base metal meet, inside surface of the plate. (517x) (Photo taken by authors in 2014)

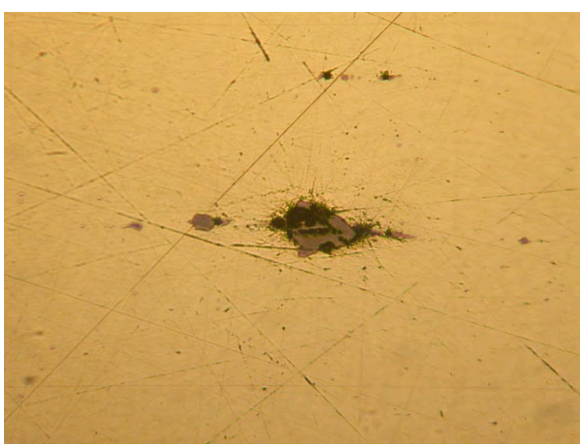


Figure A24: Micrograph, W3, plate inclusion, as-polished condition. (256x) (Photo taken by authors in 2014)

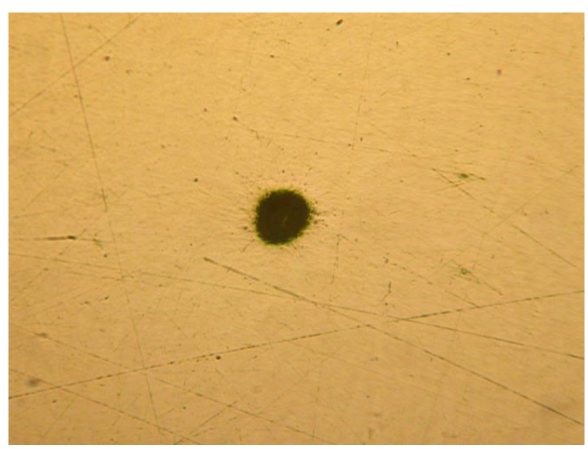


Figure A25: Micrograph, W3, weld void, approximate diameter 0.004”, shown as-polished condition. (Photo taken by authors in 2014)

Figure A26: W4 prior to removal (Photo taken by authors in 2014)

Figure A27: W4 as-received condition. (Scale=1/32") (Photo taken by authors in 2014)

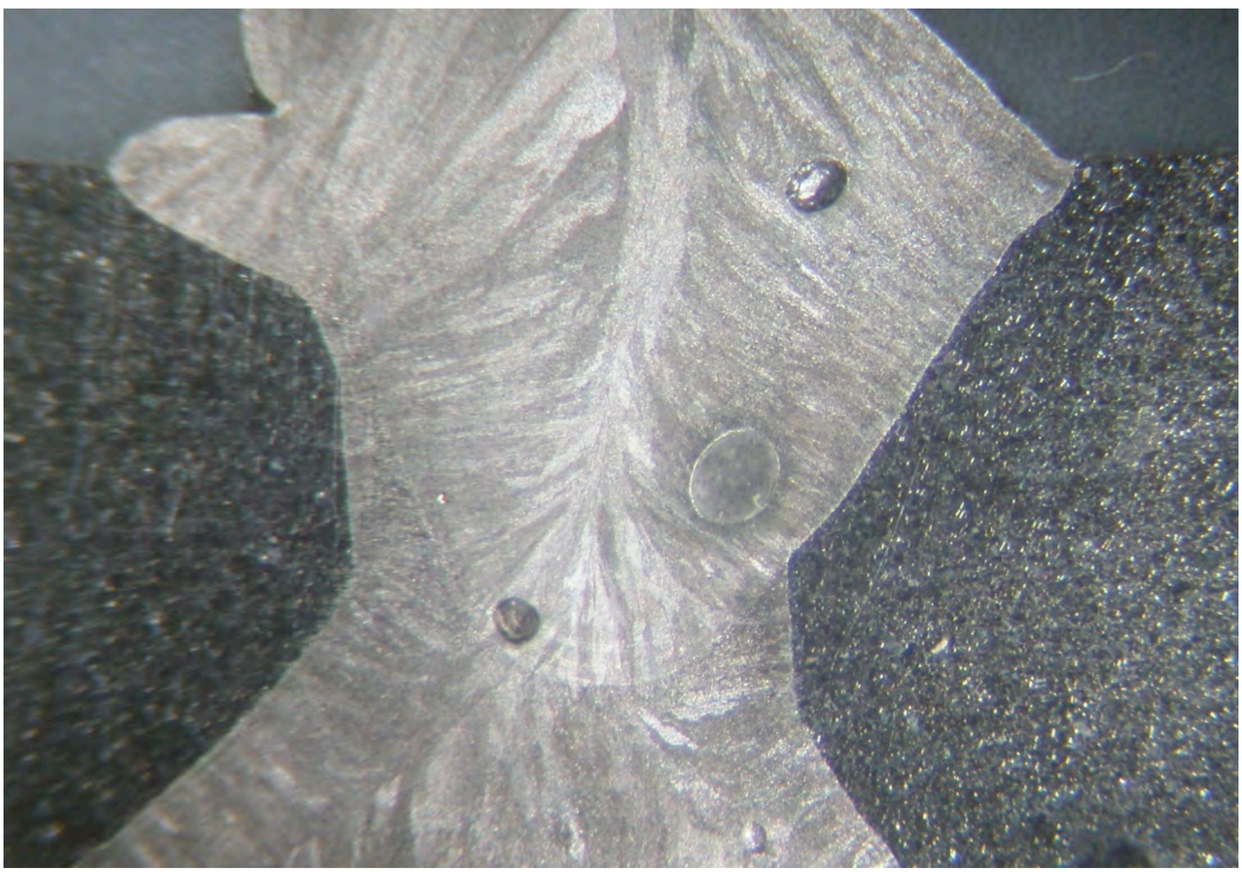


Figure A28: Macrograph, W4, etched condition, showing weld porosity. The largest void, which is located near mid thickness, has an approximate diameter of 0.04". (Photo taken by authors in 2014)

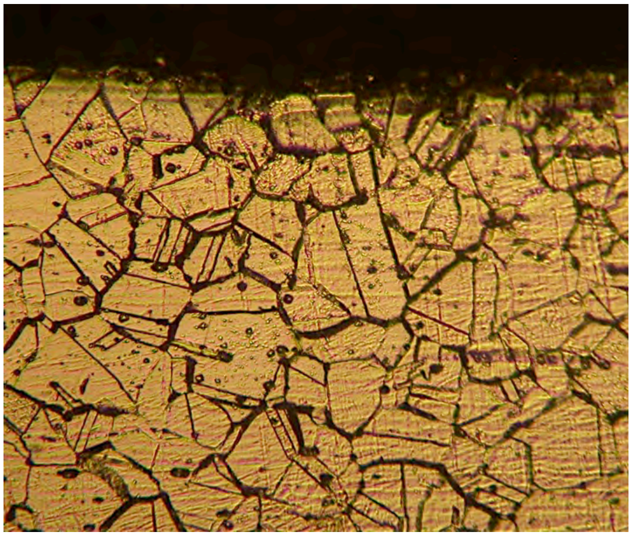


Figure A29: Micrograph, W4, etched condition showing sensitized grains near the outside surface of the plate. (256x) (Photo taken by authors in 2014)

Figure A30: W5 prior to removal (Photo taken by authors in 2014)

Figure A31: W5 as-received condition. (Scale=1/32”) (Photo taken by authors in 2014)

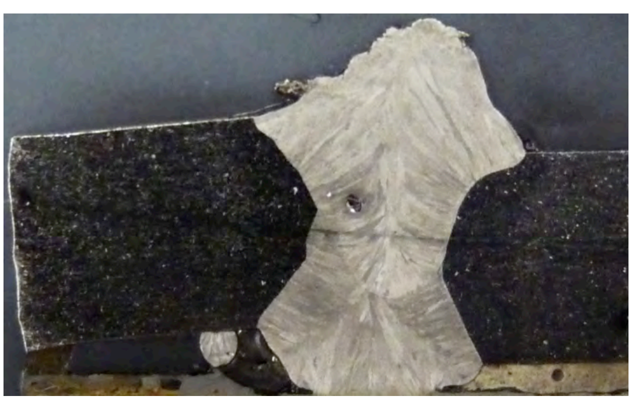


Figure A32: Macrograph W5 etched condition with a visible void. The minor plate misalignment is not a structural concern. (Photo taken by authors in 2014)

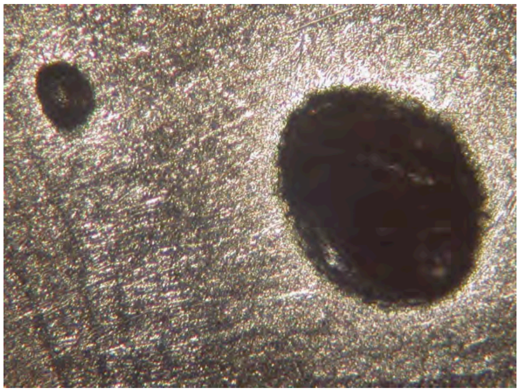


Figure A33: Micrograph W5 etched condition showing porosity in the weld metal with approximate diameter of 0.024”. (Photo taken by authors in 2014)

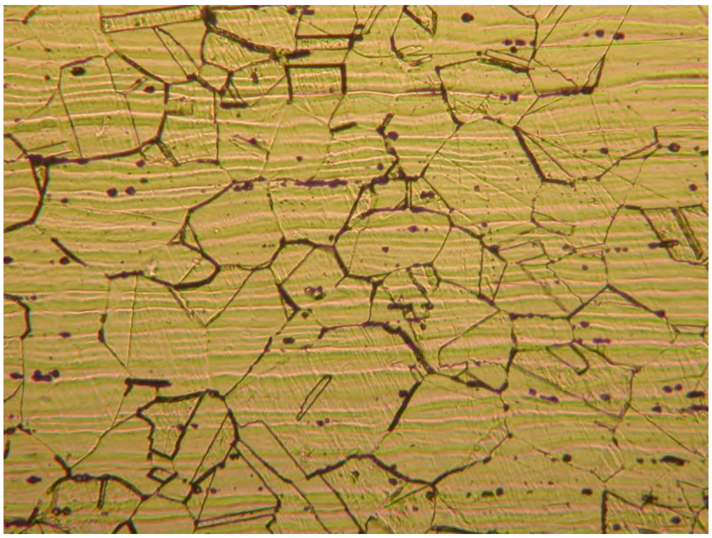


Figure A34: Micrograph sample 5, etched condition showing sensitized grains in the plate. (256x) (Photo taken by authors in 2014)

Figure A35: W5 after sectioning through weld slag contamination that was visible on the weld surface. (Photo taken by authors in 2014)

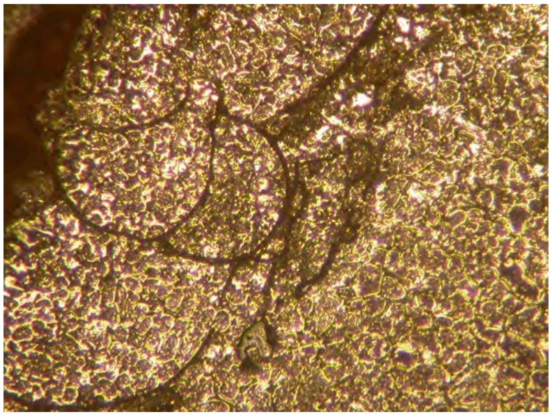


Figure A36: Micrograph of W5 same area, weld crown in the etched condition with sub surface weld slag. (256x) (Photo taken by authors in 2014)

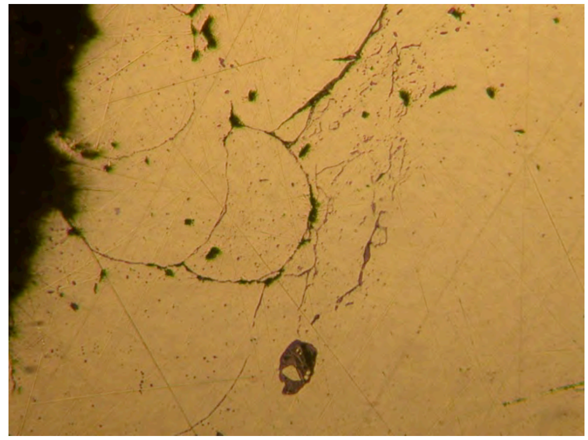
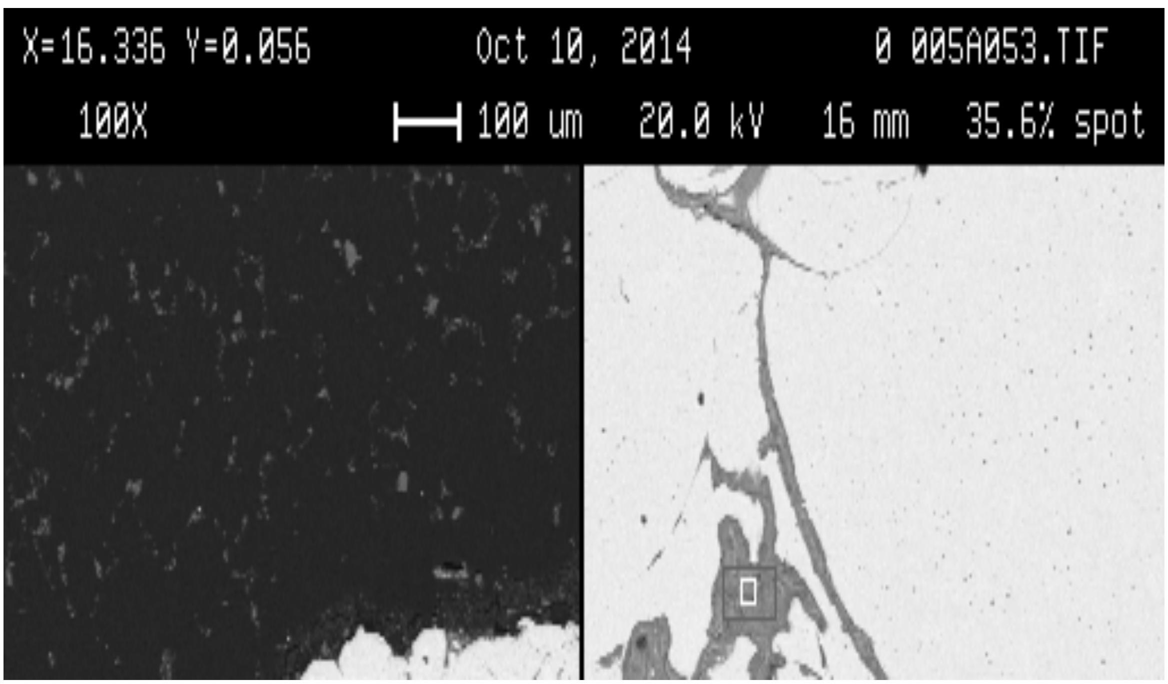


Figure A37: Micrograph W5 at the weld crown shown in the as-polished condition showing the sub surface weld slag. (256x) (Photo taken by authors in 2014)



Figures A38: SEM, same weld slag inclusion area with different magnifications (RJ Lee SEM sample scans 2014)

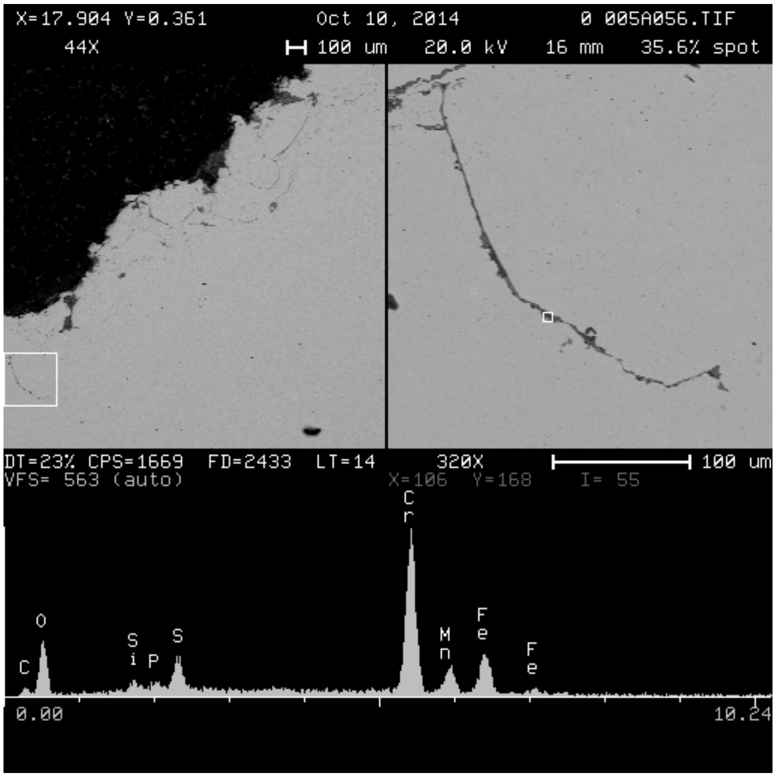


Figure A39: SEM micrograph, sample 5 same area, documenting that the observed linear areas are CrO and not cracks in all areas. No corrosion was observed. (RJ Lee SEM sample scan 2014)

Appendix B: Reference Examples of Typical Weld Imperfections

Several common weld imperfections were documented in Appendix A. TMR Consulting was asked to provide a reference Appendix describing the common weld imperfections. None of the pictures in this section were taken from Gateway Arch samples. They are for reference purposes from an industry suppliers guide.

This image is representative of the ideal appearance of a stainless steel weld: uniform with a relatively smooth, consistent, not overly large weld bead. There were many welds with this overall appearance on the Arch, particularly at elevated levels, although many had some weld spatter.

Figure B1: Ideal stainless weld appearance (Photo taken by authors, archive)

Porosity

It is not unusual to occasionally find porosity within weld beads. It can occur during all welding processes and is of greatest concern when it breaks the surface, where there are larger clusters, or when the area of porosity is large relative to the material thickness. Considerable areas of porosity maybe allowed if it is isolated and the affected areas are small relative to the thickness..

Only small isolated small areas of porosity were found within the Gateway Arch weld samples and they were not considered a problem.

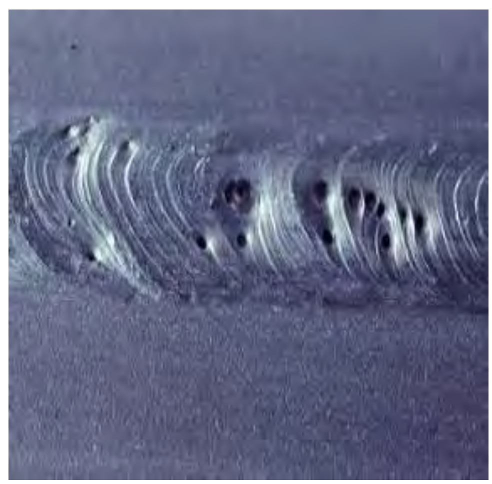


Figure B2: This image is representative of clusters of porosity breaking the surface. Nothing this severe was documented on the Arch. (Photo Avesta Welding Manual)

Weld Spatter

Some level of weld spatter (small raised areas where molten metal hit the surrounding surface) is likely with the welding method used on the Arch. Its acceptability is dependent on a specific projects aesthetic and corrosion requirements. Its presence on the Arch indicates that it was apparently considered acceptable by the inspectors.

Weld spatter can be an initiation point for corrosion and can increase surface deposit build up. Surface deposits can also cause corrosion or surface discoloration. Generally, it should be removed.

Weld spatter was documented on many of the Arch's welds although there was a great deal of variation seen. In some areas, it was obviously associated with increased surface deposit accumulation and discoloration. The image shows the typical appearance of this imperfection.

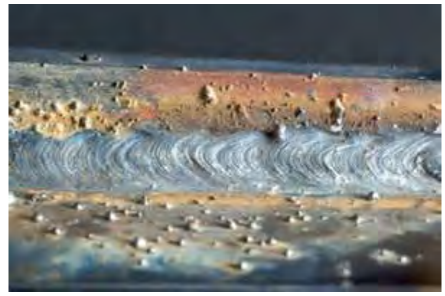


Figure B3: Weld spatter. (Photo Avesta Welding Manual)

Weld Slag Islands and Inclusions

Weld slag can be found on all weld types. Carbon and silicon are associated with these inclusions when analyzed using SEM/EDS. Small, spherical inclusions within the weld cross section are generally acceptable. The size and length of the inclusions is another factor in acceptability and potential impact on structural integrity.

Slag "islands" occur in the surface of the weld and can be a location where corrosion can initiate. Slag "islands" generally cannot be removed by brushing but light grinding is typically sufficient. Both types of imperfections were identified in the weld samples.

Figure B3: Weld slag inclusion (Photo Avesta Welding Manual)

Figure B4: Weld slag on the surface (Photo Avesta Welding Manual)

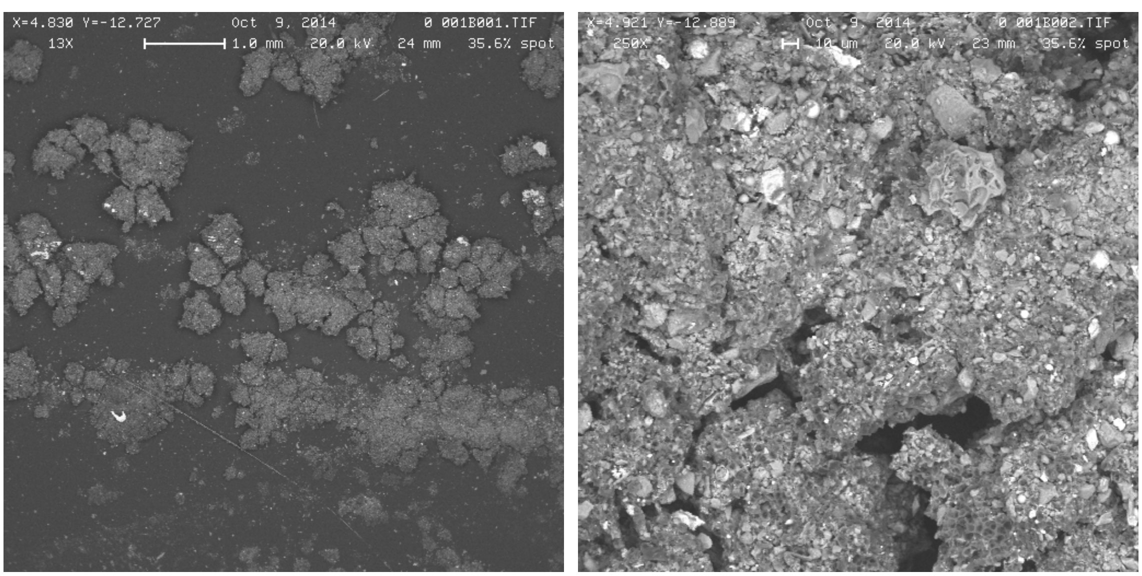
Appendix C: Surface Sample Analyses

The following SEM/EDS scans of particles found on the GSR sample strips are a representative sampling of a much larger number of scans documenting particle chemistry. See Table 4.

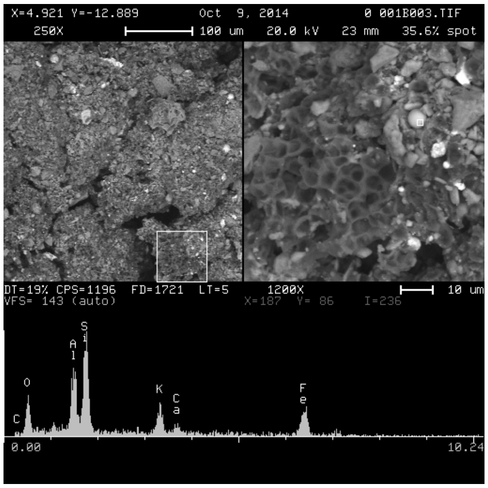
Representative SEM/EDS Scans of particles 1B and 2B

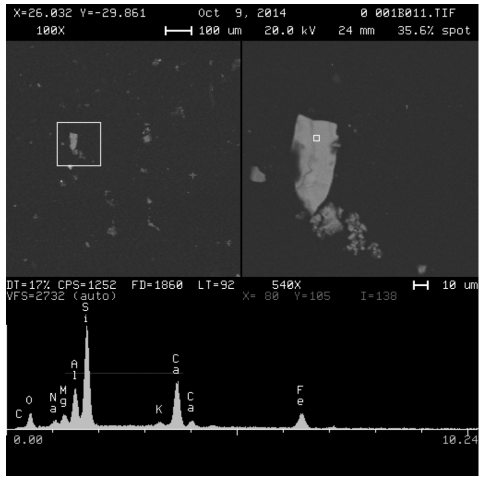
Both samples were dark in color and nearly identical in appearance and analysis. The only variation was the size of the deposit. The deposit appeared to mainly consist of particle agglomerations (Figure C1) and was largely removable with a wet cloth (Figure C2). This was representative of the appearance of the dark deposits found around welds.

Figures C1 and C2: Dark deposit accumulation around and extrados weld, before collection of sample 2B (C1, left) and after sample collection and additional cleaning with an alcohol dampened cloth (C2, right). (Photo taken by authors in 2014)

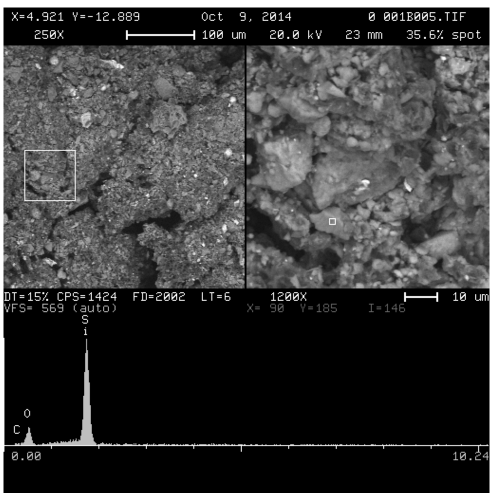


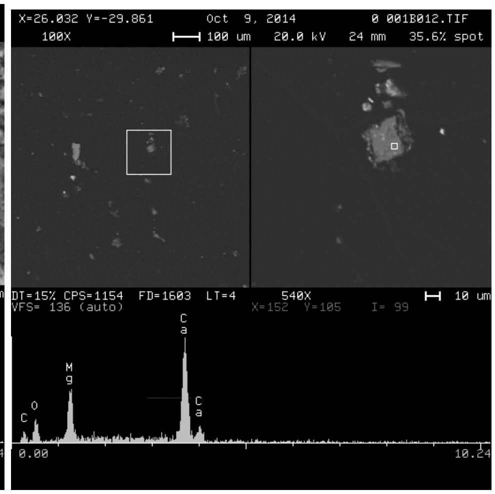
Figures C3 and C4: SEM images of the deposits at different magnifications. (RJ Lee SEM sample scans 2014)



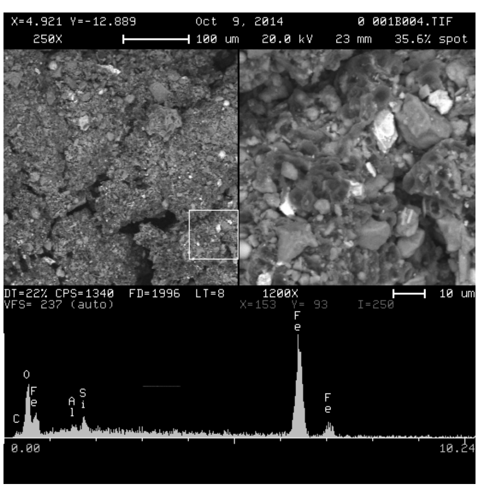


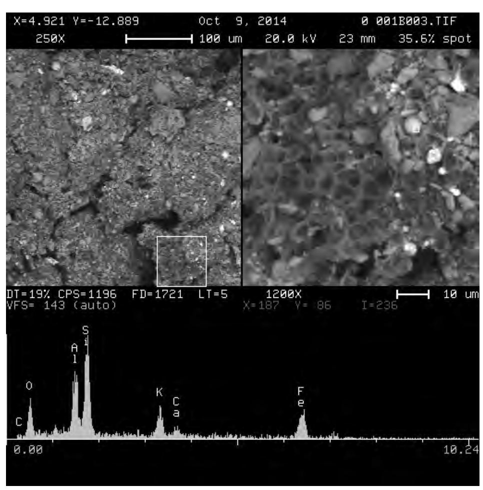
Figures C5 and C6: Representative particles of what appears to be electric arc furnace slag from steel production or fly ash with some iron particles trapped in it. (RJ Lee SEM sample scan 2014)





Figures C7 and C8: Representative scans of silica (sand) and soil (C8). (RJ Lee SEM sample scans 2014)

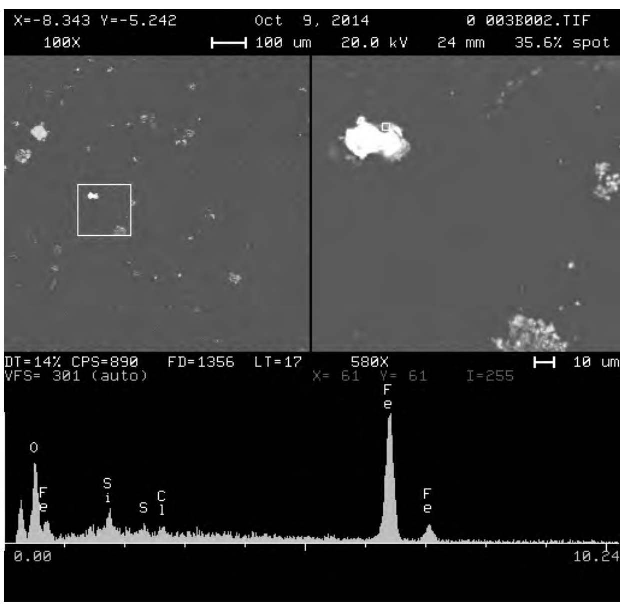




Figures C9 and C10: (C9) Iron particle from carbon or steel manufacturing or fabrication combined with oxygen (corrosion) and (C10) soil combined with iron. (RJ Lee SEM sample scans 2014)

Figure C11 and C12: Weld spatter differences in areas with minimal versus significant surface deposits. (Photos taken by authors in 2014)

Representative SEM/EDS Scans of particles 3B and 4B



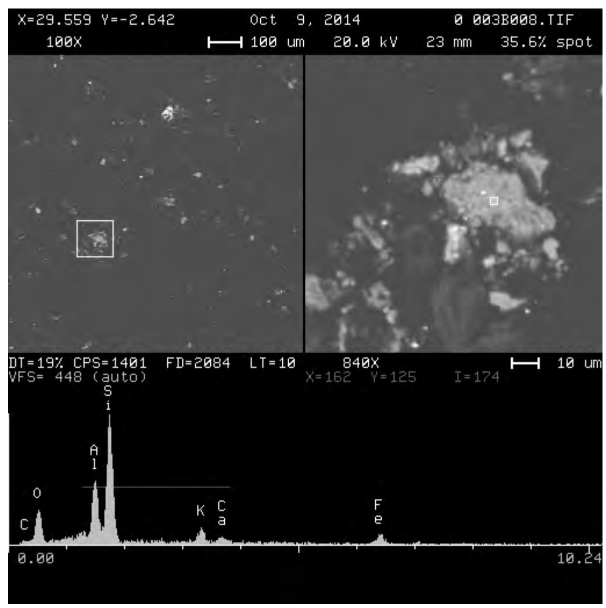


Figure C13 and C14: Iron with small amounts of silica and chlorides (left, C13) and soil with a small amount of iron (right, C14). (RJ Lee SEM sample scans 2014)

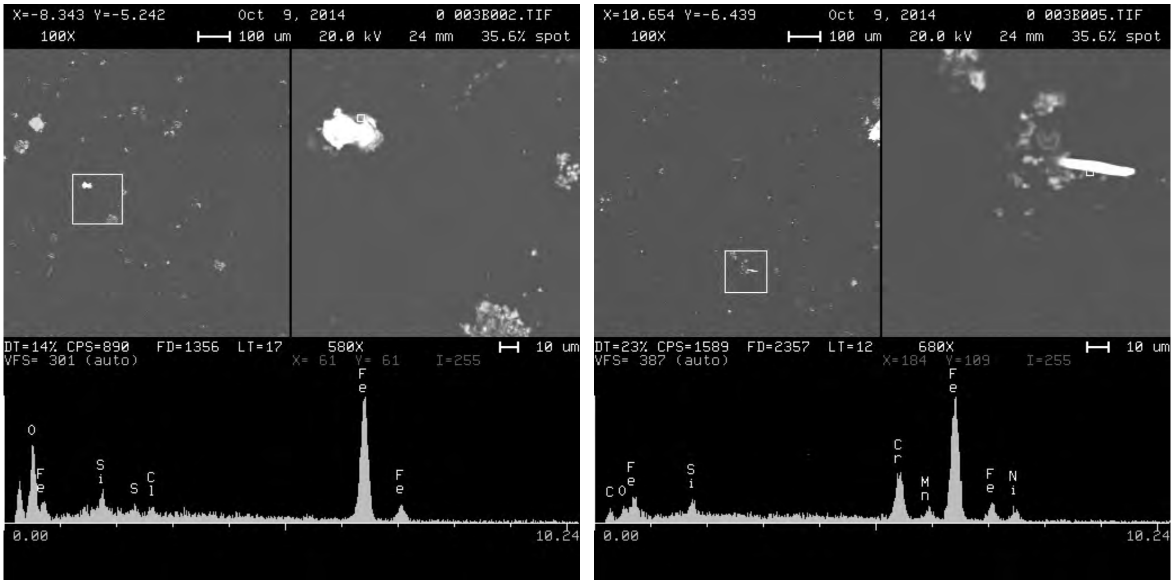


Figure C15 and C16: Iron with small amounts of soil (left, C15) and a stainless steel particle (no oxygen so it is not corrosion product) (right, C16). (RJ Lee SEM sample scans 2014)

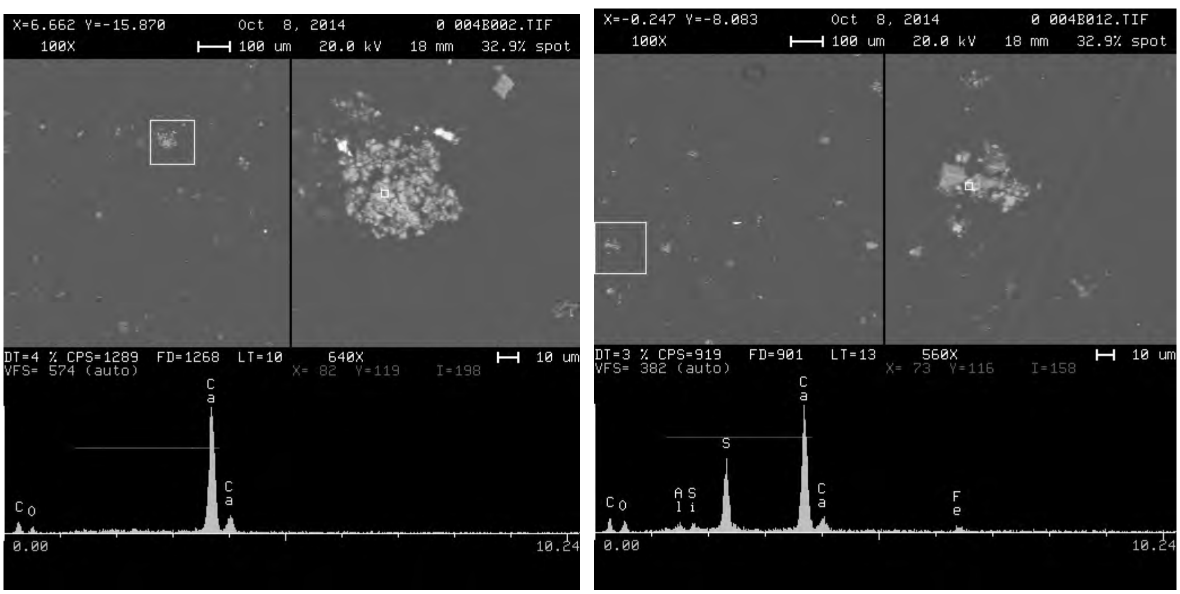


Figure C17 and C18: Calcium (left, C17) and fly ash (right, C18). (RJ Lee SEM sample scans 2014)

Representative SEM/EDS Scans of particles 5B and 6B

Many of the particles were sand or fly ash as documented in the other samples.

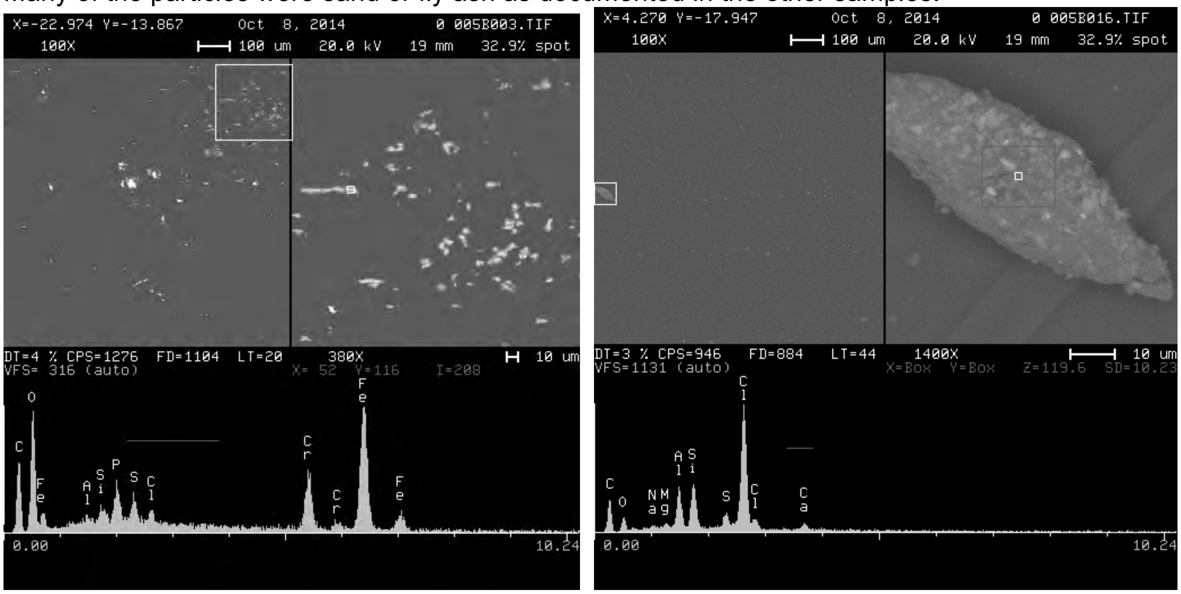


Figure C19 and C20: Ferrochrome with small amounts of chlorides and soil (left, C19) and chlorides mixed with soil (right, C20). (RJ Lee SEM sample scans 2014)

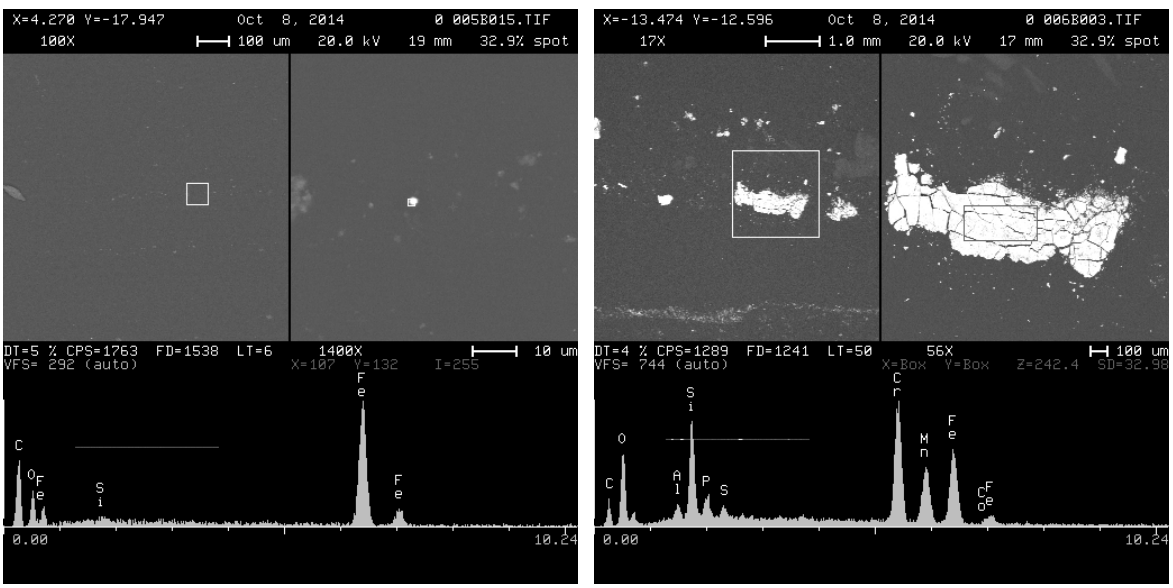


Figure C21 and C22: Iron particle (left, C21) and iron or steel slag with some soil (right, C22). (RJ Lee SEM sample scans 2014)

Representative SEM/EDS Scans of particles 7B and 8B

These scans were essentially identical.

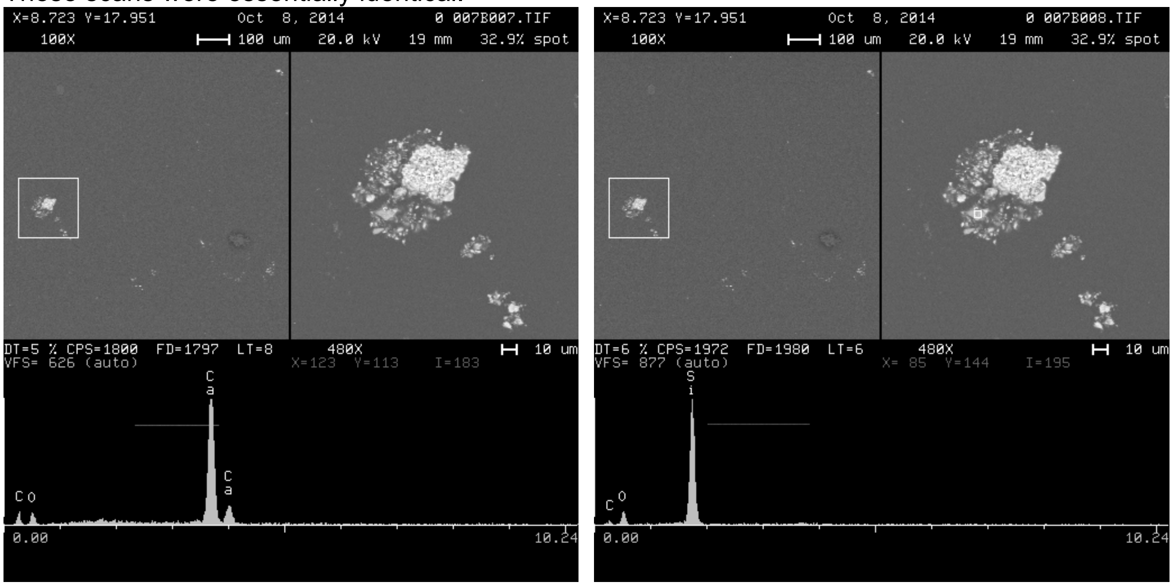


Figure C23 and C24: Calcium particle (left, C23) and silica (right, C24) (RJ Lee SEM sample scan 2014)

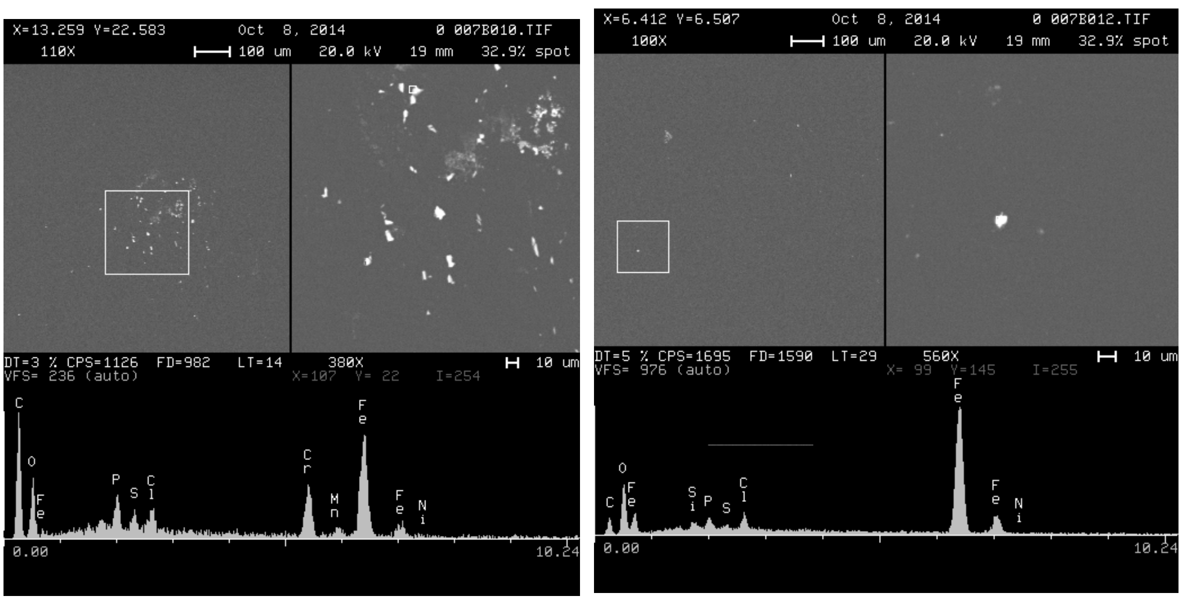


Figure C25 and C26: Probably ferrochrome with chlorides with carbon rich organics (left, C25) and iron with small amounts of chlorides and soil (right, C26). (RJ Lee SEM sample scan 2014)

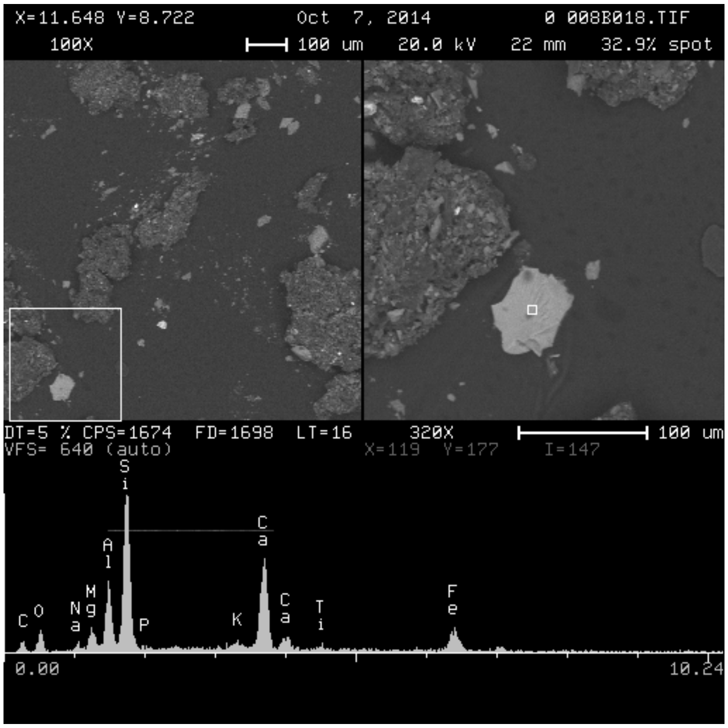
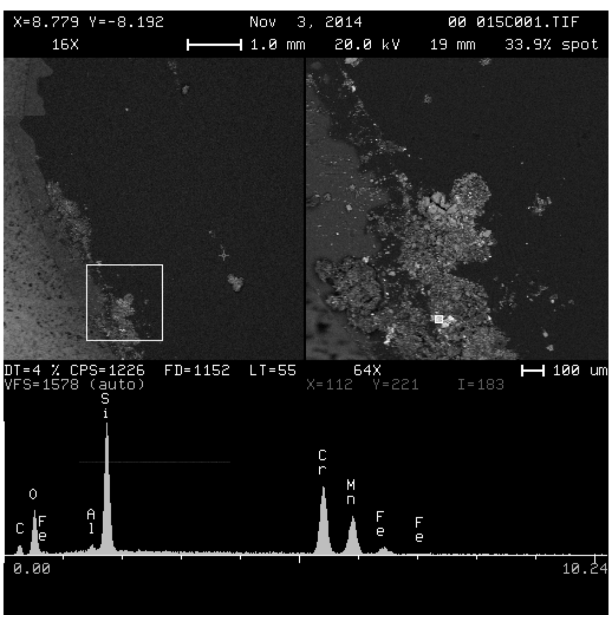


Figure C27: Fly ash, soil and a small amount of iron. (RJ Lee SEM sample scan 2014)

Representative SEM/EDS Scans of particles in Sample 4C



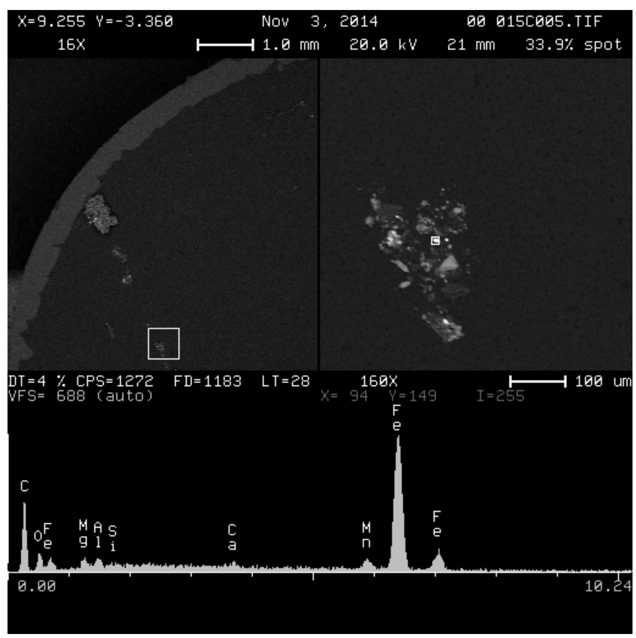


Figure C28 and C29: (left, C28) Slag from iron or steel production and (right, C29) iron with small amounts of soil and iron with soil. (RJ Lee SEM sample scans 2014)

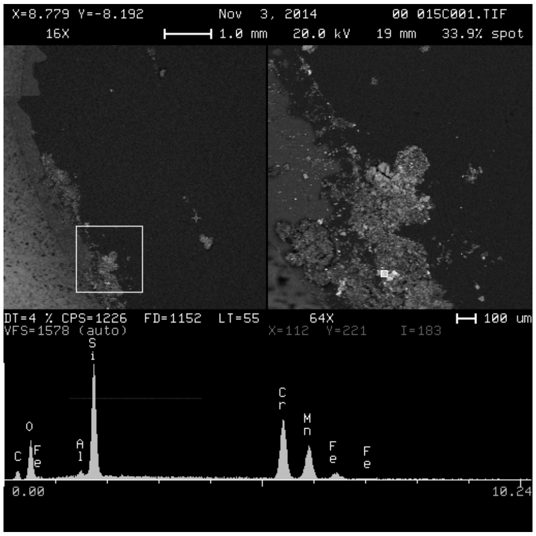
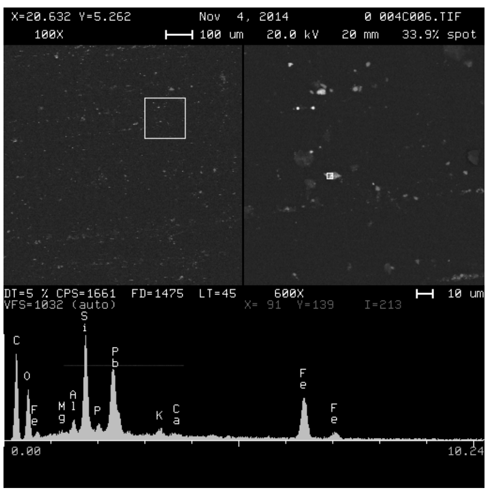


Figure C30: Soil and ferrochrome particles. (RJ Lee SEM sample scan 2014)



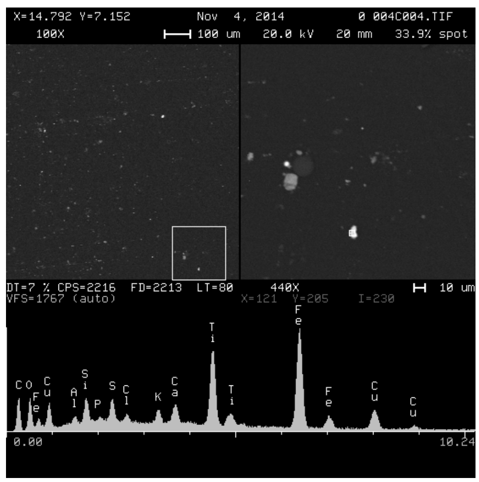


Figure C31 and C32: These particles are representative of the unusual metal particle combinations found on this sample including lead, iron, soil and carbon organics (left) and titanium with iron and smaller amounts of copper, chlorides, and soil (right). (RJ Lee SEM sample scan 2014)

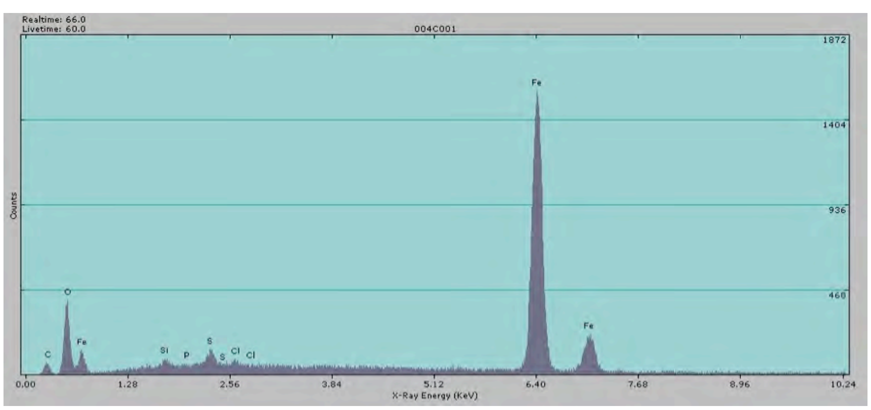


Figure C33: Iron particle with oxygen (corrosion). (RJ Lee SEM sample scan 2014)

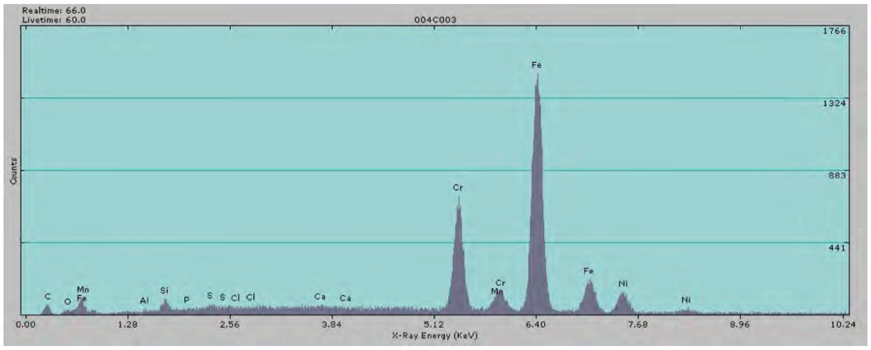


Figure C34: Stainless steel particle with no oxygen (corrosion) with minor amounts of chlorides (salt) and soil. (RJ Lee SEM sample scan 2014)

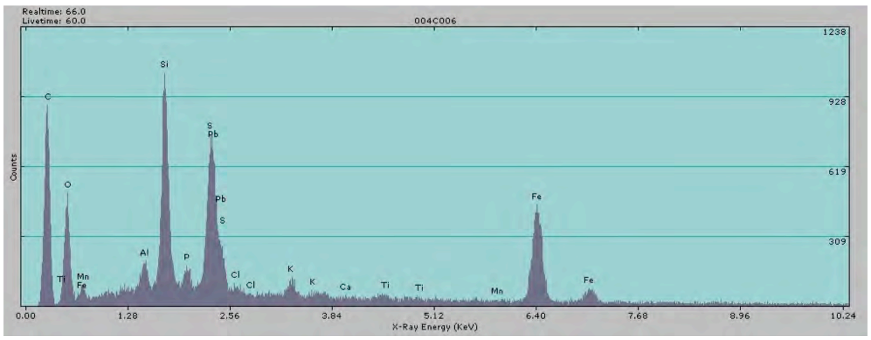


Figure C35: Soil combined with iron and steel slag and some lead. (RJ Lee SEM sample scan 2014)

Representative SEM/EDS Scans of particles in Sample 5C

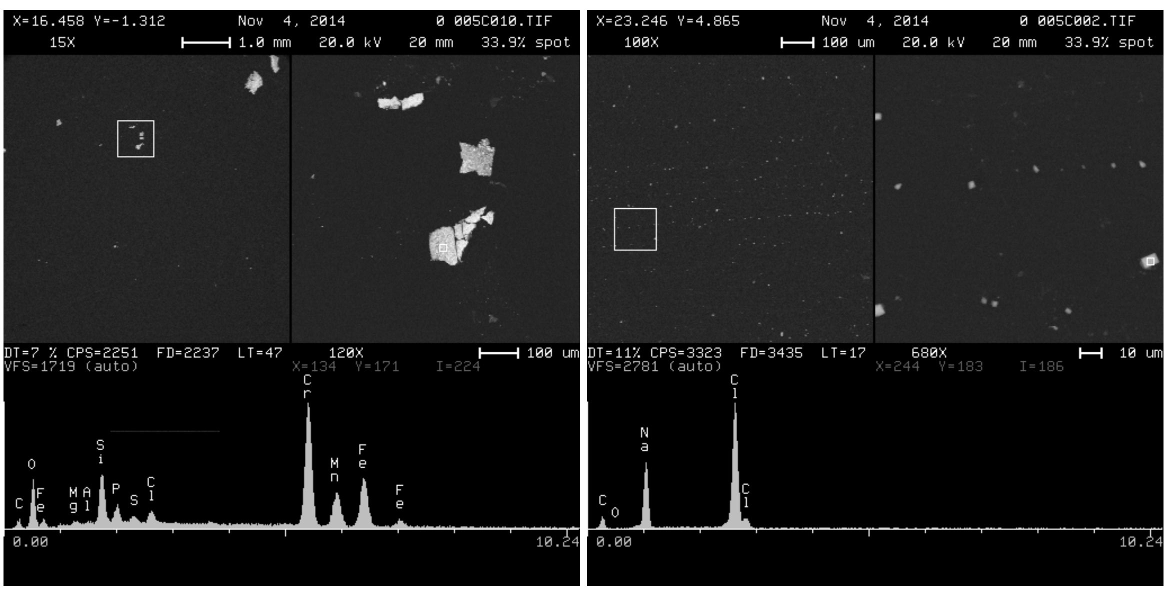


Figure C36 and C37: These were typical of the oxidized (corroded) steel or iron slag (left) and many small sodium chloride particles (deicing salt, right) on the lift. (RJ Lee SEM sample scans 2014)

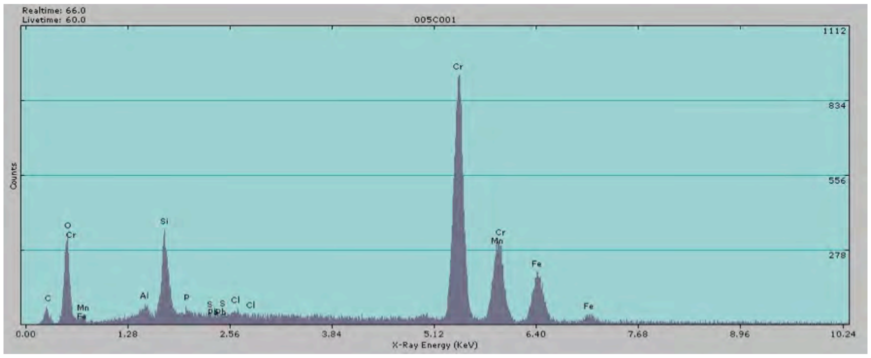


Figure C38: Ferrochrome and fly ash. (RJ Lee SEM sample scan 2014)

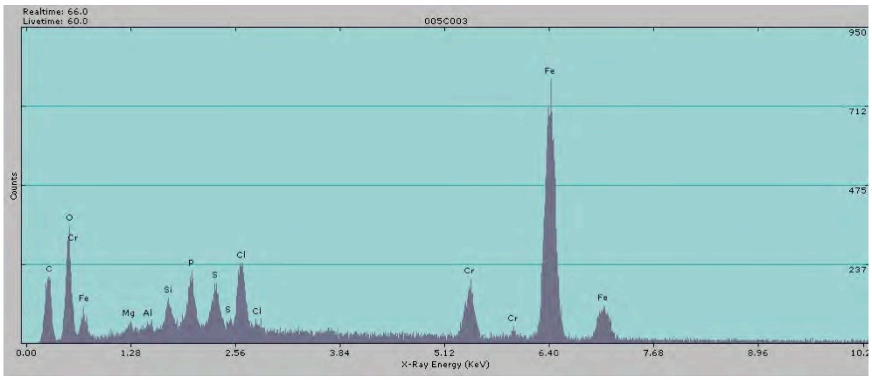


Figure C39: Ferrochrome, chlorides (salt), and soil. (RJ Lee SEM sample scan 2014)

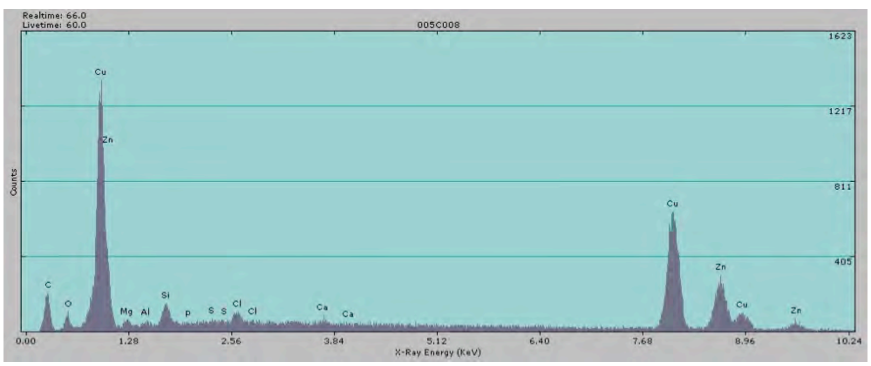


Figure C40: Copper zinc alloy particle with minor amounts of chlorides (salt) and soil. (RJ Lee SEM sample scan 2014)

Representative SEM/EDS Scans of particles in Sample 6C

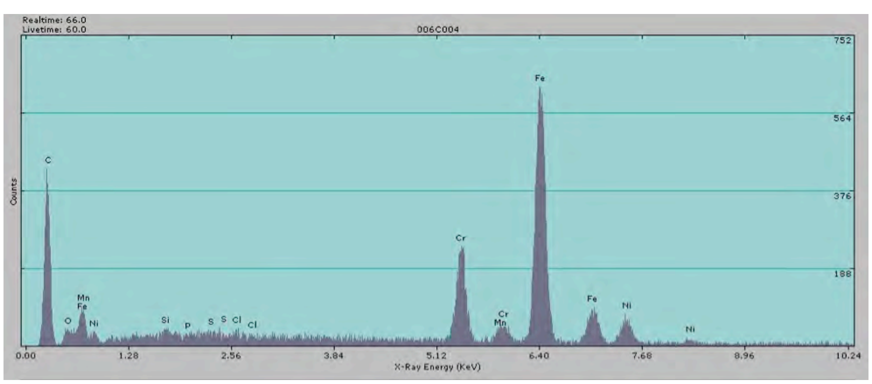


Figure C41: Most of the particles were ferrochrome combines with carbon rich organics (i.e. spores and pollen) with very small amounts of soil and chlorides (salt). (RJ Lee SEM sample scan 2014)

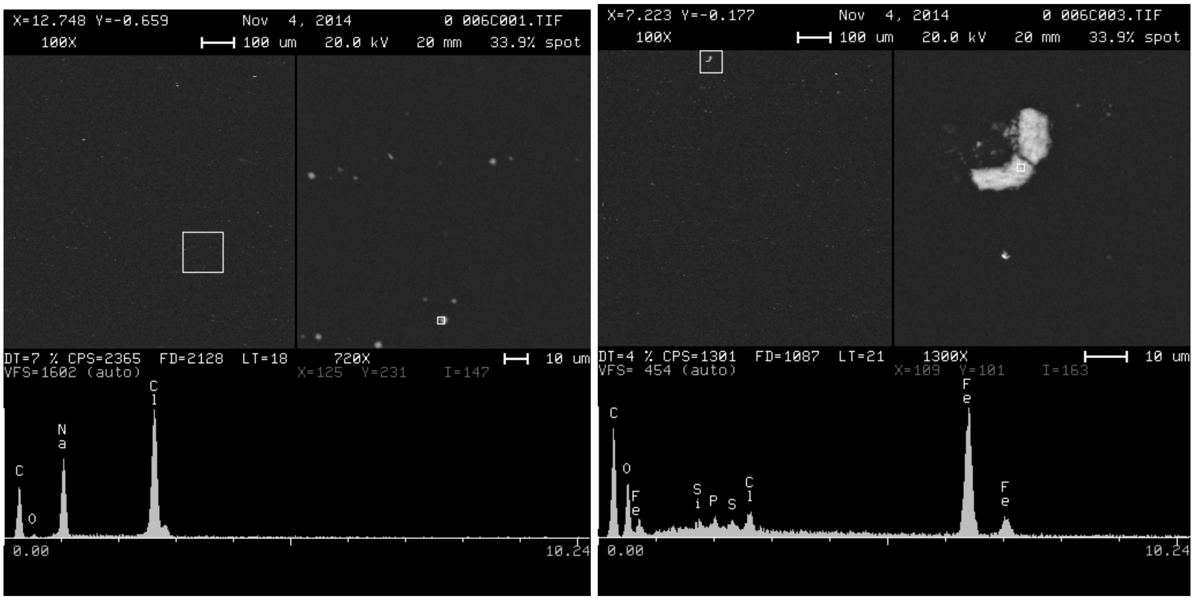


Figure C42: Sodium chloride (deicing salt) was found in combination with clay and iron/chloride/carbon organic particles were also found. (RJ Lee SEM sample scan 2014)

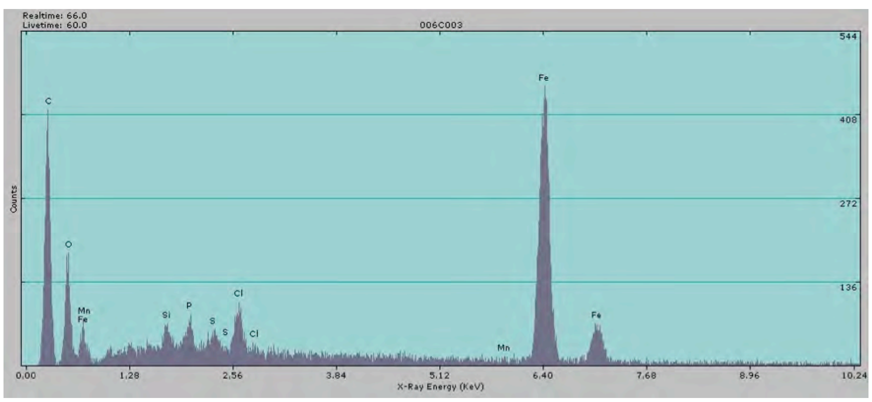
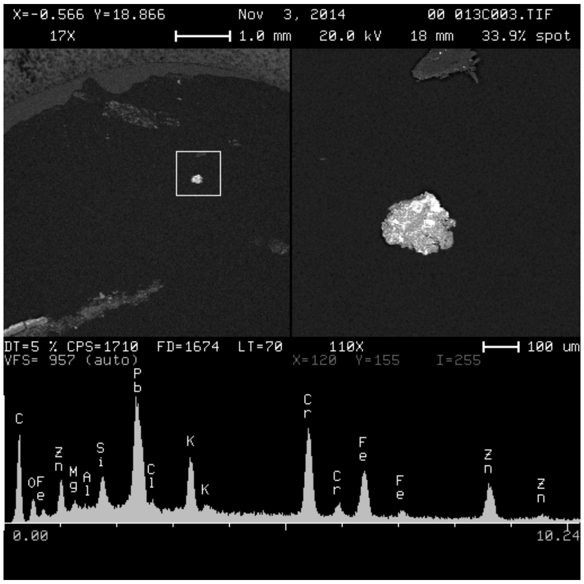


Figure C43: Iron particle combined with carbon rich organics (i.e. pollen and spores) and smaller amounts of chlorides (salt) and soil. (RJ Lee SEM sample scan 2014)

Representative SEM/EDS Scans of particles in Sample 13C

This sample was particularly chemically diverse with numerous metals that were probably from industrial emissions held together by soil or fly ash. The following scans are representative of the range of metals found.



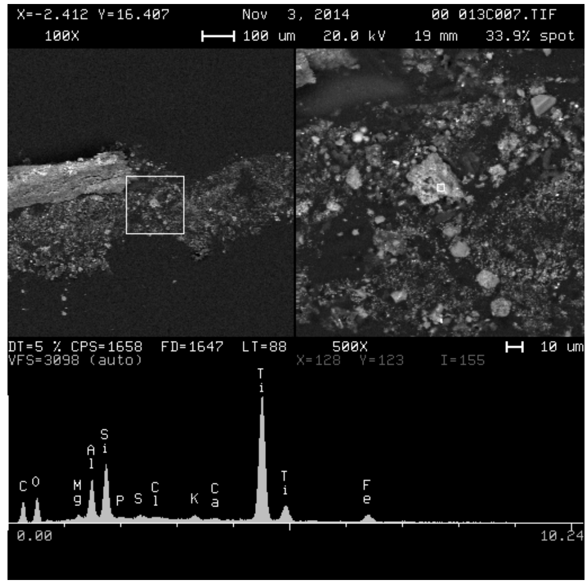


Figure C44 and C45: Iron or steel slag, zinc, lead, and potassium chloride (left) and titanium with soil and a small amount of iron and chlorides (right). (RJ Lee SEM sample scan 2014)

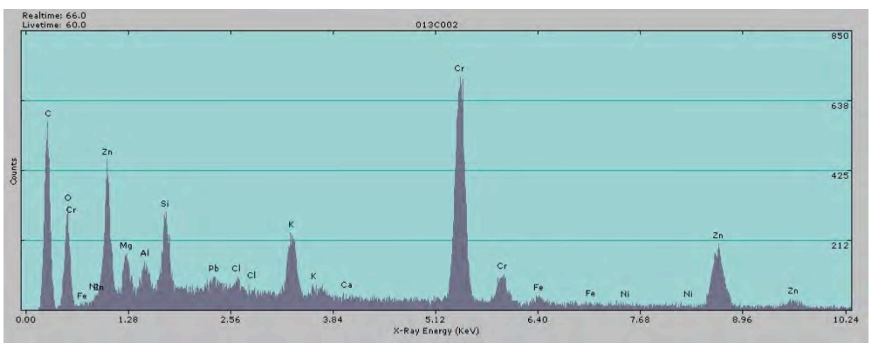


Figure C46: Carbon rich organics (i.e. pollen), chromium, zinc, and soil constituents. (RJ Lee SEM sample scan 2014)

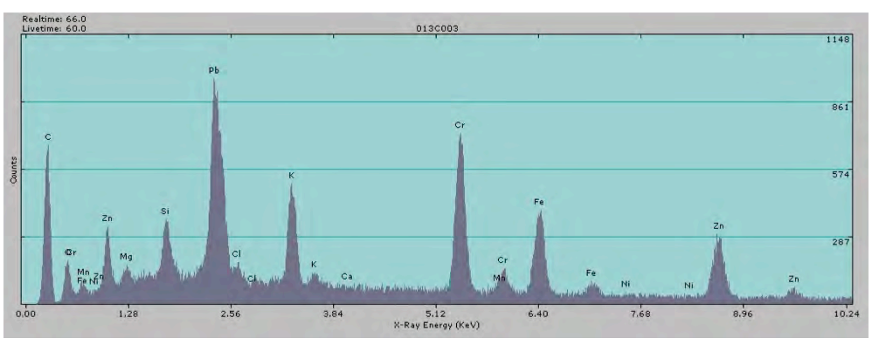


Figure C47: An amalgam of lead, chromium, zinc, iron, carbon rich organics, potassium and fly ash. (RJ Lee SEM sample scan 2014)

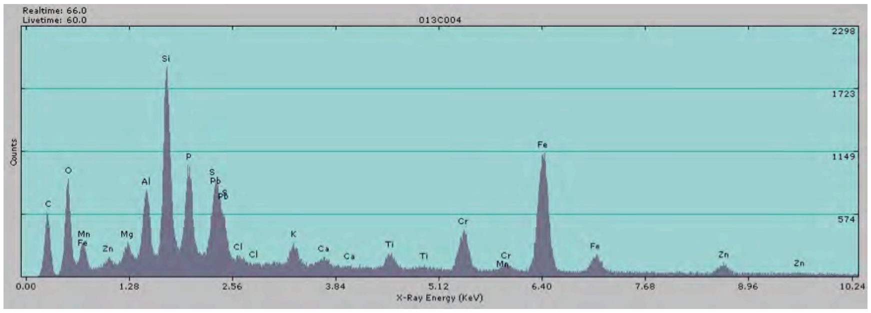


Figure C48: Ferrochrome, soil, potassium, zinc, and soil. (RJ Lee SEM sample scan 2014)

Representative SEM/EDS Scans for Sample 14C

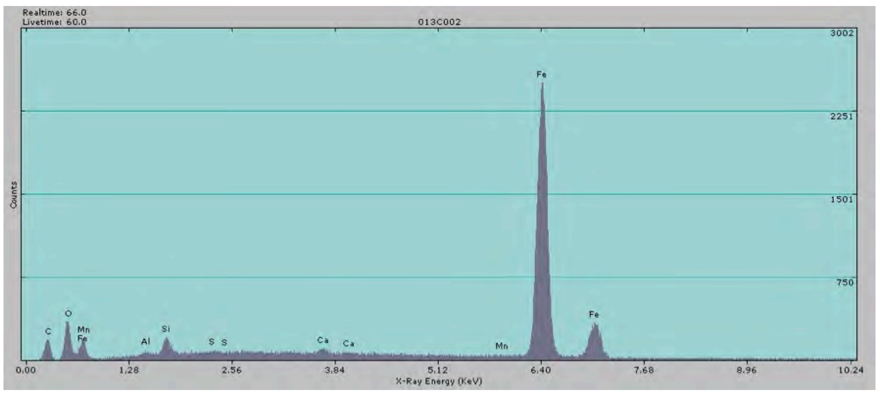


Figure C49: Iron particle with small amounts of soil. (RJ Lee SEM sample scan 2014)

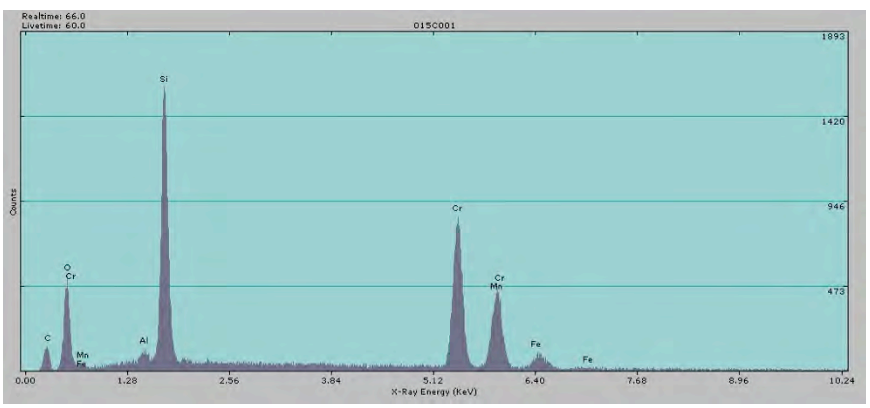


Figure C50: Ferrochrome combined with soil. (RJ Lee SEM sample scan 2014)

Representative SEM/EDS Scans of particles in Sample 15C

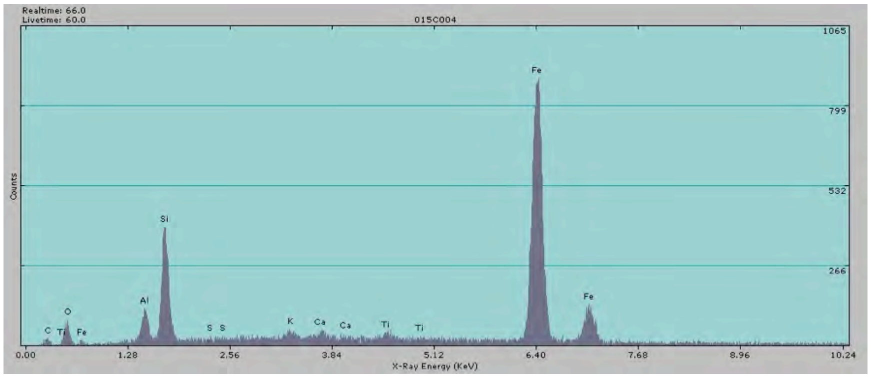


Figure C51: Most of the particles were iron combined with soil and some fly ash. (RJ Lee SEM sample scan 2014)

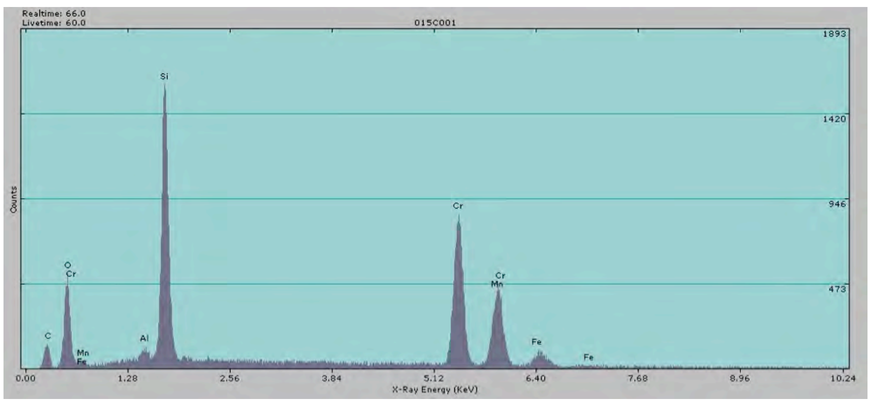


Figure C52: Ferrochrome combined with soil. (RJ Lee SEM sample scan 2014)

Appendix B - Analysis of Surface

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September 5, 2018

Reference: Jefferson Memorial
St. Louis Arch Inspection
Getty KIM Conserving the Gateway Arch

Date of Inspection: Site Visit on August 3, 2018
Ambient Conditions: Clear
Attendance: Dan Worth, Julie Cawby, Steve Kelley, Al O'Bright, Paul Kuenstner, Dan Gierer, Bill Zahner

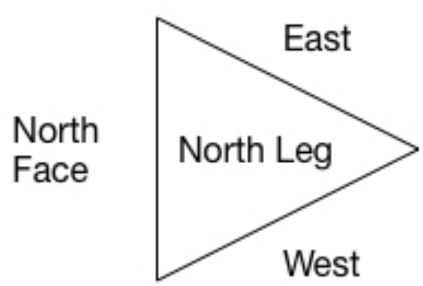
Visual Inspection:

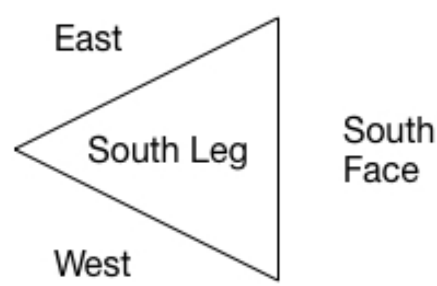
A visual inspection was made of the lower stainless steel surfaces up to the second horizontal weld line.

The arch is made up of stainless steel plate elements, approximately 60 inches wide by 144 inches in length. The plate elements are continuously welded along the horizontal and vertical seam and the corners. The vertical welds were performed in the field and are visibly coarse. The horizontal welds alternate from field to shop weld. The field welds on the horizontals are visibly coarse. The corners are field welds, somewhat smaller than the welds between the plate elements.

The stainless steel has a matte, satin, directional finish running the long direction of the plate elements. This is a common stainless steel finish applied in a factory setting by passing the plate below a polishing belt containing specific grit. The normal process is to change these belts out after so many polishing runs to keep the finish consistent.

Distortions from the welds used to affix the stiffener and stiffener supports on the reverse side are apparent when viewed at glancing angles. There appears to be a series of shorter alignment bars welded to the reverse side. These are at the field weld joints. The visible distortions correspond to a bar approximately 30 cm in length.





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North Leg:

The lower 3 meters of the north leg on each of the three faces, had an abundance of scratches. On the north face and some of the east face, hammer marks were visible on the surface. The scratches are haphazard across the finish making them more apparent. They are approximately, 2/10s of a millimeter in depth. Refer to the pdf documenting the imagery, St. Louis Arch pdf Binder.

The hammer marks are deeper, they are as much as 1 mm in depth. There are a few scratches with red rust present. This is transfer corrosion from steel used to produce the scratch.

On the east side of the north leg there is apparent 'tea stain' from de-icing salts.

The welds were dark, blackish in some areas. Under the microscope, green deposits were apparent. This is most likely organic matter living in the coarse surface of the weld.

Important note:

We did not see any pitting corrosion. We did not see any stress corrosion cracks. There is a significant amount of weld splatter around the field welds.

South Leg:

The south leg had similar scratches up to the 3 meter mark. The south leg had what appeared to be dents from a peening hammer. Round depressions versus the half moon hammer marks of carpenters hammer seen on the north leg.

The south leg had some visible 'tea staining' and the lower welds were dark.

A small crack was noticed in the southwest corner approximately 5 feet above the ground.

The east surface of the south leg appears to have had some remedial polishing performed at some time. This polishing was performed across the grains in a semicircular manner from base level to approximately 3 meters.

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Analysis:

<u>Original Finish</u>

We visually compared the surface of the arch to various samples of stainless steel produced with different abrasives types and different abrasive sieves. All of which were available and in use back when the arch was produced. We held the samples above the 3-meter point in an attempt to compare to the non-scratched surface. The team viewed the samples directly on and at angles from a distance ranging from a foot to 3 meters. The following table of finishes were compared:

Abrasive	Grit
Silicon Carbide	80
Silicon Carbide	120
Silicon Carbide	180
Silicon Carbide	220
Aluminum Oxide	80
Aluminum Oxide	120
Aluminum Oxide	180
Aluminum Oxide	220

The consensus of the team is the 180 grit is the closest of the finishes used on the surface of the arch. This is a common belt size and would correspond to a finer polish for a No. 3 finish on stainless steel.

<u>Gloss</u>

We took several gloss readings of each surface of the arch. We took these above the 3-meter line. The results of the readings are in the following tables:

Gloss Meter Set Parallel to Grain

FACE	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5	**Average**

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September 5, 2018

North-west	145	131	117	115	123	**126**
North-north	113	113	99	105	104	**107**
North-east	59	52	47	67	54	**56**
South-east	130	127	126	117	152	**130**
South-west	157	154	150	135	151	**149**
South-south	71	72	83	92	76	**79**

Gloss Meter Set Perpendicular to Grain

FACE	Reading 1	Reading 2	Reading 3	**Average**
North-west	20	20	21	**20**
North-north	18	18	17	**18**
North-east	14	12	9	**12**
South-east	26	23	24	**24**
South-west	28	31	26	**28**
South-south	12	16	16	**15**

This corresponds to similar readings of various finishes of stainless steel. The outliers are of interest though. Those would be the North Leg, East Elevation and the South Leg, South Elevation. We will want to verify these readings and determine why these measurements are less.

There was a small area on the North Leg, West Elevation that had been cleaned. The readings were:

Parallel to the grain : 260, 209, 236, 259 for an average of 241
Perpendicular to the grain: 89, 90

The following table is a record of various finishes on stainless steel.

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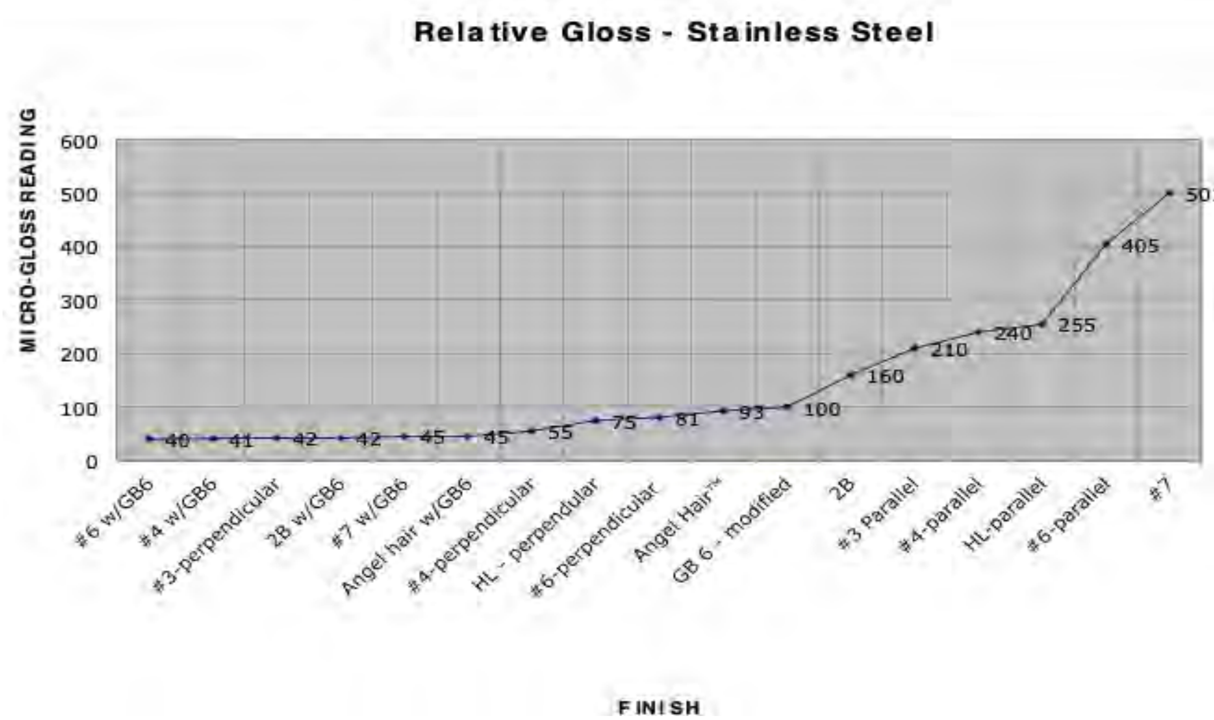

<u>Surface Texture</u>

We did not take profile readings. We did not want to add to the scratches already in abundance on the surface. It would be worthwhile to analyze the mockup in the possession of the National Park Services to record the surface profile using an Optical Profiler.

<u>Visual Analysis</u>

The surface has levels of visual undulation across it. These are induced on the stainless steel by thermal changes in the welded plate. The undulations correlate to the position of the vertical stiffeners. We did not measure the extent of the undulations from a theoretical plane. These smooth waves are apparent on all faces and up the vertical surface of the arch. In particular they are visible at night with a grazing light across the surface.

<u>Suggested further analysis:</u>

Verify the gloss readings. In particular the south face of the south leg and the east face of the north leg.

Measure the out of plane undulation of each surface.

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September 5, 2018

IMAGES:

Micro – images taken at 100 x

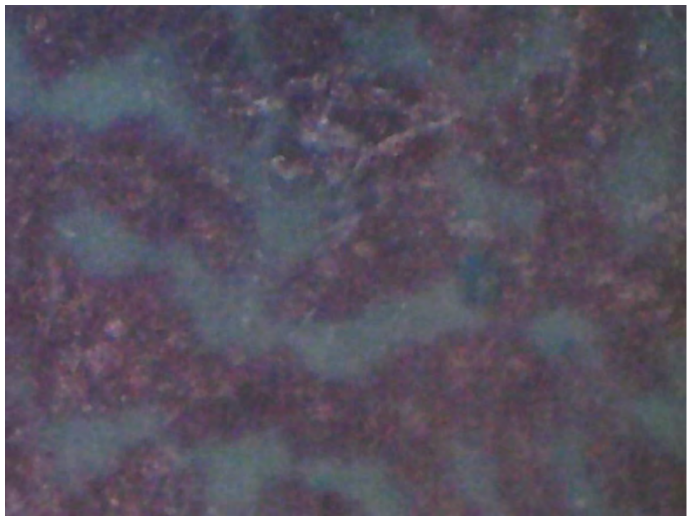

Image 1: Green color with reddish back ground at horizontal weld. North leg, West side.

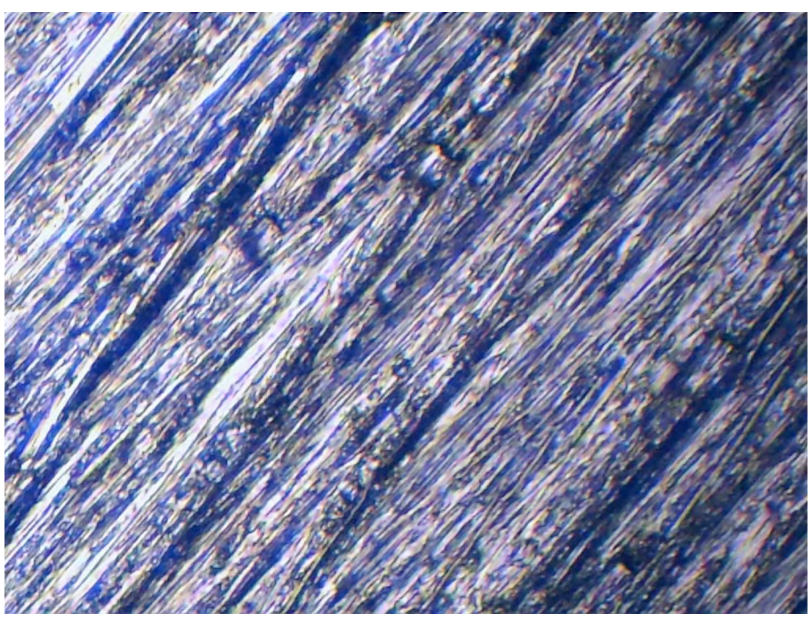

Image 2: Close up of stainless steel surface above scratch

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September 5, 2018

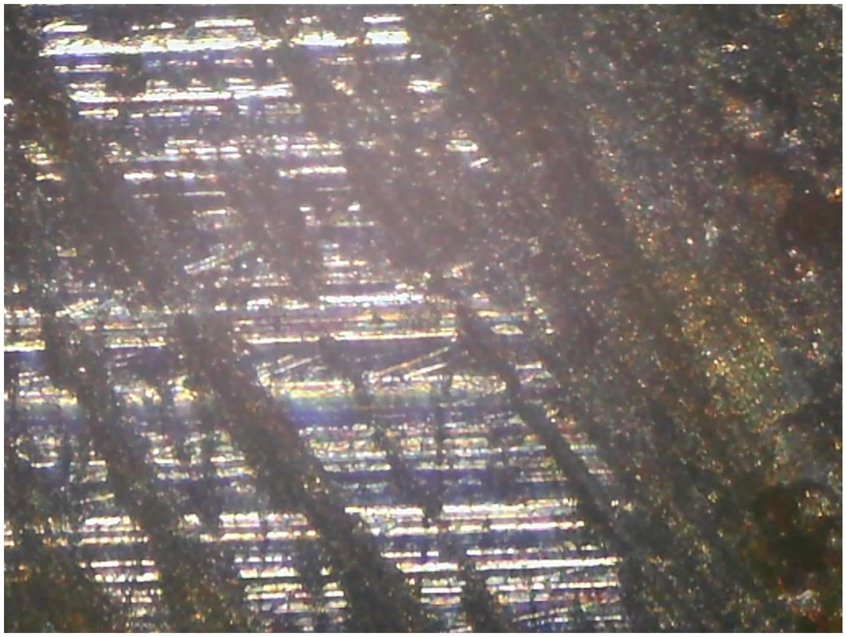

Image 3: Cross grain scratches on surface

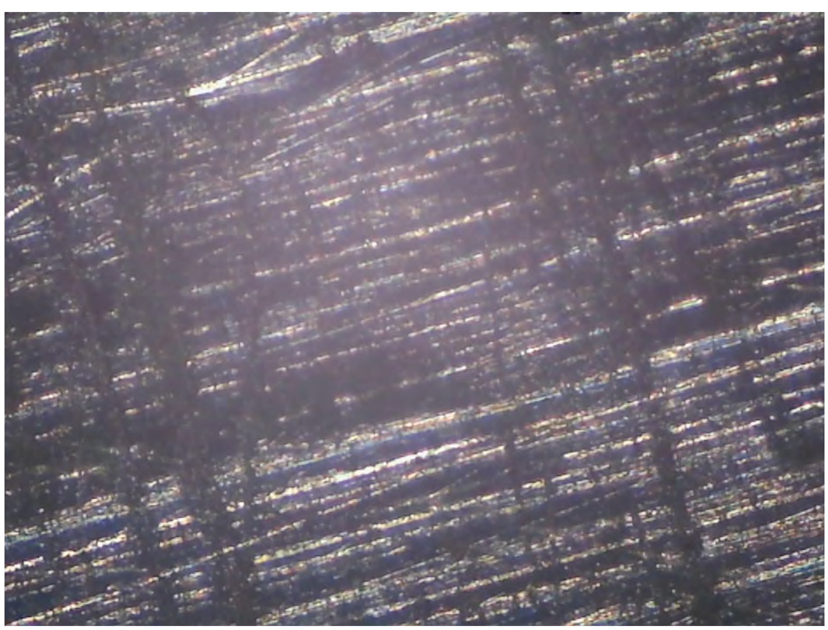

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Image 4: Cross grain scratch on stainless steel surface

Image 5: Weld and marks on surface

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September 5, 2018

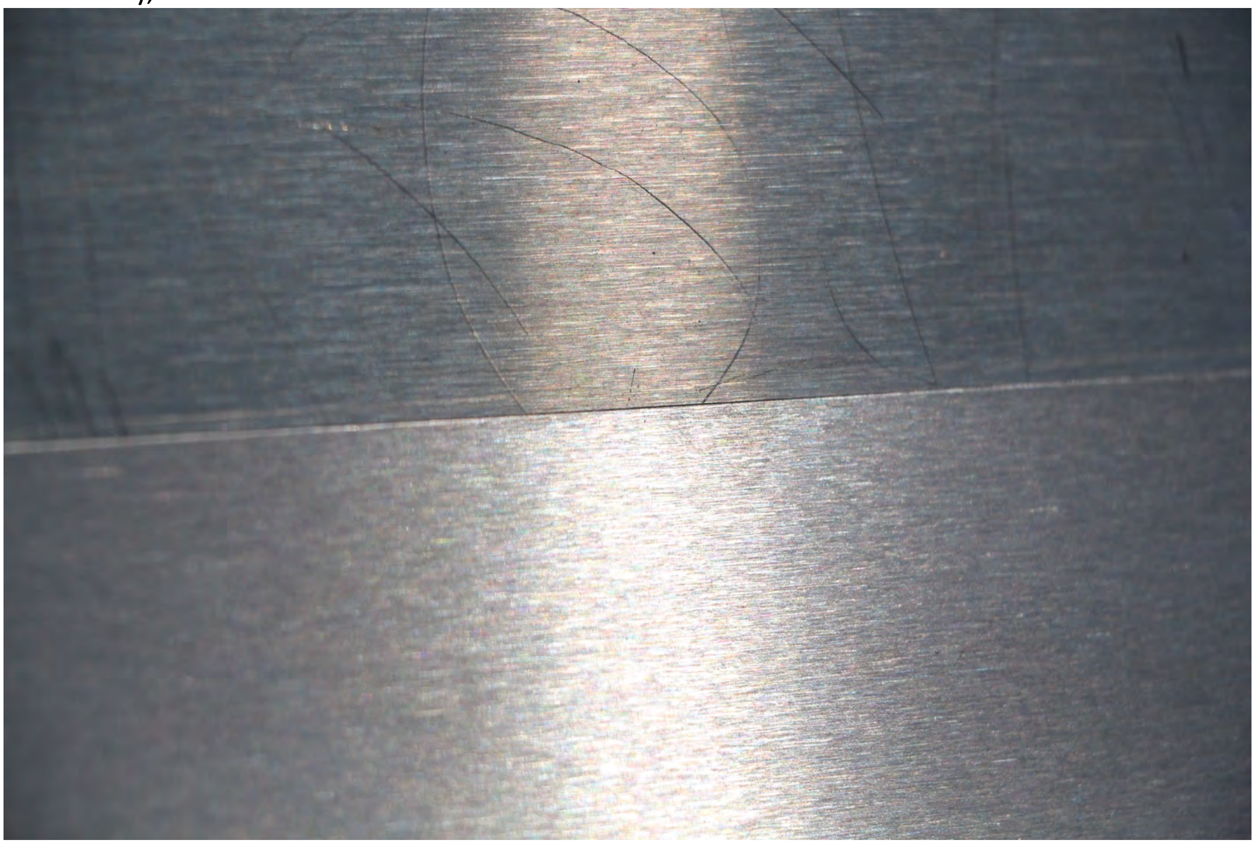

Image 6: 180 grit aluminum oxide comparison. Note color of arch is darker

Appendix C - Workshop 1

MEETING NOTES

PROJECT:	Conserving the Gateway Arch Getty Keeping it Modern Grant	**PROJECT NO.:**	BVH Project 18056
LOCATION:	Gateway Arch National Park Education Center	**DATE:**	October 2, 3 & 4, 2018
ATTENDING:	Reference Sign-in Sheets from each day of the Workshop		

OCTOBER 2 – INTRODUCTION AND SITE VISIT

1:30 PM--Welcome

1. The meeting Agenda was distributed and welcome/introductions were made. Roles with the project team were also presented. The Getty KIM Grant and purpose of the project was presented in brief.
2. Dan Worth gave an overview of the three-day workshop agenda and project timeline. Dan also thanked the Getty, APT, NPS and Bi-State Corporation for financial support and assistance in developing the KIM Grant application.
3. Frank Mares, Assistant Superintendent of the Gateway Arch National Park welcomed all participants.
4. Logistics of the session were reviewed.

1:30 to 2:15 PM– Presentation: History of the Gateway Arch (Al O' Bright)

1. Al O'Bright gave a PowerPoint presentation of the history of design and construction of the Gateway Arch.
2. Al noted that there were 172 original competition submissions. Saarinen's was the boldest and won the competition. He also noted:
    a. At 630 feet tall, weighted catenary curve to be make the arch more slender.
    b. Orthotropic structural design (meaning that the skin is also the structural system) – 3 sided "tube" with inner core of carbon steel (painted with red lead primer) and an exterior stainless steel skin
    c. Outer skin components:
        i. It is structural.
        ii. It is the primary protection against the weather.
        iii. It is the primary aesthetic for the monument.
    d. The arch segments were partially fabricated and shipped by rail from Pittsburgh to the site by rail. Segments were craned off of the rail car and moved around site with land cranes, then lifted with creeper cranes up each leg.
    e. Four original holes were placed in the extrados by the manufacturer to install the "railroad to the sky" rails for the creeper cranes.
    f. Oils, greases, other miscellaneous liquids were present during construction process.
    g. Up to 300' level – interstitial space filled with post tensioned steel rebar / concrete filled
    h. Horizontal Strut installed at 530' level
3. Catherine Houska noted that this project was the first structural SS project in the world. This project lead to the first ASCE-8 standards.
4. Construction techniques / concepts were those used in cantilevered bridge construction.
5. Current blemishes:

440 N 8th St, Ste 100 Lincoln, NE 68508 / 402.475.4551 // 901 Jones St Omaha, NE 68102 / 402.345.3060

   a. Shipping strap marks
   b. 10" diameter suction cup marks from manufacturer moving SS plates
   c. Field weld splatter (up higher in elevation is worse)
   d. Dings, scrapes, - known in field during original construction. An attempt to burnish away these blemishes was attempted during construction.
   e. Original four anchor holes patches – with square steel plate contact onto surface.
   f. After final station/section was installed, creeper crane removal began. Cleaned and passivated all surfaces all the way down
6. History of current project. In 1996 Al O'Bright and Park Superintendent noticed areas of concern including:
   a. Streaks and stains on exterior surface.
   b. Streaks emanating from the welds.
   c. Stiffener plates could be seen by oil canning of the skin.
   d. Moisture in the concrete was suspected as playing a role
   e. Other potential causes: air pollution from numerous industrial plants close to the Arch. Some have since closed but some are still in operation.
7. Phase 1 Corrosion Study was initiated in 2006 by BVH team which summarized observed deterioration and included further recommendations including and HSR. The HSR was completed soon after in 2010
8. Phases 2 and 3 Corrosion Studies were completed in 2014. These reports were distributed to all attendees. O'Bright noted that these reports included:
   a. Images of the manufacturing and construction processes.
   b. Concrete cores were taken and analyzed
   c. Above 300' – open view ports made into interstitial space through the interior carbon steel sking for inspection
   d. Additional 3" openings made through the carbon steel skin to install moisture and temperature monitoring devices 300' level and up to top. The monitoring data was collected for 1 year.
   e. Access to exterior surfaces for close up inspection
      i. Reviewed multiple means of access, most limited/not possible to get to upper heights
      ii. Industrial rope access implemented by WJE
   f. Weld cores and gunshot residue samples were taken from exterior skin.
   g. Cleaning mock ups were implemented at base using a few techniques. Houska will discuss more in her presentation.

2:30 to 5:00 PM - Tour of the Gateway Arch Facility

1. Tour of the South leg was performed to see one of the past inspection openings at Level 43. Access to this area was made via freight elevator.
2. Tour of exterior was performed to observe conditions at both north and south legs.

OCTOBER 3 - EXPERT PRESENTATIONS (EDUCATION CENTER)

9:00 to 9:30 AM- Introduction by the National Park Service (Frank Mares)

1. Public questions still occur about when Arch will be cleaned.
2. The local media are critical about costs expended for studies without cleaning being implemented.
3. Frank and NPS mediate questions from the local media and reminded that any questions should be directed to Frank.

9:30 to 9:45 AM– **Section 106 review process - State Historic Preservation Office (Amanda Burke)**

1. Need to have and understanding of how decisions on future implementation are derived.
2. Federal funding initiates
    a. Determine if resource is historic. (Done)
    b. Scope of work development (current)
    c. Impact of work
    d. Determination of impact of work on the historic resource.
    e. If impact is deemed an adverse effect, a change of scope is required.
3. The HSR recommended that the appropriate treatment for the Arch is "Preservation" as defined in the Secretary of Interiors Standards. Dan Worth provided handout of the Preservation standards for everyone's information.

9:45 to 10:45 AM – **Work performed to date and desired outcomes (Kelley, Worth)**

1. Steve summarized the projects undertaken in a PowerPoint presentation including Phase I (2005), HSR (2010), Phase II (2011), Phase III (2014) and current KIM Grant objectives
2. Issues of this current project scope:
    a. Addressing deterioration at the base of the Arch:
        i. Incised graffiti with ferrous staining
        ii. Oils from touching by humans
        iii. Scratches from snow removal equipment
        iv. Other cleaning attempts
    b. Surface corrosion
    c. Atmospheric pollutants deposits
3. Reference to previous reports are relevant to discussion of this current project scope. The past analysis helps to focus the current scope more intently.
    a. The 300 foot change from filled concrete to unfilled can be seen from exterior, in certain light.
    b. Definitions of the non-intrusive "visual" assessment: blemishes, deposits, and discoloration
    c. Visual anomalies over entire surface evident, especially from 300' change of internal material. The thermal mass does affect the system temperatures on each leg, depending on sun light on surfaces at same time.
    d. Horizontal Strut attachment points, very visible
    e. Puddle welds evident on surface from internal stiffener attachment to stainless steel
    f. Oil canning – were found to be about max of ¼" change of surface level. Oil canning is evident on entire surface though more pronounced above the concrete pour. This is a visual "product of its time" and is pertinent to its aesthetic.
    g. Original stainless steel appearance issues were discussed by entire original construction team (archive sources)
4. Review of prior visual inspections:
    a. Atmospheric pollutants
        i. Appear as vertical streaks from welds. Caused by water run off with pollutants and not from the material within the welds.
    b. Proposed cleaning area for this study: 80' / 5 segments up from grade
    c. "Sweet spot" was defined as the 422' level above where concrete fill stops.
5. Review of intrusive testing was discussed.
    a. Four field welds and one shop weld were removed

    b. Interior inspection openings thru carbon steel interior skin above concrete
    c. Interior concrete core samples
    d. Long term monitoring installed, 10: five sensors in each leg and one at exterior for dew point and surface temperatures. Results reviewed and briefly discussed.
6. Conclusions of these previous studies, analysis were reviewed and summarized on slides
    a. The only current ongoing issue is "Superficial corrosion at the base is of concern over the long term."
7. Desired outcome of the current workshop (slides outlined these key points)
8. "Cloud Gate" finish was discussed. Scratches and stickers are issue, but the removal by maintenance staff is immediate so they do not accumulate.

11:00 to 11:45 – Cleaning stainless steel (Houska)

1. Catherine gave PowerPoint presentation of Stainless Steel cleaning methods.
2. 1964 World's Fair used very similar stainless steel technology, just prior to arch construction.
3. Catherine gave a short stainless steel chemistry review
    a. Rougher surface texture – areas will retain moisture, higher corrosion. Surface roughness related to corrosion rate. Gateway Arch has relatively flat brushed finish and less than no. 3
    b. Oil canning could be from differential exp/contraction of stainless steel (16.9) vs Carbon Steel (12)
    c. Argon Oxygen Decarburization (AOD) is a way to remove impurities such as sulfur and carbon.
    d. Pitting Resistant Equivalent number (PreN) gives an idea of relative corrosion resistance.
    e. PreN = %Cr + 3.3 (%Mo) + 16 (%N)
    f. Sensitization found at either side of welds at the base
    g. AOD – assisted manufactures with ability to remove certain properties that corrode the final stainless steel product. Arch predates AOD furnace. AOD started in the USA in 1974.
    h. Arch – Bob Moore oral history conducted indicates that welders did grind out the welds in field, sometimes 2-3 times at lower levels to install acceptable full penetration welds.
    i. Bolt stainless steel patches/welded fill – Houska investigated and could not find in archive the product/stainless steel type used.
4. NPS has switched deicing salt product in conjunction with heated slab installed recently – but current mix will cause corrosion – see slides
5. Highest deicing salt residue Houska has found was up to 50th floor, 1st three floors have much higher concentrations
6. Arch: iron oxide on surface is not stainless steel corrosion of the surface.
7. Streaking of stainless steel surface at welds is related to slag on surface. There is a concentration of deposits related to slag above the streaking
8. She referenced one of prior reports, which indicate items of concern to be remedied at the base.
    a. Deicing salt corrosion and graffiti showed very tiny pits on stainless steel surface

    There were field welds vs shop welds up to 60' - 70' range that lift could reach – all field welds were redone in the field at least once, sometimes 2-3 times.
9. Question: Is there evidence that this occurred the rest of the arch as well? (that was out of reach of the personnel lift)
10. Please note additional cleaning recommendations are referenced in Thursday's discussion.

11:45 AM to 12:30 PM - Refinishing stainless steel (Zahner)

1. Bill and Dan presented and discussed the recent surface blemishes and tests completed by them at their August 2018 site visit.
    a. Some of the scratches are deeper than the original finish. Previous reports did not indicate results of scratch depth.
2. Refinish of surface IN THE FIELD
    a. Zahner noted that this would be very difficult because cannot get the "skipped" visual end result to match original belt used in manufacturing process
    b. Has base already been refinished? Grain is in between splatter welds. This should be confirmed if possible.
    c. Water jet can remove salts but not all the ferrous staining.
    d. Zahner discussed concept of cleaning the base and over-clad with art piece that could act as a sacrificial layer? But not attached to the historic surface. Mural in front of base?
    e. Cleaning could be more disruptive/shiny than current surface. Discussed that If cleaned- would surface dull? Yes, but over a long time and not quickly.
    f. Robotic cleaning – is a potential that could be used in field. Mockups of product, pressure other items would need to be done prior to any attempt.
    g. Testing mockup to be completed as part of the current project. Discussed mockups – what if deep scratches / dents are left in place BUT ferrous metal is removed so they are not so highlighted. What are these results?
3. Refinishing approach was discussed.
    a. It was noted that in refinishing, some of metal will be removed from surface. This could cause a change of appearance.
    b. Depth of some graffiti is too deep to remove – too much metal would be removed (1/32")
    c. Ferrous cleaning must be done prior to refinish/polish, etc.
    d. ALL corrosion can be removed and some scratches. Use of aluminum oxide / hydrofluoric acid -- works but would harm the granite pavers. MUST have collection system at base to catch run off.
    e. Re-finish surface and then dull surface to match higher cleaned areas.

2:00 to 2:45 – **Kärcher and water cleaning (Thorsten Moewes and Rich Barry)**

1. Thorsten and Rich described the firm's Cultural Sponsoring Program which is part of their philanthropic philosophy. Encompasses cleaning of historic monuments, for free or at little to no cost.
2. Video was played about the company and this arm of their company.
3. Presentation of elements and types of cleaning and factors involved as such.
    a. 4 ways soils stick to surface: electrostatic; adhesive; mechanical; and chemical
    b. Sinner's circle: temperature, mechanical, chemical and time. If you take away one you must make it up with the other three.
    c. Dry ice, particle blasting, water cleaning, steam cleaning
    d. Water or dry ice proposed. Dry ice for the corrosion.
    e. Cleaning method and access go hand in hand
4. Dry ice requires a stable platform, cannot be done from ropes for higher areas above lift access. Joe Sembrat w/Evergreene Architectural Arts noted that cleaning of aluminum on rocket boosters has been successfully with CO2 (Dry ices is possible for Arch skin
5. Water cleaning is possible too. Can be done and is very effective at any angle
6. Method and access go hand in hand.
7. Other considerations:

   a. Can these processes allow "feathering in" of the cleaning so there is no "surface line" on the surface?
   b. What are cleaning methods that are possible for lower (5 blocks) versus higher elevations? Same? Or different?

2:45 to 3:30 PM – Laser Ablation cleaning (Marshall Jones)

1. Marshal opened his presentation with some ideas he had from his experience the industry based on his understanding of the Arch
   a. CO2 laser glazing with robot is possible to remove the scratches
   b. Lasers are used for:
      i. Lasers used for stripping paint
      ii. Arch Dimples/deep graffitti – to infill them – By use of supersonic (velocity) laser deposition (process created at Cambridge) combines cold spray with lasers (pressure and temperature – NOT melting) Supersonic laser deposition – you can apply coatings – fill in the larger voids
      iii. None of these techniques create heat
      iv. Laser texturing
      v. To make surface hydrophobic
      vi. "Melting" microscopically - Laser glazing to "melt" the surface and scratches
      vii. Cold spray Laser capturing makes the surface hydrophobic (not this one)
      viii. Laser ablation - the process of removing material from a solid (or occasionally liquid) surface by irradiating it with a laser beam. At low laser flux, the material is heated by the absorbed laser energy and evaporates or sublimates.
2. Marshal gave a PowerPoint presentation that explained history and uses of lasers in industry and evolution of the technology.
3. Each laser shows as a different visual color. Color = intensity. Each chosen based on surface. Lasers can be used to clean a painting, for example or put a hole thru a surface.
4. Ablation approach considerations:
   a. Could remove coatings
   b. Could remove all weld splatter
   c. Residue coming off surface can be collected
   d. Laser reach to higher areas can be done with fiber optics
   e. Cold be used in selective areas or holistically
   f. Time
   g. Dep laser (KC)
   h. Surface texture removal by this process? Will not
   i. Combination of laser with other

3:45 to 4:30 PM – Chemical cleaning (AstroPak, Daryl Roll)

1. Daryl and his team gave a PowerPoint on the science and surface chemistry of stainless steel
2. Surface finish – Passive layer, transition area, alloy bulk phase. Scratches which go into the bulk phase will start to show rust. Chlorides attack passivation layers and causes pitting.
3. Passivation– remove free iron which will enhance surface corrosion.
   a. Passive layer compromised by welding, soiling, grinding, sanding, polishing, corrosion

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  b. They use Nitric acid (30 to 60 minutes dwell time) as minimum (hazardous material) or Citric acid (60 minutes or more dwell time) for cleaning and/or passivation.
  c. Passivation with phosphoric, nitric or citric acids. You need a chrome to iron ratio of 1.5 or greater.
  d. What about heat vs. chemical passivation? Apparently little difference.
  e. Can passivation be measured non-destructively? Maybe gun shot residue and SEM
  f. They use ammoniated citrate for both pickling and passivation
4. Pickling – removal of material from the surface – remove the passive layer which need to be re-formed.
  a. Nitric acid and hydrofluoric acids used for pickling. They remove both iron and chrome. Prepares surface for passivation.
5. Rouge/Rust – iron oxide
  a. Once the oxide film/ passive film layer has been removed (deep scratch) the iron in the stainless steel will continue to "rust" within pits on the surface.
  b. Houska noted that her results found that the scratches / pits were on the surface only takes a while to get the rust.
    i. Hammer hits move the original surface downward into the original metal / the original surface is not removed.
    ii. Scratches – sometimes ferrous deposits left in surface / sometimes edge of the original passive film layer "stretches" into the sides of the scratch.
    iii. Remove scratches and re-passivate, chemically. If not, a lower quality passive film will form on surface.
6. Surface Finishing- Electro plating
  a. ONLY for the welds or the deep scratches, very selective locations.
7. Profilometer measurements on their own are not valid to measure surface effects.
8. Electropolishing removes material.
9. Heat passivation has a thicker transition layer than a chemical passivation.
10. Dry ice blasting is a good cleaning technique.
11. Grit media blasting is a not recommended.

4:30 to 5:15 – The architectural conservator's perspective (Pieper)

1. Pieper noted that he had reviewed the three reports and saw a few items to comment on. A few discrepancies that should be resolved in the current study. Clarified that "discrepancy" between reports is due to more information/knowledge gained in later reports.
2. The standard is preservation
3. First do no harm – *Primum non nocere*
4. The Arch has a great surface
5. Initial tack welds at field welding is a place where the streaking occurs.
6. Do not forget what frequency of cleaning, maintenance wise, at base from snow/salt, etc. is needed.
7. Is the statement "....the key to long term preservation is to keep surfaces clean". Is this true?
8. Houska noted that some of her original cleaning methods proposed were left out of prior reports. Resolve this.
9. Why listed differences in prior reports between "deposits" vs "discoloration"?
10. Lighting and time of day have a dramatic visual change of the Arch surfaces.
11. Until the NPS initiates the prevention of graffiti, it will continue and refinishing of the base will be a lost effort. This item is imperative to be done.

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12. Commented on the collaborative nature of the process and appreciated the organization of the workshop.

5:15 PM-**SHPO reaction to previous day's presentation. (Amanda not able to attend on10-4)**

1. Do as "little as possible".
2. Address issues and stabilize. Carefully examine all options. Understand why/pro/con of each.
3. Don't forget treatment is defined as "preservation" project, not restoration.
4. Define the goals and why they are applicable.
5. This team will not be the last to treat this monument.

OCTOBER 4 - DISCUSSION

9:00 to 9:45 AM - **NPS reaction to previous day's presentation**

1. Take away's summarized by Al O'Bright:
   a. Appreciated the excellent summary/master class on stainless steel chemistry
   b. Passive layer thinness and fragile surface needs to have great care
   c. Each presenter provided approaches that provide good topics for correct method for approach
      i. 1st hammer marks by Al observed about 20 years ago
      ii. New hammer marks found on site this morning by Steve
   d. *In-situ* vs lab testing needs evaluated
   e. NPS recommends more security, enforcement, penalties. If this deep pitting continues this will cause irreversible damage
   f. Preservation philosophy and these treatments will set methodologies now and into the future.
   g. Chloride mitigation should be pursued soon.
   h. Treatment procedures and their priorities need to be defined in project.
2. Frank and Bob, Mike, Kathryn comments:
   a. Graffiti at lower sections – noted that Arch may always have some graffiti and that this maybe the way it will stay.
   b. Site management is new process with the museum addition. Assessment of the handling at the legs should be done. Fines and ticketing due to vandalism are negligible, little enforcement ability.
   c. Interpretive "fence or layer" away from base should be last resort
   d. Sacrificial layer should still be reviewed. Concepts should be created.
   e. NPS have inherent challenges – preservation vs enjoyment
   f. Go back to review expectations from beginning
   g. Michael Ward
      i. Feathering / cleaning: again do not limit to a certain height
      ii. Stopping the graffiti: Section 106 compliance: political aspect plays in as well. Weigh in What is the damage causing? This definition would be helpful.
      iii. Data collection is important to the NPS.
      iv. Cost in future / cyclical requirements is also very important.
      v. What is approach? The reasoning helps the NPS make decisions of what changes would or should be implemented.
   h. Frank M: NEPA / EA assessment of the solutions may need to be reviewed as well, as part of the recommendations if treatment triggers environmental action.
3. Bob Moore

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a. Ted Renisson in 1980's gave what may be an enlightening oral history.
b. Tram connections in certain time of year, expected 3' change in height of Arch between seasons

10:00 to 10:30 AM - Set the agenda for discussion topics: project objectives, treatment options

1. Joe Sembrat/Conservation Solutions
   a. Joe: Touching of skin does equal damage just by wear from the handling.
   b. Workshop is great format for problem solving.
2. Dan Gierer (Zahner)
   a. Confident that Arch can be cleaned up to a certain level and feathering can be accomplished
3. Bill Zahner
   a. NPS indicated: "Live with the graffiti? "What about an intermediate repairable finish at base?
   b. However, continual refinishing has issues at metal removal over time. Nevertheless, there are finishes that could be installed at base that allows repairs.
   c. What if we finish just the lower level that can be repaired and don't match the rest of the surface but let it be different?
   d. Chloride cleaning. Also noted yearly de-ionized water cleaning, very easy and effective
4. Astro-Pak/Tom Velazguez
   a. Vast array of tools available for this monument.
   b. Rinsing with de-ionized water is good solution.
   c. Amazed by the age of monument and that it is in such good condition.
   d. Any refinishing performed will in itself damage the skin.
   e. Removal of oxide layers is important
   f. Leave the graffiti in place
5. Astro-Pak/Jordan Schaecher
   a. Honored to be involved
6. Astro-Pak/Daryl Moss
   a. Thank you to NPS and team
   b. Great technical presentations. Organized treatment procedures/methods are available.
   c. Start with least invasive and then step up in method – with each being preservation minded. We can organize treatments and processes for surface from water washing through refinishing surface.
   d. Preserve the surface as it is.
   e. We would not change the surface in any way.
   f. We must passivate the surface.
   g. Refinishing can be done to some degree.
   h. You don't have to choose just one treatment.
7. BVH/Steve Kelley
   a. ISCARSAH Principles - address root causes rather than symptoms
   b. Choose interventions that are reversible or re-treatable
   c. We would use a palette of techniques – a tool kit. One size does not fit all.
   d. Principles of graffiti. Why remove it if reoccurrence will not be hindered by the park? Install a handrail that will allow limited access to surface with openings to allow persons to touch skin. Perhaps put interpretive sign about passive layer at this point
   e. Future lasers on drones? Clean with drones? Do not limit ideas of future technology inventions.
   f. Re-Treat-ability: do not limit future cleaning options by methods done today

   g. Utilize a 3D computer model to monitor the changes of the carbon to stainless steel connections, at the welds and of the skin
      i. Reviewed previous photos taken of entire segments of intrados during March 2011.
      ii. Should this photo documentation be revised in 2018-19?
8. BVH/Dan Worth
   a. Think of the future: Is graffiti a palimpsest?
   b. Allowing people to touch the Arch
   c. What is the cycle of treatment to remove surface damage at base in a life cycle (and cost) analysis. Such an analysis would be a useful piece in our future discussions.
   d. Wish we could have documented graffiti in 2005. Can we establish that baseline now?
   e. Monitoring of the base long term. To see the rate of change of the monument – overall and at base to monitor and review of these changes that may or may not be occurring? Photogrammetry, scanning, etc?
   f. The idea of refinishing is still out there to explore, even if it is not implemented, we can develop understanding before dismissing as a treatment option.
9. BVH/Julie Cawby
   a. Discovery of the treatments and the procedures / mockups and each of these and their results.
   b. Do not put limitations on cleaning heights. Why are we limiting ourselves to “80 feet high?”
10. Kärcher/Rich Barry
   a. Interpretation of our process should be implemented at the site. The care and maintenance should be part of this interpretation.
   b. The good news was that Astro Pak said the corrosion issue is real but not as aggressive as what they usually see.
   c. Visual appearance matters.
   d. Limiting to 80 feet and feathering is questionable. There is a visual parting line and it is at the concrete pour line. Can we go up to there?
   e. Politics is important – and you want tourists to know that you are maintaining the Arch.
11. Kärcher/Thorsten Moewes
   a. First, thank you very honored to be involved with high quality group of experts.
   b. Second, looking forward to offer our technologies to support you in the future.
   c. Cultural Sponsoring program can be used within its limitations.
12. Catherine Houska
   a. De-ionized water for cleaning is required by ASTM standards.
   b. What happens in the scratches of stainless steel is that it re-passivates.
   c. Deicing salts can create crevices that will cause pitting corrosion.
   d. Highest priority is getting carbon steel out of the scratch marks at base.
   e. Thinks NPS should clean the whole monument. Deicing salts found at higher reaches.
   f. Passive film – natural occurring (less pure) but will form if film is scratched.
13. Marshall Jones
   a. This workshop format is conducive to good ideas. GE implements these, as they call them “workouts.” Workshop was effective and a great learning experience for everyone.
   b. What are the structural concerns here? ¼” thick plate can take a lot of stress.
   c. Scratches. Potential defects that may grow? Which could lead to future stress areas.
   d. Lasers can be part of the “tool box” but not always the “only” solution.
14. Dean Koga
   a. This was a great Charrette process.

b. We are part of a continuum of this monument. Do as much as little as possible and as much as necessary.
c. Priority: Remove chlorides, restore passive layer and arrest surface corrosion
d. If we restore the finish we will be heartbroken when the graffiti returns. Instinct: Do NOT treat the base. Leave the shallower in place. Only tackle the deep corrosive ones.
e. Leave the graffiti – if in a hundred years the graffiti is historic
f. It is an NPS decision regarding visual appearance
g. Likes the handrail idea from Steve. A simple barrier around base = visual/mental break between harm.
h. Patina is "dirt that you like". Streaking – atmospheric.
i. Removal of weld splatter by lasers with no effect on base metal. This removal would help to eliminate the streaking.
j. What about stresses in the skin due to solar/thermal? HSR indicated movement of 17" difference in each leg / daily cycling of the movement in the sun as well. How much movement is occurring? Daily and seasonally? Stress monitor program as a future consideration of study?

15. Richard Pieper
    a. NPS and Dan Worth's idea of photo-documentation is important.
    b. Constant lighting environment is the challenge.
    c. Deans idea on monitoring movements is also important because it may help understand monument discoloration.
    d. We have an impressive palette or tools at our disposal as shown through this workshop.
    e. Three areas to treat: Graffiti at base, chloride contaminants near base, and entire monument where there is atmospheric deposition.
    f. Handrail is a good idea. Signage at exit to provide "lessons" of what they will see/ material as they exit. Install visual change in paving elevation away from surface (similar to the rail concept).
    g. Pieper is interested in chemical passivating treatments.
    h. Removal of soiling will be helpful for long term conservation.
    i. Off-site mock ups on samples should be done first before any mock ups on monument.
    j. Complemented team on process and workshop organization.

11:00 to12:00 PM – **Open discussion to determine potential mock ups.**

1. What is best way Zahner can create stainless steel surfaces in the shop that recreate mock-ups of existing Arch conditions?
1. Do we have to remove the atmospheric deposits? Is this a "patina"?
2. Discussed Mockups
    a. How to measure the results? Aesthetically and technically
        i. Base metal: leave untouched
        ii. Then add distress to each of the panels to be cleaned
        iii. Laboratory cleaning of each panel using selected techniques
        iv. Houska had comments on metallurgical requirements (Sulfur content) needed of the metals for the testing
    b. Document effect of each method in mockups
    c. Simulation/recreation of the building up of the pollutants on the surface:
        i. Will be difficult or not possible
    d. Mock up panel limitations

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i. Find a high sulfur alloy metal
ii. Recreate surface issues—including scratches, surface corrosion, deposition
iii. The welding
iv. “curved surface”

e. What size should samples be?
   i. Step 1- Houska will help find producer of same base metal
   ii. Step 2- Artificial rouging simulation / salt spray /
   iii. Step 3- Zahner: do welding samples
   iv. Step 4- Scratching / applied graffiti
   v. Step 5- Cleaning methods applied

f. Zahner: Level of finish – and taking it to only a certain level so that it can be reversed

3. Other discussion and considerations-
   a. Feathering
   b. Selective Cleaning
   c. Access
   d. Robots

12:00 to 1:00PM – Conclusion and next steps

1. Created a treatment matrix of the methods for blemishes, etc found on the Arch. See attached summary.
2. Discussed development of testing protocol and mock-ups to test treatments and evaluate their results.
3. Discussed using Zahner’s Metalab for fabricating small-scale mock-ups and testing.

Additional action items for the core team

1. Develop a method where we can quantitatively record the amount of graffiti that is presently on the base of both legs of the monument. Develop a cost estimate for its well. (Worth)
2. Develop a cost estimate to revise the photographic documentation that was first implemented on the east and west intrados of both legs. (Kelley)
3. Suggestion were made to develop a method to monitor movement of the monument. This would be beyond scope of current project.
4. Develop a testing protocol for materials testing at metal labs. (Kelley, Houska, Worth)
5. Procure samples. (Zahner, Houska)

Respectfully Submitted,

Dan M. Worth, AIA FAPT
Julie Cawby, AIA, Historical Architect
Steve Kelley, FAIA FAPT, BVH Affiliated Consultant

BVH Architecture

If you disagree with any of these notes or decisions, please respond within three working days of receipt of this document; otherwise we will assume your concurrence.

BVH ARCHITECTURE

Conserving the Gateway Arch
Conservation Planning Grant

The Getty Foundation | Keeping it Modern
Gateway Arch National Park St Louis, MO

BVH #18056
October 2, 2018

NAME		ATTENDANCE YES / NO	COMPANY	EMAIL
1.	Paul Kuenstner		APT Executive Director	PaulKuenstner@apti.org
2.	Dean Koga	✓	APT Past President	DKOGA@BCAUSA.COM
3.	Michael Ward	✓	NPS Gateway Arch National Park Superintendent	michael_ward@nps.gov Mike_Ward@nps.gov
4.	Frank Mares	✓	NPS Gateway Arch National Park Assistant Superintendent	Frank_Mares@nps.gov
5.	Rhonda Schier		NPS Gateway Arch National Park Chief of Interpretation and Education	Rhonda_Schier@nps.gov
6.	Kathryn Thomas		NPS Gateway Arch National Park Curator of Cultural Resources	Kathryn_Thomas@nps.gov
7.	Jim Cagle		NPS Gateway Arch National Park Chief of Facilities	Jim_Cagle@nps.gov
8.	Al O'Bright	✓	NPS Historical Architect	Al_O'Bright@nps.gov
9.	Chance Baragary		Bi-State Development PMP-Project Director	cmbaragary@gatewayarch.com
10.	Dan Worth	✓	BVH Architecture Principal/Project Manager	dworth@bvh.com
11.	Stephen J. Kelley	✓	BVH Architecture, Affiliated Consultant / Consultant Team Leader	steve@kelleyaia-se.com
12.	Julie Cawby	✓	BVH Architecture Historical Architect	jcawby@bvh.com
13.	Catherine Houska	✓	Catherine Houska Consulting LLC	cmhouska@outlook.com
14.	William Zahner		A. ZAHNER CO. and Metalabs, LLC CEO/President	bzahner@azahner.com
15.	Dan Gierer		A. ZAHNER CO. and Metalabs, LLC Restoration Specialist	dgierer@azahner.com
16.	Rich Barry	✓	Karcher U.S. Projects	Rich.barry@gwtc.net

BVHARCHITECTURE

NAME			COMPANY	EMAIL
17.			Karcher U.S. Projects	
18.	Marshall Jones	✓	GE Global Research Manufacturing Technologies	jonesmg@ge.com
19.			GE Global Research Manufacturing Technologies	
20.	Richard Pieper	✓	Jan Hird Pokorny Associates	pieper@jhpokorny.com
21.			Jan Hird Pokorny Associates	
22.	Jordan Schaecher	✓	Astropak	jschaecher@astropak.com
23.	Timothy Velazquez	✓	Astropak	TVelazquez@astropak.com
24.	Amanda Burke		Missouri State Historic Preservation Officer (SHPO)	Amanda.Burke@dnr.mo.gov
25.	Thom B. Kuntzman		Missouri State Historic Preservation Officer (SHPO)	Thom.Kuntzman@dnr.mo.gov
26.	DARYL ROLL	✓	ASTRO PAK CORP	droll@astropak.com
27.	Rich Barry	✓	Karchor	rich.barry@gwtc.net
28.	Thorsten Moewes	✓	Kaercher	thorsten.moewes@de.kaercher.com
29.	BOB MOORE	✓	NATIONAL PARK SERVICE	BOB_MOORE@NPS.GOV
30.	Joe Sembrat	✓	Evergreene Arch. Arts/ Conservation Solutions	jsembrat@evergreene.com
31.				
32.				
33.				

BVHARCHITECTURE

Conserving the Gateway Arch
Conservation Planning Grant

The Getty Foundation | Keeping it Modern
Gateway Arch National Park St Louis, MO

BVH #18056
October 3, 2018

	NAME	ATTENDANCE YES / NO	COMPANY	EMAIL
1.	Paul Kuenstner		APT Executive Director	PaulKuenstner@apti.org
2.	Dean Koga	✓	APT Past President	
3.	Michael Ward		NPS Gateway Arch National Park Superintendent	Mike_Ward@nps.gov
4.	Frank Mares	✓	NPS Gateway Arch National Park Assistant Superintendent	Frank_Mares@nps.gov
5.	Rhonda Schier		NPS Gateway Arch National Park Chief of Interpretation and Education	Rhonda_Schier@nps.gov
6.	Kathryn Thomas	✓	NPS Gateway Arch National Park Curator of Cultural Resources	Kathryn_Thomas@nps.gov
7.	Jim Cagle		NPS Gateway Arch National Park Chief of Facilities	Jim_Cagle@nps.gov
8.	Al O'Bright	✓	NPS Historical Architect	Al_O'Bright@nps.gov
9.	Chance Baragary		Bi-State Development PMP-Project Director	cmbaragary@gatewayarch.com
10.	Dan Worth	✓	BVH Architecture Principal/Project Manager	dworth@bvh.com
11.	Stephen J. Kelley	✓	BVH Architecture, Affiliated Consultant / Consultant Team Leader	steve@kelleyaia-se.com
12.	Julie Cawby	✓	BVH Architecture Historical Architect	jcawby@bvh.com
13.	Catherine Houska	✓	Catherine Houska Consulting LLC	cmhouska@outlook.com
14.	William Zahner	YES	A. ZAHNER CO. and Metalabs, LLC CEO/President	bzahner@azahner.com
15.	Dan Gierer	YES	A. ZAHNER CO. and Metalabs, LLC Restoration Specialist	dgierer@azahner.com
16.	Rich Barry	✓	Karcher U.S. Projects	Rich.barry@gwtc.net

BVHARCHITECTURE

NAME			COMPANY	EMAIL
17.			Karcher U.S. Projects	
18.	Marshall Jones	✓	GE Global Research Manufacturing Technologies	jonesmg@ge.com
19.			GE Global Research Manufacturing Technologies	
20.	Richard Pieper	✓	Jan Hird Pokorny Associates	pieper@jhpokorny.com
21.			Jan Hird Pokorny Associates	
22.	Jordan Schaecher	✓	Astropak	jschaecher@astropak.com
23.	Timothy Velazquez	✓	Astropak	TVelazquez@astropak.com
24.	Amanda Burke	yes	Missouri State Historic Preservation Officer (SHPO)	Amanda.Burke@dnr.mo.gov
25.	Thom B. Kuntzman	No	Missouri State Historic Preservation Officer (SHPO)	Thom.Kuntzman@dnr.mo.gov
26.	joe sembrat	yes	Evergreene Arch. Arts/ Conservation Solutions	jsembrat@evergreene.com
27.	DARYL ROLL	YES	ASTRO PAK CORP.	droll@ASTROPAK.COM
28.	Al O'Bright	✓	NPS-MWRO	al_o'bright@nps.gov
29.	THORSTEN Moewes	✓	KAERCHER	thorsten.moewes@de.kaercher.com
30.	BOB MOORE	✓	NPS	BOB_MOORE@NPS.GOV
31.				
32.				
33.				

BVHARCHITECTURE

Conserving the Gateway Arch
Conservation Planning Grant

The Getty Foundation | Keeping it Modern
Gateway Arch National Park St Louis, MO

BVH #18056
October 4, 2018

	NAME	ATTENDANCE YES / NO	COMPANY	EMAIL
1.	Paul Kuenstner		APT Executive Director	PaulKuenstner@apti.org
2.	Dean Koga	✓	APT Past President	
3.	Michael Ward	✓	NPS Gateway Arch National Park Superintendent	Mi~~ke~~ Ward@nps.gov
4.	Frank Mares	✓	NPS Gateway Arch National Park Assistant Superintendent	Frank_Mares@nps.gov
5.	Rhonda Schier		NPS Gateway Arch National Park Chief of Interpretation and Education	Rhonda_Schier@nps.gov
6.	Kathryn Thomas	✓	NPS Gateway Arch National Park Curator of Cultural Resources	Kathryn_Thomas@nps.gov
7.	Jim Cagle		NPS Gateway Arch National Park Chief of Facilities	Jim_Cagle@nps.gov
8.	Al O'Bright	✓	NPS Historical Architect	Al_O'Bright@nps.gov
9.	Chance Baragary		Bi-State Development PMP-Project Director	cmbaragary@gatewayarch.com
10.	Dan Worth	DW.	BVH Architecture Principal/Project Manager	dworth@bvh.com
11.	Stephen J. Kelley	SJK	BVH Architecture, Affiliated Consultant / Consultant Team Leader	steve@kelleyaia-se.com
12.	Julie Cawby	JC.	BVH Architecture Historical Architect	jcawby@bvh.com
13.	Catherine Houska	CH	Catherine Houska Consulting LLC	cmhouska@outlook.com
14.	William Zahner	YES	A. ZAHNER CO. and Metalabs, LLC CEO/President	bzahner@azahner.com
15.	Dan Gierer	YES	A. ZAHNER CO. and Metalabs, LLC Restoration Specialist	dgierer@azahner.com
16.	Rich Barry	✓	Karcher U.S. Projects	Rich.barry@gwtc.net

BVHARCHITECTURE

NAME			COMPANY	EMAIL
17.			Karcher U.S. Projects	
18.	Marshall Jones	MJ	GE Global Research Manufacturing Technologies	jonesmg@ge.com
19.			GE Global Research Manufacturing Technologies	
20.	Richard Pieper	RDP	Jan Hird Pokorny Associates	pieper@jhpokorny.com
21.			Jan Hird Pokorny Associates	
22.	Jordan Schaecher	YES	Astropak	jschaecher@astropak.com
23.	DARYL ROLL	YES	Astropak	droll@astropak.com
24.	Amanda Burke		Missouri State Historic Preservation Officer (SHPO)	Amanda.Burke@dnr.mo.gov
25.	Thom B. Kuntzman		Missouri State Historic Preservation Officer (SHPO)	Thom.Kuntzman@dnr.mo.gov
26.	Joe Sembrat	Yes	Evergreene Architectural Arts Conservation Solutions	jsembrat@evergreene.com
27.	Tim Velazquez	yes	Astro Pak	tvelazquez@astropak.com
28.	Al O'Bright	✓	NPS-MWRO	al_o'bright@nps.gov
29.	Thorsten Moewes	✓	KAERCHER	thorsten.moewes@de.kaercher.com
30.	Bob Moore	✓	NPS	BOB_MOORE@NPS.GOV
31.	FRANK MARES	✓	NPS	FRANK_MARES@NPS.GOV
32.				
33.				

Appendix D - Kärcher

Kärcher Testing Report

Stainless Steel Cleaning Panels

Zahner Metalab

Kansas City, Missouri

Kärcher International

Alfred Kärcher SE & Co. KG

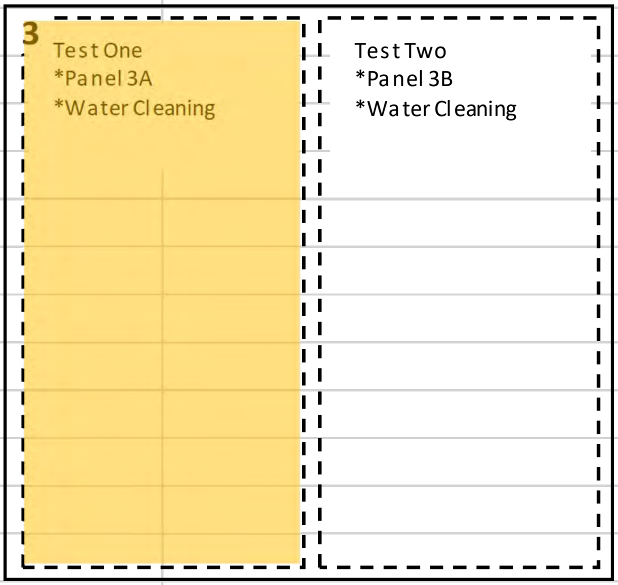
Alfred-Kärcher-Strasse 28-40

71364 Winnenden / Germany

Test 3A: High Pressure

Karcher - Gateway Arch Mock Up Test Plan

Test Date: March 26th, 2019

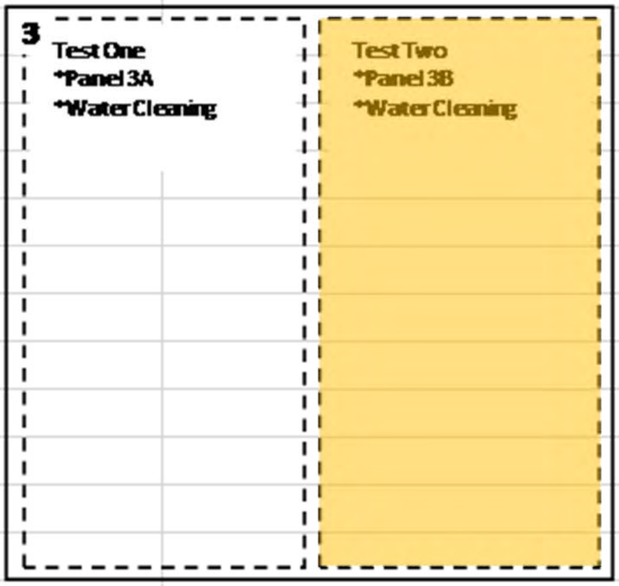


Test One (3A)	High Pressure
Machine	Karcher-HDS 5.0/30-4S
ChlorRid Dilution Ratio	1 to 100 (1%) for normal concentration of salts
Water Source	Potable
Working Pressure	2600 psi (hose)
Water Flow Rate	5.0 gpm
Working Temperature	189°F (hose)
Nozzle Type	2.883-894 Power Nozzle 25°
Nozzle Size	0.062 in
Spray Angle	25 deg
Spray Shape	Flat
Spray Distance	6 in
Impact Pressure	≈15-30 psi
Chloride Removal	*** PATINA See note.*
Corrosion Removal	
Iron Particle Removal	
Surface Finish	

Test 3B: Steam

Karcher - Gateway Arch Mock Up Test Plan

Test Date: March 26th, 2019

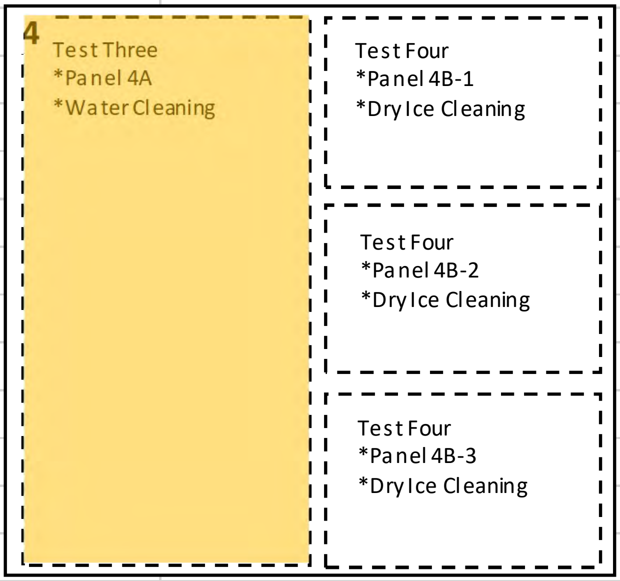


Test Two (3B)	Steam Temperature
Machine	Karcher-HDS 5.0/30-4S
ChlorRid Dilution Ratio	1 to 100 (1%) for normal concentration of salts
Water Source	Potable
Working Pressure	800 psi (hose)
Water Flow Rate	2.5 gpm
Working Temperature	275°F (hose) / ≈212°F (steam at 1 atmosphere)
Nozzle Type	4.116-001.0 Steam Jet Nozzle 50°
Nozzle Size	0.079 in
Spray Angle	50 deg
Spray Shape	Flat
Spray Distance	4 to 6 in
Impact Pressure	≈7-9 psi
Chloride Removal	*** PATINA See note.*
Corrosion Removal	
Iron Particle Removal	
Surface Finish	

Test 4A: Ultra-high Pressure

Karcher - Gateway Arch Mock Up Test Plan

Test Date: March 26th, 2019

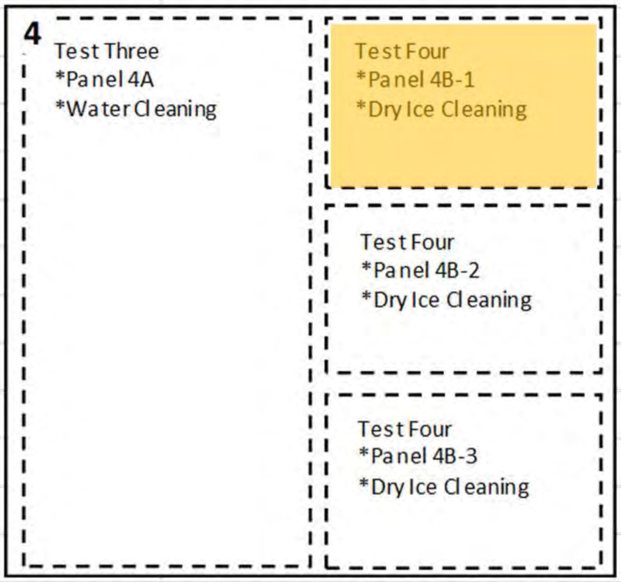


Test Three: (4A)	Ultra-high Pressure (low range)
Machine	Karcher-HD 9/50
ChlorRid Dilution Ratio	1 to 100 (1%) for normal concentration of salts
Water Source	Potable
Working Pressure	7250 psi (hose)
Water Flow Rate	4.0 gpm
Working Temperature	≈60°F (Ambient air of water stored in tank)
Nozzle Type	2.883-390 Power Nozzle 15°
Nozzle Size	0.028 in
Spray Angle	15 deg
Spray Shape	Flat
Spray Distance	2-4 in
Impact Pressure	≈45-75 psi
Chloride Removal	*** PATINA See note.*
Corrosion Removal	
Iron Particle Removal	
Surface Finish	

Test 4B-1: Dry Ice

Karcher - Gateway Arch Mock Up Test Plan

Test Date: March 26th, 2019

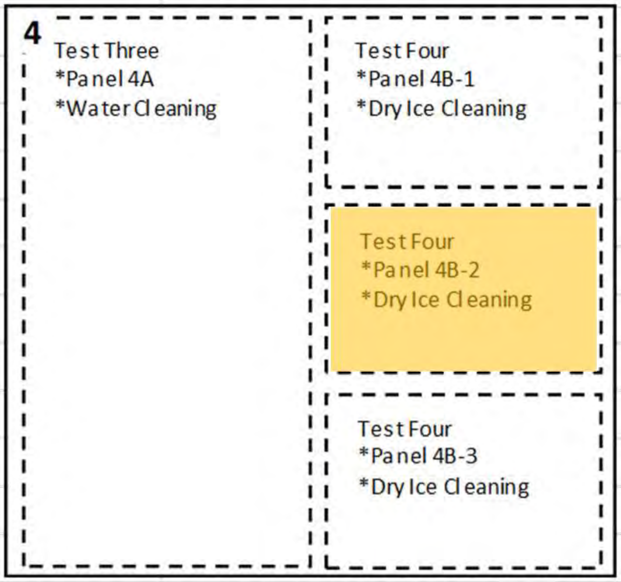


Test Four (4B-1)	Dry Ice
Machine	Karcher-IB 15/120
Nozzle type	4.574-048 Round Spray Nozzle M, Long
Nozzle size	0.28 in
Scrambler	None
Working pressure	43 psi
Working flow rate	88 lb/hr
Working temperature	≈-110°F (dry ice) / 36°F (surface after cleaned)
Spray distance	4 to 6 in
Impact Pressure	No estimate currently available
Chloride Removal	** PATINA See note.
Corrosion Removal	
Iron Particle Removal	
Surface Finish	

Test 4B-2: Dry Ice

Karcher - Gateway Arch Mock Up Test Plan

Test Date: March 26th, 2019

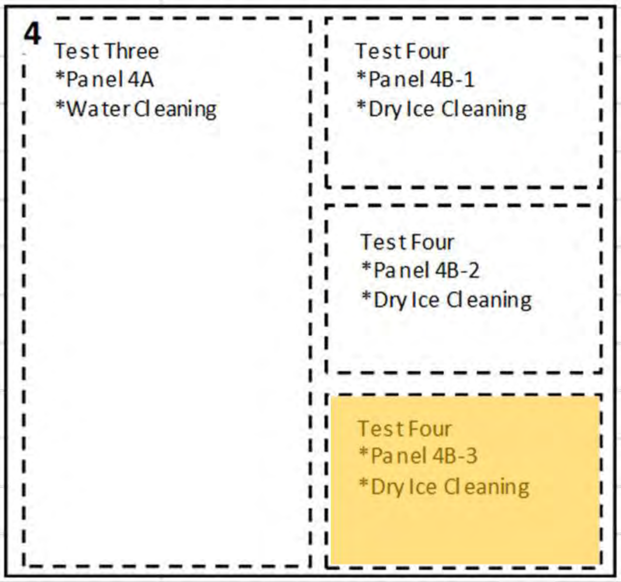


Test Four (4B-2)	Dry Ice
Machine	Karcher-IB 15/120
Nozzle size	4.574-048 Round Spray Nozzle M, Long
Nozzle type	0.28 inches
Scrambler	None
Working pressure	87 psi
Working flow rate	176 lb/hr
Working temperature	≈-110°F (dry ice) / 33°F (surface after cleaned)
Spray distance	4 to 6 in
Impact Pressure	No estimate currently available
Chloride Removal	** PATINA See note.
Corrosion Removal	
Iron Particle Removal	
Surface Finish	

Test 4B-3: Dry Ice

Karcher - Gateway Arch Mock Up Test Plan

Test Date: March 26th, 2019

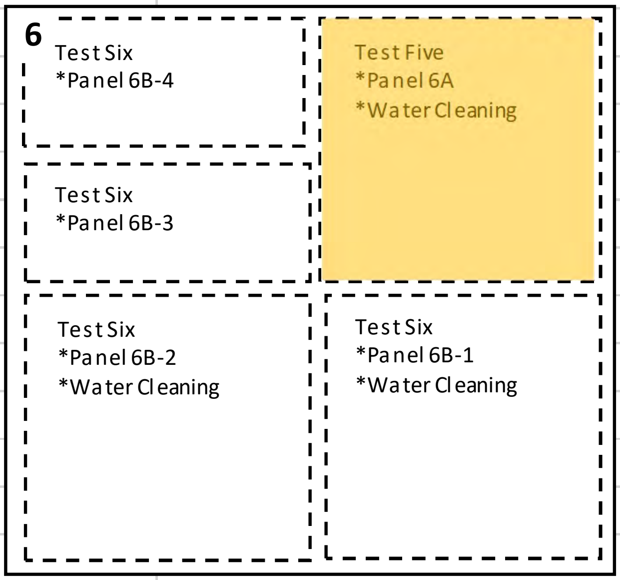


Test Four (4B-3)	Dry Ice
Machine	Karcher-IB 15/120
Nozzle size	4.574-048 Round Spray Nozzle M, Long
Nozzle type	0.28 in
Scrambler	None
Working pressure	123 psi
Working flow rate	264 lb/hr
Working temperature	≈-110°F (dry ice) / 27°F (surface after cleaned)
Spray distance	4 to 6 in
Impact Pressure	No estimate currently available
Chloride Removal	** PATINA See note.
Corrosion Removal	
Iron Particle Removal	
Surface Finish	

Test 6A: Ultra-high Pressure (mid range)

Karcher - Gateway Arch Mock Up Test Plan

Test Date: May 17th, 2019 - Test Five) / July 9th, 2019 - Test Six

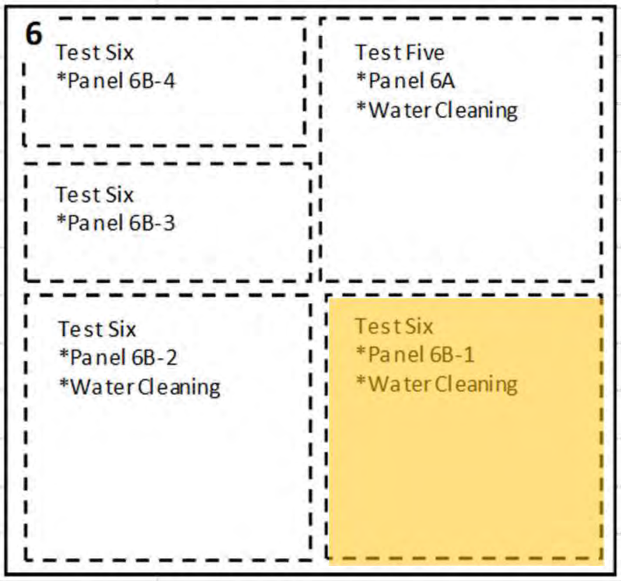


Test Five (6A)	Ultra-high Pressure (mid range)
Machine	Karcher-HD 9/100
ChlorRid Dilution Ratio	None
Water Source	Potable
Working Pressure	14,504 psi / 1000 bar (hose)
Water Flow Rate	3.9 gpm
Working Temperature	≈50°F (Ambient tap)
Nozzle Type	6.025-466 Power Nozzle 20°
Nozzle Size	0.043 in
Spray Angle	20 deg
Spray Shape	Flat
Spray Distance	1-2 inches
Impact Pressure	≈145 psi / ≈10 bar
Chloride Removal	*** PATINA See note.*
Corrosion Removal	
Iron Particle Removal	
Surface Finish	

Test 6B-1: Ultra-high Pressure (high range)

Karcher - Gateway Arch Mock Up Test Plan

Test Date: May 17th, 2019 - Test Five) / July 9th, 2019 - Test Six

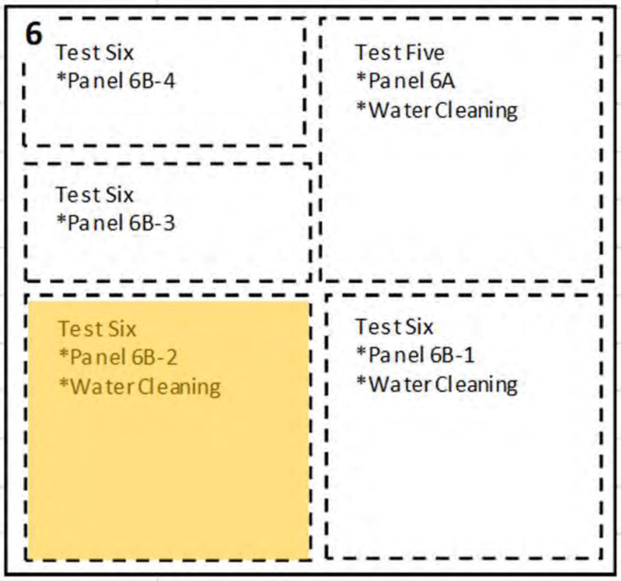


Test Six (6B-1)	Ultra-high Pressure (high range)
Machine	Woma-MK3 2800/26
ChlorRid Dilution Ratio	None
Water Source	Potable
Working Pressure	21,756 psi / 1500 bar (hose)
Water Flow Rate	3.7 gallons per minute
Working Temperature	≈150° F due to mechanical compression
Nozzle Type	9.886-043.0 Flat Jet Nozzle Form 8
Nozzle Size	0.039 in
Spray Angle	10 deg
Spray Shape	Flat
Spray Distance	1-2 in
Impact Pressure	≈218-290 psi / ≈15-20 bar
Chloride Removal	** PATINA See note.
Corrosion Removal	
Iron Particle Removal	
Surface Finish	

Test 6B-2: Ultra-high Pressure (high range)

Karcher - Gateway Arch Mock Up Test Plan

Test Date: May 17th, 2019 - Test Five) / July 9th, 2019 - Test Six

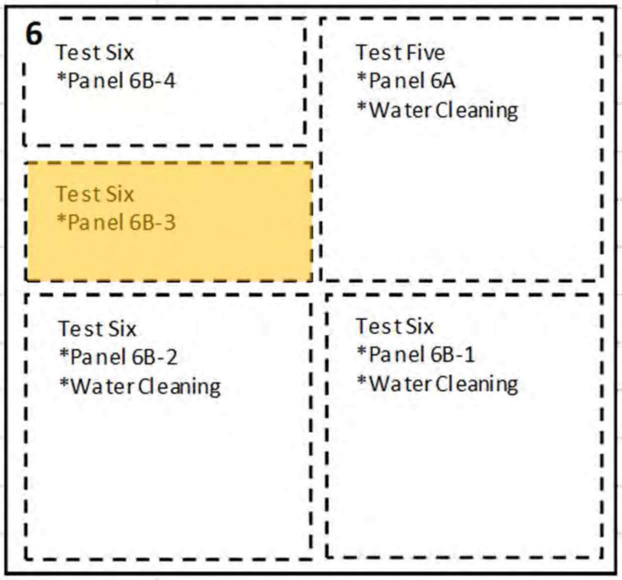


Test Six (6B-2)	Ultra-high Pressure (high range)
Machine	Woma-MK3 2800/26
ChlorRid Dilution Ratio	None
Water Source	Potable
Working Pressure	31,908 psi / 2200 bar (hose)
Water Flow Rate	5.0 gpm
Working Temperature	≈150°F (Due to mechanical compression)
Nozzle Type	9.886-043.0 Flat Jet Nozzle Form 8
Nozzle Size	0.039 in
Spray Angle	10 deg
Spray Shape	Flat
Spray Distance	1-2 in
Impact Pressure	≈290-363 psi / ≈20-25 bar
Chloride Removal	** PATINA See note.
Corrosion Removal	
Iron Particle Removal	
Surface Finish	

Test 6B-3: Ultra-high Pressure (high range)

Karcher - Gateway Arch Mock Up Test Plan

Test Date: May 17th, 2019 - Test Five) / July 9th, 2019 - Test Six

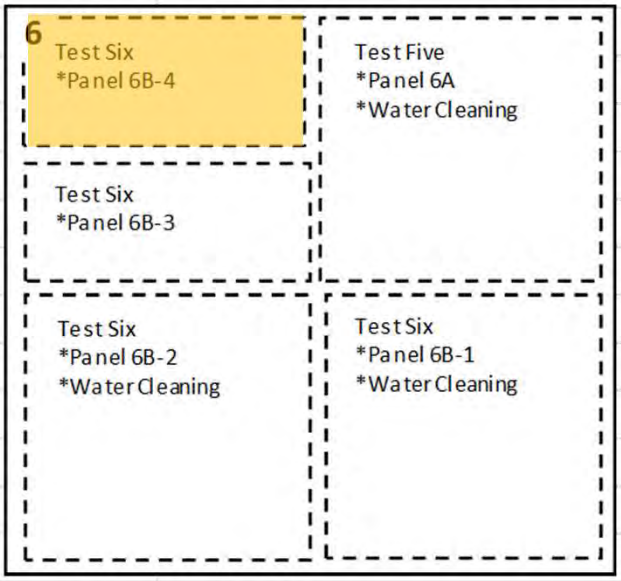


Test Six (6B-3)	Ultra-high Pressure (high range)
Machine	Woma-MK3 2800/26
ChlorRid Dilution Ratio	None
Water Source	Potable
Working Pressure	43,511 psi / 3000 bar (hose)
Water Flow Rate	3.7 gpm
Working Temperature	≈150°F (Due to mechanical compression)
Nozzle Type	9.886-043.0 Flat Jet Nozzle Form 8
Nozzle Size	0.039 in
Spray Angle	10 deg
Spray Shape	Flat
Spray Distance	1-2 in
Impact Pressure	≈435-508 / ≈30-35 bar
Chloride Removal	** PATINA See note.
Corrosion Removal	
Iron Particle Removal	
Surface Finish	

Test 6B-4: Ultra-high Pressure (high range)

Karcher - Gateway Arch Mock Up Test Plan

Test Date: May 17th, 2019 - Test Five) / July 9th, 2019 - Test Six



Test Six (6B-4)	Ultra-high Pressure (high range)
Machine	Woma-MK3 2800/26
ChlorRid Dilution Ratio	None
Water Source	Potable
Working Pressure	43,511 psi / 3000 bar (hose)
Water Flow Rate	3.7 gpm
Working Temperature	≈150°F (Due to mechanical compression)
Nozzle Type	9.886-875.0 Nozzle Carrier Head TD06-3000 - 30°
Nozzle Size	6 x 0.016 in
Spray Angle	30 deg
Spray Shape	Round
Spray Distance	1-2 in
Impact Pressure	No estimate currently available
Chloride Removal	** PATINA See note.
Corrosion Removal	
Iron Particle Removal	
Surface Finish	

Appendix E - Astropak

ASTRO PAK CORPORATION

PROCESS PROCEDURE DOCUMENT #:
AP04-300-P138 – BVH Gateway Arch

DOCUMENT TITLE:
PHARM PROCESS FOR CLEANING (IPA), DEROUGING (AP-401), AND PASSIVATION (UltraPass) OF STAINLESS STEEL

OWNER / CLIENT: __**BVH Architecture**________________

LOCATION: __**A. Zahner Co., Kansas City**______________

PROJECT: __**Gateway Arch 304 Panel Testing**_________

SYSTEM: ___**Panel #7**______________________________

TRACKING NUMBER: ___**BVH Project #18056**_________

Astro Pak Document No.	AP04	300	P	138	BVH
	Application code	Function code	Document type	Sequence No	Rev No
Prepared by	Checked by	Reviewed by	QA Review by	Approved by	Issued/Revised
D. Roll	T. Tate	T. Sowell	D. Roll	D. Roll	03-25-2019

REVISION HISTORY

This page is a record of all revisions to the Process Procedure Document referenced above.

Record field changes or revisions made to this document to meet changed or added requirements of the contract. Approvals shall be obtained from the Astro Pak Project Leader (PL) and Owner / Client Representative, both of whom shall sign all changes.

All changes shall be referenced on this page and changed in the document.06

REV	DATE	REVISED BY	APPROVED BY	REVISION REASON
0	02-14-08	Daryl Roll	Daryl Roll	Revision of AP-04-P-057 Gel Pass (09-02-05)
1	06-07-13	Hyder Razvi	Daryl Roll	Modified Process chemistry and sequence to meet Spec 1108-09810 Rev C.
2	12-20-16	Hyder Razvi	Brent Ekstrand	Updated to current standard and format.
BVH	03-25-2019	Daryl Roll	Daryl Roll	Specific Procedure for BVH project

SIGNATURE LOG

COMPANY	PRINT NAME	SIGNATURE	INITIALS	DATE
Astro Pak	Daryl Roll		DLR	12-25-2019
Astro Pak	Jordan Schaecher		JS	12-25-2019
Astro Pak	Tim Velazquez		TV	12-25-2019

CONTENTS

1. PROCEDURE REVIEW AND APPROVAL OF SCOPE OF WORK

1.1. The undersigned have reviewed and hereby approve the following process procedure:

COMPANY / DEPARTMENT	REPRESENTATIVE NAME	SIGNATURE / DATE
Cleaning / Passivation Contractor: **ASTRO PAK CORPORATION**	Jordan Schaecher	JS -- 03/25/2019
Owner / Client:		
Other Representative:		

Note: These approvals to be obtained prior to commencing these procedures.

2. NON-DISCLOSURE AGREEMENT

2.1. This document is comprised of **trade secret** information that shall not be disclosed outside of the companies to which it is submitted, and shall not be duplicated, incorporated as a part of another document, or otherwise utilized, in whole or in part, for any purpose other than evaluation by the intended parties.

3. APPLICABILITY

3.1. This procedure is applicable to exterior surfaces constructed of type 304 stainless steel.

4. SCOPE OF PROCEDURE

4.1. This document describes the procedures that Astro Pak utilized to clean, derouge and passivate external stainless steel surfaces of the subject panel; in order to ensure that the surfaces are suitable for BVH Architecture. It is also intended to demonstrate that Astro Pak understands the scope of work and to provide sequential guidance to Astro Pak and Owner / Client's project personnel.

4.2. The list of items that will be processed using this procedure is shown in Attachment "A", List of Items Processed.

5. GENERAL

5.1. This procedure uses a multi-stage process designed to remove organic material, debris, free iron, derouge and passivate weld areas and stainless steel surfaces. The process utilizes degreasing agents, Phosphoric and Citric acids, multiple chelants and surface-active agents for the removal of organic material, metal oxides and other corrosion-promoting impurities. The process is designed for non-circulated components or systems.

5.2. The Ultra Pass passivation process is specifically designed to enhance corrosion resistance within the system by increasing the chromium-to-iron ratio at the weld or contact surface and meets the requirements of ASTM A-380 and ASTM A-967.

5.3. Astro Pak proposes to provide the personnel, equipment, chemicals, technical expertise, process documentation and certification necessary to accomplish the work in accordance with the procedures and conditions given within this document.

5.4. The following activities will be executed per this procedure:

- Pre-process preparation
- Process set-up
- Cleaning process
- Derouging process
- Passivation process
- Final rinse and testing
- Inspection and site clean-up

6. REFERENCES

6.1. The content in this procedure is in accordance with accepted ASTM standards as practiced throughout industry.

7. PROCESS CHEMICALS, WATER AND EQUIPMENT SET

7.1. Process Chemicals

7.1.1. Attachment “C”, Chemical Components and Waste Disposal Plan gives details of the chemicals used in this procedure for organic cleaning, derouging and passivation.

7.2. Process Water

7.2.1. Water used for this process shall be deionized (DI). DI water is defined for the purposes of this document as water demonstrating a conductivity of less than 5.0 microSiemens/cm (µS /cm). Water with a higher conductivity value shall be noted as a variance.

7.3. Equipment Set

7.3.1. Astro Pak shall provide as needed, chemical applicators, mixing containers, reagents, safety gear and small tools.

8. PRE-PROCESS PREPARATION

8.1. Astro Pak PL shall meet with the Owner / Client representative to discuss and implement the issues listed in section 9.1.1 through 9.1.7.

8.1.1. Provide Owner / Client representative with a list of Astro Pak personnel on project, obtain access to plant area and arrange for required site orientation.

8.1.2. Confirm schedule, sequence and priority of all panels to be cleaned, derouged and passivated by Astro Pak and complete project activities on time.

8.1.3. Hold a safety meeting to discuss work plan, site safety and PPE issues with all participating personnel.

8.1.4. Perform a walk-down of the system with Owner / Client representative to identify, resolve any interferences, restrictions and other issues that will impact the work plan.

8.1.5. Resolve any issues such as pH, volume of waste solutions and rinsate; sampling, testing of waste process liquid prior to transfer to process drains, waste collection and storage.

DESCRIPTION	SIGN / DATE
Confirm completion of Sections 8.1.1 to 8.1.5.	JS -- 03/25/2019

8.2. Astro Pak PL shall continue with the pre-process preparation and documentation:

8.2.1. List the description, location and equipment / component ID number of items included in this system in Attachment “A”.

8.2.2. Confirm that the subject area / system have been isolated in order to perform this process procedure in a safe manner.

8.2.3. Obtain approval from Owner / Client representative to proceed with procedure execution and set-up for cleaning, derouging and passivation as approved during the walk-down of the system.

DESCRIPTION	SIGN / DATE
Confirm completion of Sections 8.2.1 to 8.2.3.	JS -- 03/25/2019

9. CLEANING PROCESS FOR EXTERNAL SURFACES

The objective of the alkaline cleaning process is to remove organic deposits and loose particles from subject surfaces and welds.

9.1. Apply a uniform layer of Isopropyl alcohol cleaner on clean wipe to the subject area(s) at a minimum surface temperature of 15 °C (or 60 °F); keep the subject area(s) wet and wipe to remove film or other debris.

9.2. Visually inspect subject area(s) to confirm acceptable cleanliness level; repeat step 9.1 if necessary.

DESCRIPTION	SIGN / DATE
Confirm completion of Sections 9.1 to 9.2	JS -- 03/25/2019

10. DEROUGING PROCESS FOR EXTERNAL SURFACES

The objective of the derouging process is to remove free iron, rouge and metal oxide deposits from subject surfaces and welds.

10.1. Apply a uniform layer of the AP 401 gel to the surface area(s) of Panel #7 at a minimum surface temperature of 15 °C; keep the subject area(s) wet; allow the paste to work for duration of 30 - 120 minutes, until the surface is visually free of rouge and weld stains.

10.2. Apply AP 401 to white Scotch Brite (WSB) pad and scrub surface lightly. Panel #7 will be treated on the top half by scrubbing the surface by hand and the bottom half will be treated with AP 401 and scrubbed with the WSB pad aided by an orbital sander/polisher. Treat surface as recorded on Attachment "B".

10.3. After completion of derouging process, spray the subject area(s) with DI water to rinse, wipe with IPA clean wipe and remove residual AP 401 gel and other debris.

10.4. **Neutralize rinsate effluent as necessary prior to discharge to an approved drain**, effluent collection or disposal location per waste disposal plan. Document process completion in Attachment "B".

DESCRIPTION	SIGN / DATE
Confirm completion of Sections 10.1 to 10.4	JS -- 03/25/2019

11. PASSIVATION PROCESS FOR EXTERNAL SURFACES

The objective of the passivation process is specifically designed to enhance corrosion resistance within the system by increasing the chromium-to-iron ratio at the contact surfaces.

11.1. Apply a uniform layer of UltraPass gel passivation solution on all subject external surfaces of panel #7; keep the subject area(s) wet and allow the passivation solution to work for duration of 30 to 120 minutes.

11.2. Spray the panel area(s) with DI water to rinse and wipe with clean wipe to remove the passivation solution residue and other debris.

11.3. **Neutralize** rinsate **as necessary prior to discharge** to an approved drain, effluent collection or disposal location. Document process completion in Attachment "B".

11.4. Visually inspect subject area(s) to confirm removal of discoloration and cleanliness level.

DESCRIPTION	SIGN / DATE
Confirm completion of Sections 11.1 to 11.4	JS -- 03/25/2019

12. FINAL RINSE AND TESTING FOR INTERNAL SURFACES

12.1. Wipe subject panel area(s) with IPA clean wipe to insure cleanliness and allow to air dry.

12.2. Visually inspect subject area(s) to confirm removal of discoloration and cleanliness level.

12.3. Clean surface areas of other support equipment to remove residual chemicals and insure cleanliness of work area.

13. INSPECTION

13.1. Inspect subject panel visually for cleanliness along with Owner / Client Representative and confirm acceptance. See step 14.4 for clarification.

14. PROCESS COMPLETION

14.1. Review this procedure to ensure completeness.

14.2. Remove Astro Pak furnished equipment from subject system / area, and ensure all chemicals have been removed and empty bags/containers disposed of properly.

14.3. Return Client's system to pre-service status and Client's environment/ site to pre-Astro Pak state or better.

14.4. Walk site with Client representative showing all work complete and condition of process area.

DESCRIPTION	SIGN / DATE
Confirm completion of work listed in Section 14.1 to 14.4.	JS -- 03/25/2019

15. SYSTEM ACCEPTANCE AND CERTIFICATION

15.1. The undersigned has reviewed and accept the completion of the process procedures for the subject system as documented above. **This confirms the Certification of Cleaning, Derouging and Passivation for the above listed panel.**

COMPANY / DEPARTMENT	REPRESENTATIVE NAME	SIGNATURE / DATE
Cleaning / Passivation Contractor: **ASTRO PAK CORPORATION**	Jordan Schaecher	JS -- 03/25/2019
Owner / Client:		

Note: To be signed on completion of all procedures listed in this document.

16. DOCUMENTATION

16.1. Astro Pak representative shall review documentation and field records with Owner / Client representative.

16.2. Astro Pak representative shall submit copy of completed and signed PPD (Process Procedure Document) to Owner / Client representative on completion of work and document review by Astro Pak.

17. ATTACHMENT LIST

A. List of items processed

B. Process Documentation

C. Chemical Components and Waste Disposal Plan

ASTRO PAK Process Procedure Document #: AP04-300-P138 Rev BVH Cleaning(IPA), Derouging(AP 410), Passivation(UltraPass) of Stainless Steel

Issued / Revised: 03/25/2019 Astro Pak Job #: Panel #: **7**

Owner / Client: **BVH Architecture** Project: **Gateway Arch 304 Panel Testing**

Location: **A. Zahner Co., Kansas City** System: **Panel #7**

ATTACHMENT "A" - LIST OF ITEMS PROCESSED*		
		Page ___ of ___
EQUIPMENT / COMPONENT ID	**DESCRIPTION**	**LOCATION**
Panel #7/ Sections A & B	Sample test panel #7 to be cleaned, derouged and passivated with IPA clean wipe; AP 401 derouging and UltraPass passivation gels	Completed at A. Zahner Co.'s shop in Kansas City, KS

*Add copies of blank Attachment if additional pages are necessary.

NOTES:	
ASTRO PAK REPRESENTATIVE SIGNATURE: JS	DATE:03/25/2019

ASTRO PAK

Process Procedure Document #: AP04-300-P138 Rev BVH Cleaning(IPA), Derouging(AP 410), Passivation(UltraPass) of Stainless Steel

Issued / Revised: 03/25/2019 Astro Pak Job #: Panel #: **7**

Owner / Client: **BVH Architecture** Project: **Gateway Arch 304 Panel Testing**

Location: **A. Zahner Co., Kansas City** System: **Panel #7**

ATTACHMENT "B" - PROCESS DOCUMENTATION*									
EXTERNAL SURFACE (Circle one) Panel #7					**Page ___ of ___**				
EQUIPMENT / COMPONENT ID	**CLEANING TIME:**		**DEROUGING TIME:**		**PASSIVATION TIME:**		**RINSE TIME:**		
	Start	**End**	**Start**	**End**	**Start**	**End**	**Start**	**End**	
Wipe with IPA clean wipe	1:43 pm	1:44 pm							
Apply AP 401 solution			1:44 pm	1:45					
Brush surface with white Scotch Brite (WSB) pad			1:45	1:50					
Wipe center horizontal area with DI water and alcohol wipe; then applied separator tape			1:50	1:54					
Apply AP 401 to Section 7A (top) with WSB pad			1:54	1:58					
Apply AP 401 to Section 7B (bottom) with orbital sander and WSB pad			1:55	1:58					
Wiped off panel #7 with DI water and IPA wipes			2:00	2:05					
Inspected Panel #7 Sections A & B			2:00	2:15					
Re-Apply AP 401 to Panel #7			2:15						
Use Orbital polisher on section B (bottom 1/2)			2:16	2:20					
Apply AP 401 using WSB pad to scrub surfaces every 10 to 15 minutes			2:30	3:20					
DI Rinse panel #7 and Wipe with IPA clean wipe			3:26	3:30 pm					
Apply UltraPass gel with brush every 10 – 15 min					4:57 pm	6:27 pm			

DI water rinse and wipe Panel #7 with DI water and IPA clean wipe							6:28 pm	6:28	
Final clean with IPA clean wipe							6:29	6:29 pm	
ASTRO PAK REPRESENTATIVE SIGNATURE: Jordan Schaecher								DATE: 03/25/2019	

ATTACHMENT "C" - CHEMICAL COMPONENTS AND WASTE DISPOSAL PLAN

CHEMICAL COMPONENTS

PROCESS CHEMICALS	MANUFACTURER	LOT NUMBER	
Cleaning spray/wipe – IPA Cleaner on clean wipe	Texwipe - TechniSat	TX 1065	
Derouging Solution – AP 401 on white Scotch Brite pad	Avesta and Astro Pak chemistry	Blended on 03/25/2019	
Sodium bicarbonate -- Neutralizer			
Passivation Spray – UltraPass	Astro Pak		
KimTech wipes	KIMTECH W4 PURE* Brand wipes	33330 – C07G218LTA 0:742	

WASTE DISPOSAL PLAN

WASTE DESCRIPTION	DISPOSAL LOCATION	COMMENTS
Hand wiping of residual solids	Separate waste bag	
Hand wiping of residual liquids / rinse water	Neutralized and rinsed to waste collection – very minor amounts	

NOTES:	
ASTRO PAK REPRESENTATIVE SIGNATURE: Jordan Schaecher	DATE: 03/25/2019

Summary of BVH Procedures for cleaning of the sample panels 304 – 2'x2'

Panel No. 8 (3/25/2019)

8 A	B1
	B2
C	D

Steps: - Time (per shop clock – actual time is +1hour)

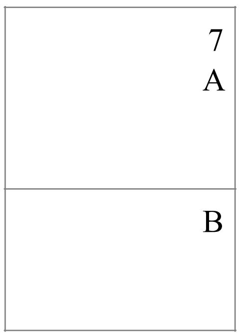
1. - Wipe surface with alcohol wipe (TX1065 Technisat)
   - 10:07 am Clean section 8A, Clean Section 8C, Clean Section 8B, Clean Section 8D – adhesive from Chloride Test not removed – used Acetone and straight edge to remove
   - 10:19 adhesive, then wipe with alcohol wipe.

2. – DI water spray rinse & brush.
   - 10:20 DI Rinse Section A
   - 10:25 DI Rinse Section C
   - 10:30 DI Rinse Section B and Section D

3 - Spray Derouging treatment solution onto the panel and brush surface. Use white Scotch Brite (wSB) pad to assist cleaning of desired panel sections
   - 10:22 Spray UltraPass solution onto Section 8A and brush
   - 10:25 Spray 401 solution onto Section 8C and brush
   - 10:30 Spray 410 solution onto Section 8B and brush
   - 10:40 Spray 401 solution onto Section 8D and apply with white SB pad while applying light to moderate pressure
   - 10:50 Re apply 401 onto 8B and 8D using (Scotch Brite) SB pad on section 8D
   - 11:00 Continue to apply test solution to each section every 10 to 15 minutes. Scrub the surface as instructed.
   - 11:22 am DI water rinse the #8 plate Sections A-D

- 11:30 Alcohol wipe the surface of Sections A-D
- 12:28 Apply 410 to ½ of Section B – label 8B2 and apply 410 solution with light to moderate pressure of Scotch Brite pad.
- 12:29 Apply UltraPass to section A and assist cleaning with light to moderate pressure on white SB pad

Panel #7:



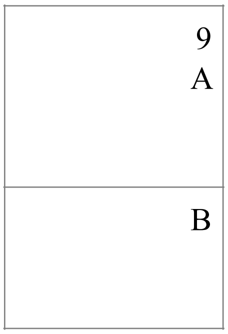
Steps: (Panel #7 (A & B) (3/25/2019)

1 12:43pm Wipe Panel #7 with alcohol wipe
2 12:44 Spray 401 solution onto Panel #7
3 12:47 Brush surface with white Scotch Brite (wSB) pad and 401 solution.
4 12:50 Spray DI water rinse and wipe clean to place tape to divide panel in half -- horizontal divider (top half – A, bottom half – B). Spray and brush sections A and B with 401 solution and white SB pad.
5 12;55 Orbital polish with white SB pad and 401 solution on bottom half of panel 7, now section 7B.
6 12:58 DI water rinse and wipe section 7B. Wipe with acetone clean wipe to dry and inspect immediate results
7 1:00 Bottom section inspected and no measureable visual change in surface from use of polisher
8 1:15 Apply 401 solution on panel #7 with white SB pad
9 1:16 Orbital polish with white SB pad and 401 solution on section 7B
10 1:30 Apply 401 solution on both panel sections with white SB pad and orbital polish section 7B ever 10 to 15 minutes
11 2:26 Rinse Panel #7 with DI water and wipe with clean wipe
12 3:57 Apply Panel #7 with UltraPass solution and brush evenly with clean paint brush
13 4:10 Brush apply UltraPass solution every 10 to 15 minutes

14 5:27 DI water rinse and brush Panel #7. Wipe clean with DI water and clean wipe.

15 5:29 pm Alcohol wipe Panel #7

Panel #9:



<u>Steps: Panel #9B (3/25/2019)</u>

1 1:17 pm Wipe Panel #9 with alcohol wipe

2 1:18 DI water wash Panel #9

3 1:23 Apply 410 solution onto Panel section 9B (bottom half) with white SB pad.

4 1:26 Orbital polish section 9B with white SB pad and 410 solution

5 1:38 Apply 410 solution to 9B surface and orbital polish surface every 10 to 15 minutes

6 2:23 Rinse Panel #9B with DI water and wipe with clean wipe

7 3:57 Apply Panel #9B with UltraPass solution and brush evenly with clean paint brush

8 4:12 Apply UltraPass solution every 10 to 15 minutes with brush

9 5:27 DI water rinse and brush section. Wipe clean with DI water and clean wipe.

10 5:30 pm Alcohol wipe Panel 9B

Panel #9A:

<u>Steps: Panel 9A (3/27/2019)</u>

1 11:50am Mix NeutraRouge process solution chemistry

2 12:00pm Wipe Panel #9 section A with alcohol clean wipe.

3	12:02pm	Rinse and wipe with DI water
4	12:30	Rinse and wipe with DI water
5	12:32	Apply NeutraRouge solution with brush, followed by white SB pad on section 9A
6	12:36	Brush apply NeutraRouge and use Orbital polisher with white Scotch Brite (WSB)
7	12:48	Brush apply NeutraRouge and use orbital polisher with WSB pad. Continue to apply and brush every 10 to 15 minutes
8	1:32	Rinse and wipe surface of section 9A with DI water
9	1:34	Wipe Panel 9 surface with IPA wipe
10	1:50	IPA wipe section 9A and rinse with DI water
11	1:52	Brush apply UltraPass passivation gel
12	2:02	Brush apply UltraPass gel and continue process each 10 to 15 minutes
13	2:52	Complete passivation process; Wipe and DI water rinse
14	3:00 pm	IPA wipe Panel #9 with alcohol clean wipe.

Panel 7, Panel 9A and Panel 9B have been recorded in a PPD (Process Procedure Document) report to document the exact procedure and timing of the process as separate reports included in this documentation package. Panel 8 was divided into a number of sections in order to establish and determine the better test/process methods to be used on full panels and therefore a specified PPD procedure was not created for the variety of processes tried on this panel. Panels #7, #9A and #9B were submitted for surface analyses, while Panel #8 was not tested.

Thanks,

DARYL ROLL
Technical Consultant
Astro Pak Corporation
03/28/2019

ASTRO PAK CORPORATION

PROCESS PROCEDURE DOCUMENT #:
AP04-300-P138 – BVH Gateway Arch

DOCUMENT TITLE:
PHARM PROCESS FOR CLEANING (IPA), DEROUGING (NeutraRouge), AND PASSIVATION (UltraPass) OF STAINLESS STEEL

OWNER / CLIENT: __**BVH Architecture**________________

LOCATION: __**A. Zahner Co., Kansas City**______________

PROJECT: __**Gateway Arch 304 Panel Testing**__________

SYSTEM: ___**Panel #9A**______________________________

TRACKING NUMBER: ___**BVH Project #18056**__________

Astro Pak Document No.	AP04	300	P	138	BVH
	Application code	Function code	Document type	Sequence No	Rev No
Prepared by	Checked by	Reviewed by	QA Review by	Approved by	Issued/Revised
D. Roll	T. Tate	T. Sowell	D. Roll	D. Roll	03-25-2019

REVISION HISTORY

This page is a record of all revisions to the Process Procedure Document referenced above.

Record field changes or revisions made to this document to meet changed or added requirements of the contract. Approvals shall be obtained from the Astro Pak Project Leader (PL) and Owner / Client Representative, both of whom shall sign all changes.

All changes shall be referenced on this page and changed in the document.06

REV	DATE	REVISED BY	APPROVED BY	REVISION REASON
0	02-14-08	Daryl Roll	Daryl Roll	Revision of AP-04-P-057 Gel Pass (09-02-05)
1	06-07-13	Hyder Razvi	Daryl Roll	Modified Process chemistry and sequence to meet Spec 1108-09810 Rev C.
2	12-20-16	Hyder Razvi	Brent Ekstrand	Updated to current standard and format.
BVH	03-25-2019	Daryl Roll	Daryl Roll	Specific Procedure for BVH project

SIGNATURE LOG

COMPANY	PRINT NAME	SIGNATURE	INITIALS	DATE
Astro Pak	Jordan Schaecher		JS	12-25-2019
Astro Pak	Tim Velazquez		TV	12-27-2019
Astro Pak	Daryl Roll		DLR	12-27-2019

CONTENTS

1. PROCEDURE REVIEW AND APPROVAL OF SCOPE OF WORK

1.1. The undersigned have reviewed and hereby approve the following process procedure:

COMPANY / DEPARTMENT	REPRESENTATIVE NAME	SIGNATURE / DATE
Cleaning / Passivation Contractor: **ASTRO PAK CORPORATION**	Jordan Schaecher	JS -- 03/25/2019
Owner / Client:		
Other Representative:		

Note: These approvals to be obtained prior to commencing these procedures.

2. NON-DISCLOSURE AGREEMENT

2.1. This document is comprised of **trade secret** information that shall not be disclosed outside of the companies to which it is submitted, and shall not be duplicated, incorporated as a part of another document, or otherwise utilized, in whole or in part, for any purpose other than evaluation by the intended parties.

3. APPLICABILITY

3.1. This procedure is applicable to exterior surfaces constructed of type 304 stainless steel.

4. SCOPE OF PROCEDURE

4.1. This document describes the procedures that Astro Pak utilized to clean, derouge and passivate external stainless steel surfaces of the subject panel; in order to ensure that the surfaces are suitable for BVH Architecture. It is also intended to demonstrate that Astro Pak understands the scope of work and to provide sequential guidance to Astro Pak and Owner / Client's project personnel.

4.2. The list of items that will be processed using this procedure is shown in Attachment "A", List of Items Processed.

5. GENERAL

5.1. This procedure uses a multi-stage process designed to remove organic material, debris, free iron, derouge and passivate weld areas and stainless steel surfaces. The process utilizes degreasing agents, sodium hydrosulfite and citric acid, multiple chelants and surface-active agents for the removal of organic material, metal oxides and other corrosion-promoting impurities. The process is designed for non-circulated components or systems.

5.2. The Ultra Pass passivation process is specifically designed to enhance corrosion resistance within the system by increasing the chromium-to-iron ratio at the weld or contact surface and meets the requirements of ASTM A-380 and ASTM A-967.

5.3. Astro Pak proposes to provide the personnel, equipment, chemicals, technical expertise, process documentation and certification necessary to accomplish the work in accordance with the procedures and conditions given within this document.

5.4. The following activities will be executed per this procedure:

- Pre-process preparation
- Process set-up
- Cleaning process
- Derouging process
- Passivation process
- Final rinse and testing
- Inspection and site clean-up

6. REFERENCES

6.1. The content in this procedure is in accordance with accepted ASTM standards as practiced throughout industry.

7. PROCESS CHEMICALS, WATER AND EQUIPMENT SET

7.1. Process Chemicals

7.1.1. Attachment “C”, Chemical Components and Waste Disposal Plan gives details of the chemicals used in this procedure for organic cleaning, derouging and passivation.

7.2. Process Water

7.2.1. Water used for this process shall be deionized (DI). DI water is defined for the purposes of this document as water demonstrating a conductivity of less than 5.0 microSiemens/cm (µS /cm). Water with a higher conductivity value shall be noted as a variance.

7.3. Equipment Set

7.3.1. Astro Pak shall provide as needed, chemical applicators, mixing containers, reagents, safety gear and small tools.

8. PRE-PROCESS PREPARATION

8.1. Astro Pak PL shall meet with the Owner / Client representative to discuss and implement the issues listed in section 9.1.1 through 9.1.7.

8.1.1. Provide Owner / Client representative with a list of Astro Pak personnel on project, obtain access to plant area and arrange for required site orientation.

8.1.2. Confirm schedule, sequence and priority of all panels to be cleaned, derouged and passivated by Astro Pak and complete project activities on time.

8.1.3. Hold a safety meeting to discuss work plan, site safety and PPE issues with all participating personnel.

8.1.4. Perform a walk-down of the system with Owner / Client representative to identify, resolve any interferences, restrictions and other issues that will impact the work plan.

8.1.5. Resolve any issues such as pH, volume of waste solutions and rinsate; sampling, testing of waste process liquid prior to transfer to process drains, waste collection and storage.

DESCRIPTION	SIGN / DATE
Confirm completion of Sections 8.1.1 to 8.1.5.	JS -- 03/25/2019

8.2. Astro Pak PL shall continue with the pre-process preparation and documentation:

8.2.1. List the description, location and equipment / component ID number of items included in this system in Attachment "A".

8.2.2. Confirm that the subject area / system have been isolated in order to perform this process procedure in a safe manner.

8.2.3. Obtain approval from Owner / Client representative to proceed with procedure execution and set-up for cleaning, derouging and passivation as approved during the walk-down of the system.

DESCRIPTION	SIGN / DATE
Confirm completion of Sections 8.2.1 to 8.2.3.	JS -- 03/25/2019

9. CLEANING PROCESS FOR EXTERNAL SURFACES

The objective of the alkaline cleaning process is to remove organic deposits and loose particles from subject surfaces and welds.

9.1. Apply a uniform layer of Isopropyl alcohol cleaner on clean wipe to the subject Panel #9A area(s) at a minimum surface temperature of 15 °C (or 60 °F); keep the subject area(s) wet and wipe to remove film or other debris.

9.2. Visually inspect subject area(s) to confirm acceptable cleanliness level; repeat step 9.1 if necessary.

DESCRIPTION	SIGN / DATE
Confirm completion of Sections 9.1 to 9.2	TV -- 03/27/2019

10. DEROUGING PROCESS FOR EXTERNAL SURFACES

The objective of the derouging process is to remove free iron, rouge and metal oxide deposits from subject surfaces and welds.

10.1. Brush apply a uniform layer of the NeutraRouge solution to the surface area(s) of Panel #9A at a minimum surface temperature of 15 °C; keep the subject area(s) wet; allow the fluid to work for duration of 30 - 120 minutes, until the surface is visually free of rouge and weld stains.

10.2. Apply NeutraRouge to white Scotch Brite (WSB) pad and scrub surface lightly. Panel #9A will be treated on the top half with NeutraRouge and scrubbed with the WSB pad aided by an orbital sander/polisher. Treat surface as recorded on Attachment "B".

10.3. After completion of derouging process, spray the subject area(s) with DI water to rinse, then wipe with IPA clean wipe and remove residual NeutraRouge and other debris.

10.4. **Rinse surface as necessary prior to discharge to an approved drain**, effluent collection or disposal location per waste disposal plan. Document process completion in Attachment "B".

DESCRIPTION	SIGN / DATE
Confirm completion of Sections 10.1 to 10.4	TV -- 03/27/2019

11. PASSIVATION PROCESS FOR EXTERNAL SURFACES

The objective of the passivation process is specifically designed to enhance corrosion resistance within the system by increasing the chromium-to-iron ratio at the contact surfaces.

11.1. Apply a uniform layer of UltraPass gel passivation solution on all subject external surfaces of panel #9A; keep the subject area(s) wet and allow the passivation solution to work for duration of 30 to 120 minutes.

11.2. Spray the panel area(s) with DI water to rinse and wipe with clean wipe to remove the passivation solution residue and other debris.

11.3. **Neutralize** rinsate **as necessary prior to discharge** to an approved drain, effluent collection or disposal location. Document process completion in Attachment "B".

11.4. Visually inspect subject area(s) to confirm removal of discoloration and cleanliness level.

DESCRIPTION	SIGN / DATE
Confirm completion of Sections 11.1 to 11.4	TV -- 03/27/2019

12. FINAL RINSE AND TESTING FOR INTERNAL SURFACES

12.1. Wipe subject panel #9A area(s) with IPA clean wipe to insure cleanliness and allow to air dry.

12.2. Visually inspect subject area(s) to confirm removal of discoloration and cleanliness level.

12.3. Clean surface areas of other support equipment to remove residual chemicals and insure cleanliness of work area.

13. INSPECTION

13.1. Inspect subject panel visually for cleanliness along with Owner / Client Representative and confirm acceptance. See step 14.4 for clarification.

14. PROCESS COMPLETION

14.1. Review this procedure to ensure completeness.

14.2. Remove Astro Pak furnished equipment from subject system / area, and ensure all chemicals have been removed and empty bags/containers disposed of properly.

14.3. Return Client's system to pre-service status and Client's environment/ site to pre-Astro Pak state or better.

14.4. Walk site with Client representative showing all work complete and condition of process area.

DESCRIPTION	SIGN / DATE
Confirm completion of work listed in Section 14.1 to 14.4.	DLR -- 03/27/2019

15. SYSTEM ACCEPTANCE AND CERTIFICATION

15.1. The undersigned has reviewed and accept the completion of the process procedures for the subject system as documented above. **<u>This confirms the Certification of Cleaning, Derouging and Passivation for the above listed panel.</u>**

COMPANY / DEPARTMENT	REPRESENTATIVE NAME	SIGNATURE / DATE
Cleaning / Passivation Contractor: **ASTRO PAK CORPORATION**	Daryl L. Roll	DLR -- 03/27/2019
Owner / Client:		

Note: To be signed on completion of all procedures listed in this document.

16. DOCUMENTATION

16.1. Astro Pak representative shall review documentation and field records with Owner / Client representative.

16.2. Astro Pak representative shall submit copy of completed and signed PPD (Process Procedure Document) to Owner / Client representative on completion of work and document review by Astro Pak.

17. ATTACHMENT LIST

A. List of items processed

B. Process Documentation

C. Chemical Components and Waste Disposal Plan

ASTRO PAK®

Process Procedure Document #: AP04-300-P138 Rev BVH Cleaning(IPA), Derouging(AP 410), Passivation(UltraPass) of Stainless Steel

Issued / Revised: 03/25/2019 Astro Pak Job #: Panel #: **9**

Owner / Client: **BVH Architecture** Project: **Gateway Arch 304 Panel Testing**

Location: **A. Zahner Co., Kansas City** Section: **Panel #9A**

ATTACHMENT "A" - LIST OF ITEMS PROCESSED*		
		Page ___ of ___
EQUIPMENT / COMPONENT ID	**DESCRIPTION**	**LOCATION**
Panel #9/ Section A (top section)	Sample test panel #9A to be cleaned, derouged and passivated with IPA clean wipe; NeutraRouge derouging and UltraPass passivation gel	Completed at A. Zahner Co.'s shop in Kansas City, KS

*Add copies of blank Attachment if additional pages are necessary.

NOTES:	
ASTRO PAK REPRESENTATIVE SIGNATURE: Tim Velazquez	DATE:03/27/2019

ATTACHMENT "B" - PROCESS DOCUMENTATION*									
EXTERNAL SURFACE (Circle one) Panel #9A 03/27/2019								**Page ___ of ___**	
EQUIPMENT / COMPONENT ID	**CLEANING TIME:**		**DEROUGING TIME:**		**PASSIVATION TIME:**		**RINSE TIME:**		
	Start	**End**	**Start**	**End**	**Start**	**End**	**Start**	**End**	
Mix NeutraRouge chemistry	11:50 am	11:55							
Wipe Panel 9A with IPA clean wipe	12:00 pm	12:01 pm							
Spray and wipe Section 9A with DI water	12:02	12:02							
Mix final active ingredient into NeutraRouge solution			12:20 pm						
Spray rinse and wipe Section 9A			12:30						
Brush apply NeutraRouge to 9A surface with White SB pad			12:32	12:33					
Apply NeutraRouge to Section 9A (top) with orbital polisher/sander and WSB pad			12:36	12:38					
Apply NeutraRouge solution with brush to surface and orbital polisher every 10 – 15 minutes			12:38	1:32					
Wipe off panel #9A with DI water and IPA wipes			1:32	1:34					
Inspect Panel #9 Section A then wipe with IPA and DI rinse			1:34	1:50 pm					
Apply UltraPass gel with brush every 12 – 15 min					1:52 pm	2:52 pm			
DI water rinse and wipe Panel #7 with DI water and IPA clean wipe							2:52 pm	2:58	

Final clean with IPA clean wipe							3:00	3:02 pm	

NOTES:	
ASTRO PAK REPRESENTATIVE SIGNATURE: Daryl L. Roll	DATE: 03/27/2019

ATTACHMENT "C" - CHEMICAL COMPONENTS AND WASTE DISPOSAL PLAN

CHEMICAL COMPONENTS

PROCESS CHEMICALS	MANUFACTURER	LOT NUMBER	
Cleaning spray/wipe – IPA Cleaner on clean wipe	Texwipe - TechniSat	TX 1065	
Derouging Solution – NeutraRouge on white Scotch Brite pad	Astro Pak chemistry	Blended on 03/27/2019	
Sodium bicarbonate -- Neutralizer			
Passivation gel– UltraPass	Astro Pak		
KimTech wipes	KIMTECH W4 PURE* Brand wipes	33330 – C07G218LTA 0:742	

WASTE DISPOSAL PLAN

WASTE DESCRIPTION	DISPOSAL LOCATION	COMMENTS
Hand wiping of residual solids	Separate waste bag	
Hand wiping of residual liquids / rinse water	Neutralized and rinsed to waste collection – very minor amounts	

NOTES:	
ASTRO PAK REPRESENTATIVE SIGNATURE: Daryl L. Roll	DATE: 03/27/2019

ASTRO PAK CORPORATION

PROCESS PROCEDURE DOCUMENT #:
AP04-300-P138 – BVH Gateway Arch

DOCUMENT TITLE:
PHARM PROCESS FOR CLEANING (IPA), DEROUGING (AP-410), AND PASSIVATION (UltraPass) OF STAINLESS STEEL

OWNER / CLIENT: __**BVH Architecture**_______________

LOCATION: __**A. Zahner Co., Kansas City**_____________

PROJECT: __**Gateway Arch 304 Panel Testing**_________

SYSTEM: ___**Panel #9B**_____________________________

TRACKING NUMBER: ___**BVH Project #18056**_________

Astro Pak Document No.	AP04	300	P	138	BVH
	Application code	Function code	Document type	Sequence No	Rev No
Prepared by	Checked by	Reviewed by	QA Review by	Approved by	Issued/Revised
D. Roll	T. Tate	T. Sowell	D. Roll	D. Roll	03-25-2019

REVISION HISTORY

This page is a record of all revisions to the Process Procedure Document referenced above.

Record field changes or revisions made to this document to meet changed or added requirements of the contract. Approvals shall be obtained from the Astro Pak Project Leader (PL) and Owner / Client Representative, both of whom shall sign all changes.

All changes shall be referenced on this page and changed in the document.06

REV	DATE	REVISED BY	APPROVED BY	REVISION REASON
0	02-14-08	Daryl Roll	Daryl Roll	Revision of AP-04-P-057 Gel Pass (09-02-05)
1	06-07-13	Hyder Razvi	Daryl Roll	Modified Process chemistry and sequence to meet Spec 1108-09810 Rev C.
2	12-20-16	Hyder Razvi	Brent Ekstrand	Updated to current standard and format.
BVH	03-25-2019	Daryl Roll	Daryl Roll	Specific Procedure for BVH project

SIGNATURE LOG

COMPANY	PRINT NAME	SIGNATURE	INITIALS	DATE
Astro Pak	Jordan Schaecher		JS	12-25-2019
Astro Pak	Tim Velazquez		TV	12-27-2019
Astro Pak	Daryl Roll		DLR	12-27-2019

CONTENTS

1. PROCEDURE REVIEW AND APPROVAL OF SCOPE OF WORK

1.1. The undersigned have reviewed and hereby approve the following process procedure:

COMPANY / DEPARTMENT	REPRESENTATIVE NAME	SIGNATURE / DATE
Cleaning / Passivation Contractor: **ASTRO PAK CORPORATION**	Jordan Schaecher	JS -- 03/25/2019
Owner / Client:		
Other Representative:		

Note: These approvals to be obtained prior to commencing these procedures.

2. NON-DISCLOSURE AGREEMENT

2.1. This document is comprised of **trade secret** information that shall not be disclosed outside of the companies to which it is submitted, and shall not be duplicated, incorporated as a part of another document, or otherwise utilized, in whole or in part, for any purpose other than evaluation by the intended parties.

3. APPLICABILITY

3.1. This procedure is applicable to exterior surfaces constructed of type 304 stainless steel.

4. SCOPE OF PROCEDURE

4.1. This document describes the procedures that Astro Pak utilized to clean, derouge and passivate external stainless steel surfaces of the subject panel; in order to ensure that the surfaces are suitable for BVH Architecture. It is also intended to demonstrate that Astro Pak understands the scope of work and to provide sequential guidance to Astro Pak and Owner / Client's project personnel.

4.2. The list of items that will be processed using this procedure is shown in Attachment "A", List of Items Processed.

5. GENERAL

5.1. This procedure uses a multi-stage process designed to remove organic material, debris, free iron, derouge and passivate weld areas and stainless steel surfaces. The process utilizes degreasing agents, Phosphoric and Citric acids, multiple chelants and surface-active agents for the removal of organic material, metal oxides and other corrosion-promoting impurities. The process is designed for non-circulated components or systems.

5.2. The Ultra Pass passivation process is specifically designed to enhance corrosion resistance within the system by increasing the chromium-to-iron ratio at the weld or contact surface and meets the requirements of ASTM A-380 and ASTM A-967.

5.3. Astro Pak proposes to provide the personnel, equipment, chemicals, technical expertise, process documentation and certification necessary to accomplish the work in accordance with the procedures and conditions given within this document.

5.4. The following activities will be executed per this procedure:

- Pre-process preparation
- Process set-up
- Cleaning process
- Derouging process
- Passivation process
- Final rinse and testing
- Inspection and site clean-up

6. REFERENCES

6.1. The content in this procedure is in accordance with accepted ASTM standards as practiced throughout industry.

7. PROCESS CHEMICALS, WATER AND EQUIPMENT SET

7.1. Process Chemicals

7.1.1. Attachment “C”, Chemical Components and Waste Disposal Plan gives details of the chemicals used in this procedure for organic cleaning, derouging and passivation.

7.2. Process Water

7.2.1. Water used for this process shall be deionized (DI). DI water is defined for the purposes of this document as water demonstrating a conductivity of less than 5.0 microSiemens/cm (µS /cm). Water with a higher conductivity value shall be noted as a variance.

7.3. Equipment Set

7.3.1. Astro Pak shall provide as needed, chemical applicators, mixing containers, reagents, safety gear and small tools.

8. PRE-PROCESS PREPARATION

8.1. Astro Pak PL shall meet with the Owner / Client representative to discuss and implement the issues listed in section 9.1.1 through 9.1.7.

8.1.1. Provide Owner / Client representative with a list of Astro Pak personnel on project, obtain access to plant area and arrange for required site orientation.

8.1.2. Confirm schedule, sequence and priority of all panels to be cleaned, derouged and passivated by Astro Pak and complete project activities on time.

8.1.3. Hold a safety meeting to discuss work plan, site safety and PPE issues with all participating personnel.

8.1.4. Perform a walk-down of the system with Owner / Client representative to identify, resolve any interferences, restrictions and other issues that will impact the work plan.

8.1.5. Resolve any issues such as pH, volume of waste solutions and rinsate; sampling, testing of waste process liquid prior to transfer to process drains, waste collection and storage.

DESCRIPTION	SIGN / DATE
Confirm completion of Sections 8.1.1 to 8.1.5.	JS -- 03/25/2019

8.2. Astro Pak PL shall continue with the pre-process preparation and documentation:

8.2.1. List the description, location and equipment / component ID number of items included in this system in Attachment “A”.

8.2.2. Confirm that the subject area / system have been isolated in order to perform this process procedure in a safe manner.

8.2.3. Obtain approval from Owner / Client representative to proceed with procedure execution and set-up for cleaning, derouging and passivation as approved during the walk-down of the system.

DESCRIPTION	SIGN / DATE
Confirm completion of Sections 8.2.1 to 8.2.3.	JS -- 03/25/2019

9. CLEANING PROCESS FOR EXTERNAL SURFACES

The objective of the alkaline cleaning process is to remove organic deposits and loose particles from subject surfaces and welds.

9.1. Apply a uniform layer of Isopropyl alcohol cleaner on clean wipe to the subject Panel #9B area(s) at a minimum surface temperature of 15 °C (or 60 °F); keep the subject area(s) wet and wipe to remove film or other debris.

9.2. Visually inspect subject area(s) to confirm acceptable cleanliness level; repeat step 9.1 if necessary.

DESCRIPTION	SIGN / DATE
Confirm completion of Sections 9.1 to 9.2	TV -- 03/25/2019

10. DEROUGING PROCESS FOR EXTERNAL SURFACES

The objective of the derouging process is to remove free iron, rouge and metal oxide deposits from subject surfaces and welds.

10.1. Apply a uniform layer of the AP 410 gel to the surface area(s) of Panel #9B at a minimum surface temperature of 15 °C; keep the subject area(s) wet; allow the paste to work for duration of 30 - 120 minutes, until the surface is visually free of rouge and weld stains.

10.2. Apply AP 401 to white Scotch Brite (WSB) pad and scrub surface lightly. Panel #9B will be treated on the bottom half with AP 410 and scrubbed with the WSB pad aided by an orbital sander/polisher. Treat surface as recorded on Attachment “B”.

10.3. After completion of derouging process, spray the subject area(s) with DI water to rinse, then wipe with IPA clean wipe and remove residual AP 410 gel and other debris.

10.4. **Neutralize rinsate effluent as necessary prior to discharge to an approved drain**, effluent collection or disposal location per waste disposal plan. Document process completion in Attachment “B”.

DESCRIPTION	SIGN / DATE
Confirm completion of Sections 10.1 to 10.4	TV -- 03/25/2019

11. PASSIVATION PROCESS FOR EXTERNAL SURFACES

The objective of the passivation process is specifically designed to enhance corrosion resistance within the system by increasing the chromium-to-iron ratio at the contact surfaces.

11.1. Apply a uniform layer of UltraPass gel passivation solution on all subject external surfaces of panel #9B; keep the subject area(s) wet and allow the passivation solution to work for duration of 30 to 120 minutes.

11.2. Spray the panel area(s) with DI water to rinse and wipe with clean wipe to remove the passivation solution residue and other debris.

11.3. **Neutralize** rinsate **as necessary prior to discharge** to an approved drain, effluent collection or disposal location. Document process completion in Attachment "B".

11.4. Visually inspect subject area(s) to confirm removal of discoloration and cleanliness level.

DESCRIPTION	SIGN / DATE
Confirm completion of Sections 11.1 to 11.4	TV -- 03/25/2019

12. FINAL RINSE AND TESTING FOR INTERNAL SURFACES

12.1. Wipe subject panel #9B area(s) with IPA clean wipe to insure cleanliness and allow to air dry.

12.2. Visually inspect subject area(s) to confirm removal of discoloration and cleanliness level.

12.3. Clean surface areas of other support equipment to remove residual chemicals and insure cleanliness of work area.

13. INSPECTION

13.1. Inspect subject panel visually for cleanliness along with Owner / Client Representative and confirm acceptance. See step 14.4 for clarification.

14. PROCESS COMPLETION

14.1. Review this procedure to ensure completeness.

14.2. Remove Astro Pak furnished equipment from subject system / area, and ensure all chemicals have been removed and empty bags/containers disposed of properly.

14.3. Return Client's system to pre-service status and Client's environment/ site to pre-Astro Pak state or better.

14.4. Walk site with Client representative showing all work complete and condition of process area.

DESCRIPTION	SIGN / DATE
Confirm completion of work listed in Section 14.1 to 14.4.	JS -- 03/25/2019

15. SYSTEM ACCEPTANCE AND CERTIFICATION

15.1. The undersigned has reviewed and accept the completion of the process procedures for the subject system as documented above. **This confirms the Certification of Cleaning, Derouging and Passivation for the above listed panel.**

COMPANY / DEPARTMENT	REPRESENTATIVE NAME	SIGNATURE / DATE
Cleaning / Passivation Contractor: **ASTRO PAK CORPORATION**	Jordan Schaecher	JS -- 03/25/2019
Owner / Client:		

Note: To be signed on completion of all procedures listed in this document.

16. DOCUMENTATION

16.1. Astro Pak representative shall review documentation and field records with Owner / Client representative.

16.2. Astro Pak representative shall submit copy of completed and signed PPD (Process Procedure Document) to Owner / Client representative on completion of work and document review by Astro Pak.

17. ATTACHMENT LIST

A. List of items processed

B. Process Documentation

C. Chemical Components and Waste Disposal Plan

Owner / Client: **BVH Architecture** Project: **Gateway Arch 304 Panel Testing**

Location: **A. Zahner Co., Kansas City** Section: **Panel #9B**

ATTACHMENT "A" - LIST OF ITEMS PROCESSED*		
		Page ___ of ___
EQUIPMENT / COMPONENT ID	**DESCRIPTION**	**LOCATION**
Panel #9/ Section B (bottom section)	Sample test panel #9 to be cleaned, derouged and passivated with IPA clean wipe; AP 410 derouging and UltraPass passivation gels	Completed at A. Zahner Co.'s shop in Kansas City, KS

*Add copies of blank Attachment if additional pages are necessary.

NOTES:	
ASTRO PAK REPRESENTATIVE SIGNATURE: JS	DATE:03/25/2019

ASTRO PAK

Process Procedure Document #: AP04-300-P138 Rev BVH Cleaning(IPA), Derouging(AP 410), Passivation(UltraPass) of Stainless Steel

Issued / Revised: 03/25/2019 Astro Pak Job #: Panel #: **9**

Owner / Client: **BVH Architecture** Project: **Gateway Arch 304 Panel Testing**

Location: **A. Zahner Co., Kansas City** Section: **Panel #9B**

ATTACHMENT "B" - PROCESS DOCUMENTATION*										
EXTERNAL SURFACE (Circle one) ___Panel #9B										**Page ___ of ___**
EQUIPMENT / COMPONENT ID	**CLEANING TIME:**		**DEROUGING TIME:**		**PASSIVATION TIME:**		**RINSE TIME:**			
	Start	**End**	**Start**	**End**	**Start**	**End**	**Start**	**End**		
Wipe Panel 9B with IPA clean wipe	2:17 pm	2:18 pm								
Apply AP 410 solution			2:23 pm							
Orbital brush surface with white Scotch Brite (WSB) pad			2:23							
Apply AP 410 to Section 9B (bottom) with orbital polisher/ sander and WSB pad			2:30	3:23						
Wiped off panel #9B with DI water and IPA wipes			3:25	3:26						
Inspected Panel #9 Section B			3:26	3:30						
DI Rinse panel #7 and Wipe with IPA clean wipe			3:26	3:30 pm						
Apply UltraPass gel with brush every 12 – 15 min					4:57 pm	6:28 pm				
DI water rinse and wipe Panel #7 with DI water and IPA clean wipe							6:28 pm	6:29		
Final clean with IPA clean wipe							6:29	6:30 pm		

NOTES:

ASTRO PAK Process Procedure Document #: AP04-300-P138 Rev BVH Cleaning(IPA), Derouging(AP 410), Passivation(UltraPass) of Stainless Steel

Issued / Revised: 03/25/2019 Astro Pak Job #: Panel #: **9**

Owner / Client: **BVH Architecture** Project: **Gateway Arch 304 Panel Testing**

Location: **A. Zahner Co., Kansas City** Section: **Panel #9B**

ASTRO PAK REPRESENTATIVE SIGNATURE: Jordan Schaecher	DATE: 03/25/2019

ATTACHMENT "C" - CHEMICAL COMPONENTS AND WASTE DISPOSAL PLAN

CHEMICAL COMPONENTS

PROCESS CHEMICALS	MANUFACTURER	LOT NUMBER	
Cleaning spray/wipe – IPA Cleaner on clean wipe	Texwipe - TechniSat	TX 1065	
Derouging Solution – AP 410 on white Scotch Brite pad	Avesta and Astro Pak chemistry	Blended on 03/25/2019	
Sodium bicarbonate -- Neutralizer			
Passivation Spray – UltraPass	Astro Pak		
KimTech wipes	KIMTECH W4 PURE* Brand wipes	33330 – C07G218LTA 0:742	

WASTE DISPOSAL PLAN

WASTE DESCRIPTION	DISPOSAL LOCATION	COMMENTS
Hand wiping of residual solids	Separate waste bag	
Hand wiping of residual liquids / rinse water	Neutralized and rinsed to waste collection – very minor amounts	

NOTES:

ASTRO PAK REPRESENTATIVE SIGNATURE: Jordan Schaecher	DATE: 03/25/2019

Appendix F - Adapt Laser

ADAPT LASER SYSTEMS STATE-OF-THE-ART LASER CLEANING SOLUTIONS

Application Testing Report

The Gateway Arch
St. Louis MO

Adapt Laser Systems
1218 Guinotte Avenue
Kansas City, MO 64120
PH: 816.531.7402

Laser Testing - Application Summary

TREATMENT DATE:	3/27/2019
APPLICATION GOAL:	Architectural Metal Cleaning
SUBSTRATE MATERIAL:	Stainless Steel
TARGET MATERIAL:	Oxides/ Contaminants
QUALITY REQUIREMENTS:	Post Cleaning Appearance & Weathering Results
Laser Systems Tested & Configurations:	CL300 w/2D Scanning Optic f = 160mm aperture lens CL50 w/2D Scanning Optic f = 160mm aperture lens
NOTES:	Samples Produced to Represent Architectural Panels Post-Cleaning for Further Testing & Analysis Test Panels not Exact Representation of Actual

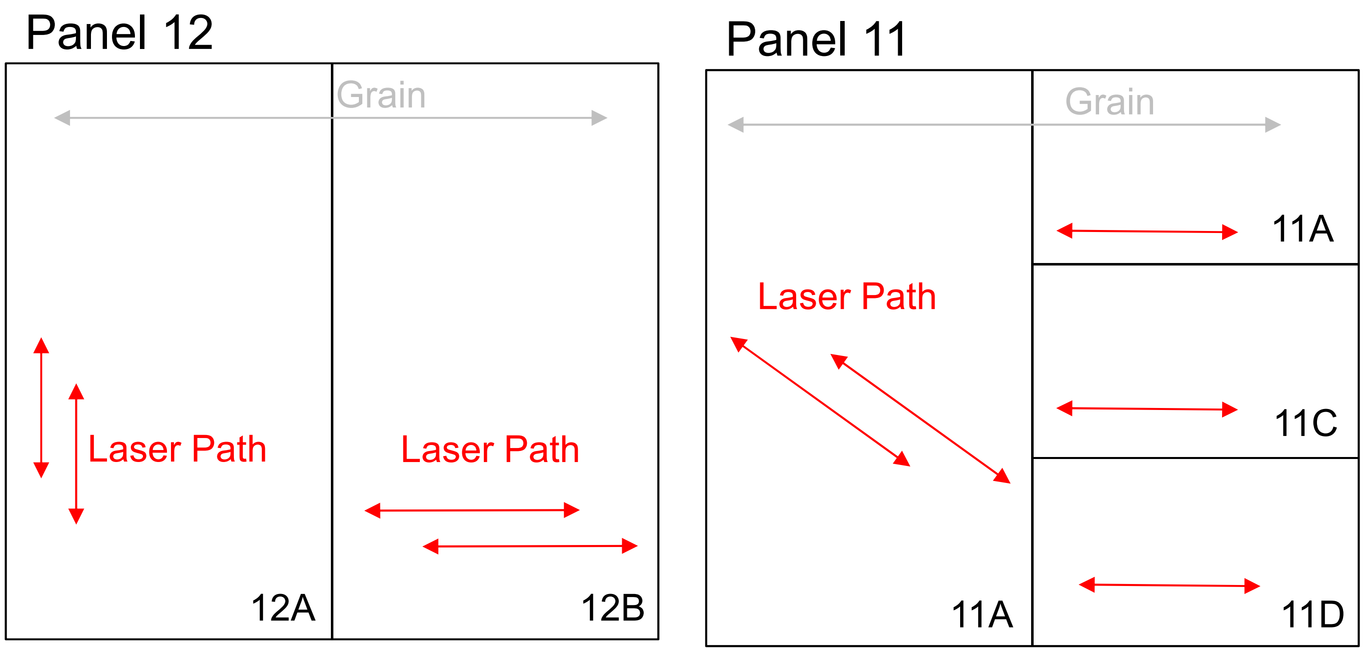
Before Treatment

ADAPT LASER SYSTEMS

Laser Testing Parameters

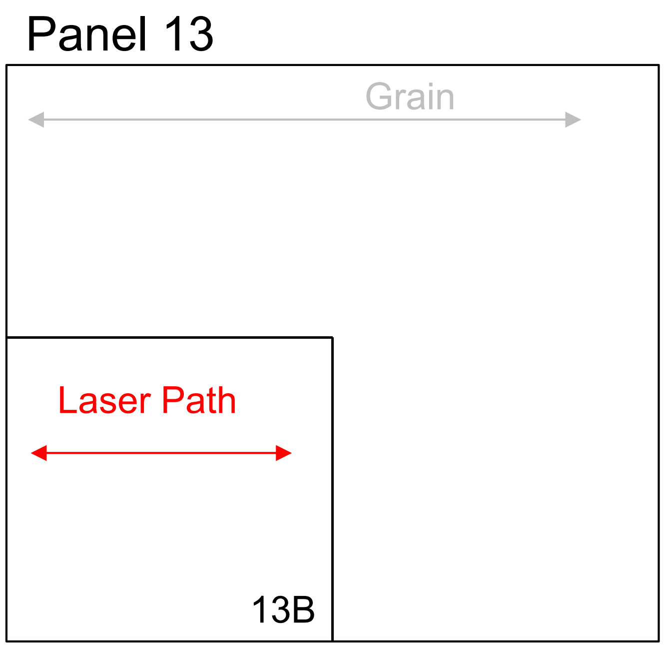
Sample # Location	Orientation	Power	Pulse Frequency	Mark Speed (mm/s)	Scan Width	Beam Spot Size	Spot Overlap %	Sweep Speed	Number of Passes	Angle	Pulse Intensity (MW/cm2)	Fluence (J/cm2)	Peak Power (kW)	Rate area/min
12 A	↕	50 W	50 kHz	8120	100 mm	232	30	13.19	1	~90	12	1.6	6.6	13.19
12B	↔	50 W	50 kHz	8120	100 mm	232	30	13.19	1	~90	12	1.6	6.6	13.19
11A	⤢	50 W	50 kHz	8120	100 mm	232	30	13.19	1	~90	12	1.6	6.6	13.19
11B	↔	50 W	50 kHz	5800	100 mm	232	50	6.73	1	~90	12	1.6	6.6	6.73
11C	↔	50 W	50 kHz	3480	100 mm	232	70	2.42	1	~90	12	1.6	6.6	2.42
11D	↔	300 W	25 kHz	8563	100 mm	685	50	29.33	1	~90	24	3	88.6	29.33
13B	↔	300 W	25 kHz	8563	100 mm	685	50	29.33	1	~90	24	3	88.6	29.33

Test Panels 11 & 12 – Laser Treatment Orientation



ADAPT LASER SYSTEMS

Test Panel 13 – Laser Treatment Orientation



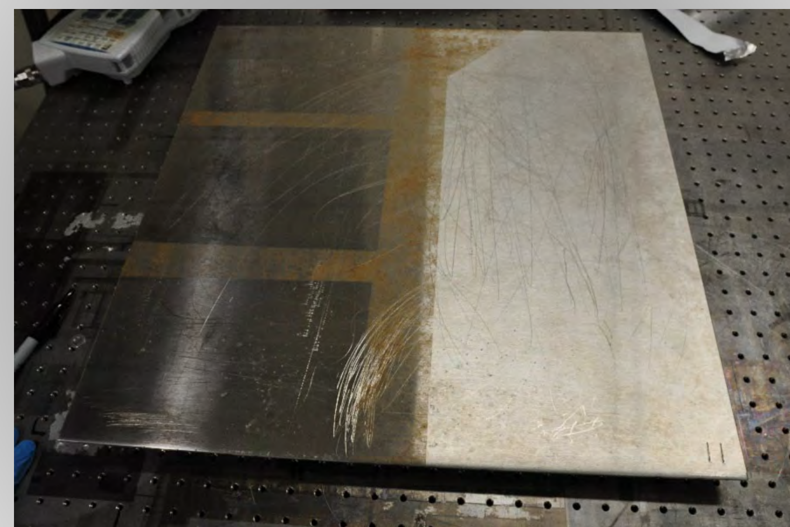
ADAPT LASER SYSTEMS

Test Results

Summary

- Surface Cleaning Successful
- Panels Are Not Identical to Target Material
  - Additional Parameter Testing Necessary
- Overlap of Beam Path Evident on Samples
  - This Condition Can be Avoided During Actual Application
  - Methods of Preventing Overlap Lines
    - EMS – Electric Margin Shielding
    - Tilted Optic
    - Minimal Programed Overlap
- Successful Parameters
  - Parameter 11B
    - CL50FFC
    - Area Rate of Removal = 6.71 cm^2/s
  - Parameter 13B
    - CL300FFC
    - Area Rate of Removal = 29.33 cm^2/s
- Further Evaluation & Test Sample Analysis Pending by Others

Processed Sample



Your Contact Person:

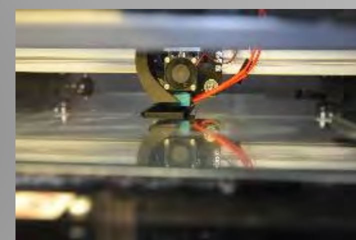
Tim Niemeier

T: 610.395.8110

E: timn@adapt-laser.com

Contact & General Information




Adapt Laser Systems

1218 Guinotte Ave
Kansas City, MO 64120
T: 816-531-7402
F: 816-531-7403
E: info@adapt-laser.com

Lab Capabilities

- Low-Mid Range Laser Systems
- High Precision Surface Analysis Tools
- 4-Axis Automated CleanCell
- Yaskawa Motoman Robot
- UR10 Robot
- Fusion3D Printer

ADAPT LASER SYSTEMS

Appendix G - Houska 2020

125 Forest Avenue, Pittsburgh, Pennsylvania 15202
412-874-9074
Catherine@HouskaConsulting.com

Gateway Arch Cleaning Trials: Metallurgical Assessment of the Stainless Steel Finish and Cleaning Trials

Final Report Issued: May 19, 2020

A – Investigation Summary, Goal and Approach

This investigation was conducted on Type 304 (UNS S30400) stainless steel plate. A. Zahner polished the plate to simulate the current finish. It was then aggressively scratched to embed carbon steel into the surface followed by exposure to deicing salts. This simulated the condition and appearance of the bottom row of plates on the exterior of the Gateway Arch by A. Zahner for the cleaning trials. The Type 304 stainless steel plate obtained was deliberately higher in sulfur and carbon to simulate the corrosion response of the original plate, which was manufactured prior to the introduction of A.O.D. (Argon Oxygen Decarborization) in the United States. Higher sulfur levels are associated with more inclusions, particularly sulfides, and higher carbon levels, particularly with welding or other heat application, increase the likelihood of sensitization.[1] Both factors influence corrosion performance. [2]

The goal of the cleaning trials was to assess the effectiveness and appropriateness of each cleaning process and determine whether a cleaning procedure changed the finish morphology relative to the original control sample surface. Significant surface morphology changes adversely affect finish matching.

---

1 As was reported in the subconsultant's report issued by Catherine Houska, TMR Consulting, "14-944 Gateway Arch, St. Louis, Missouri Metallurgical Assessment of the Stainless Steel Exterior Including: Weld Condition, Overall Performance, Site, Surface Discoloration and Deposit Evaluation" February 27, 2015, all of the welds on the lower levels of the Gateway Arch that had laboratory metallurgical assessment were sensitized and archive documentation indicated that all of the welds (shop and field) at the lower levels were welded two to three times after through penetration welding problems were found and 100% inspection mandated with some rewelding also occurring at the upper levels.

2 Sensitization is the precipitation of carbides or migration of carbon to the grain boundaries of a stainless steel adjoining the welds, causing it to be susceptible to intergranular corrosion. Rapid corrosive attack of immediately adjacent grain boundaries with little or no attack of the grains is called Intergranular Corrosion. Rapid attack at the grain boundaries can result in grains "dropping" or falling out of the metal surface resulting in the disintegration of the steel. The Houska report (1) found sensitization but no evidence of intergranular corrosion as the service environment was not severe enough for that to occur.

The primary technical reason for cleaning the base of the monument was to remove the deeply embedded iron particles from the scratches because the crevice created by the iron corrosion product could cause accelerated corrosion of the underlying stainless steel, which is only 0.25-inch thick. [3]

The deicing salts staining of the base of the monument is superficial with such shallow pitting that removal of this corrosion staining is considered aesthetic, but this study also explored appropriate means of removing it to improve the appearance. The samples did not simulate the industrial deposits, which were the primary cause of surface discoloration at the higher levels of the monument, but some of these removal methods could be considered for them.

A. Zahner, AstroPak, Karcher and Adapt conducted the cleaning trials described below between March 24 and 27, 2019 at A. Zahner Company's Kansas City, Missouri location. The metallurgical assessment described in this report included gloss (reflectivity), surface roughness and microscopic surface evaluation. Commentary on the metallurgical factors associated with appropriateness of each cleaning method has also been provided.

B – Conclusions

1. The specular gloss and surface roughness values of the Astropak samples, particularly sample #9 (410/hand buffed and neutra rouge/top), were closest to the control sample, indicating that minimal surface morphology change occurred during cleaning. Unless a decision is made to refinish, surface morphology changes should be minimized.
2. None of the high pressure water and dry ice cleaning trials conducted by Karcher effectively removed either the deicing salts staining or the embedded iron. Dry ice is commonly used to remove some deposits from stainless steel but the pressure levels required are much higher than those for other materials. While the unit brought to the site reduced the amount of staining, the pressure levels were not adequate to remove it.
3. All the Adapt samples exhibited heat related oxidation of the surface and, in one case, surface melting. Either causes a substantial reduction in the corrosion resistance of stainless steel, so this result is not acceptable. A thorough review of published research papers on the cleaning of steels and testing, including corrosion assessment, would be needed if this method were to be considered.
4. All the samples were assessed microscopically. The proposed Astropak cleaning methods were the most effective in removing both embedded carbon steel and deicing salt corrosion staining.
5. Refinishing (polishing) would also remove corrosion staining, embedded iron and scratches as was documented in a demonstration by A. Zahner.
6. Electropolishing could be used in combination with refinishing but it is not an appropriate standalone solution since it substantially increased surface reflectivity as was documented by gloss testing.

---

[3] Crevice corrosion is similar to pitting corrosion but occurs where deposits or other materials block the oxygen access needed to maintain the passive film. Corrosion can occur if salts, such as those used for deicing, and moisture (rainwater, humidity, fog or condensation) is present in a tight crevice. It is more likely with lower-alloyed stainless steels like Type 304, particularly where the crevice gap is very small such as under embedded carbon steel. See Catherine Houska, "Stainless Steel in Architecture, Building and Construction: Guidelines for Corrosion Prevention", Nickel Institute Reference Book Series No. 11 024.

7. A white toned surface deposit was observed on several samples after cleaning. The source was unknown and, since it is not a known Arch condition, its' continued presence on the surface after cleaning was not considered relevant to the study.
8. The stainless steel used for the Gateway Arch is high in sulfur. For that reason, the final step after completion of the memorial prior to turnover was chemical passivation, as was documented by a review of the archives in my prior report. Chemical passivation is critical for achieving full corrosion resistance and any future cleaning or resurfacing of the monument must be followed by chemical passivation, which if properly done in accordance with ASTM A967/A967M, will have no effect on appearance. [4]

C – Executive Summary

The top and bottom of Astropak sample #9 provided the closest match to the original finish when both surface morphology measurements were considered (gloss and surface roughness) and cleaning method effectiveness were considered. Chemical cleaning of stainless steel is common. ASTM A380/A380M and A967/A967M are the applicable standards for embedded iron, heat tint and surface contamination removal.

Neither the high pressure cleaning nor laser cleaning techniques used produced acceptable results.

Due to the high sulfur content of the Gateway Arch's stainless steel, chemical passivation in accordance with ASTM A976/A967M should be required after any cleaning or refinishing work.

D - Equipment List

The gloss meter, profilometer and microscope calibrations were checked at regular intervals.

- Camera: Sony DSC-RX10 III Cyber-shot Digital Still Camera
- Gloss meter: MeterTo 3nh Tri gloss meter features with 20, 60 and 85°angle
  - Manufactured according to ISO2813 and GB/T 9754
  - Complies with ISO 2813, GB/T 9754, ASTM D 523, ASTM D 2457
- Profilometer: VTSYIQI Surftest KR200 Portable Profilometer Large Capacity Data Memory
  - Parameter: Ra, Rz, Rq, Rx, Rt, Rp, Rv, R3z, R3y, RzJIS, Rsk, Rku, Rsm, Rmr.
  - Filter: RC, PCRC, Gauss, ISO13565
  - Compatible with ISO, DIN, ANSI, JIS standards
- Microscope: Dino-Lite USB Digital Microscope AF4915ZT, 0.3MP, 10x~230x Optical
  - MicroTouch (MT), Measurement (MS), Polarization (PZ), Interchangeable Cap (IC), Enhanced Depth of Field(ED), Automatic Magnification Reader (AMR), Flexible LED Control (FLC), 1280 x 1024 image resolution, 30 FPS (video)
  - Microscope stand: Dino-Lite MS09B Portable Microscope Stand
- Handheld LED Magnifying Glass: MANLI LED Magnifying Glass 3X + 45X

E – Plate Used for Cleaning Trials

[4] Unless the stainless steel is properly passivated, the sulfides present in high sulfur stainless steels can form initiation sites for localized corrosion attack and make the stainless steel susceptible to corrosion that might not otherwise occur. Appropriate chemical passivation of sulfur-containing stainless steel alloys, removes sulfides present at the metal surface and should be done in accordance with ASTM A967/A967 Standard Specification for Chemical Passivation Treatments for Stainless Steel Parts in order to maximize the inherent corrosion resistance of the stainless steel.

E.1 Plate Purchase Requirements and Preparation

A. Zahner Co. purchased high sulfur content Type 304 plate from New Castle Stainless Plate (NCSP) for the cleaning trials. A predecessor company of NCSP was one of the two stainless steel plate suppliers for the Gateway Arch. The arch was constructed prior to the introduction of the AOD furnace into the United States so the stainless steel was high in both carbon and sulfur. Higher sulfur levels cause inclusions (i.e. surface sulfides), which make stainless steel more susceptible to corrosion unless it is chemically passivated, which is why the final step in arch construction was chemical passivation. This made use of a higher sulfur plate preferable for the trials.

The plate was polished in preparation for the testing to simulate the appearance of the Gateway Arch's stainless steel plate base prior to its' scratching and corrosion staining damage. The current appearance of the base of the Gateway Arch was simulated. They deliberately scratched the surface with carbon steel. The accelerated weathering was accomplished by placing the plates outside during the winter on the firm's property in Kansas City with repeated applications of deicing salts. Heavy spring rainstorms had washed the salts from the surface prior to testing as was documented by Chlor-Test kit readings.

A control sample of the original finish had been retained for metallurgical assessment and comparison with the cleaning trail samples. The gloss (reflectivity), surface roughness and photomicrograph surface analysis of that sample was used in the assessment of the post-cleaning trial samples.

E.2 The Science of Metal Finish Analysis

The ability to obtain close finish matching is critical for all bare metal products, such as appliances, consumer products and architectural metals. It is not unusual for architects to require a finish supplier to place panels outdoors so they can be observed at various angles, to determine if there is close panels matching and consistency. Natural lighting conditions can vary substantially which can undermine visual analysis and the underlying cause of variations must be understood in order to correct them.

The most demanding of stainless steel finish end use application is larger multi-component appliances, such as stoves, where numerous adjoining components must exactly match under all lighting conditions even though the stainless steel, finishers and fabricators are often different. Stringent finish standards make that possible. Despite common misconceptions to the contrary, different alloys in the same family can be finished to match one another exactly if the science of finishing is well understood.

Substantial research has been done globally over many decades to determine the quantifiable characteristics of metal finish morphologies critical to appearance consistency under all viewing and lighting conditions. Aluminum, stainless steel and copper alloys have been studied and the same basic rules apply to all these metals.

The standard quantifiable evaluation parameters for bare metal finish surface texture analyses are roughness, gloss and color. In all cases, gloss (reflectivity) increases exponentially as the arithmetical mean surface roughness (Ra) value becomes smaller. When either the gloss of the specimen surface or the color lightness L value is measured, the value of the other can be estimated because on their close correlation. The arithmetical mean roughness Ra value also correlates to color. As Ra decreases, the measurable blue tones in the surface color will increase. In more complex analyses and high-end finish supplier internal product specifications, other surface roughness measurements and even 2- or 3-dimensional surface mapping are used.

E.3 Control Sample - Gloss Analysis

Figure E.3A shows the average specular gloss (reflectivity) measurements made on the control sample. The meter automatically determined readings at 20, 60 or 85° angles. Multiple measurements were taken at different locations both across and along the polish grain, since surface morphology variations across a sample can result in significant variations. The standard deviation in each direction is quite low documenting the consistency of the finish that A. Zahner applied. This indicates that, other than in the deliberately scratched areas, the test sample surfaces should be quite consistent, if the cleaning method is effective in removing surface staining and does not change the surface morphology. The values are substantially different in each direction (with and across the grain), which is typical for a rougher polished finish.

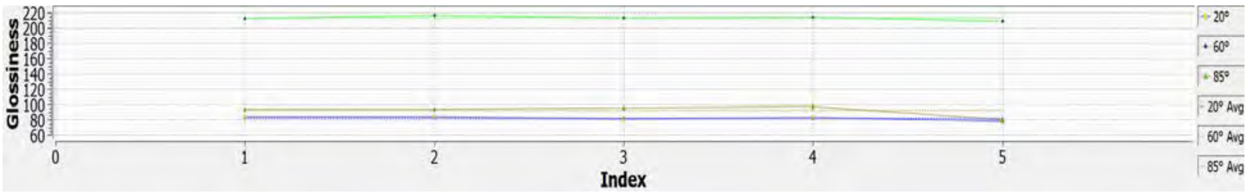
For bare metal gloss testing, the 60° angle geometry is always used for initial comparison of specimens to determine the appropriate angle of measurement. When the 60° angle gloss values are higher than 70, the 20° angle geometry is the most accurate measurement for comparing specimens.

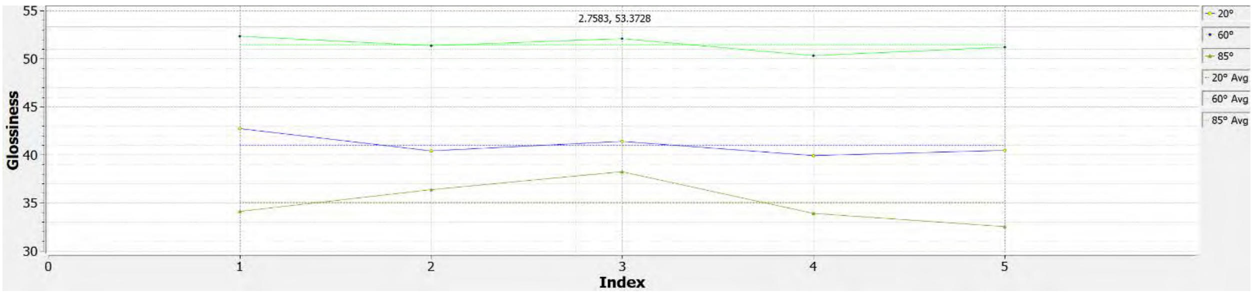
Measurements are made at an 85° angle geometry when specimens have 60° gloss values that are lower than 10. The test results for the control sample indicate that the correct angle geometries for sample comparison are 60° for measurements across the grain and 20° for measurements with the grain. These angles of measurement were used for post-cleaning specular gloss comparison in this report. Figure E.3B shows graphs of the gloss measurements.

Figure E.3A: Control Sample Specular Gloss with Appropriate Angle of Measurement for Each Direction Identified

Angle	Avg	Max	Min	StdDev
Across the polish grain				
20°	41.0	42.7	39.9	1.1
60°	51.5	52.3	50.3	0.8
85°	35.0	38.2	32.5	2.3
With the polish grain				
20°	81.8	83.8	78.2	2.3
60°	213.0	216.6	208.7	2.9
85°	92.2	97.3	80.0	7.0

Figure E.3B Control Sample Gloss Test Scans (Top with the grain, Bottom across the grain)





E.4 Control Sample – Photomicrograph Appearance

A representative photomicrograph of the control sample finish is provided in Figure E.4A. The finish was cleanly cut with minimal areas of surface overlap (smearing) or visible tearing. A cleanly cut surface provides better corrosion performance than a finish of equivalent surface roughness which has these defects. This image is provided for comparison with the later images illustrating the effectiveness of cleaning trials.

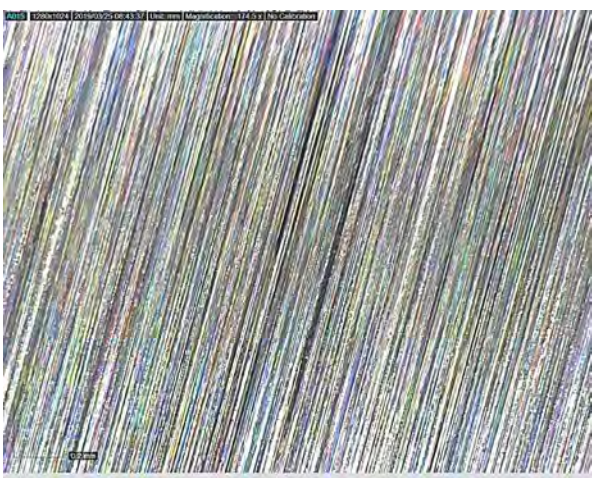


Figure E.4A: Representative photomicrograph of the control sample finish, 175X

E.5 Control Sample – Surface Roughness

Many surface roughness measurements are possible with a more sophisticated profilometer. The profilometer used for this assessment automatically measured twenty-one characteristics. The average values for the three primary measurements used in the assessment were (Ra, Rz and Rmax). See Figure E5.A. At least five measurements were taken in each direction on the control sample.

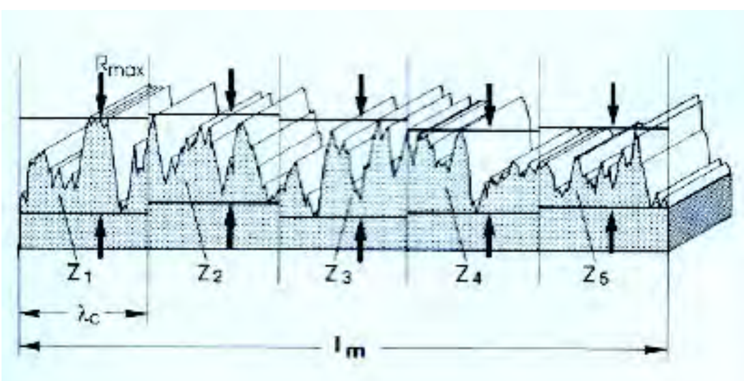
The arithmetical mean surface roughness measurement, Ra, is the most widely used roughness parameter in both international standards and production. The derivation of Ra is shown in Figure E. 5B. Ra is the average deviation of the profile from the mean line and does not differentiate between peaks and valleys. Rz(DIN) is the average of the 5 peak-to-valley heights, while Rmax is the maximum peak-to-valley height within one measurement area. These additional parameters are valuable tools for assessing finish variation. Figure E.5C illustrates the Rz(DIN) and Rmax measurements.

Figure E.5A: Average surface roughness of the control sample in micro-inches

Orientation	Ra	Rz	Rmax
Across grain	23	214	333
With grain	17	98	184

Figure E5.B: A graphical depiction of Ra surface measurement

Figure E5.C: Derivation of the parameters Rz(DIN) and Rmax



F – Cleaning Trial Specular Gloss and Surface Roughness Comparisons

F.1 Specular Gloss and Surface Roughness Data

The primary focus of this study was to completely clean the surface without substantially changing the original surface finish morphology or, if the cleaning resulted in a texture change, to restore the finish to the original texture as part of the process. Only gloss and surface roughness were checked since both can be used to predict color as was discussed in the previous section. Figure F.1A summarizes the specular gloss data and Figure F.1B summarizes the surface roughness data for the samples. At least three and as many as seven measurements were taken for each reading. Any significant outlier value(s) was eliminated. When surfaces had higher degrees of inconsistency, as can be seen by looking at standard deviations, more measurements were taken to ensure a representative average value. The samples were measured in areas, which had superficial light corrosion staining prior to the cleaning trials, but not deep scratching damage from the embedded iron simulation.

The test results for some cleaning methods had quite high data standard deviations relative to the original finish. This was attributed to a higher level of scratching on some samples. The most minimally scratched areas were used during measurement of the Ra and gloss values. Both tables compare the cleaned specimens with the control sample.

Zahner also provided abrasive blasted samples. Abrasive blasting produced a significant change in finish appearance and surface roughness. Since that was not considered a viable option, the data has not been included in these tables. Zahner electrolytically polished a sample and that was also considered too large a change; only gloss data is provided to show the significant increase in reflectivity. The surface of one of the Adapt samples melted and that data is also not included in the tables.

The specular gloss values for Astropak sample #9 for the 410, hand buffed/bottom and neutral rouge/top were closest to the control sample with the neutra rouge/top having a substantially smaller standard deviation. When all three surface roughness parameters were considered, the Astropak samples were more similar in surface roughness to the control samples. Data for some of the samples was corrupted during the upload and that was not discovered during the site visit.

The surface roughness of the Karcher samples and some of the Adapt samples were not tested. There was too much remaining corrosion product on the surface. Profilometer needles are essentially very fine phonograph needles but are more delicate. They cannot be replaced in the field and careful calibration is required. Since those cleaning methods clearly were ineffective and to avoid making a critical piece of test equipment unusable, only more substantially cleaned surfaces were tested.

Figure F.1A: Specular Gloss Comparison

Sample	Avg	Max	Min	StdDev
Across the polish grain 60° angle				
Control	51.5	52.3	50.3	0.8
Astropak				
#9, 410 hand buffed, bottom	48.7	62.7	0.8	26.9
#9, neutra rouge, top	50.9	54.0	49.5	1.8
Karcher				
#3A	26.4	32.6	21.7	5.6
#3B	26.8	30.8	19.9	6.0
#4A water clean	31.5	33.5	28.8	2.4
#4B1 dry ice	36.5	41.2	30.6	5.4
#4B2 dry ice	36.4	39.8	30.2	5.3
#4B3 dry ice	37.3	45.0	27.8	8.8
Adapt				
#11A	43.0	46.5	37.8	4.6
#11B	38.9	41.8	36.7	2.6
#11C	48.1	58.5	41.6	9.0
#11D	50.9	71.5	40.5	17.8
#12A	38.6	39.4	38.1	0.7
#12B	40.7	44.9	37.6	3.8
#13B	45.9	48.3	43.5	2.1
Zahner 10 refinished	46.3	49.0	44.6	1.7
Zahner electrolytic cleaning	59.9	63.1	57.8	2.8
With the polish grain 20° angle				
Control	81.8	83.8	78.2	2.3
Astropak				
#7, 401 and buffer	91.5	101.0	73.0	10.8
#7, 401 and hand buffed	76.4	84.0	67.8	7.0
#9, 410 hand buffed, bottom	91.5	95.4	88.3	3.0
#9, neutra rouge, top	80.8	91.4	76.2	6.3
Karcher				
#3A	33.9	39.3	29.9	4.9
#3B	39.0	39.9	37.8	1.1
#4A water clean	42.7	55.9	34.5	11.6

#4B1 dry ice	60.7	66.5	52.7	7.1
#4B2 dry ice	49.7	62.9	24.1	22.2
#4B3 dry ice	49.9	58.6	45.5	7.5
Adapt				
#11A	61.0	66.8	52.7	7.4
#11B	57.1	59.9	54.2	2.9
#11C	57.7	62.6	54.7	4.3
#11D	44.8	52.0	36.1	8.1
#12A	60.0	62.5	58.5	2.2
#12B	56.1	58.6	51.8	3.7
#13B	52.2	60.4	29.7	13.0
Zahner 10 refinished	47.8	49.8	45.7	1.7
Zahner electrolytic cleaning	175.5	179.2	170.8	4.3

Note: The gloss meter data for two across the grain Astropak samples did not upload as part of a combined data file for those samples and that was not observed until data analysis began.

Figure F.1B: Surface Roughness Comparison, micro-inches

Sample	Ra	Rz	Rmax
Across the polish grain 60° angle			
Control	23	214	333
Astropak			
#7, 401 and buffer	32	319	446
#7, 401 and hand buffed	33	317	478
#9, 410 hand buffed, bottom	22	228	320
#9, neutra rouge, top	20	190	336
Adapt			
#12A	33	307	523
#12B	37	307	442
#13B	30	268	413
Zahner 10 refinished	39	268	363
With the polish grain 20° angle			
Control	17	98	184
Astropak			

#7, 401 and buffer	13	104	233
#7, 401 and hand buffed	12	70	147
#9, 410 hand buffed, bottom	14	110	228
#9, neutra rouge, top	8	48	193
Adapt			
#12A	18	130	312
#12B	23	149	236
#13B	10	71	161
Zahner 10 refinished	11	70	116

F.2 Ranking Using Specular Gloss and Surface Roughness Data

A method of ranking samples was necessary for comparative purposes. Please see the discussion in Section E about the science of surface analysis. To simplify the ranking method, the gloss measurement in the higher reflectivity direction (with the finish grain) and arithmetical mean surface roughness measurement Ra across the polish grain (rougher finish) were used. The deviation of both values from the average control sample values was determined and averaged.

As was noted in the previous section, the level of remaining corrosion product or degree of surface damage caused by each cleaning process effected the ability to measure surface roughness without damaging the profilometer. For those samples, only the gloss measurement data was used.

The relative rank was based on total deviation from the control sample. A rank of “5” would indicate perfect matching with the control sample, which is highly unlikely given the damage inflicted on the surface during the accelerated aging trials. Lower numbers indicate more substantial variation from the original control sample and therefore a lower rank. Figure F.2A shows the calculations.

Figure F.2A Calculation of Cleaning Trial Rank With “5” Being A Perfect Match with the Control Sample and Lower Values Indicating Less Satisfactory Performance

With the polish grain 20° angle	Avg. Gloss	Avg. Dev. from Control	Across the polish grain 60° angle	Avg. Ra	Avg. Dev. from Control	Avg. Dev. of Gloss & Ra from Control	Calculated Rank Based on Dev. From Control Sample
Control	81.8		Control	23			
Astropak			Astropak				
#7, 401 and buffer	91.5	9.7	#7, 401 and buffer	32	9	9.35	4.065
#7, 401 and hand buffed	76.4	5.4	#7, 401 and hand buffed	33	10	7.7	4.23
#9, 410 hand buffed, bottom	91.5	9.7	#9, 410 hand buffed, bottom	22	1	5.35	4.465
#9, neutra rouge, top	80.8	1	#9, neutra rouge, top	20	3	2	4.8
Karcher							
#3A	33.9	47.9			0.0	47.9	0.21
#3B	39	42.8			0.0	42.8	0.72
#4A water clean	42.7	39.1			0.0	39.1	1.09
#4B1 dry ice	60.7	21.1			0.0	21.1	2.89
#4B2 dry ice	49.7	32.1			0.0	32.1	1.79
#4B3 dry ice	49.9	31.9			0.0	31.9	1.81
Adapt		81.8			0.0	81.8	3.18
#11A	61	20.8			0.0	20.8	2.92
#11B	57.1	24.7			0.0	24.7	2.53
#11C	57.7	24.1			0.0	24.1	2.59
#11D	44.8	37	Adapt		0.0	37	1.3
#12A	60	21.8	#12A	33	10	15.9	3.41
#12B	56.1	25.7	#12B	37	14	19.85	3.015
#13B	52.2	29.6	#13B	30	7	18.3	3.17
Zahner 10 refinished	47.8	34	Zahner 10 refinished	39	16	25	2.5

G – General Metallurgical Commentary on Cleaning Methods

As was previously mentioned, the Type 304 stainless steel that was used for the Gateway Arch must be assumed to be high in both sulfur and carbon based on the technology of the period. The weld samples analyzed during prior assessments confirmed the high carbon content since the base metal adjoining the welds was sensitized. (See prior footnote about sensitization.) Sulfides were observed in the microstructure.

Furthermore, the final step prior to turnover was to chemically passivate the surface to remove surface sulfides and obtain optimal corrosion resistance. Unfortunately the mill certificates with the heat chemistries were not in the archives but all of the circumstantial evidence makes it clear that it will be critical to require chemical passivation as the final step after any cleaning or refinishing step if the memorial is to have optimal corrosion performance.

G.1 Chemical Cleaning

Chemical cleaning in accordance with ASTM A380/A380M and A967/A967M separately with or without mild to more aggressive abrasion is the most widely used method for removing heat, embedded iron, corrosion staining and many surface deposits from stainless steel. Appropriate methods have the well documented ability to substantially improve corrosion performance.

Chemical cleaning must be combined with other cleaning methods, such as degreasing or adhesive removers, if there are substances on the surface are not broken down by these chemicals. The unknown surface deposit found on some of these samples clearly required some other removal method, but its' analysis was considered unnecessary because it was not representative of the Gateway Arch surface.

Some of the chemicals, which do not naturally break down into water, must, by regulation or legislation, be captured and properly handling making it critical to assess their SDS's. Large scale encapsulation to capture the chemicals is done in the field by specialist firms but does require scaffolding.

G.2 High Pressure Water and Dry Ice Cleaning

Stainless steel is much less susceptible to yielding under micro-abrasion by blunt or sharp contact then other steels, iron, titanium, copper or aluminum alloys. Very high force levels and more aggressive types of blast media are required to produce change in stainless steel surface texture. For that reason, high pressure blasting, typically with mild abrasives like dry ice, walnut shells and other substances, is commonly used to remove very adherent substances and embedded carbon steel from stainless steel surfaces. The pressures used during these testing trials were inadequate for cleaning the surface.

G.3 Laser Cleaning

Laser cleaning has been used for a variety of materials and the appropriate process and parameters vary with the characteristics of the base material and the substance being removed. The laser cleaning trials on the samples were unsuccessful.

Several factors would have to be further researched if this cleaning method were to be used, including the corrosion resistance of the cleaned surface.

French research published on the removal of high temperature oxidized layers from stainless steel using nanosecond pulsed laser irradiation found that non-transparent oxide layers absorbed the energy of the laser leading to a temperature increase, which substantially softening or even melted the surface and lead to unsatisfactory material removal.[5] Another paper, documented that nanosecond pulsed laser irradiation was successful in removing continuous tightly adhering oxides because they mechanically spalled off but the removal of non-continuous oxide layers was not satisfactory.[6] Neither research study assessed the corrosion resistance of the cleaned surface. None of the oxides on the Gateway Arch are tightly adhering. They are also not continuous, and, while all of the deposits found on the Gateway Arch are oxides, they are not transparent. Microscopic analysis of the surface of the Adapt samples (Section H) documented heat damage and surface melting, which decrease the corrosion resistance of stainless steel.

Research on the use of laser cleaning of stainless steel for industrial purposes also documented stainless steel substrate damage if the power input exceeded 400 W. At a 500 W power input level, there was serious oxidation of the stainless steel microstructure, which would cause a significant decrease in corrosion resistance.[7]

Research done on laser cleaning of iron found that the corrosion rate of the laser cleaned iron surfaces was 50% higher than that of a mechanically cleaned area on the same sample. The higher corrosion rate was caused by the heat of the laser, which caused a microstructural transformation of the iron at the metal's surface.[8]

The welds on the Gateway Arch have already been sensitized as the result of the stainless steel's higher carbon levels and excessive heat input from repeated rewelding. This already makes them very susceptible to sensitization related corrosion, so added heat damage would be highly problematic. [1] At the higher elevations, one of the primary surface deposit composition constituents is industrial coke (fuel used in smelting iron ore), the presence of a fuel on the surface presents additional temperature control challenges.

If laser cleaning is considered, a very thorough literature review by a metallurgical engineer who specializes in stainless steel and testing is necessary. Metallurgical evaluation of surface microstructure and electrochemical corrosion testing should be considered prior to any use of this method on the Gateway Arch.

The standard industry test used to assess the pitting corrosion performance of a stainless steel surface is Cyclic Polarization (CCP). Cyclic polarization measurements are typically used to characterize metals and alloys that derive their corrosion resistance from the formation of a thin passive film. Materials that exhibit higher pitting potential (EP) values and repassivation potential (ER) are more resistant to pitting corrosion. Stainless steel meets this description and CCP is commonly used within the industry to quickly assess whether a specific alloy and finish provide the expected level of corrosion performance. A control sample of Type 304 with an

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[5] P. Pasquet, P. Psyllaki, R. Oltra, P. Meja and M. Autric, "Laser Cleaning of Oxidized Fe-alloys", Surface Modification Technologies XIV, Edited by T.S. Sudarshan, M. Jeandin, and K.A. Khor © ASM International, Materials Park, Ohio, 2000

[6] Pandora Psyllaki, Roland Oltra, "Preliminary study on the laser cleaning of stainless steels after high temperature oxidation", Materials Science and Engineering A282 (2000) 145–152

[7] Guoxing Chen*, Haifeng Lu, Ying Zhao, Huiwei Zhang, Shaochong Wei, Hua Ji, Shuhui Wu and Yiling Shi, "Effect of power on laser cleaning result of stainless steel surface", Opto-Electronic Engineering, 2017, 44(12): 1217–1224, DOI: 10.3969/j.issn.1003-501X.2017.12.010

[8] Bojana M. Radojković*, Bore V. Jegdić, Biljana M. Bobić, Slavica Ristić, Suzana Polić, "Corrosion characteristics of laser-cleaned surfaces on iron artefact", ISSN 0351-9465, E-ISSN 2466-2585 UDC: 628.147.22:66.088: 661.872 doi:10.5937/zasmat2001041R

ASTM A480 No. 3 finish should be used for the comparison and the CCP testing should be done by testing lab with significant stainless steel experience. (Note: CCP testing has been used to study chemical cleaning and passivation methods.)

G.4 Electropolishing

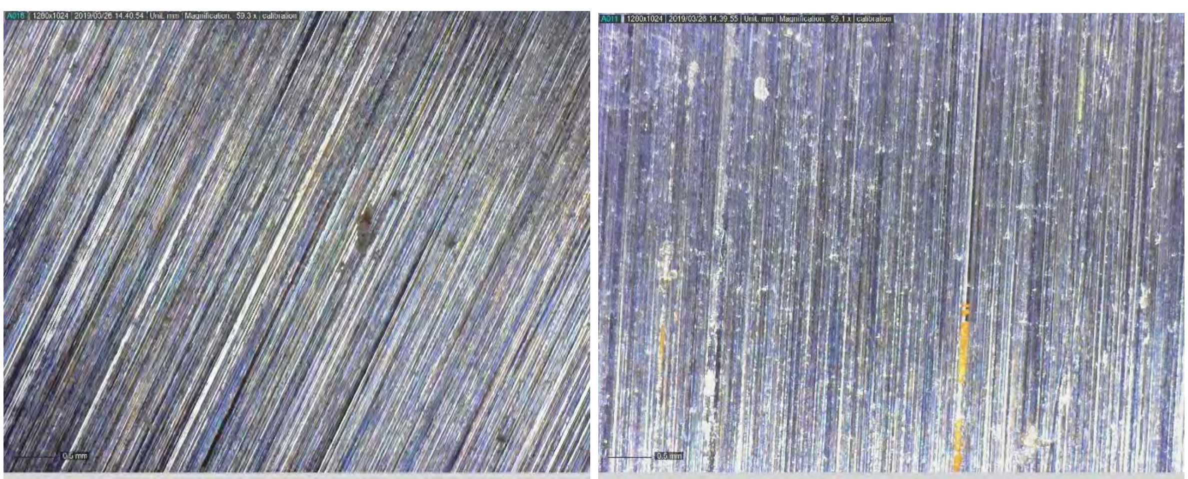
Electropolishing can be a very effective means of selectively removing embedded iron. It does however substantially smooth the surface which increases the gloss (reflectivity). Treated areas would be very visible. This could be combined with refinishing and chemical passivation to remove surface sulfides.

H - Representative Microscopic Images of the Cleaning Trial Samples

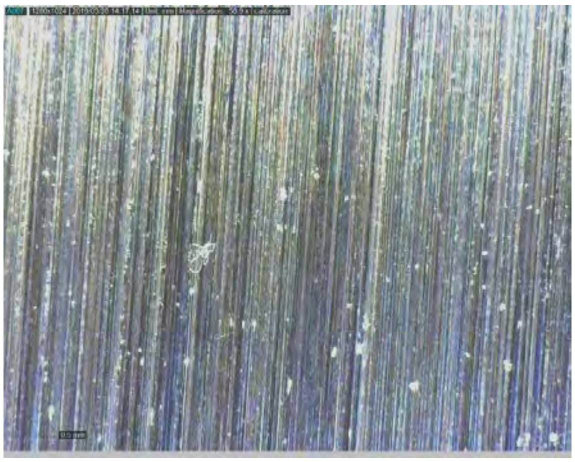
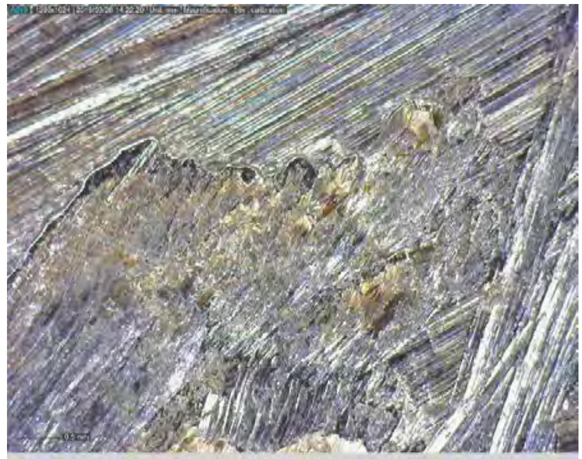
The images and commentary in this section document the range of finish conditions seen under magnification and the relative effectiveness of each cleaning method given the two primary goals of this testing program:

1. Removal of deicing salt related corrosion staining and
2. Removal of embedded iron.

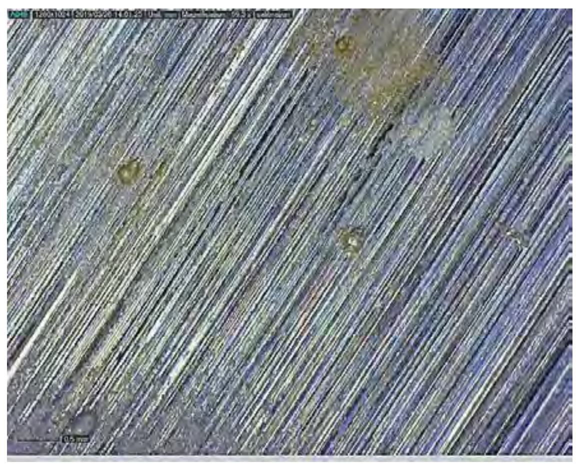
Astropak Samples



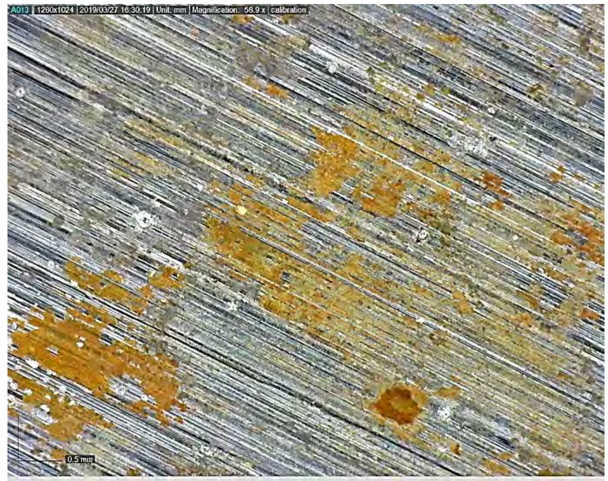
H.1 Sample Astropak #7 401 buffer 59.1x images: (L) Deicing salts staining was completely removed with some minor surface pitting observed, (R) Some embedded iron particles and resultant staining were still present on the surface but only clearly visible under microscopic examination.

H.2 Sample Astropak #7 hand buffed images: (L) Deicing salts staining was completely removed with some minor surface pitting observed 58.9x, (R) This area was particularly aggressively scratched. Some very small embedded iron particles and resultant staining were still present on the surface but only visible under microscopic examination 59x.

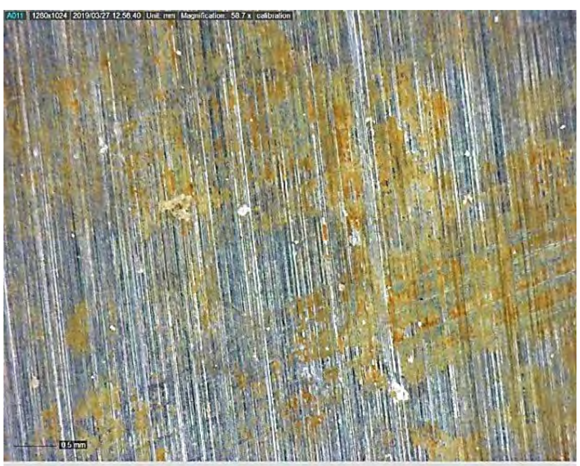
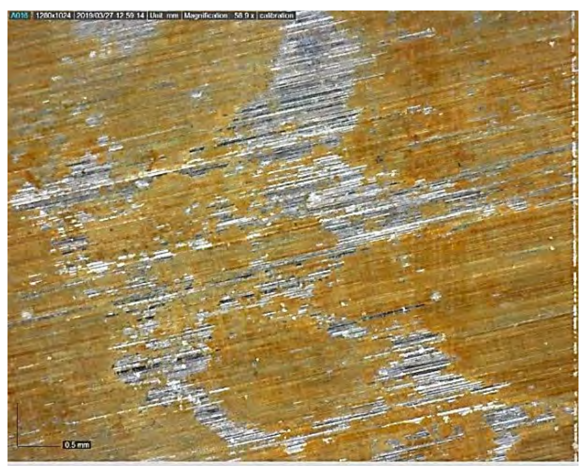
 

H.3 Sample Astropak #9 hand buffed bottom images: (L) Deicing salts staining was completely removed. This sample had numerous areas with the unidentified surface deposit, which is also shown in this image. 58.8x, (R) No embedded iron particles were observed but some residual staining was still present on the surface. The unidentified deposit appeared to be holding these remaining particles onto the surface, so the cleaning method was considered effective in meeting the goals of the project. The effect of the deposit was only clearly visible under microscopic examination. 59.3x.

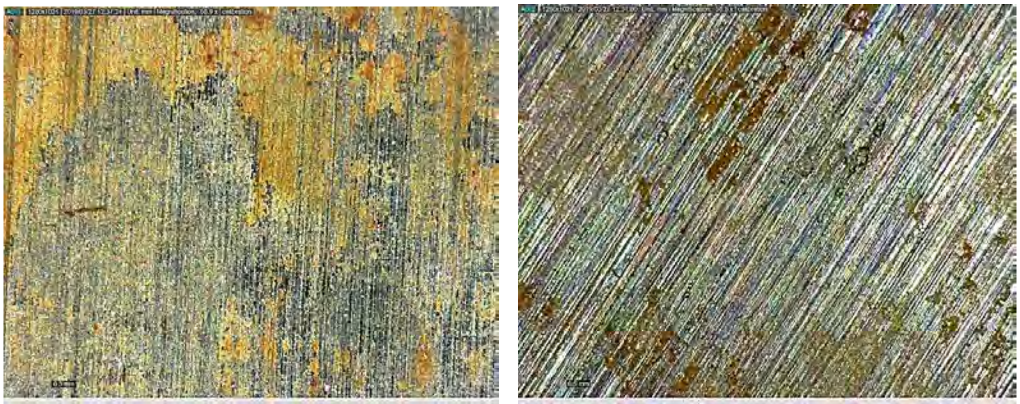
 

H.4 Sample Astropak #9 neutra rouge top images: (L) Deicing salts staining was completely removed from the shallow surface pits and the carbon steel had been removed from the deeper scratches. 58.5x, (R) Pitted areas where all staining had been removed were clearly visible (small white toned pits). No embedded iron particles were observed. The staining was only found adhering to the unidentified surface deposit as was confirmed by focusing on different features in these areas at different magnifications. Therefore, the cleaning method was considered effective in meeting the goals of the project. 58.9x.

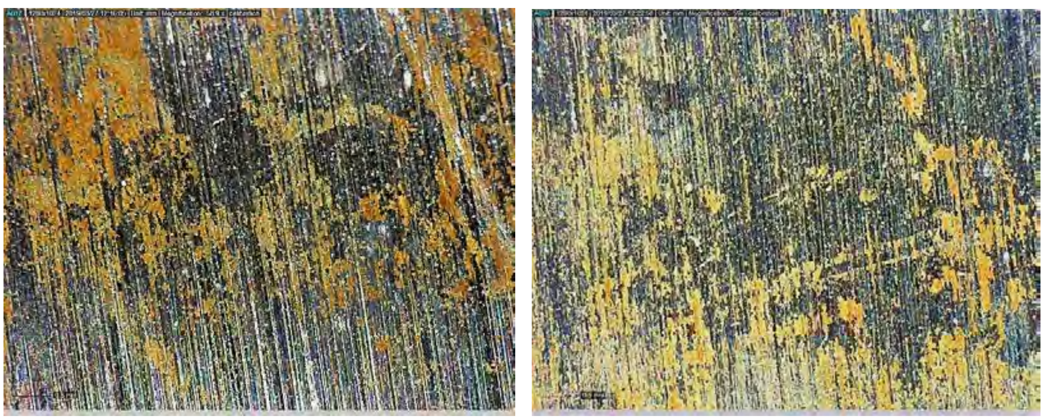
Karcher Samples

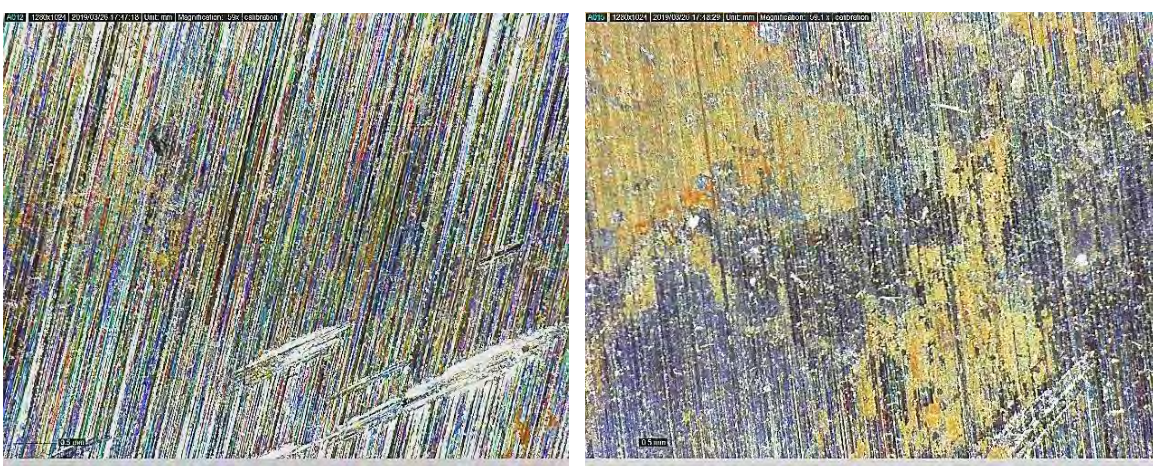
H.5 Sample Karcher sample 3A images: (L) Neither the deicing salts nor the embedded carbon steel staining had been completely removed from the surface. 58.7x, (R) Staining around visible areas of deicing salts pitting was visible. The cleaning method was not considered effective. 58.9x



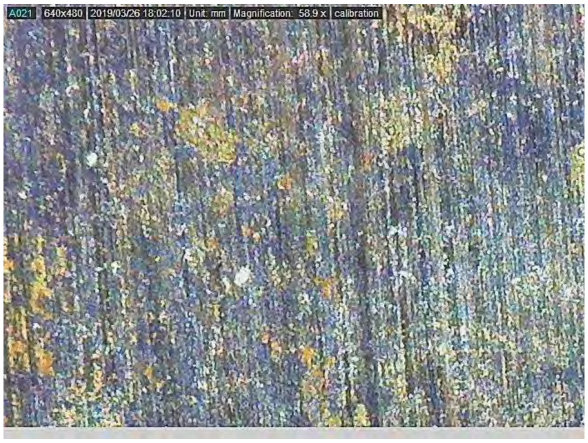
H.6 Sample Karcher sample 3B images: (L) Neither the deicing salts nor the embedded carbon steel had been removed from the surface. 58.9x, (R) Staining around visible areas of embedded iron was visible. The cleaning method was not considered effective. 58.8x.

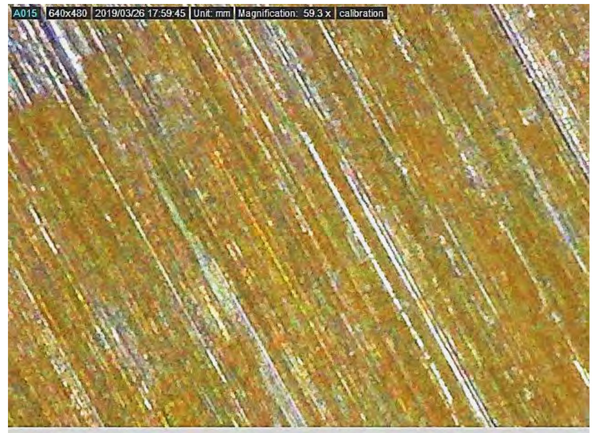


H.7 Sample Karcher sample 4A water cleaning images: (L) The significant visible remaining staining was associated with deicing salts pitting. 58.9x, (R) Staining around areas with embedded iron in scratches was visible indicating that it had not been removed. The cleaning method was not considered effective. 59x.

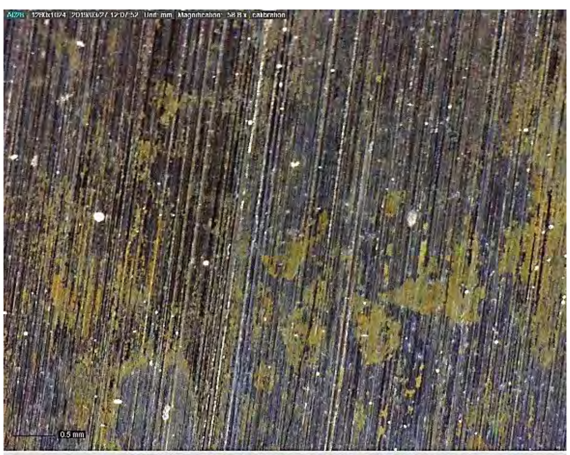
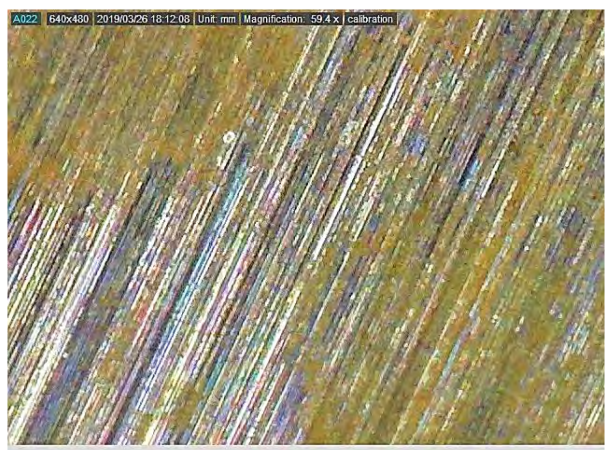


H.8 Sample Karcher sample 4B1 dry ice 1 cleaning images: The effectiveness of this cleaning method varied by area. (L) The deicing salts staining and carbon steel contamination related corrosion were reduced but not eliminated in some areas. 59x, (R) There was significant residual deicing salts and embedded iron corrosion visible in many areas indicating that it had not been removed. The cleaning method was not considered effective. 59x.



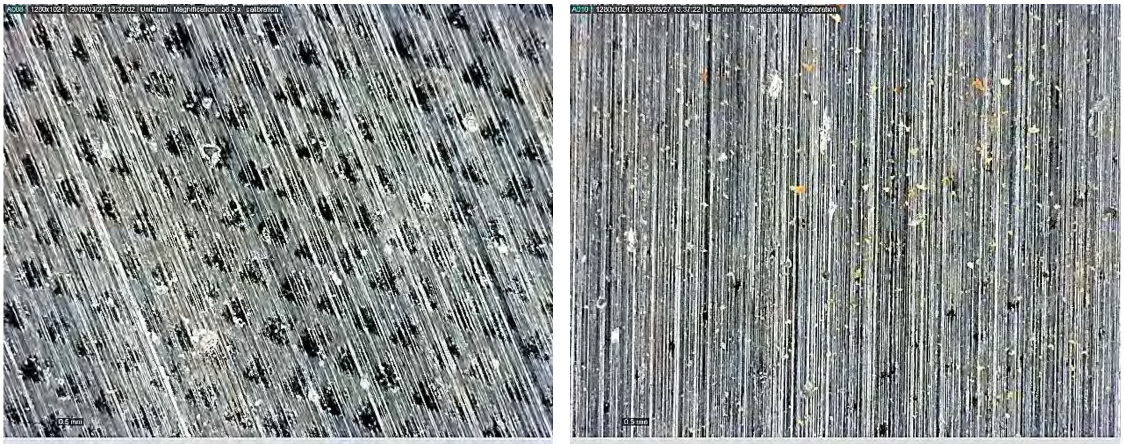


H.9 Sample Karcher sample 4B2 dry ice 2 cleaning images: The effectiveness of this cleaning method varied by area. (L) The deicing salts staining and carbon steel contamination related corrosion on the surface were reduced but not eliminated in some areas. 58.9x, (R) Other areas were still substantially stained. The cleaning method was not considered effective. 59.3x.

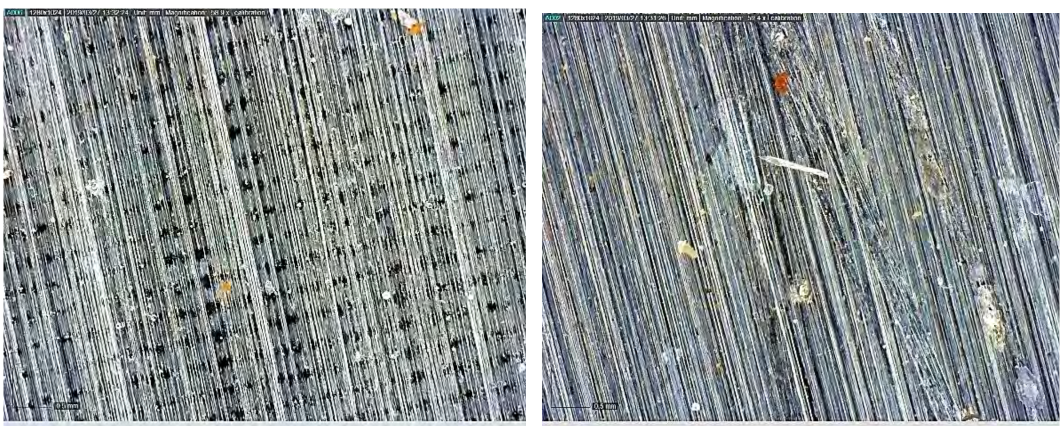



H.10 Sample Karcher sample 4B3 dry ice 3 cleaning images: The effectiveness of this cleaning method varied by area. It was not considered effective. (L) The deicing salts staining and carbon steel contamination related corrosion on the surface were reduced but not eliminated in some areas. 58.8x, (R) Other areas were still substantially stained. 59.4x.

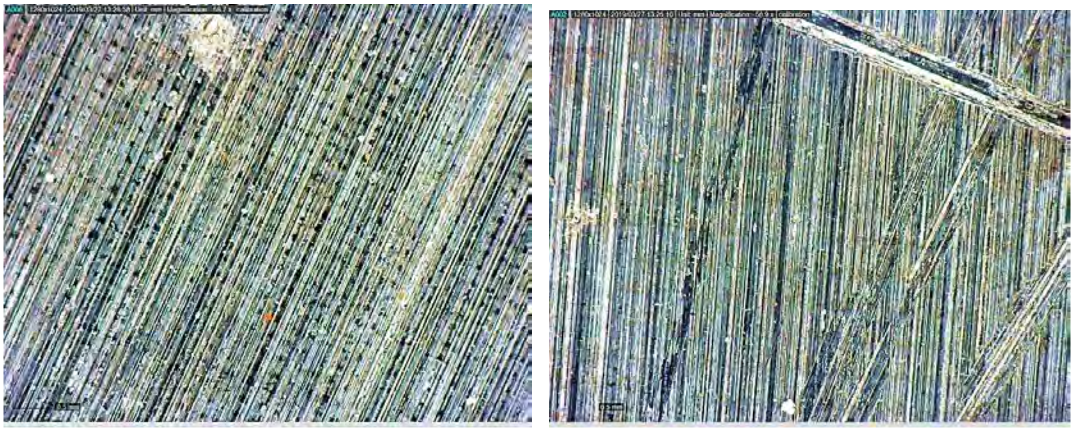
Adapt Samples



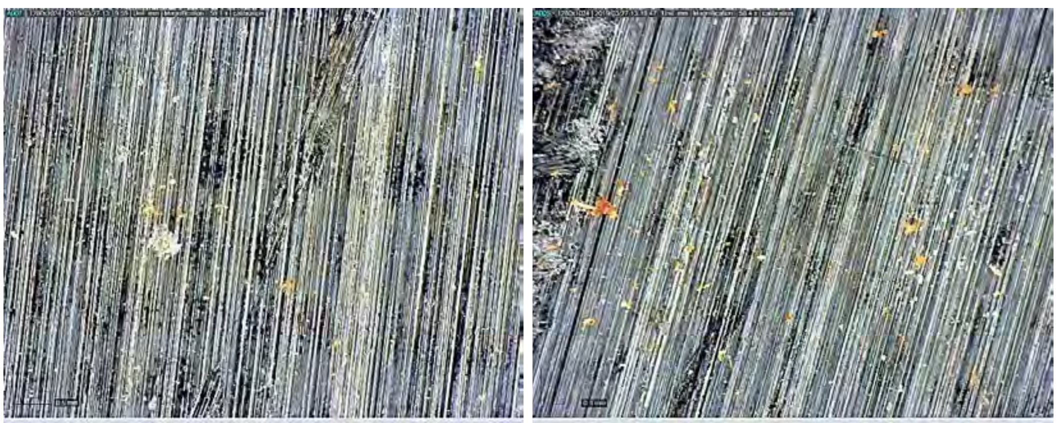
H.11 Sample Adapt laser cleaning sample 11A cleaning images: The embedded carbon steel and corrosion staining were substantially reduced but still visible but significant heat related surface damage (dark areas) was observed. (L) Heat related damage was visible. 58.9x, (R) Other areas had less heat damage but still had visible surface contamination. 59x. See Section G.3 for commentary about laser cleaning heat damage.



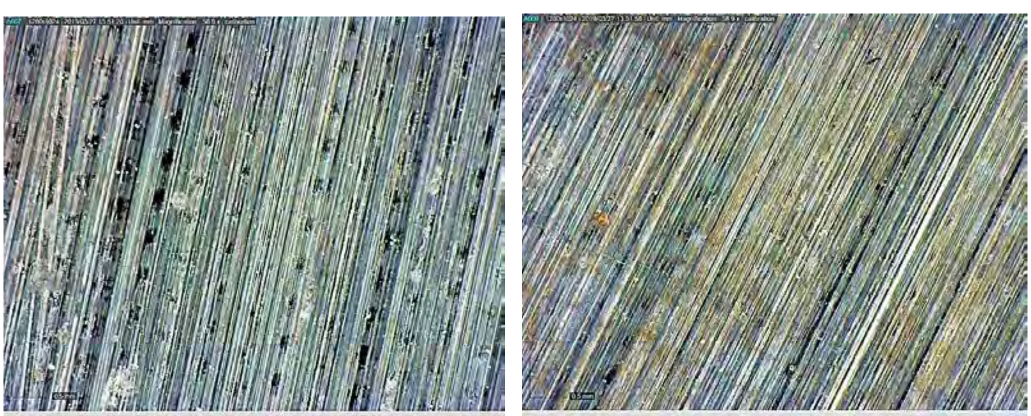
H.12 Sample Adapt laser cleaning sample 11B cleaning images: Most of the embedded carbon steel and corrosion staining were removed with only a few scattered remaining spots but heat related surface damage (dark areas) was observed. (L) Heat related surface damage was clearly visible on the surface along with some embedded iron. 58.9x, (R) Other areas had less heat damage but still had visible surface contamination. 59x. See Section G.3 for commentary about laser cleaning heat damage.



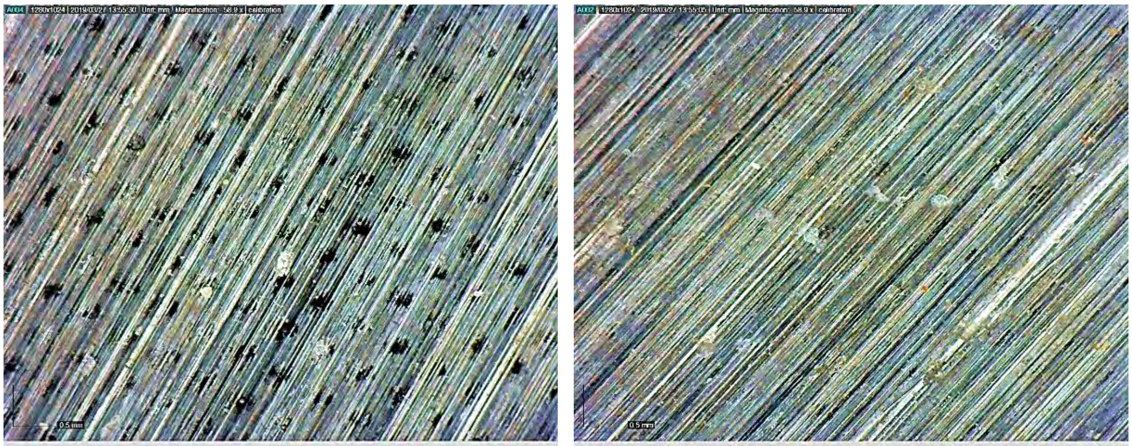
H.13 Sample Adapt laser cleaning sample 11C cleaning images: The embedded carbon steel and corrosion staining were reduced but still visible and heat related surface damage (dark areas) was observed. (L) Heat related surface damage and the embedded iron were visible. 58.7x, (R) Other areas had less heat damage but still had visible corrosion staining. 58.9x. See Section G.3 for commentary about laser cleaning heat damage.



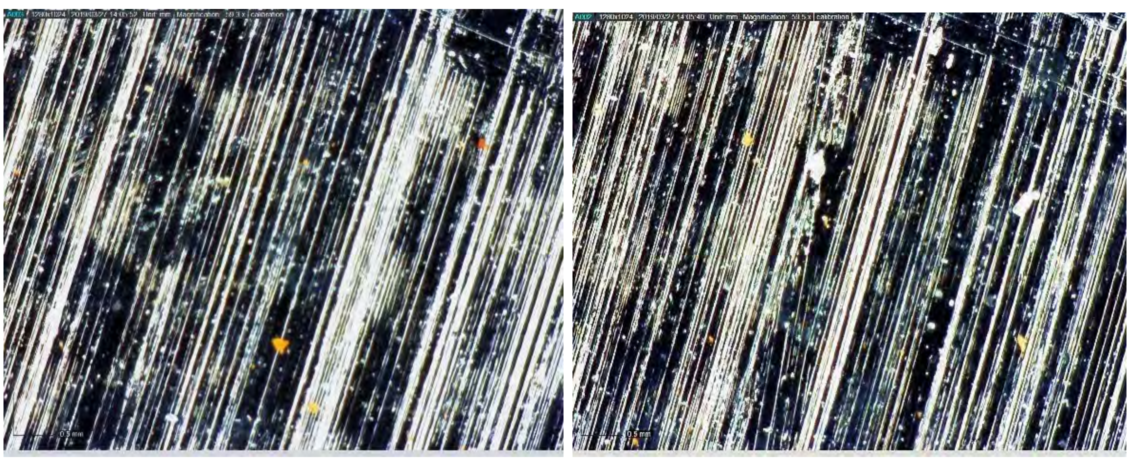
H.14 Sample Adapt laser cleaning sample 11D cleaning images: (L, 59.1x and R, 58.4x) Some embedded carbon steel and corrosion staining were visible and heat related surface damage (dark areas). See Section G.3 for commentary about laser cleaning heat damage.



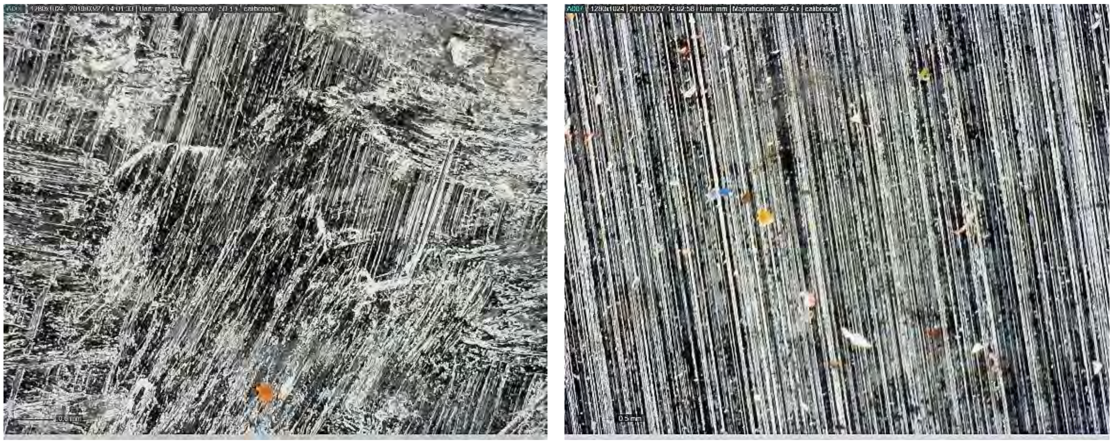
H.15 Sample Adapt laser cleaning sample 12A cleaning images: (L) The embedded carbon steel and corrosion staining were removed other than very small particles from the areas with more significant heat related surface damage (dark areas). 58.9x, (R) Other areas had less heat damage but still had visible surface contamination from corrosion staining and embedded iron. 50.9x. See Section G.3 for commentary about laser cleaning heat damage.



H.16 Sample Adapt laser cleaning sample 12B cleaning images: (L) Remnants of the corrosion staining were still visible and there was significant heat related surface damage (dark areas). 58.9x, (R) Other areas had less heat damage and visible corrosion staining. 58.9x. See Section G.3 for commentary about laser cleaning heat damage.

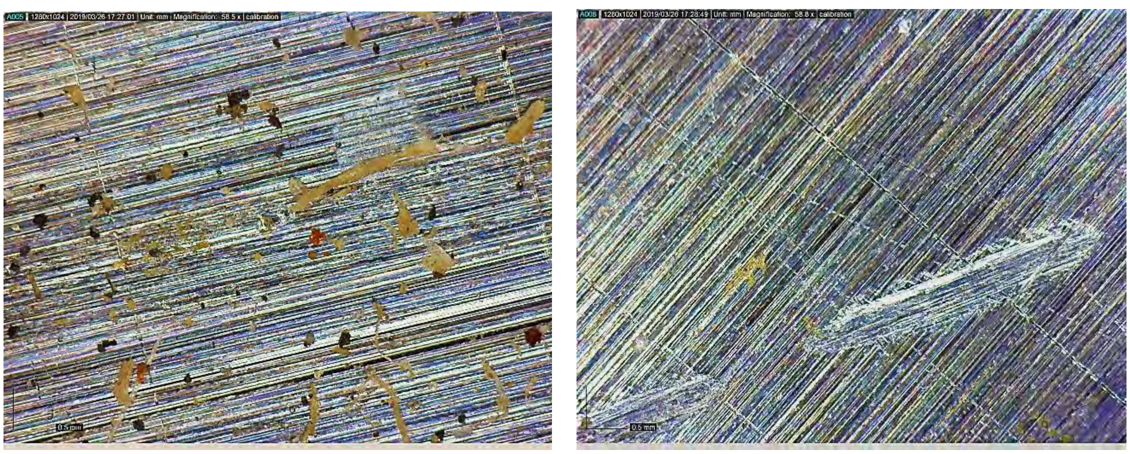


H.17 Sample Adapt laser cleaning sample 13 cleaning images: (L, 59.3x and R, 59.5x) Embedded carbon steel particles were visible and some very light corrosion staining. There was significant heat related surface damage (dark areas) over the entire surface and some areas had melted (polished grain line was gone). See Section G.3 for commentary about laser cleaning heat damage.



H.18 Sample Adapt laser cleaning sample 13B cleaning images: (L, 59.1x and R, 59.4x) The sample was consistent in appearance. Some scattered embedded carbon steel particles were visible. There was significant heat related surface damage (dark areas) over the entire surface. See Section G.3 for commentary about laser cleaning heat damage.

A. Zahner Sample



H.19 Zahner electropolished sample (L, 59.5x and R, 59.8x) The surface was visibly smoother with much shallower polishing lines as occurs with electropolishing, which also increases reflectivity and gloss. The level of residual embedded carbon steel particles visible on the surface varied with the area as is shown in these images.

I – Additional Commentary on the Testing

A white toned discoloration was observed on several trial samples after cleaning trials. Under microscopic evaluation, it was determined to be a surface deposit. The source of these deposits could not be determined. Since they did not simulate known conditions on the Gateway Arch, they were not considered during candidate cleaning option evaluation.

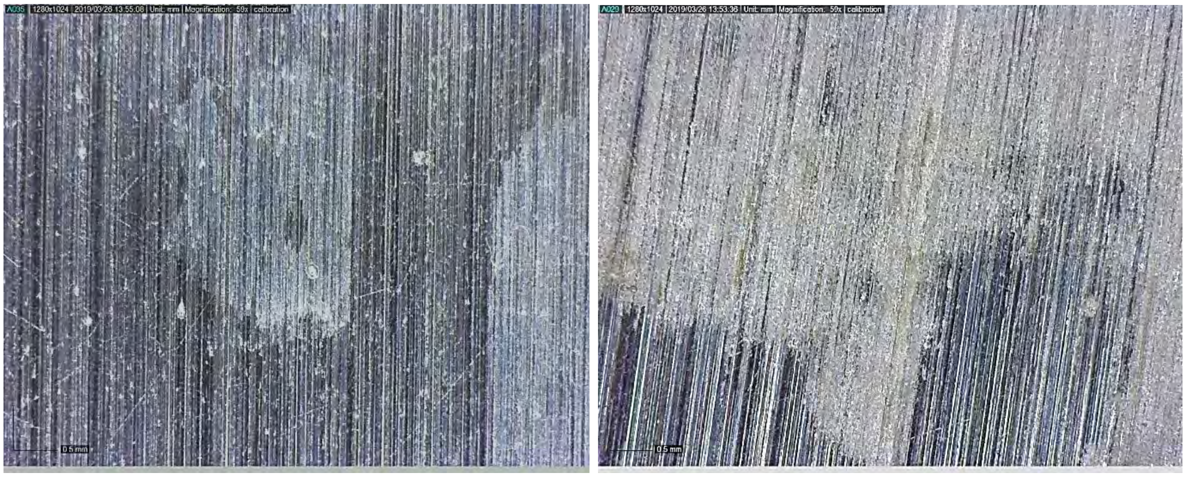


Figure I.1: Unidentified white toned surface deposit at (L) 10X and (R) 60X

BVH
ARCHITECTURE

IN ASSOCIAITON WITH THE **ASSOCIATION FOR PRESERVATION TECHNOLOGY, NATIONAL PARK SERVICE,** AND THE **GETTY FOUNDATION**