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# **Chloride Contamination Remediation of Steel Bridges**

**Kentucky Transportation Center Research Report — KTC-16-08/SPR14-484-1F**

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**Research Report**  
KTC-16-08/SPR14-484-1F

**Chloride Contamination Remediation on Steel Bridges**

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| <b>16. Abstract</b><br>Researchers evaluated 32 steel surface preparation methods to determine how effectively they remove chloride from corroded chloride-contaminated steel panels. Wet methods proved more effective than dry methods. The three most effective wet methods injected mineral slag abrasives in a water stream and resulted in less than 1% chlorides remaining. Most dry surface preparation methods left significantly more chloride contamination after surface preparation. The three most effective dry methods used multiple blast cleaning cycles. These methods approached the effectiveness of the best wet methods, with 1.6 to 2.0% chlorides remaining. The least effective surface preparation was a single abrasive blast cleaning with a 40/50 steel grit mix. This resulted in 6.5 % chlorides remaining. No surface preparation method evaluated resulted in chloride contamination less than 5 µg/cm <sup>2</sup> . Analyses with scanning electron microscopy revealed that the remaining chloride contamination (5.3 to 23.9 µg/cm <sup>2</sup> ) was randomly deposited in individual <i>hot spots</i> distributed across the steel's surface. This contamination would probably cause premature coating failure. Wet methods are significantly more effective than a single abrasive blast cleaning, irrespective of the abrasive material type or grit size used. Although, multiple iterations of blast cleaning approached the effectiveness of the best wet methods. |   |   |                  |
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## EXECUTIVE SUMMARY

ASTM A 572 steel test panels were preconditioned by exposing them to 2,000 hours of ASTM G85 – 11 “Standard Practice for Modified Salt Spray (Fog) Testing”. After the exposure period ended, the panels were corroded, pitted, and heavily contaminated. Panels were evaluated to determine the chloride remediation effectiveness of surface preparations methods made before the application of protective coatings. Surface roughness of the preconditioned panels was approximately 20 mils and chloride contamination averaged about 500  $\mu\text{g}/\text{cm}^2$ .

Researchers evaluated 32 surface preparation methods. Eight of these were dry methods, with different combinations of abrasive material (steel grit, mineral slag, glass, and aluminum oxide), abrasive size, and re-blasting (after flash rusting). Twenty-four were wet methods, with different combinations of water pressure, water abrasive mixes, water temperature, and chemical additives. Following surface preparation, the cleanliness of panels prepared using dry methods met SSPC-SP10 (Near-White Clean Blasting) surface preparation standards; the cleanliness of panels prepared with wet methods approximated the SSPC VIS-4D WJ-1 standard. When this work was conducted Wet Abrasive Blast cleaning standards were not available.

Wet methods proved more effective than dry methods. The three most effective wet methods injected mineral slag abrasive into a water stream and resulted in less than 1% chlorides remaining. Most dry surface preparation methods left significantly more chloride contamination after surface preparation. The three most effective dry methods used multiple blast cleaning cycles. These methods approach the effectiveness of the best wet methods, with 1.6 to 2.0% chlorides remaining. The least effective surface preparation was a single abrasive blast cleaning with a 40/50 steel grit mix. This resulted in 6.5 % chlorides remaining. No surface preparation method evaluated resulted in chloride contamination less than 5  $\mu\text{g}/\text{cm}^2$ . Analyses with scanning electron microscopy revealed that the remaining chloride contamination (5.3 to 23.9  $\mu\text{g}/\text{cm}^2$ ) was randomly deposited in individual *hot spots* distributed across the steel’s surface and would probably cause premature coating failure.



## BACKGROUND

The Kentucky Transportation Cabinet (KYTC) has approximately 1,200 bridges with steel superstructures, and most of its 11,000 bridges have steel bearings. The best way to protect structural steel on bridges is with liquid applied coatings (paint). The current life expectancy for field-applied protective coatings (maintenance painting) is about 20 years (1). KYTC usually employs a remove-and-replace strategy for maintenance painting, with unit costs often in excess of \$10.00 per ft<sup>2</sup>. The cost of maintaining a protective coating during the service life of a bridge may approach the bridge's original construction costs. Extending the service life of protective bridge coatings is critical for maintenance managers given that funding is becoming more limited.

KYTC bridges have a well-documented history of chloride contamination. Chloride contamination has been measured as part of multiple KTC studies (2,3) and on construction projects. The protective coatings industry has long recognized that chlorides are detrimental to protective coatings. Recent efforts by KTC for the National Surface Treatment Center – Conductivity Testing and Comparative Analysis (3) have documented that there are no reliable field test methods for identifying problematic quantities and distribution of chlorides. Previous research has shown that KYTC bridges painted with relatively low levels of chloride contamination (by industry standards) often result in premature coating failures on those contaminated steel surface areas. With the increased use of deicing chemicals, it is clear that the issue of chloride contamination will not go away. The current situation can be summed up as follows — chlorides are present on KYTC bridges and we cannot effectively measure them, therefore obtaining a reasonable service life for protective coatings is only possible if the chlorides are remediated. At this time no one has adequately addressed the effectiveness of chloride remediation techniques.

Conventional maintenance painting practice begins with abrasive blasting and/or pressure washing to remove soils, surface rust, and intact remnants of the existing coatings. Recent research has shown that this practice leaves residual chlorides trapped in high concentrations in microscopic pits (shown in Figure 1) (4). This leftover contamination creates *hot spots* where follow-on corrosion occurs after the new coating is applied. This reduces the service life of coatings. New surface preparation methods must be identified to reduce or eliminate residual chloride hot spots and provide painting substrates with no, or very low, chloride contamination to achieve the maximum service lives of maintenance painting projects. Since field chloride test methods do not identify hot spots, an effective surface preparation method must be identified in the laboratory. Once identified, it can be implemented on future maintenance bridge painting projects.

## OBJECTIVES

The objectives of this research were to:

- 1) Review current processes for surface preparation and chloride contamination remediation used industrywide.
- 2) Develop a test matrix of potential remediation methodologies.
- 3) Treat uncoated steel panels by cyclic salt fog testing to promote corrosion and determine contamination levels.

- 4) Clean the corroded steel panels with candidate surface preparation methods identified from Objective 2.
- 5) After cleaning, measure the retained chlorides on segments of the panels by boiling extraction. For segments of panels not cleaned by boiling extraction, use a scanning electron microscope (SEM) to evaluate surfaces created by the various cleaning methods. Use SEM to determine the disposition of any retained chlorides on the resulting substrates.
- 6) Provide recommendations for future surface preparation methods for steel bridge maintenance painting.
- 7) Work with KYTC officials to incorporate the use of these methods on an experimental basis.

## **RESEARCH APPROACH**

Previous KYTC efforts to assess the impact of chlorides on coating performance relied on spreading a salt solution (charging) on steel panels. That approach was flawed because an even distribution of chloride did not necessarily trigger early coating failure, while a much lower level of chloride, as measured with field test methods (sleeve and patch), did (3). That work also identified high concentrations of chloride in pits (hot spots) as the instigator of corrosion. Field work on KYTC bridges also resulted in premature coating failure on in-service steel bridges where corroded and pitted steel was too cleaned (SSPC SP3 – wire brush) and washed (4,500 psi) prior to applying coatings (2). This study attempts to replicate the field condition of corroded and pitted steel.

Based on information from the previous work, different analytical methods were used. The field test methods currently available for chlorides are insufficient to determine chloride deposition. While they accurately quantify chlorides over a large area ( $\pm 10 \text{ cm}^2$ ), they do not identify hot spots. This study used boiling extraction (SSPC TECHNOLOGY GUIDE 15 Field Methods for Retrieval and Analysis of Soluble Salts on Steel and Other Nonporous Substrates – Method C) to quantify chlorides at different points in the process. Researchers used a SEM to measure deposition of the chlorides after surface preparation.

ASTM A 572 steel panels (4 inch by 6 inch) were used to evaluate the effectiveness of surface preparation. After they were preconditioned to replicate corroded bridge steel, a segment of each panel was removed using a band saw and tested for chloride content. Three panels were selected for each surface preparation method. After the surfaces had been prepared, a segment from each panel was removed by sawing and retested for chloride content. The remaining panel portion was analyzed for chloride deposition using an SEM. The panels apportionment is shown in Figure 2.

### **Surface Preparation Methods**

After reviewing current practices, researchers selected 32 different steel surface preparation methods for evaluation. Eight of the methods were dry with different combinations of abrasive material (steel grit, mineral slag, glass, and aluminum oxide), abrasive size, and re-blasting (after flash rusting). Twenty-four methods were wet with varying combinations of water pressure, water abrasive mixes, water temperature, and chemical additives. Table 1 describes the surface preparation methods.

## **Panel Pre-conditioning**

Steel test panels were preconditioned to replicate corroded bridge steel by exposing them to 2,000 hours of ASTM G85 – 11 “Standard Practice for Modified Salt Spray (Fog) Testing”. Mill scale was removed by grinding before the panels were preconditioned (Figure 3). Panels were rotated to different positions in the salt fog chamber at 500-hour intervals to equalize exposure to salt fog. After preconditioning, panels had developed heavy stratified rust and chloride deposits (Figure 4). The total chloride available prior to disturbing the rust and deposits on one panel was measured by boiling extraction at  $2,335 \mu\text{g}/\text{cm}^2$ .

KYTC bridge cleaning Special Notes generally require removal of stratified rust prior to abrasive blast cleaning. Therefore, this study replicated that process. Preconditioned panels were cleaned using a dull scraper and hand wire brushing to remove most of the rust and chloride deposits (Figures 5 and 6). The resulting surface condition matched the SSPC-SP2 D standard (Figure 7); surface roughness measured at 20 mils. Each panel was placed in a zip-lock bag and labeled for tracking. Three panels were randomly selected for each surface preparation method. A band saw was used to remove a 1 inch by 4 inch segment from each panel. The removed panel segments for each method were combined into a single sample for boiling extraction (Figure 8).

Chloride contents on the SSPC-SP2 D panel segments, consisting of averages from the three segments, ranged from  $307.7$  to  $741.1 \mu\text{g}/\text{cm}^2$  and averaged  $506.9 \mu\text{g}/\text{cm}^2$  for the 32 groups of panels. The average chloride content was comparable to worst case field measurements of  $432 \mu\text{g}/\text{cm}^2$  (3), but the range of chloride contents was unexpected. Table 2 (wet preparation methods) and Table 3 (dry preparation methods) summarize the chloride content of each group of panels prior to surface preparation.

## **Surface Preparation**

All dry surface preparation methods and low pressure/low temperature wet methods were performed at KTC’s facility. High pressure ( $>5,000$  psi) and high temperature ( $>$ ambient) methods were completed by Aqua Mister in Charleston, South Carolina, with KTC oversight, Figure 9. Panel cleanliness after surface preparation was consistent with the SSPC-SP10 (Figure 10) standard for dry methods, and approximated a SSPC VIS-4 D WJ-1 (Figure 11) for wet methods. The WJ conditions were intended for application of water jetting only, not for all wet preparation methods, but similar conditions were attained for all wet methods. Since this research was completed, the industry has published Wet Abrasive Blasting (WAB) standards. A 1 inch by 4 inch segment of each panel was removed after surface preparation and retained for examination by SEM.

## **Chloride Content**

The chloride content on each panel after surface preparation was measured by boiling extraction of the 4 inch by 4 inch panel segment. Following dry surface preparation, chloride content ranged from  $6.1$  to  $23.9 \mu\text{g}/\text{cm}^2$ . Of the dry methods, re-blasting after flash rusting yielded the lowest chloride content. The three re-blasting methods resulted in chloride contents of  $6.1$ ,  $7.5$ , and  $7.9 \mu\text{g}/\text{cm}^2$ , respectively. All other dry preparation methods produced significantly higher chloride contents ranging from  $20.5$  to  $23.9 \mu\text{g}/\text{cm}^2$ . The highest chloride content measured after dry surface preparation occurred with the standard method of abrasive blasting using a 40/50 mix of steel grit. The chloride content of panels after wet surface preparation methods ranged from

5.3 to 17.8  $\mu\text{g}/\text{cm}^2$ . Table 2 (wet preparation methods) and Table 3 (dry preparation methods) shows chloride contents after surface preparation.

The chloride content prior to surface preparation ranged from 307.7 to 741.1  $\mu\text{g}/\text{cm}^2$ . Since the initial chloride varied so much there was concern that the chloride content after cleaning may not accurately indicate the effectiveness of the method used. The effectiveness of each surface preparation method was calculated as a percentage of remaining chlorides to initial chloride content. For dry methods, the percent chloride remaining ranged from 1.6 to 6.5%; for wet methods, it ranged from 0.8 to 4.2%. The order of surface preparation (most effective to least effective) methods, as listed in Table 2 and Table 3, differed somewhat with respect to total remaining chloride content and effectiveness. Figure 12 graphically illustrates the total remaining chlorides and Figure 13 illustrates the effectiveness of each method.

### **Chloride Deposition**

Chloride levels on the steel after surface preparation is key to the performance of protective coatings. Low levels of chloride contamination can cause premature coating failure, but higher levels of chlorides, if evenly distributed, might not result in corrosion cells as quickly. To evaluate the chlorides on a steel surface — either by field methods (sleeve or patch) or by laboratory methods (boiling extraction) — investigators averaged the total chloride content over the total surface measured. In this study, the area measured was approximately 10  $\text{cm}^2$  for field methods and 200  $\text{cm}^2$  for laboratory panel segments.

Each surface preparation method had three panels, and the 1 inch by 4 inch segments derived from two of those surface preparation methods were scanned at various locations across their surfaces. There were no observable differences among scans from different areas of a panel segment, nor were there differences among different panel segments for any particular surface preparation method. The SEM process is time consuming (hours per scan) so only one panel segment per method was examined in three locations (panel ends and their middle sections) to assess chloride distribution.

Chlorides on the panel after surface preparation were generally in 2 to 5 mil diameter deposits. About 25% of the scans indicated clumping of individual deposits into circular areas 20 to 30 mils in diameter. There was no evident correlation between preparation method and the clumping of chloride. SEM scanning images are located in Appendix A. Chlorides are colored red or purple, however, interpretation of the scans is problematic because there are reflections showing lighter shades of red (purple). These reflections could be reduced or eliminated by running the scans longer. Time and budget constraints did not allow that for in this study. At least one of the deposits positively identified as chloride is marked with an arrow in each image.

## **CONCLUSIONS**

Wet surface preparation methods are more effective and result in lower remaining chloride levels than dry methods when cleaning corroded, chloride-contaminated steel surface. The three most effective wet methods injected mineral slag abrasive into a water stream and resulted in less than 1% chlorides remaining. The other variables in the wet methods (water pressure, water temperature, abrasive, chemical additives) did not result in discernable trends.

Most dry surface preparation methods leave significantly more chloride contamination on steel surfaces than wet methods. The three most effective dry methods were those which used multiple blast cleaning cycles. These three methods approach the effectiveness of the best wet methods, with 1.6 to 2.0% chlorides remaining. The least effective surface preparation was a single abrasive blast cleaning with a 40/50 steel grit mix, which resulted in 6.5% chlorides remaining.

None of the 32 surface preparation methods assessed resulted in less than 5  $\mu\text{g}/\text{cm}^2$  chloride contamination as measured with boiling extraction. Boiling extraction averages the total chlorides available over the entire surface area tested but does not address concentrations.

SEM analysis of the remaining chloride contamination (5.3 to 23.9  $\mu\text{g}/\text{cm}^2$ ) indicated the chloride was randomly deposited in individual hot spots across the steel's surface. Currently, it is difficult — if not impossible — to characterize the chloride content in hot spots. There is no published method for detecting hot spots outside of microscopic/SEM evaluations

The remaining quantity and distribution of chloride contamination after any of the 32 surface preparation methods used will cause premature coating failure.

## **RECOMMENDATIONS**

KYTC should assume that chloride contamination is present on all bridge surfaces exposed to water run-off or traffic aerosols. In lieu of better surface preparation methods, KYTC should, as the first step in preparing bridge steel for maintenance painting, mandate abrasive blast cleaning of all corroded steel surfaces before cleaning the entire bridge. If recyclable abrasives are used, they should be tested for chloride contamination. The second step of abrasive cleaning the entire steel surface that will be painted is the best practice currently available to KYTC.

Washing all bridge surfaces (slated for painting) and the drainage system prior to surface preparation for painting would minimize surface contamination and thus extend the service life of maintenance painting.

KYTC should continue to seek more effective chloride remediation methods.

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## TABLES

Table 1. Description of surface preparation method.

|   |
|---|
| <p><u>Method 1 - Chlor-rid Water/Mineral Slag</u> – Chlor-rid mixed at 100:1 ratio applied to steel surface then flushed with distilled water then dried, medium grit mineral slag injected into water stream, water at 4 gallons per minute at 4,000 to 5,000 psi.</p>   |
| <p><u>Method 2 - Salt-Away Water/Mineral Slag</u> - Salt-Away mixed at 256:1 ratio applied to steel surface then flushed with distilled water then dried, medium grit mineral slag injected into water stream, water at 4 gallons per minute at 4,000 to 5,000 psi.</p>   |
| <p><u>Method 3 - Water / Mineral Slag</u> - Medium grit, mineral slag injected into water stream, water at 4 gallons per minute at 4,000 to 5,000 psi</p>   |
| <p><u>Method 4 - Salt-Away Water Jetting</u> - Salt-Away mixed at 256:1 ratio applied to steel surface then flushed with distilled water then dried. Washed at 15,000 to 20,000 psi , 3 gal/min, 0 degree spinner tip, 5 sec/side</p>   |
| <p><u>Method 5- Hot Wash, Steel Grit 40/50 Mix</u>– Washed at 3,500 psi, 160 ° F at 4 gal/min, 5 sec/side, 0 degree spinner tip dried and stored in closed container, Abrasive blasted with a 40/50 mix of steel grit to SSPC SP 10.</p>  |
| <p><u>Method 6 - Salt-Away, Air/Water/Mineral Slag</u> - Salt-Away mixed at 256:1 ratio applied to steel surface then flushed with distilled water then dried, 340 cfm air compressor, 60 psi water injected into air/abrasive stream (via water ring), Abrasive was medium mineral slag. Cleaned to SP 10.</p> |
| <p><u>Method 7 - Hot Wash, Steel Grit 40/50/120 Mix</u> - Washed at 4,000 to 5,000 psi, 160 ° F at 4 gal/min, 5 sec/side, 0 degree spinner tip dried and stored in closed container, Abrasive blasted with a 40/50/120 mix of steel grit to SP 10.</p>  |
| <p><u>Method 8 - Chlor-rid/Steel Grit 40/50 Mix</u> - Chlor-rid mixed at 100:1 ratio applied to steel surface then flushed with distilled water then dried, Abrasive blasted with a 40/50 mix of steel grit to SSPC SP 10.</p>  |
| <p><u>Method 9 - Salt-Away, Steel Grit 40/50/120 Mix</u> - Salt-Away mixed at 256:1 ratio applied to steel surface then flushed with distilled water then dried, Abrasive blasted with a 40/50/120 mix of steel grit to SSPC SP 10.</p>   |
| <p><u>Method 10 - Hot Wash, Mineral Slag</u> - Washed at 4,000 to 5,000 psi, 160 ° F at 4 gal/min, 5 sec/side, 0 degree spinner tip dried and stored in closed container, Abrasive blasted with a medium mineral slag to SP 10.</p>   |
| <p><u>Method 11 - Chlor-rid/Mineral Slag</u> - Chlor-rid mixed at 100:1 ratio applied to steel surface then flushed with distilled water then dried, Abrasive blasted with a medium mineral slag to SSPC SP 10.</p>   |
| <p><u>Method 12 – Hot Wash 7,000 psi, Steel Grit 40/50/120 Mix</u> - Washed at 7,000 psi, 190 ° F at 3 gal/min, 5 sec/side, 0 degree spinner tip dried and stored in closed container, Abrasive blasted with a 40/50/120 mix of steel grit to SSPC SP 10</p>  |
| <p><u>Method 13 - Wash, Mineral Slag</u> - Washed at 4,000 to 5,000 psi, 50 to 60 ° F at 6 gal/min, 5 sec/side, 0 degree spinner tip dried and stored in closed container, Abrasive blasted with a medium mineral slag to SSPC SP 10.</p>   |
| <p><u>Method 14 - Hot Wash 7,000 psi, Mineral Slag</u> - Washed at 7,000 psi, 190 ° F at 3 gal/min, 5 sec/side, 0 degree spinner tip dried and stored in closed container, Abrasive blasted with a medium mineral slag to SSPC SP 10.</p>   |
| <p><u>Method 15 - Salt-Away, Mineral Slag</u> - Salt-Away – Mineral - Salt-Away mixed at 256:1 ratio applied to steel surface then flushed with distilled water then dried, Abrasive blasted with a medium mineral slag to SSPC SP 10.</p>  |

Method 16 - Chlor-rid Steel Grit 40/50/120 Mix - Chlor-rid mixed at 100:1 ratio applied to steel surface then flushed with distilled water then dried, Abrasive blasted with a 40/50/120 mix of steel grit to SSPC SP 10.

Method 17 - Salt-Away, Steel Grit 40/50 Mix – Salt-Away mixed at 256:1 ratio applied to steel surface then flushed with distilled water then dried, Abrasive blasted with a 40/50 mix of steel grit to SP 10.

Method 18 - Water Jetting - Washed at 15,000 to 20,000 psi , 3 gal/min, 0 degree spinner tip, 5 sec/side

Method 19 - Wash 4-5,000 psi, Steel Grit 40/50/120 Mix - Washed at 50 to 60 ° F at 6 gal/min, 5 sec/side, 0 degree spinner tip dried and stored in closed container, Abrasive blasted with a 40/50/120 mix of steel grit to SSPC SP 10.

Method 20 – Hot Wash 7,000 psi, Steel Grit 40/50 Mix - Washed at 190 ° F at 3 gal/min, 5 sec/side, 0 degree spinner tip dried and stored in closed container, Abrasive blasted with a 40/50 mix of steel grit to SSPC SP 10

Method 21 - Air/Water/Abrasive Mineral Slag - 340 cfm air compressor, 60 psi water injected into air/abrasive stream (via water ring), Abrasive was medium mineral slag. Cleaned to SSPC SP 10.

Method 22 - Chlor-rid, Water Jetting – Chlor-rid mixed at 100:1 ratio applied to steel surface then flushed with distilled water then dried. Washed at 15,000 to 20,000 psi , 3 gal/min, 0 degree spinner tip, 5 sec/side

Method 23 - Wash 4-5,000 psi, Steel Grit 40/50 Mix - Washed at 50 to 60 ° F at 6 gal/min, 5 sec/side, 0 degree spinner tip dried and stored in closed container, Abrasive blasted with a 40/50 mix of steel grit to SSPC SP 10.

Method 24 - Chlor-rid Air/Water/Mineral Slag – Chlor-rid mixed at 100:1 ratio applied to steel surface then flushed with distilled water then dried, 340 cfm air compressor, 60 psi water injected into air/abrasive stream (via water ring), Abrasive was medium mineral slag. Cleaned to SSPC SP 10.

Method 25 – Steel Grit 40/50 Mix Blast/Flash Rust/ Re-blast 3 Times - Surface was abrasive blast cleaned to SSPC SP 10 three times. After each cleaning, panels were stored overnight at ambient conditions to allow flash rusting between cleaning..

Method 26 - Steel Grit 40/50 Mix Blast/Flash Rust/Re-blast 2 Times - Surface was abrasive blast cleaned to SSPC SP 10 two times. After each cleaning, panels were stored overnight at ambient conditions to allow flash rusting between cleaning.

Method 27 - Steel Grit 40/50 Mix Blast/Flash Rust/Re-blast 4 Times – Surface was abrasive blast cleaned to SSPC 10 four times. After each cleaning, panels were stored overnight at ambient conditions to allow flash rusting between cleaning.

Method 28 - Crushed Glass – Surface was abrasive blast cleaned with a mix (equal parts 50/80 and 10/40 grit) glass to SSPC SP 10. Compressor rated at 120 psi at 100 cfm.

Method 29- Steel Grit 40/50/120 Mix - Surface was abrasive blast cleaned to SSPC SP 10 using a steel grit mix of 40/50/120. Compressor rated at 120 psi at 100 cfm.

Method 30 - Mineral Slag - Surface was abrasive blast cleaned to SSPC SP 10. Compressor rated at 120 psi at 100 cfm.

Method 31 - Aluminum Oxide - Surface was abrasive blast cleaned with a mix (equal parts 40/80/100 grit) aluminum oxide to SSPC SP 10. Compressor rated at 120 psi at 100 cfm.

Method 32 - Steel Grit 40/50 Mix - Surface was abrasive blast cleaned to SSPC SP 10 using a 40/50 mix of steel grit. Compressor rated at 120 psi at 100 cfm.

Table 2. Effectiveness of wet surface preparation methods in removing chloride contamination.

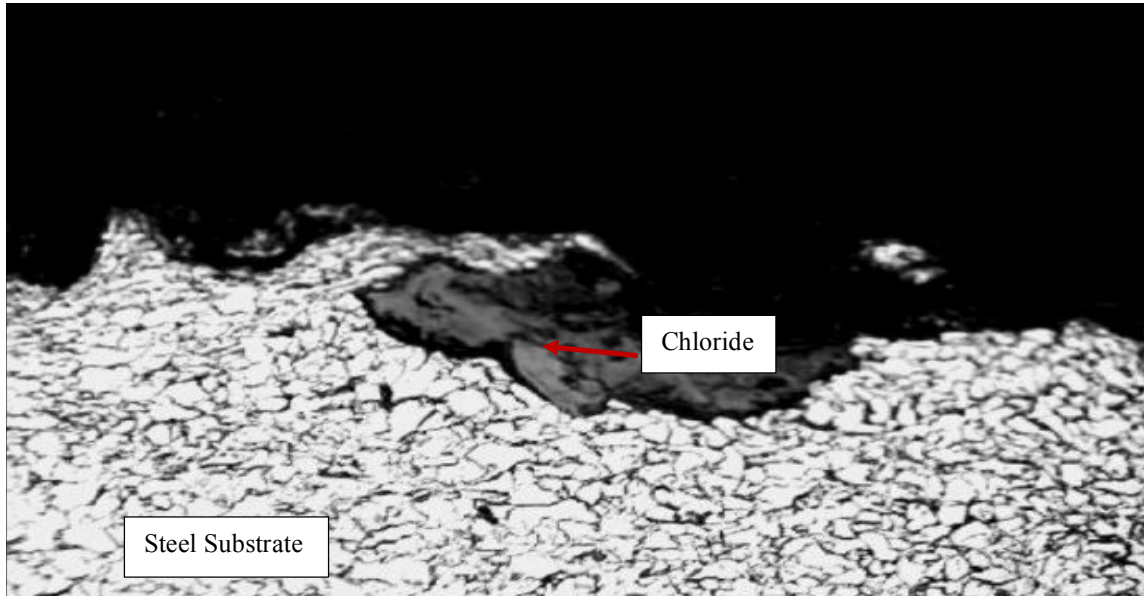
| Wet Surface Preparation Method                   | Pre-Cleaning Chloride Contamination $\mu\text{g}/\text{cm}^2$ | Post Cleaning Chloride Contamination $\mu\text{g}/\text{cm}^2$ | Cleaning Effectiveness % Chloride Remaining |
|--|---|--|---|
| 1. Chlor-rid Water/Mineral Slag                  | 699.9   | 5.3  | 0.8   |
| 2. Salt-Away Water/Mineral Slag                  | 719.9   | 6.4  | 0.9   |
| 3. Water / Mineral Slag                          | 602.6   | 5.4  | 0.9   |
| 4. Salt-Away Water Jetting                       | 679.3   | 10.3   | 1.5   |
| 5. Hot Wash, Steel Grit 40/50 Mix                | 402.2   | 6.4  | 1.6   |
| 6. Salt-Away, Air/Water/Mineral Slag             | 741.1   | 13.3   | 1.8   |
| 7. Hot Wash, Steel Grit 40/50/120 Mix            | 498.9   | 9.3  | 1.9   |
| 8. Chlor-rid/Steel Grit 40/50 Mix                | 404.7   | 7.9  | 1.9   |
| 9. Salt-Away, Steel Grit 40/50/120 Mix           | 676.7   | 13.3   | 2.0   |
| 10. Hot Wash, Mineral Slag                       | 519.0   | 10.3   | 2.0   |
| 11. Chlor-rid/Mineral Slag                       | 508.0   | 10.3   | 2.0   |
| 12. Hot Wash 7,000 psi, Steel Grit 40/50/120 Mix | 446.5   | 10.3   | 2.3   |
| 13. Wash, Mineral Slag                           | 471.3   | 13.3   | 2.8   |
| 14. Hot Wash 7,000 psi, Mineral Slag             | 431.2   | 12.3   | 2.9   |
| 15. Salt-Away, Mineral Slag                      | 567.2   | 17.6   | 3.1   |
| 16. Chlor-rid Steel Grit 40/50/120 Mix           | 570.2   | 17.8   | 3.1   |
| 17. Salt-Away, Steel Grit 40/50 Mix              | 492.9   | 16.0   | 3.3   |
| 18. Water Jetting                                | 437.5   | 14.2   | 3.3   |
| 19. Wash 4-5,000 psi, Steel Grit 40/50/120 Mix   | 461.5   | 15.4   | 3.3   |
| 20. Hot Wash 7,000 psi, Steel Grit 40/50 Mix     | 400.9   | 13.9   | 3.5   |
| 21. Air/Water/Abrasive Mineral Slag              | 384.6   | 13.4   | 3.5   |
| 22. Chlor-rid, Water Jetting                     | 309.2   | 11.1   | 3.6   |
| 23. Wash 4-5,000 psi, Steel Grit 40/50 Mix       | 421.4   | 17.1   | 4.1   |
| 24. Chlor-rid Air/Water/Mineral Slag             | 372.0   | 15.6   | 4.2   |



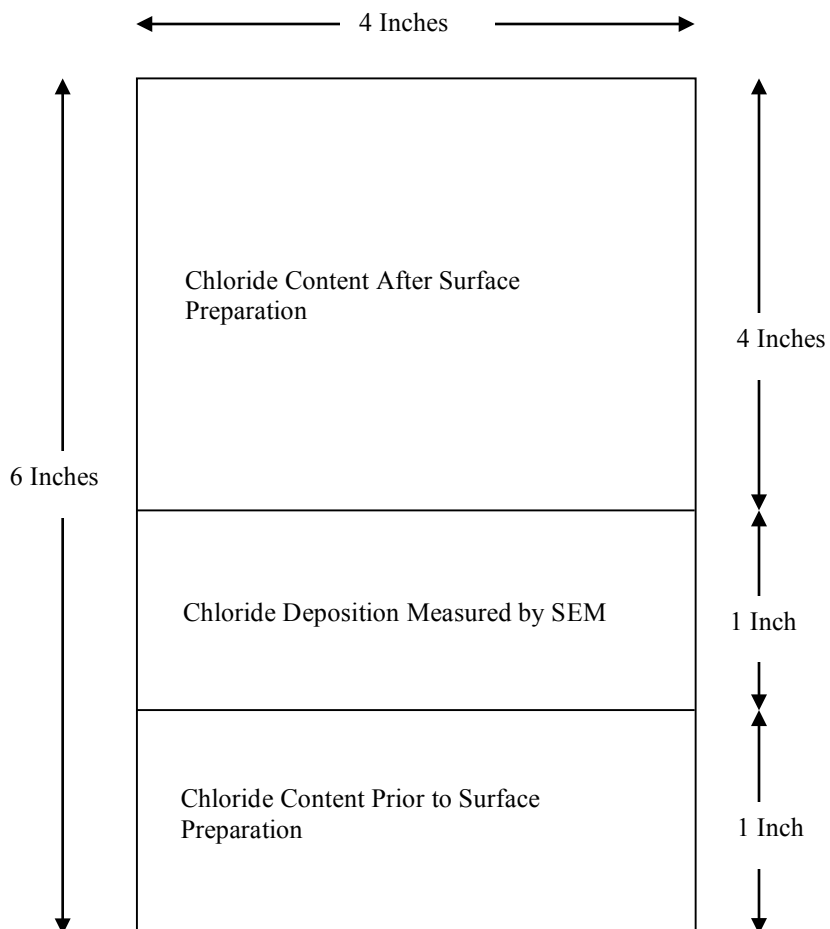
Table 3. Effectiveness of dry surface preparation methods in removing chloride contamination.

| Dry Surface Preparation Method                             | Pre-Cleaning Chloride Contamination $\mu\text{g}/\text{cm}^2$ | Post Cleaning Chloride Contamination $\mu\text{g}/\text{cm}^2$ | Cleaning Effectiveness % Chloride Remaining |
|--|---|--|---|
| 25. Steel Grit 40/50 Mix Blast/Flash Rust/Re-blast 3 Times | 480.6   | 7.5  | 1.6   |
| 26. Steel Grit 45/50 Mix Blast/Flash Rust/Re-blast 2 Times | 505.4   | 7.9  | 1.6   |
| 27. Steel Grit 45/50 Mix Blast/Flash Rust/Re-blast 4 Times | 307.7   | 6.1  | 2.0   |
| 28. Crushed Glass  | 693.8   | 20.5   | 3.0   |
| 29. Steel Grit 40/50/120 Mix                               | 527.8   | 17.6   | 3.3   |
| 30. Mineral Slag   | 497.2   | 17.2   | 3.5   |
| 31. Aluminum Oxide   | 667.3   | 23.9   | 3.6   |
| 32. Steel Grit 40/50 Mix                                   | 323.6   | 21.2   | 6.5   |

## FIGURES



**Figure 1. Chloride in occlusion of abrasive blast cleaned steel (Ref. 1).**



**Figure 2. Apportionment of steel panels for laboratory analyses.**



**Figure 3. Steel panels with mill scale removed by grinding prior to preconditioning.**



**Figure 4. Panels with rust and chloride contamination after preconditioning.**



**Figure 5. SSPC SP2 cleaning of panels with dull scraper.**



**Figure 6. SSPC SP2 cleaning of panels with wire brush.**



**Figure 7. SSPC SP2 D condition prior to surface preparation.**



**Figure 8. Boiling extraction to measure chloride of three panel segments.**



**Figure 9. Pressure washing surface preparation.**



**Figure 10. Cleanliness condition SSPC SP 10 after dry surface preparation methods.**



**Figure 11. Cleanliness condition SSPC VIS4 WJ-1 after wet surface preparation methods.**

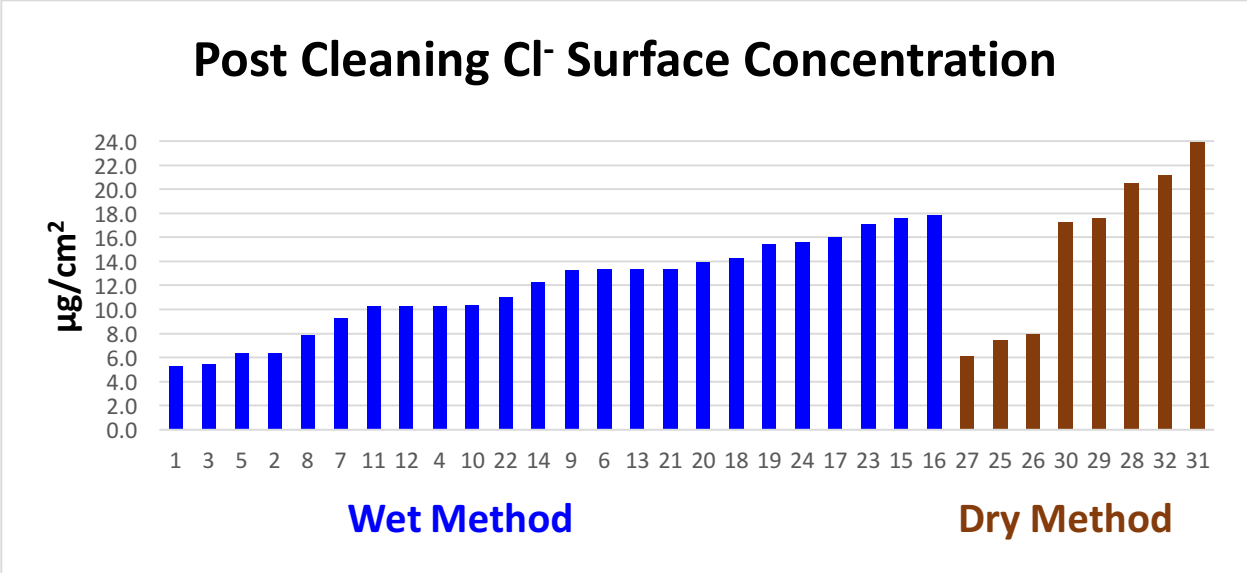


Figure 12. Chloride remaining on panel surface after surface preparation.

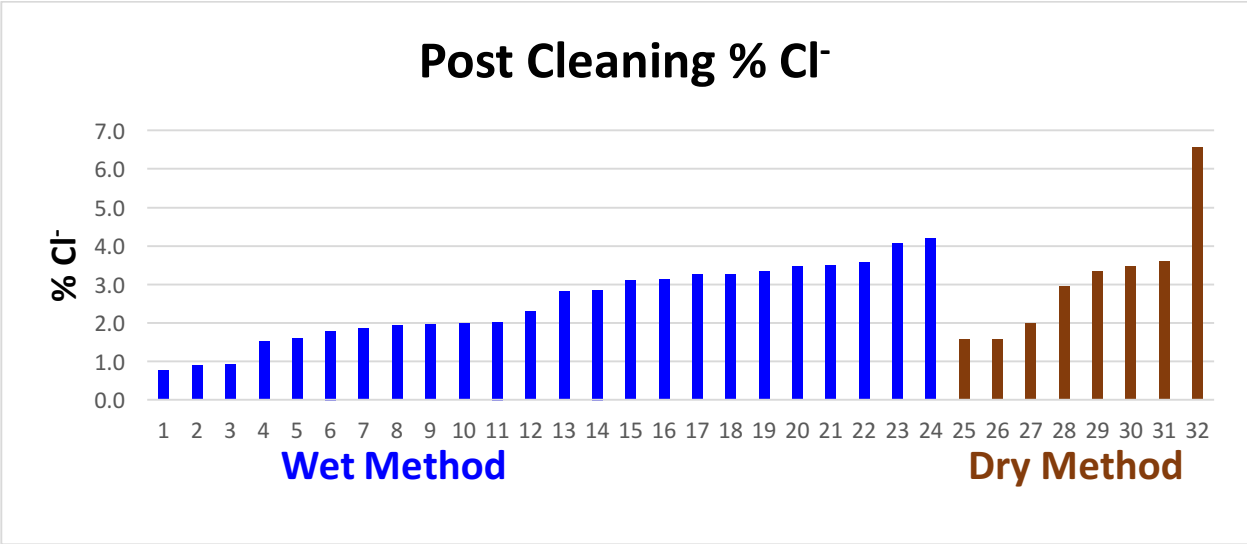


Figure 13. Effectiveness of surface preparations by percent chloride remaining.

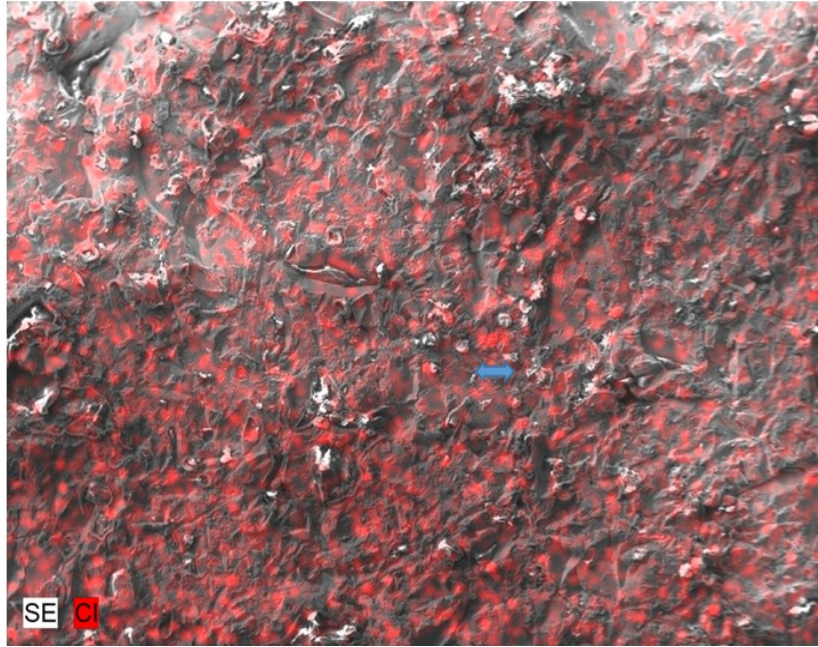
## **APPENDIX A**

Scanning Electron Microscope Pictures of Prepared Surfaces  
Showing Chloride “HOT SPOTS”



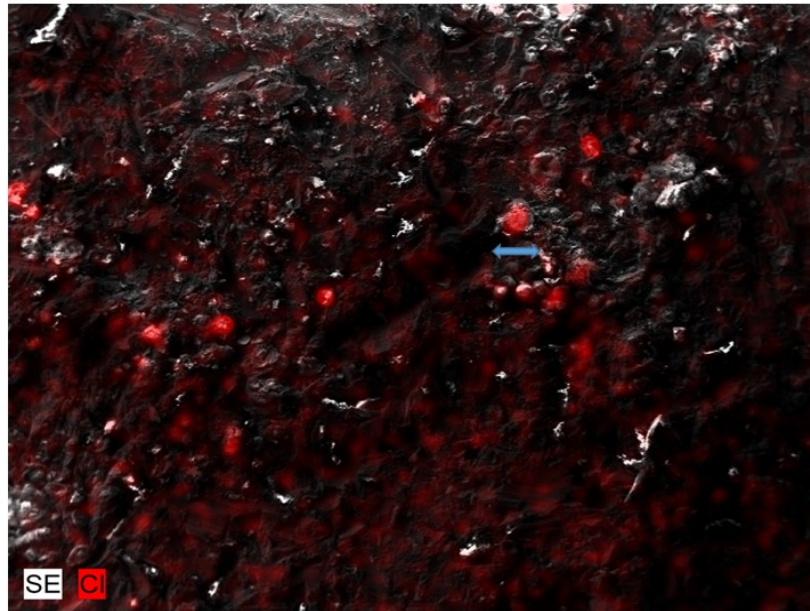
## Chlor-Rid Water/Abrasive

1. Map is 184 mils x 138 mils.
2. Spot is 5.3 mils across the horizontal axis.
3. Chloride removed – 99.2%
4. Chloride – 5.3  $\mu\text{g}/\text{cm}^2$



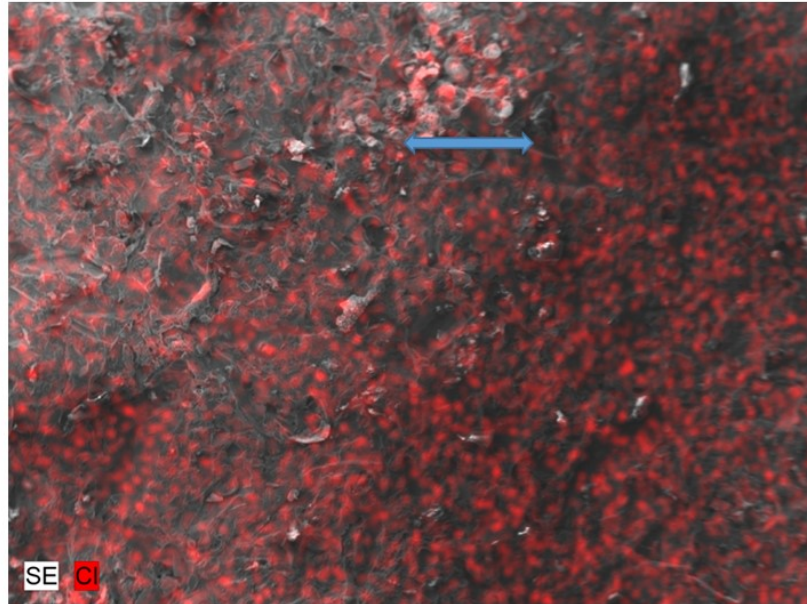
## Salt-Away Water/Abrasive

1. Map is 73 mils x 59 mils.
2. Spot is 4.7 mils across the horizontal axis.
3. Chloride removed – 99.1%
4. Chloride – 6.4  $\mu\text{g}/\text{cm}^2$



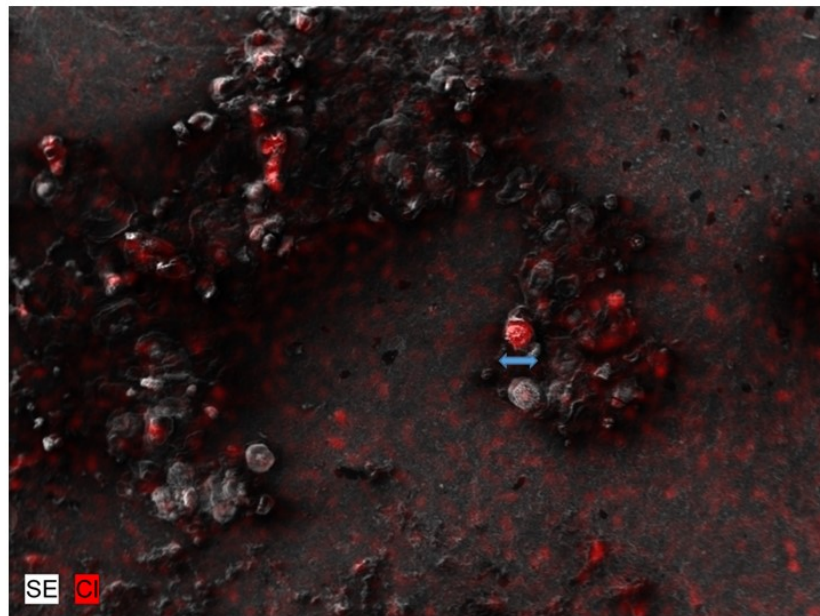
## Water/Abrasive

1. Map is 186 mils x 140 mils.
2. Spot is 34.7 mils across the horizontal axis.
3. Chloride removed – 99.1%
4. Chloride –  $5.4 \mu\text{g}/\text{cm}^2$



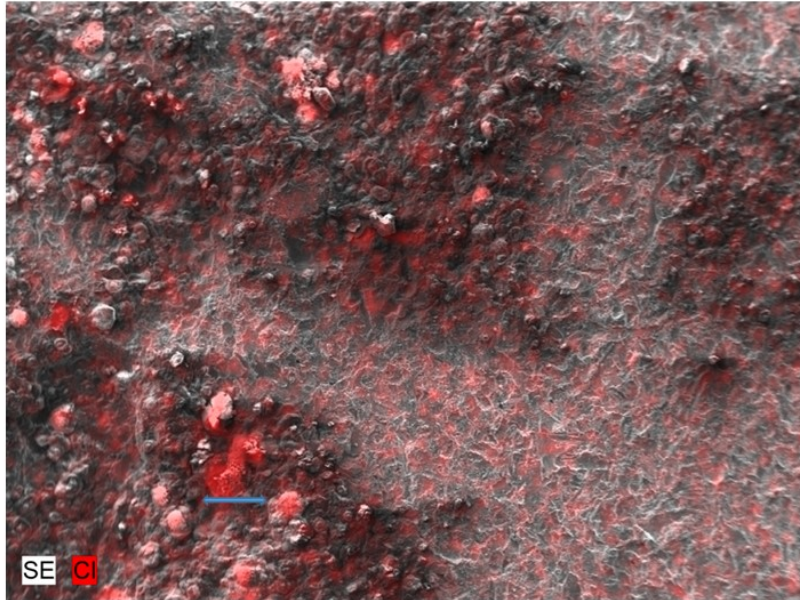
## Salt-Away Water Jetting

1. Map is 50 mils x 37.5 mils.
2. Spot is 2.25 mils across the horizontal axis.
3. Chloride removed – 98.5%
4. Chloride –  $10.3 \mu\text{g}/\text{cm}^2$



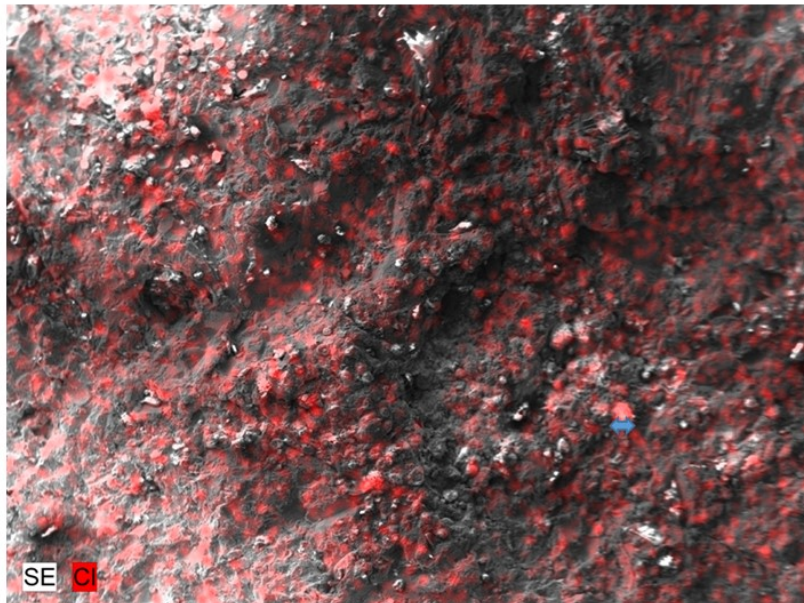
## 185°F 3.5k psi wash, Steel Grit 40/50

1. Map is 63 mils x 49 mils.
2. Spot is 5.5 mils across the horizontal axis.
3. Chloride removed – 98.4%
4. Chloride – 6.4  $\mu\text{g}/\text{cm}^2$



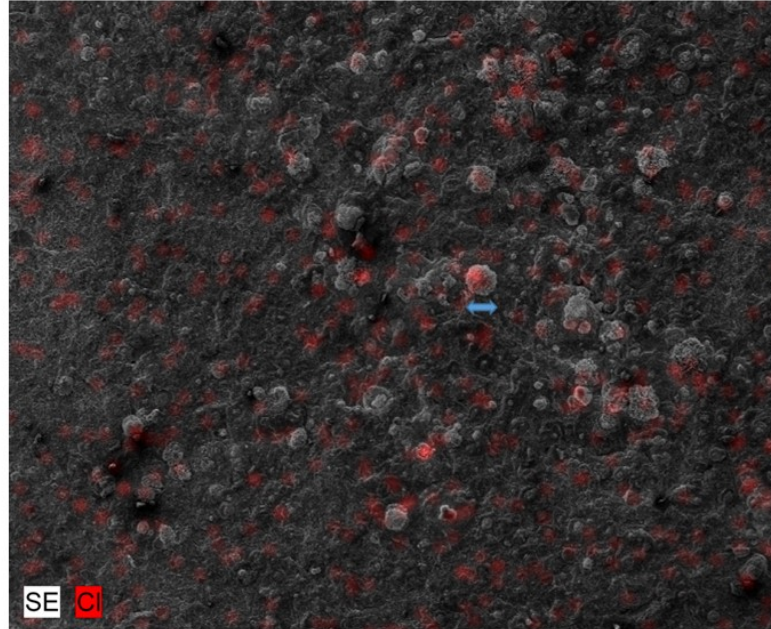
## Salt-Away Air/Water/Abrasive

1. Map is 182 mils x 140 mils.
2. Spot is 5.1 mils across the horizontal axis.
3. Chloride removed – 98.2%
4. Chloride – 13.3  $\mu\text{g}/\text{cm}^2$



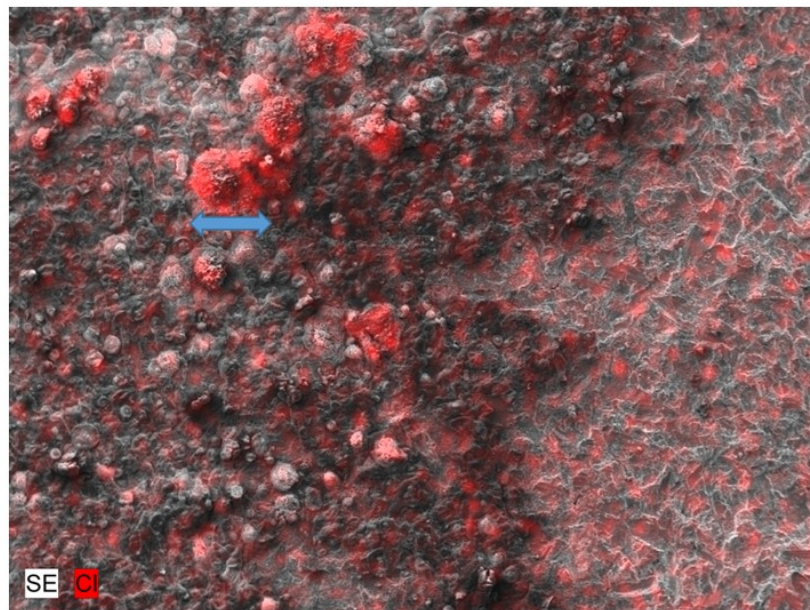
## 160°F 7K psi wash, Steel Grit 40/50/120

1. Map is 102 mils x 82 mils.
2. Spot is 11.4 mils across the horizontal axis.
3. Chloride removed – 98.1%
4. Chloride – 9.3  $\mu\text{g}/\text{cm}^2$



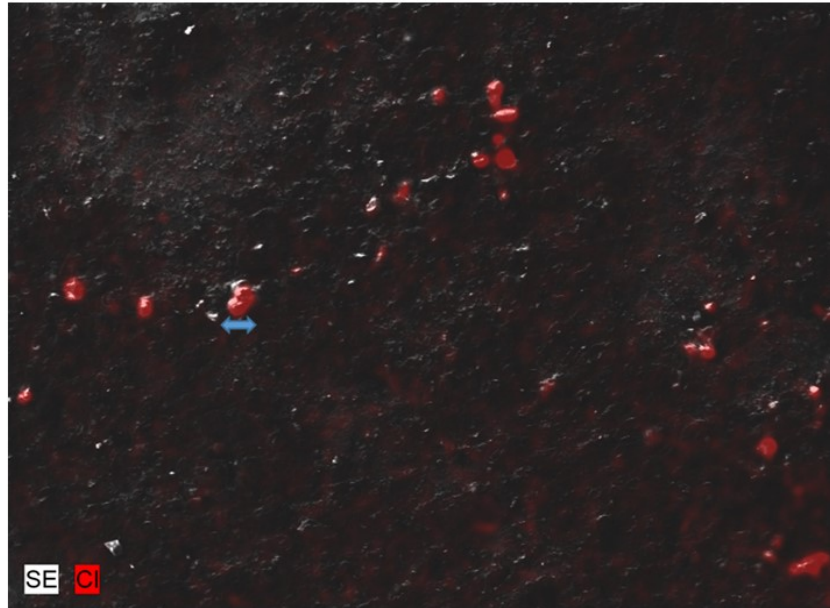
## Chlor-Rid Steel Grit 40/50

1. Map is 49 mils x 37 mils.
2. Spot is 3.6 mils across the horizontal axis.
3. Chloride removed – 98.1%
4. Chloride – 7.9  $\mu\text{g}/\text{cm}^2$



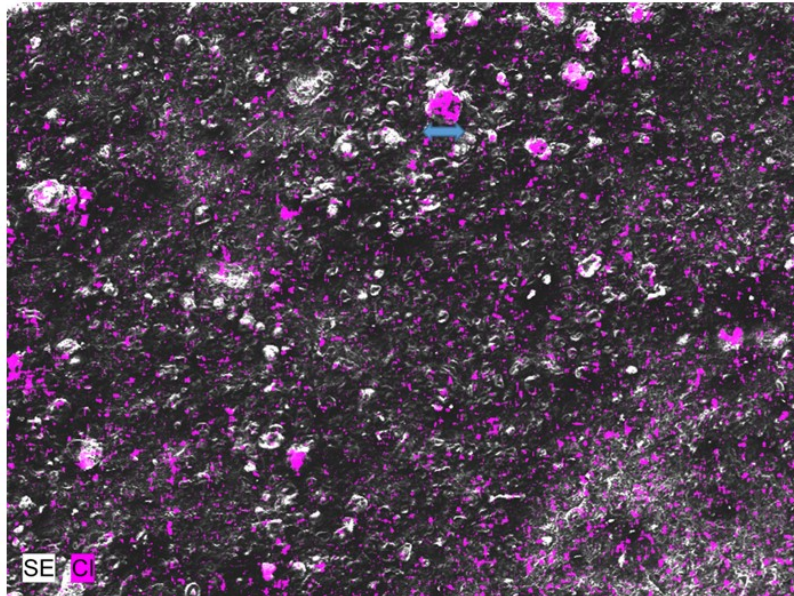
## Salt-Away Steel Grit 40/50/120

1. Map is 54 mils x 40.5 mils.
2. Spot is 4.5 mils across the horizontal axis.
3. Chloride removed – 98.0%
4. Chloride – 13.3  $\mu\text{g}/\text{cm}^2$



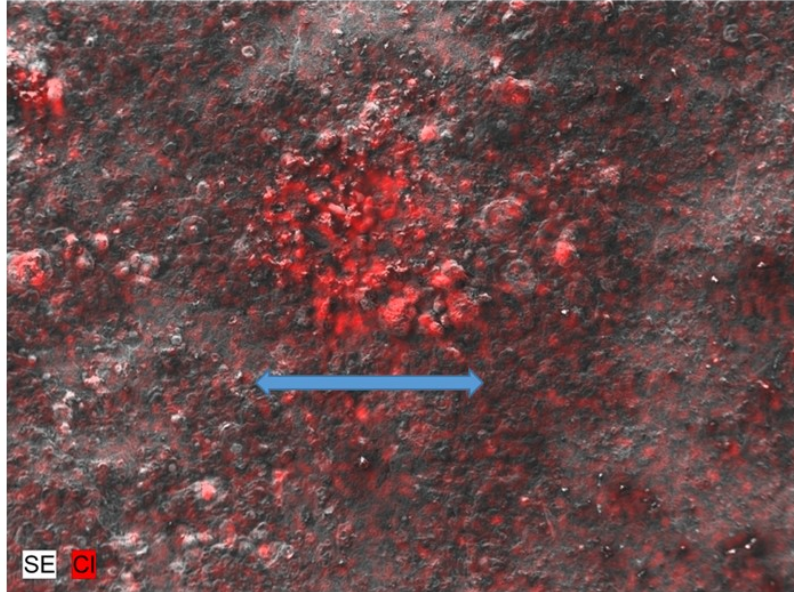
## 160°F 7k psi wash, Mineral Slag

1. Map is 94 mils x 65 mils.
2. Spot is 4.7 mils across the horizontal axis.
3. Chloride removed – 98.0%
4. Chloride – 10.3  $\mu\text{g}/\text{cm}^2$



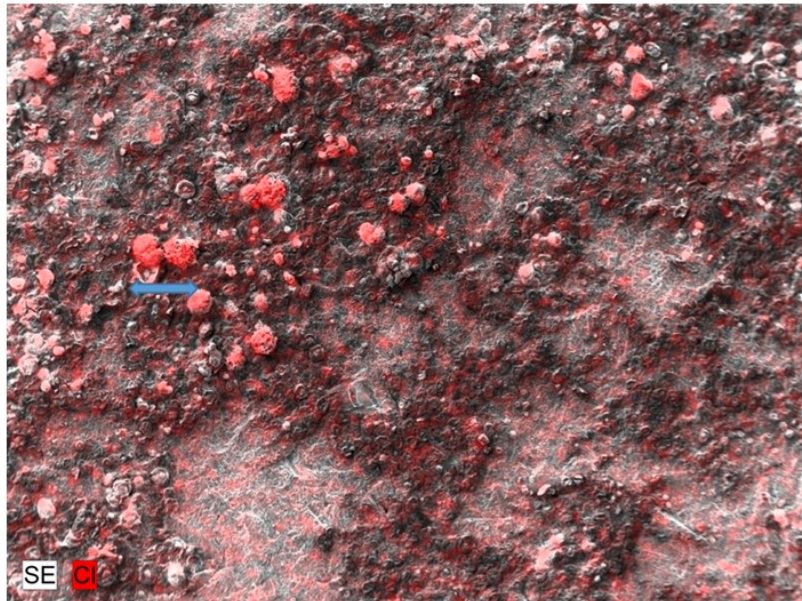
## Chlor-Rid Mineral Slag

1. Map is 117 mils x 88 mils.
2. Spot is 30.0 mils across the horizontal axis.
3. Chloride removed – 98.0%
4. Chloride – 10.3  $\mu\text{g}/\text{cm}^2$



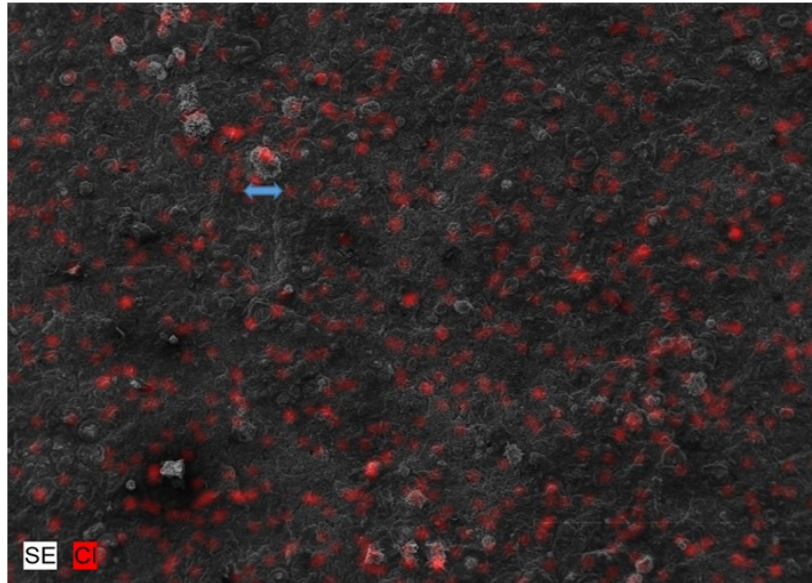
## 185°F 7k psi wash, Steel Grit 40/50/120

1. Map is 63 mils x 50 mils.
2. Spot is 5.5 mils across the horizontal axis.
3. Chloride removed – 97.7%
4. Chloride – 10.3  $\mu\text{g}/\text{cm}^2$



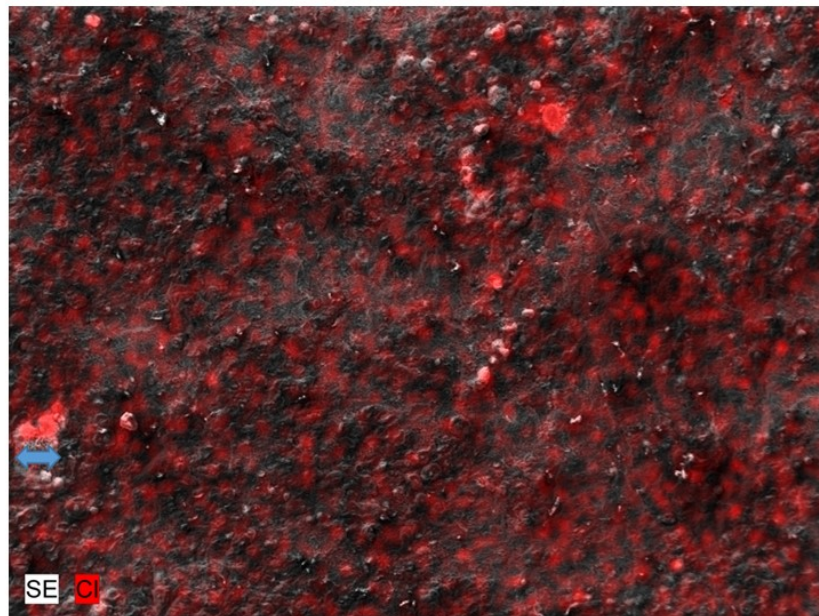
## 4.8K psi wash, Mineral Slag

1. Map is 86 mils x 57 mils.
2. Spot is 3.6 mils across the horizontal axis.
3. Chloride removed – 97.2%
4. Chloride – 13.3  $\mu\text{g}/\text{cm}^2$



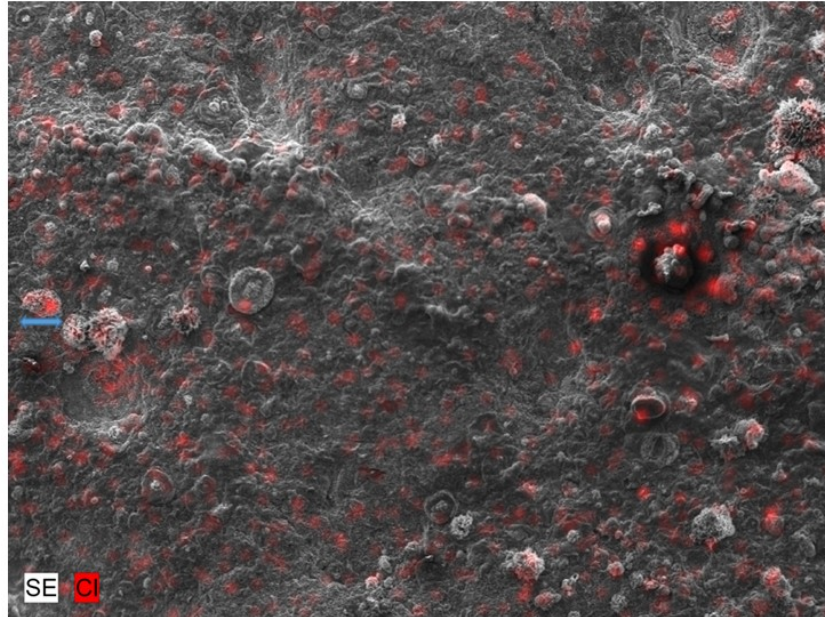
## 185°F 7k psi wash, Mineral Slag

1. Map is 50 mils x 37 mils.
2. Spot is 3.5 mils across the horizontal axis.
3. Chloride removed – 97.1%
4. Chloride – 12.3  $\mu\text{g}/\text{cm}^2$



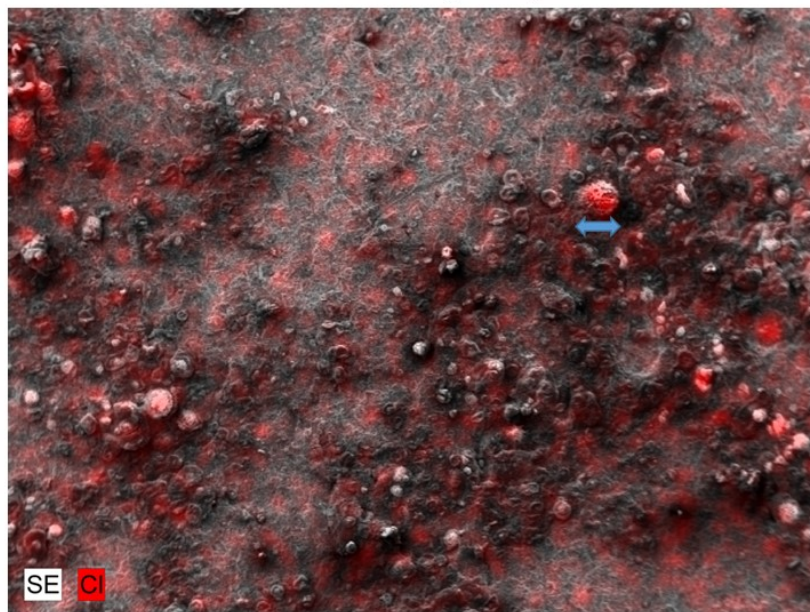
## SaltAway Mineral Slag

1. Map is 80 mils x 59 mils.
2. Spot is 4.8 mils across the horizontal axis.
3. Chloride removed – 96.9%
4. Chloride – 17.6  $\mu\text{g}/\text{cm}^2$



## Chlor-Rid Steel Grit 40/50/120

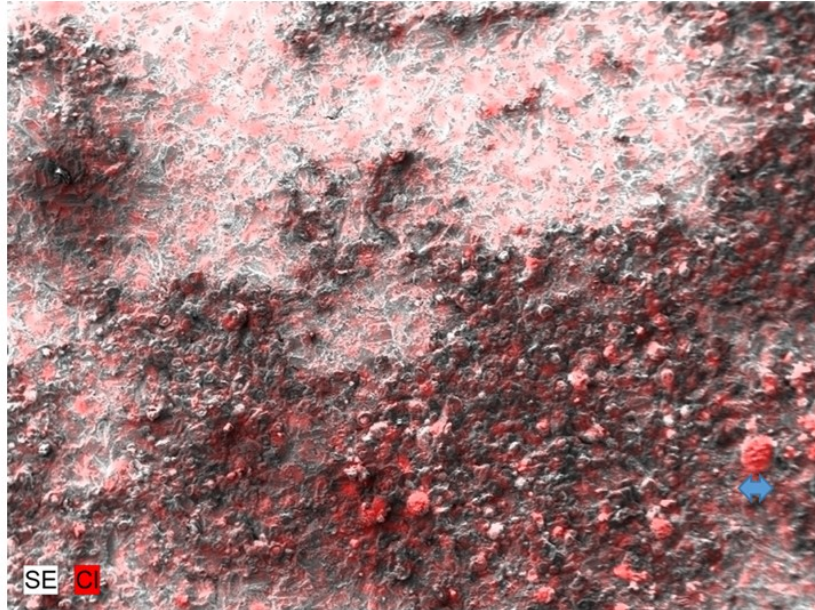
1. Map is 91 mils x 66 mils.
2. Spot is 4.4 mils across the horizontal axis.
3. Chloride removed – 96.9%
4. Chloride – 17.8  $\mu\text{g}/\text{cm}^2$





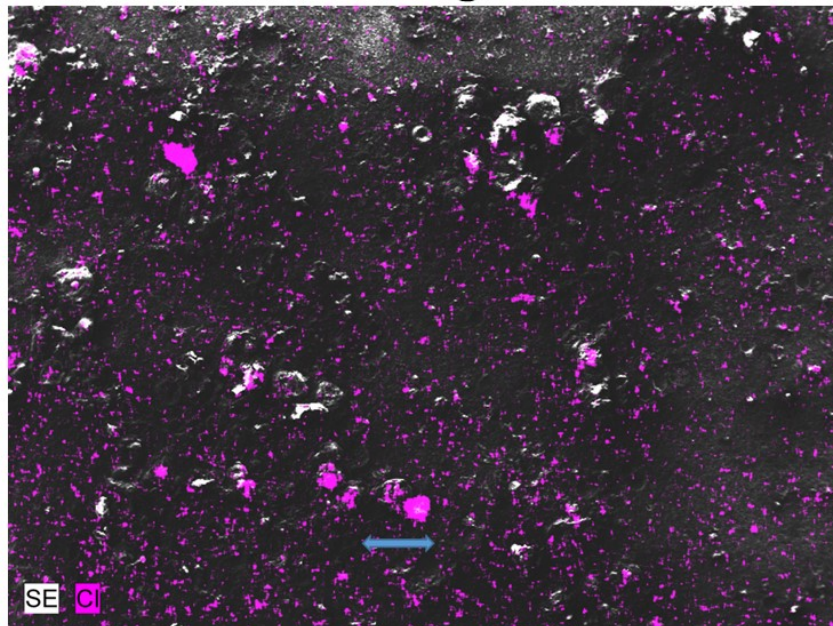
## Salt-Away Steel Grit 40/50

1. Map is 67 mils x 50 mils.
2. Spot is 2.7 mils across the horizontal axis.
3. Chloride removed – 96.7%
4. Chloride – 16.0  $\mu\text{g}/\text{cm}^2$



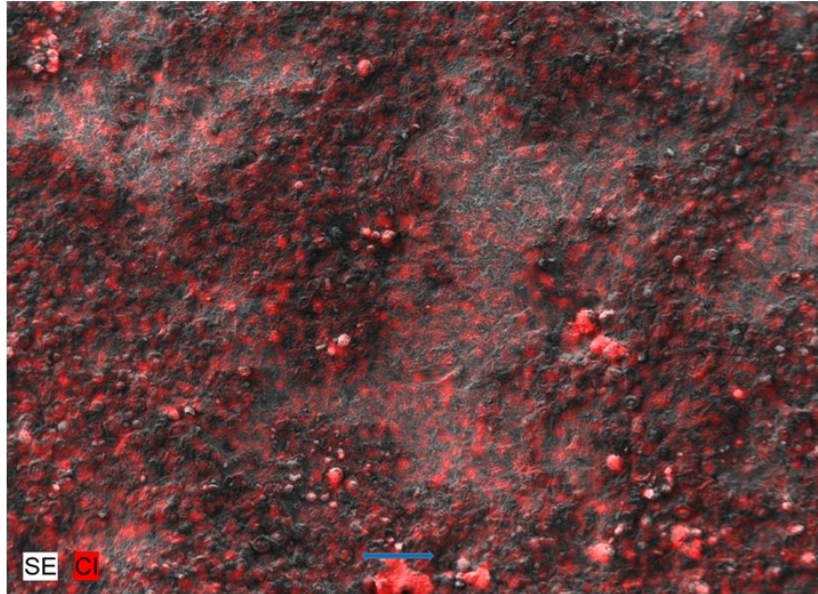
## Water Jetting

1. Map is 98 mils x 65 mils.
2. Spot is 6.5 mils across the horizontal axis.
3. Chloride removed – 96.7%
4. Chloride – 14.2  $\mu\text{g}/\text{cm}^2$



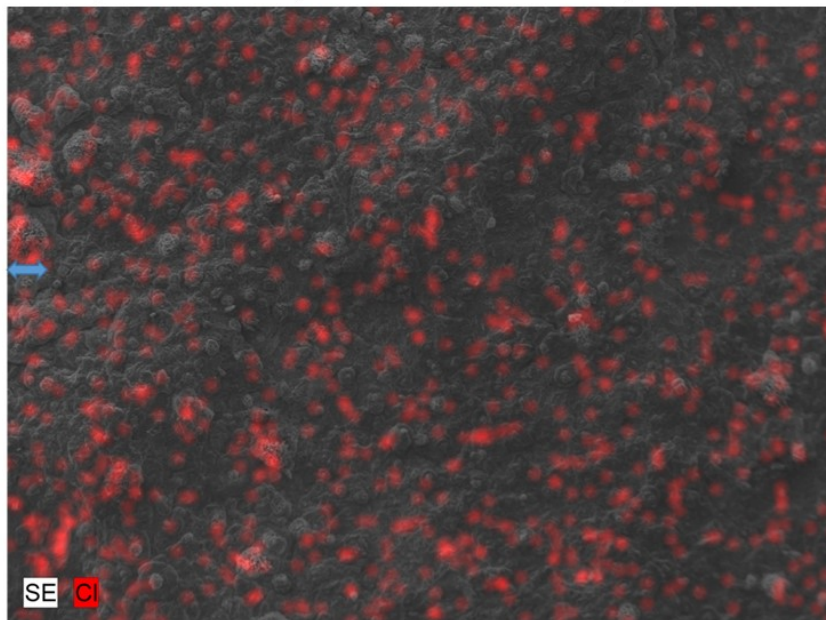
## 4.8K psi wash, Steel Grit 40/50/120

1. Map is 66 mils x 50 mils.
2. Spot is 5.0 mils across the horizontal axis.
3. Chloride removed – 96.7%
4. Chloride – 15.4  $\mu\text{g}/\text{cm}^2$



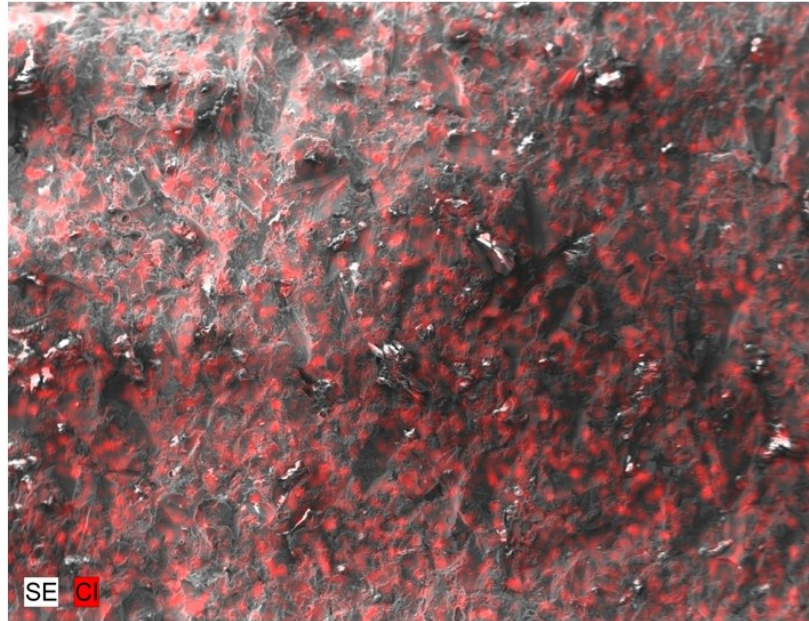
## 160°F 7K psi wash, Steel Grit 40/50

1. Map is 86 mils x 60 mils.
2. Spot is 8.0 mils across the horizontal axis.
3. Chloride removed – 96.5%
4. Chloride – 13.9  $\mu\text{g}/\text{cm}^2$



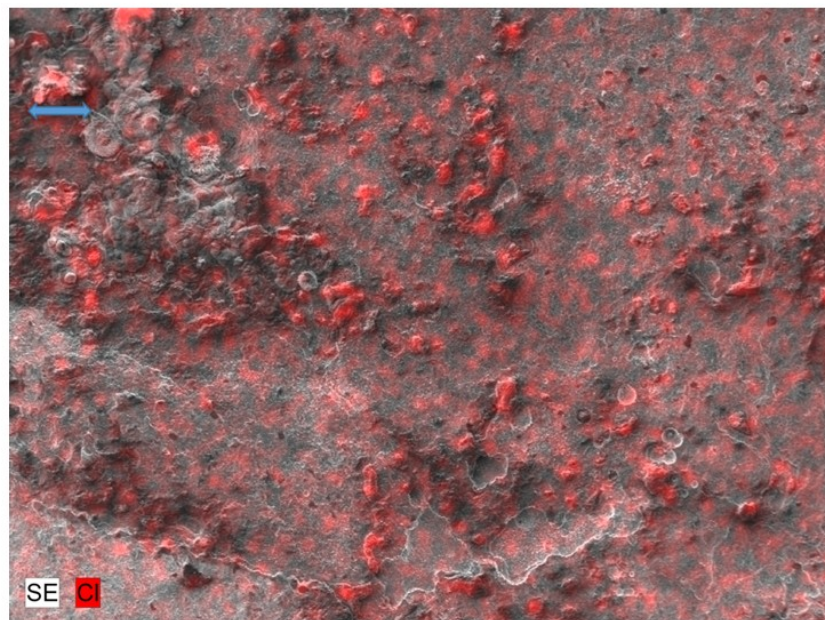
## Air Water Abrasive Mineral Slag

1. Map is 186 mils x 150 mils.
2. No distinctive chloride spot.
3. Chloride removed – 96.5%
4. Chloride – 13.4  $\mu\text{g}/\text{cm}^2$



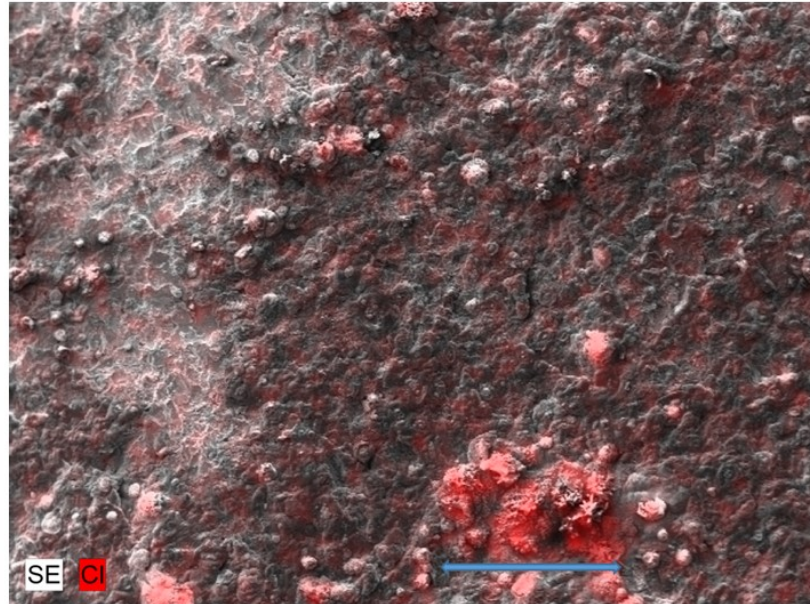
## Chlor-Rid Water Jetting

1. Map is 49 mils x 37 mils.
2. Spot is 4.3 mils across the horizontal axis.
3. Chloride removed – 96.4%
4. Chloride – 11.1  $\mu\text{g}/\text{cm}^2$



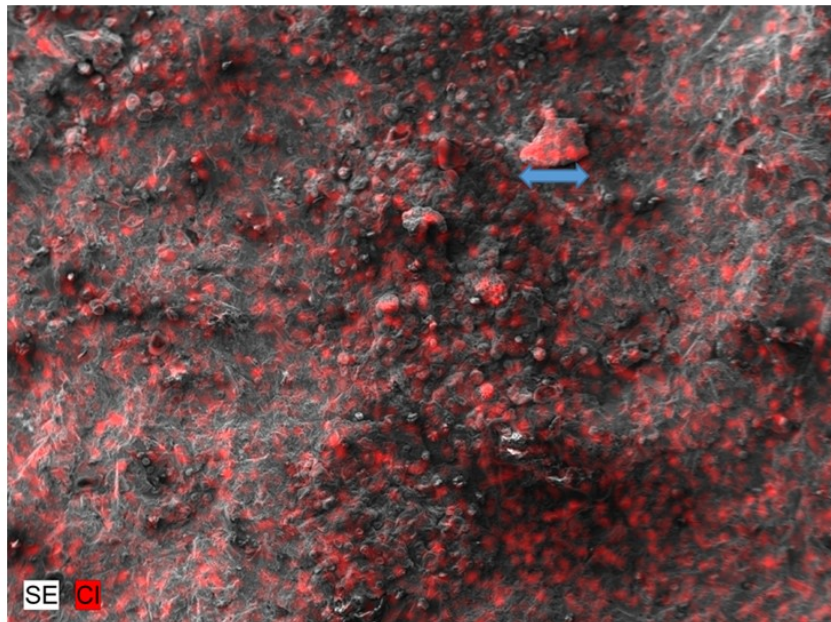
## 4.8K psi wash, Steel Grit 40/50

1. Map is 86 mils x 60 mils.
2. Spot is 18.1 mils across the horizontal axis.
3. Chloride removed – 95.9%
4. Chloride – 17.1  $\mu\text{g}/\text{cm}^2$



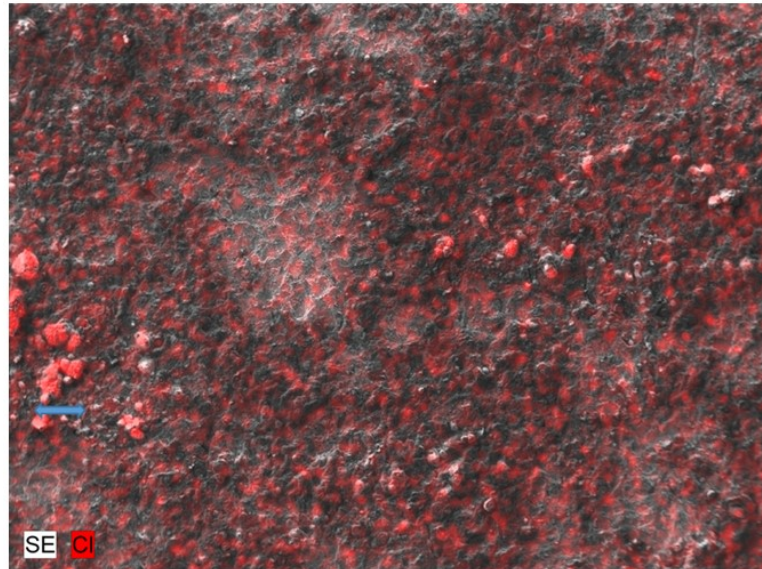
## Chlor-Rid Air/Water/Abrasive

1. Map is 186 mils x 140 mils.
2. Spot is 18.0 mils across the horizontal axis.
3. Chloride removed – 95.8%
4. Chloride – 15.6  $\mu\text{g}/\text{cm}^2$



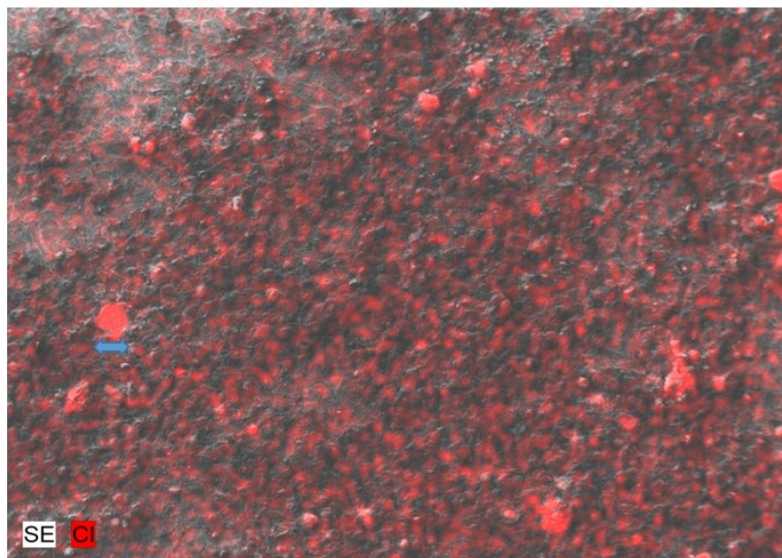
## Steel Grit 40/50 – Blast/flash/reblast, 3 Times

1. Map is 112 mils x 89 mils.
2. Spot is 6.8 mils across the horizontal axis.
3. Chloride removed – 98.4%
4. Chloride - 7.5  $\mu\text{g}/\text{cm}^2$



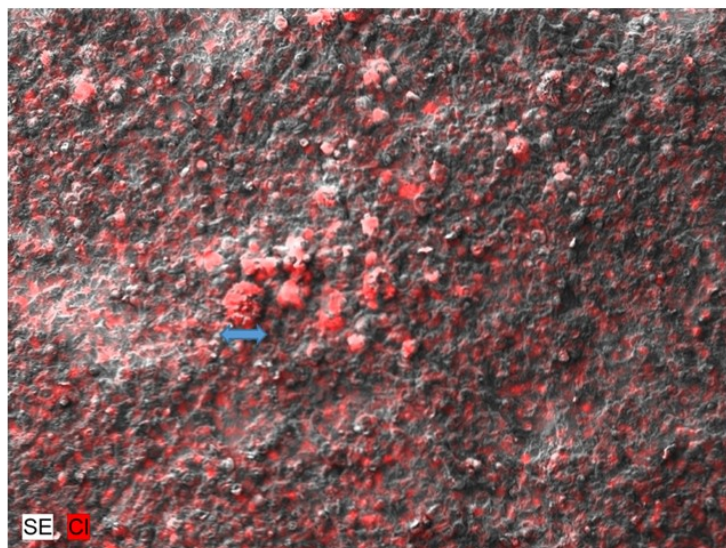
## Steel Grit 40/50 – Blast/flash/reblast, 2 Times

1. Map is 116 mils x 87 mils.
2. Spot is 6 mils across the horizontal axis.
3. Chloride removed – 98.4%
4. Chloride – 7.9  $\mu\text{g}/\text{cm}^2$



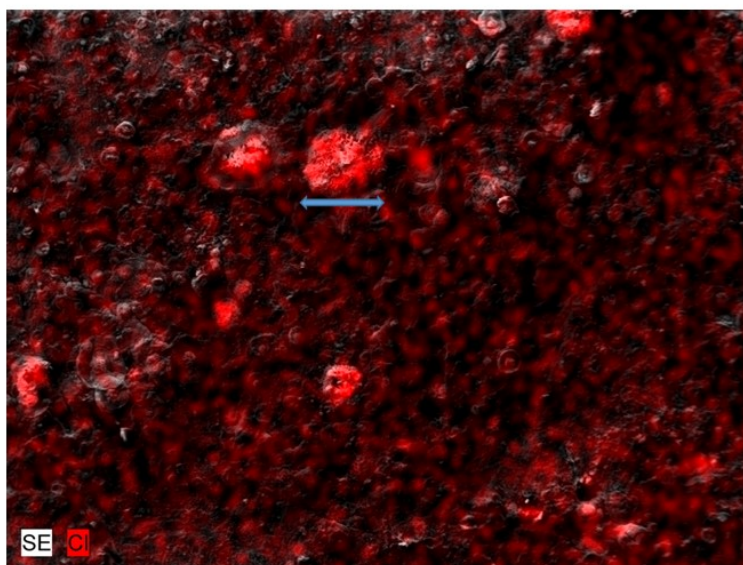
## Steel Grit 40/50 – Blast/flash/Reblast, 4 Times

1. Map is 190 mils x 144 mils .
2. Spot is 10.2 mils across the horizontal axis.
3. Chloride removed – 98.0%
4. Chloride – 6.1  $\mu\text{g}/\text{cm}^2$



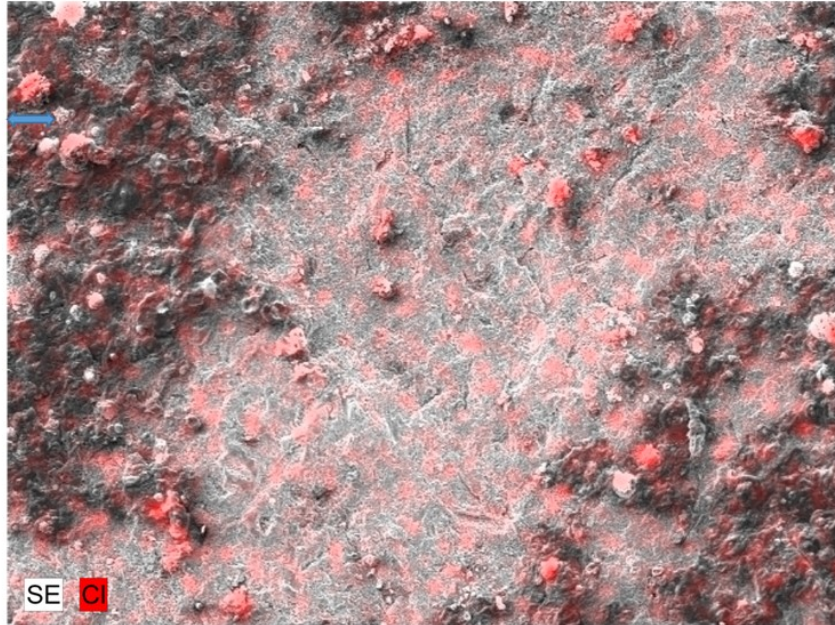
## Crushed Glass

1. Map is 88 mils x 62 mils .
2. Spot is 9.0 mils across the horizontal axis.
3. Chloride removed – 97.0%
4. Chloride – 20.5  $\mu\text{g}/\text{cm}^2$



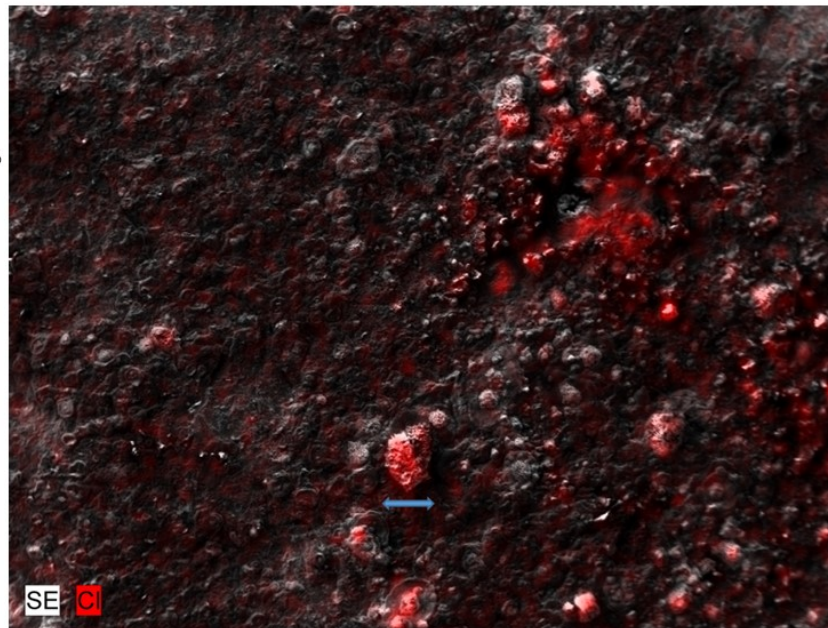
## Steel Grit 40/50/120

1. Map is 71 mils x 53 mils .
2. Spot is 3.5 mils across the horizontal axis.
3. Chloride removed – 96.7%
4. Chloride – 17.6  $\mu\text{g}/\text{cm}^2$



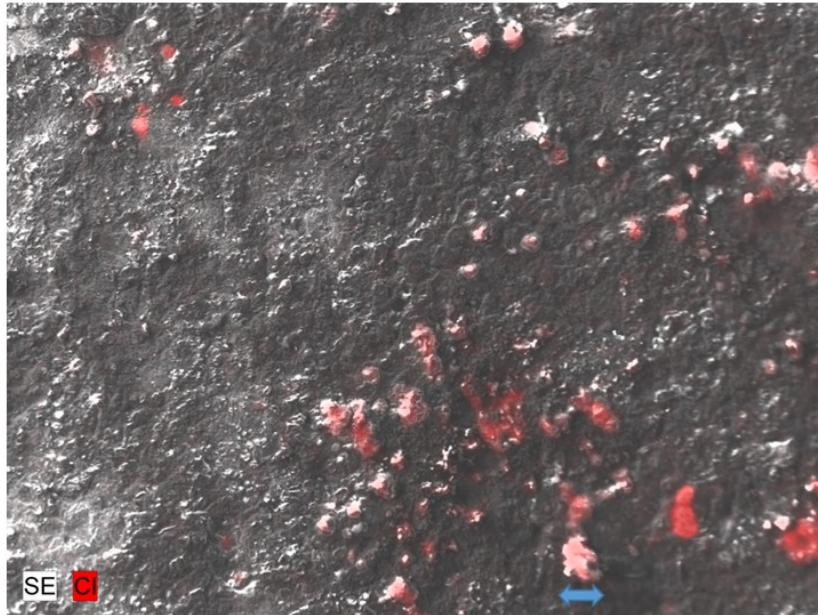
## Mineral Slag

1. Map is 49 mils x 37 mils.
2. Spot is 2.9 mils across the horizontal axis.
3. Chloride removed – 96.5%
4. Chloride – 17.2  $\mu\text{g}/\text{cm}^2$



## Aluminum Oxide

1. Map is 94 mils x 70 mils.
2. Spot is 4.2 mils across the horizontal axis.
3. Chloride removed – 96.4%
4. Chloride – 23.9  $\mu\text{g}/\text{cm}^2$



## Steel Grit 40/50

No Data

