RECLAMATION

Managing Water in the West

Technical Memorandum No. MERL-2011-41

Investigation of Overcoating Coal Tar Enamel with Foul Release Coatings

Materials Engineering and Research Laboratory,
Technical Service Center

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U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

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U.S. DEPARTMENT OF THE INTERIOR
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Executive Summary

Foul release coatings present one potential solution by reducing or preventing mussel attachment on coated substrates. An ongoing field study at Parker Dam has identified several coatings which perform well however, many facility operators are reluctant to embrace foul release coatings. One reason is that completely removing the existing coating systems can be costly and pose logistical challenges. In addition, coal tar enamel provides superior corrosion protection and service life which is unmatched by modern coating systems. The cost of deploying a foul release coating could be lowered if the new system could be applied without removal of the coal tar enamel i.e. overcoating. An additional benefit is that long term corrosion protection could be maximized by leaving the CTE intact. The current study examines the practical issues associated with overcoating coal tar enamel with foul release coatings through a series of laboratory tests.

Four candidate foul release systems were identified through an ongoing research study being performed by Reclamation at Parker Dam. Steel samples were coated with coal tar enamel (CTE) and then with one of the four systems prior to undergoing laboratory evaluation which included static immersion in a Harrison solution or deionized water, high flow immersion testing (deionized water), waterjet testing, and adhesion testing.

Evaluation of the results from each test conducted suggests that overcoating coal tar enamel with a foul release coating will likely cause a decrease in the expected service life of the coating system especially in situations with high flow velocities. Immersion resulted in the development of cracks at the border between the coal tar enamel and overcoated portion of the sample. In addition, the high flow immersion test caused catastrophic failures in the form of macroscopic damage i.e. removal of the overcoat and CTE.

In contrast, the overcoated refrigerated control samples which were not exposed to an immersion environment experienced no cracking. The cracks are likely a result of residual stresses that are developed within the coating system due to a differential in expansion / contraction following water uptake. CTE is a relatively soft material and is unable to support large tensile stresses which causes cracking to occur. In addition, adhesion tests showed that the strength of the coal tar enamel was lowered in cases where the overcoat primer contained solvent even when the solvent was present in small amounts.

Submerged waterjet testing produced topcoat failures in the silicone bases foul release systems prior to damaging the coal tar primer interface. The Duromar system outperformed the silicone foul release systems in the waterjet tests.

The coal tar enamel appears to be the weakest link for all of the systems present. In general, the presence of solvent in the overcoating material appears to have a detrimental effect on the integrity of the CTE which further weakens the system. Finally, subjecting the material to immersion or high flow immersion creates stresses in the coating system which ultimately led to failure. The results suggest that one possible solution to increase the probability of a successful overcoat application would be to use a 100% solids primer system. In it is desirable to select a system that minimizes the number of total coats. Another approach would be to key the overcoat material in to the coal tar enamel by scoring a notch into the material. This would increase the surface area for the bonded interface at the leading edge thereby potentially lowering the stresses acting to remove the overcoat material. This approach was not investigated in this study.

Introduction

Reclamation is involved in interdisciplinary research to anticipate and mitigate the realized and expected impacts of macrofouling organisms; namely zebra and quagga mussels which were recently introduced to Reclamation waters. The mussels have the ability to attach to hard surfaces including existing coatings such as coal tar enamel (CTE) creating the potential impacts ranging from increased frictional head loss to complete occlusion in system with flowing water. Foul release coatings present one potential solution by reducing or preventing mussel attachment on coated substrates. An ongoing field study at Parker Dam has identified several coatings which perform well however, many facility operators are reluctant to embrace foul release coatings. One reason is that completely removing the existing coating systems can be costly and pose logistical challenges. In addition, coal tar enamel provides superior corrosion protection and service life which is unmatched by modern coating systems. The cost of deploying a foul release coating could be lowered if the new system could be applied without removal of the coal tar enamel i.e. overcoating. An additional benefit is that long term corrosion protection could be maximized by leaving the CTE intact. The current study examines the practical issues associated with overcoating coal tar enamel with foul release coatings through a series of laboratory tests. Details of the test results implications are presented in the following sections.

Sample Preparation

3”x6” and 1”x6” steel substrates were cleaned, abrasive blasted, and shipped to Lone Star Specialties to be coated on one side with coal tar enamel. The coal tar enamel was prepared using a sweep blast SSPC-SP7 technique using a coal slag abrasive to create a 1/16” profile to facilitate adhesion between the overcoat material and coal tar enamel.

Four foul release systems were selected for testing. Three of the systems silicone based coatings and are performing well in field tests at Parker Dam. The forth system is a silicone epoxy system which was added to the field test program in November 2010. Although test results for the silicone epoxy hybrid system are currently pending, the system was sufficiently different from the other systems to be included in the current study.

Primer Selection

Initial results of previous testing at Reclamation showed that 100% solids primers possessed the greatest adhesion strengths to coal tar enamel. This seemed to support that solvent borne systems may soften or weaken the underlying coal tar. However, as testing continued all systems lost adhesion strength and the differences between solvent borne systems and 100% solids systems became less significant.

There is little test data from manufacturers for overcoating coal tar. One manufacture representative believed that some solvent in the primer would help “bite” into the coal tar enamel (Sigmaglide). Another manufacturer recommended a surface tolerant primer which is commonly used in marine applications (Fuji). Duromar’s foul release system is designed to work with a single primer and Enviroline performed well in the previous test program as an overcoat material.

The primers used for each system were as follows:
Euronavy ES301K is a 97% by volume solids epoxy primer (Fuji)
Enviroline 376 is a 100% solids epoxy (Intersleek)
Amercoat 240 is an 87% solids epoxy (Sigmaglide)
Duromar HPL-2510 is a 100% solid epoxy (Duromar)

The samples were coated with 2 coats of primer. The first coat of Euronavy primer caused the coal tar enamel to bleed slightly, therefore a second coat was required. The last coat of primer was slightly tacky when the Sherwin Williams Seaguard Sher-release tie coat was applied. The following day the Sherwin Williams Seaguard Sher-release surface coat was applied to finish off the system. Intersleek and sigmaglide required similar application processes. The Duromar did not require a tie coat or a wet on wet application which simplified the application process. Table 1 gives a summary of each system tested.

Table 1: Coating systems tested

System	Existing Substrate	Primer(s)	Tie Coat	Top Coat
1	Coal tar	SW Euronavy 301K	Fuji Tie Coat	Fuji smart surface
2	Coal tar	Enviroline 376	International Intersleek 731	International Intersleek 970
3	Coal tar	HPL-2510	N/A	Duromar HPL-2510-FR
4	Coal tar	Amercoat 240, Sigmashield 620	Sigmaglide 790	Sigmaglide 890

Testing Protocol

Testing was initiated April 5, 2011 when the 3 x 6 inch panels were immersed in Harrison solution and Deionized solution and 1 x 6 panels were placed in the high flow immersion test pipe (DIFT). Two sets of panels were placed in a refrigerated environment where the temperature was held fairly constant at approximately 40 ^{o}F. These samples were used as a control group for the immersion tests and high flow tests. After the immersion tests were concluded, the refrigerated samples were used for waterjet testing and immersion testing.

Harrison and Deionized Immersion Tests

The Harrison immersion test solution consists of 3.5 grams ammonium sulfate ($(NH_4)_2SO_4$) and 0.5 grams of sodium chloride (NaCl) per liter of deionized water. The test is intended to simulate an aggressive/corrosive environment. In the Deionized immersion test, samples are immersed in Deionized water with no additives. Both tests are conducted at room temperature. Water is circulated in each tank in order to discourage stagnation but flow rates in the tank are negligible.

High Flow Testing

A high flow test was assembled using a reservoir tank, PVC piping, and a pump to produce high water velocities across the sample surface. An acoustic flow meter was used to measure the flow of water through the pipe which was relatively constant at about 95 GPM. The water velocity will vary inversely with cross sectional area and will accelerate in locations where the pipe is partially obstructed due to the presence of samples. The velocity across the samples is estimated to be between 25 – 30 ft/s.

This setup simulates flow rates seen in penstocks and outlet works throughout Reclamation's infrastructure. Due to the limited laboratory space, the set up had a number of bends as seen in Figure 1.

Figure 1: High Flow Water Test set up. Samples are placed inside the PVC pipe.

The test apparatus utilized a 7.5 HP pump operating at 3450 RPM with 3 inch PVC piping on the inlet and discharge sides. The PVC is reduced to 1.5 inch diameter where the samples are placed. Water is discharged into a 100 gallon tank and recirculated from there. The piping is fitted with coupling to allow access to individual sections. Figure 2 and Figure 3 show how the samples are arranged inside the piping. For each system, two coal tar coated panels were overcoated such that some of the underlying coat was exposed to the flowing water. A third sample was coated with the just the foul release system (primer, tie coat, and top coat) direct to steel (no coal tar enamel).

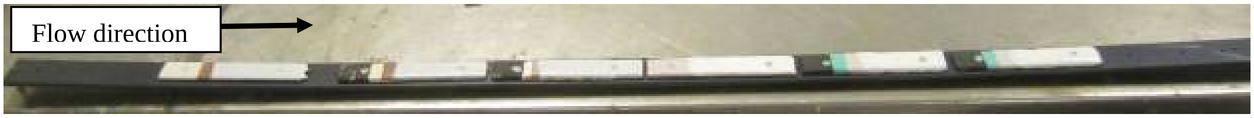


Figure 2: Sample placement

Figure 3: Cross sectional view of sample placement inside PVC piping.

The pump on the high flow test was run each day for approximately 2 hrs. The water temperature in the DIFT test ranged from 65 ^{o}F to 105 ^{o}F. On a few occasions the tank was run for longer and the water temperature reached 118 ^{o}F.

Samples were removed from testing and photographed periodically throughout the duration of the test. Testing was concluded after approximately 4 months testing. The hours of exposure are as follows:

DI Immersion: 3336 hrs
HAR Immersion: 3048 hrs
DIFT Immersion: 2928 hrs (196 hrs of high flow condition)

Immersion Waterjet Testing

A waterjet test fixture (shown in Figure 4) was designed to test the ability of coating systems to withstand high pressures in service. An automated cleaning system is one example where the coatings would be exposed to high pressures.

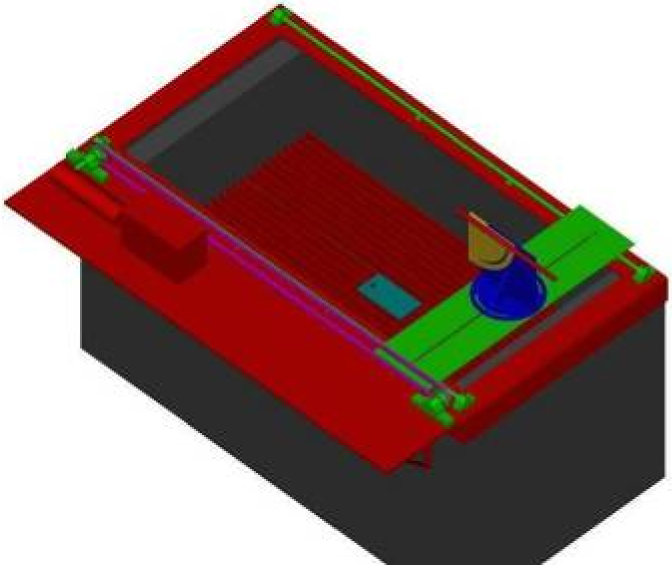


Figure 4: 3D CAD model of the waterjet test setup. The test fixture can be configured for multiple angles and translational speeds.

Although the waterjet test apparatus was designed and built under WOID X1740 to test coating durability for mussel removal, waterjet testing may also provide an indication of the adhesion of a coating to the substrate. This is valuable for foul release coatings because it is difficult to directly measure adhesion of a foul release coating by conventional means since the glue does not adhere well to a foul release coating making attachment of the adhesion dolly difficult. Therefore, it was decided to test each coating system with a spot nozzle set at an impingement angle 60^{o} with respect to the horizontally oriented sample. The setup allows for stationary testing or for a moving jet. A schematic of the test procedure used is shown below. The calculated distance from the nozzle tip to the coal tar is about 3/8 inch. Details of the test configuration are shown in Figure 6.

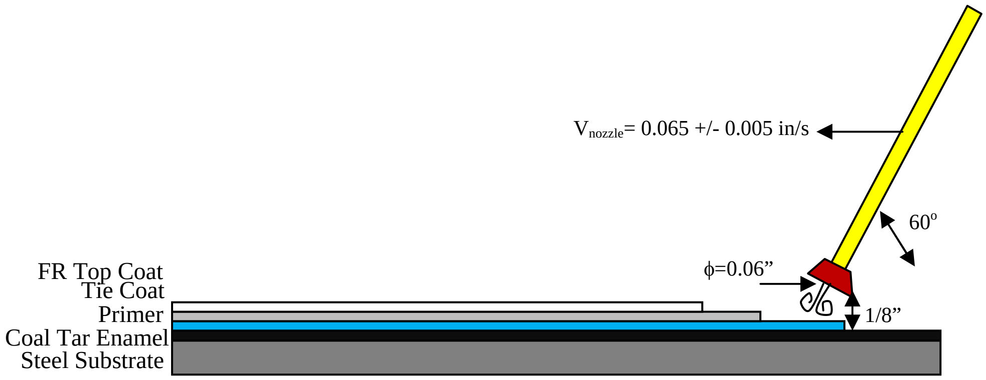


Figure 5: Waterjet test schematic

Samples in the waterjetting tank were fastened down using a jig as shown in Figure 6. The nozzle which was mounted on a traveling base was set to a translational velocity of approximately 0.065 inches per second. The idea was to allow enough time for damage to occur in the sample and also to expose each coating interface to the jet for an equal amount of time.


Figure 6: Waterjetting test samples immediately prior to testing.

The nozzle was fed by a pressure washer with an adjustable valve allowing the pressure to be adjusted up to 850 psi. The test was initiated with a discharge pressure of 200 psi. For each trial, the nozzle was allowed to travel along the sample to a predetermined position before the pressure washer was switched off and the nozzle was returned to the initial position. For each subsequent test, the pressure was increased by 100 psi to the maximum of 850 psi or until complete failure (whichever occurred first). Increasing the pump pressure increases flow rate and which in turn increases the jet velocity at the nozzle and impact pressure at the coated surface. The linear dependence of flow rate (and nozzle velocity) on pump pressure is illustrated in Figure 7. A second effect of increasing nozzle velocity is the introduction of cavitation bubbles into the jet stream.

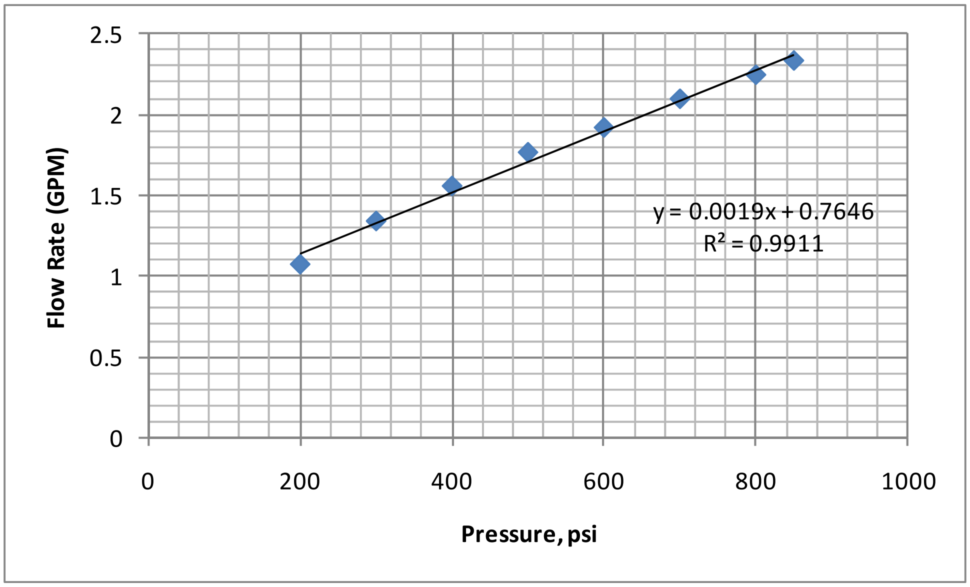


Figure 7: Dependence of Nozzle flow rate on pump pressure

Adhesion Testing

Adhesion dollies were glued to the exposed primer on 3 x 6 inch coated samples. Each dolly was allowed to cure for 24 hours prior to testing. Prior to testing, each sample was scored around the dolly using a serrated hole-saw. A hydraulic test device was affixed to the dolly and a tensile load was applied in a direction perpendicular to the sample. The load was increased gradually until a failure occurred. The highest strength prior to failure is the reported measurement. The force was divided by the dolly's area to determine pressure. The failure mode was also evaluated and reported.

Results

Immersion results

The results of immersion testing are summarized in Table 2. In the Harrison test, one panel from each system was coated sequentially exposing each coat and giving the sample a striped appearance. These samples are denoted with an "s" in Table 2. One variation was the Duromar system in which no portion of the coal tar was left exposed.

For the deionized immersion test, each coat completely covered the underlying coat and therefore no coal tar enamel was left exposed.

Table 2: Immersion test results

System	Sample	HAR Immersion	DI Immersion
1: Fuji Smart Surface	A	Obvious cracking running along edge ~ 9”	Obvious cracking running along edge 13 ½”
	B	Obvious cracking running along edge ~ 7”	Moderate cracking running along edge 6 ½”
	C-s	Cracking observed at the coal tar – primer interface and along edges ~ 11” total	N/A
2: International Intersleek 970	A	No cracking observed	No cracking observed
	B	One very minor crack ~ ¼”	One very minor crack ~ ¼”
	C-s	Very minor cracking on edges of striped panel ~ ½”	N/A
3: Duromar HPL-2510FR	A	Minor cracking on edges ~ 3”	Slight cracking on bottom edge ~ 1”
	B	No cracking observed	Slight cracking on bottom edge ~ 2”
	C-s	Minor cracking on edges ~ 1” *note: no CTE exposed	N/A
4: PPG Sigmaglide	A	Obvious cracking running along edge ~ 7.5”	Obvious cracking running along edges and bottom ~ 11”
	B	Obvious cracking running along edge ~ 8”	Moderate cracking running along edges and bottom ~ 1 ¾”
	C-s	Cracking observed at the coal tar – primer interface and along edges ~4” total	N/A

On the striped panels, it was common to observe cracking on the coal tar enamel – primer interface. On panels with only the topcoat exposed, there was sometimes cracking noted on the backside edges along the CTE – primer interface. Figure 8 illustrates the damage that is representative of the immersion samples. Examination of Table 2 shows that for the un-striped samples, the amount of cracking in the DI and HAR samples was similar.

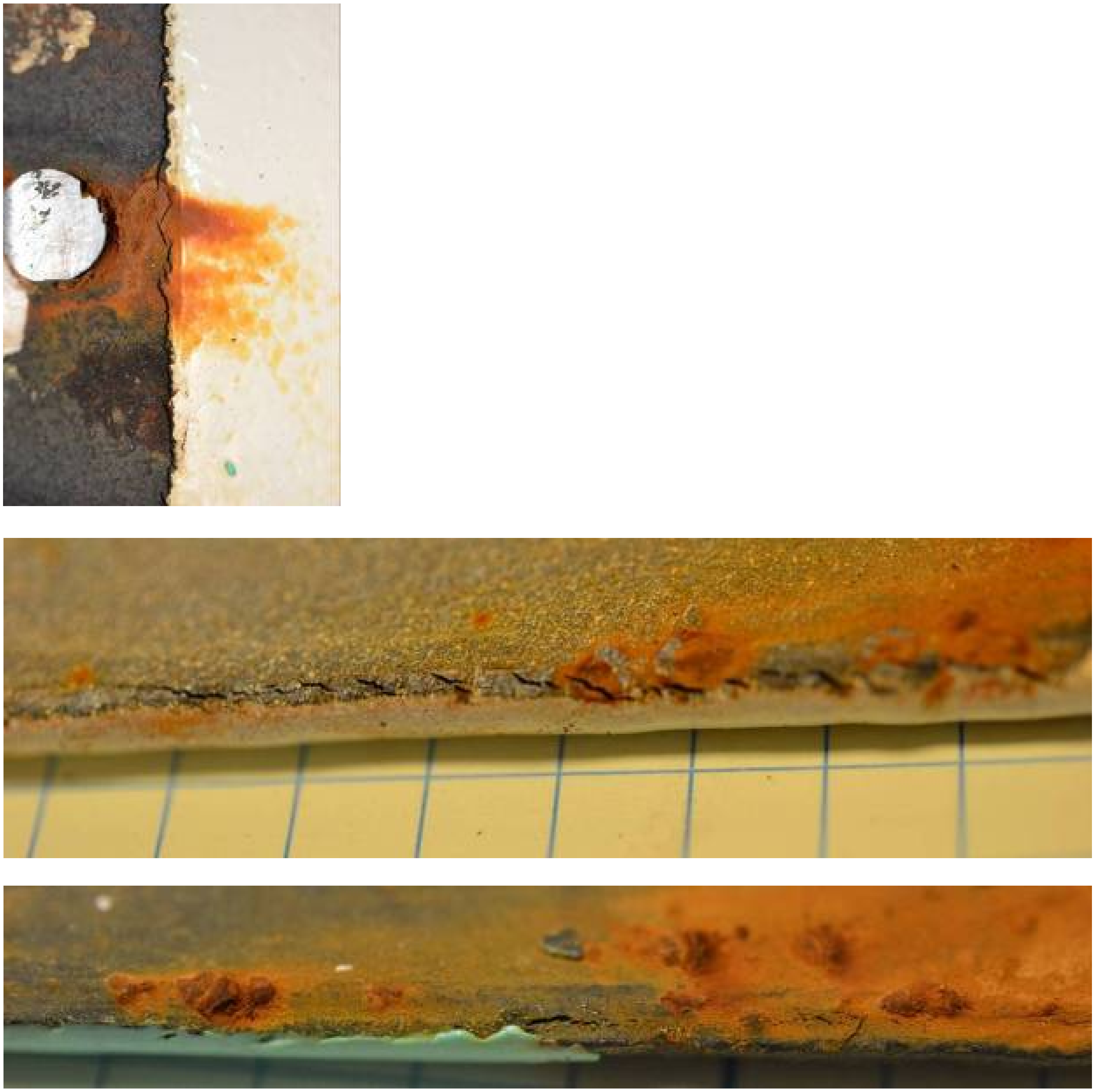


Figure 8: Cracking observed in Harrison immersion test samples after 3048 hrs exposure: (a) At the interface between the coal tar enamel and primer on Fuji smart surface sample (b) Along the plate edge on Fuji smart surface sample (c) Along the plate edge on Intersleek 970 sample.

High flow test Results

Table 3 summarizes the final condition of the panels which were exposed to high flow rates. None of the overcoated systems that were tested were able to withstand the test without at least one of the samples sustaining significant damage.

Also tested were control samples which consisted of the identical coating system applied to blasted steel instead of coal tar enamel. In contrast to the overcoated samples, none of the controls for any of the systems evaluated sustained damage during the test.

Table 3: High flow test results

System	Sample	Final Evaluation
1: Fuji Smart Surface	A	Complete removal of coating down to bare metal underneath overcoat ~ 45%. Cracking at CTE – primer interface and on edges.
	B	Coating is fully intact. Cracking at CTE – primer interface and on edges
	Control	No Damage
2: International Intersleek 970	A	Complete removal of coating down to bare metal underneath overcoat ~ 5%. CTE left intact and overcoat removed ~30%. Moderate cracking at CTE – primer interface and on edges.
	B	Coating is fully intact. Minor cracking at CTE – primer interface and on edges
	Control	No Damage
3: Duromar HPL-2510FR	A	Complete removal of coating down to bare metal underneath overcoat ~ 10%. CTE left intact and overcoat removed ~65%. Minor cracking at CTE – primer interface and on edges.
	B	Coating is fully intact. Minor-moderate cracking at CTE – primer interface and on edges
	Control	No Damage
4: PPG Sigmaglide	A	Overcoating and CTE are partially disbanded from metal substrate. Coating remains intact. Cracking at CTE – primer interface.
	B	Overcoating and CTE are partially disbanded from metal substrate. Coating remains intact. Cracking at CTE – primer interface.
	Control	No Damage

Detailed photographs show the damage progression from start to finish for each system (Figure 9 - Figure 12). All of the samples had experienced significant damage by 130 hours of testing. Interestingly, the Intersleek 970 and Duromar HPL-2510FR systems which had developed cracking to a lesser extent than the other two systems each had experienced failures by 120 hours (10 hours sooner).

In some cases, the overcoated system had disbonded from the coal tar indicating inadequate adhesion between the two surfaces. However, in several samples, the coal tar failed as well leaving bare metal exposed. In the Duromar and Intersleek systems, the damage initiated at the coal tar / primer interface. Once the overcoat system was removed, the coal tar began to fail. It is likely that the combination of immersion, high velocity flow rates, and elevated temperatures each contributed to cause failures in each of the systems. Obviously this failure would be unacceptable in the field.

Another interesting result from this test is that coal tar failure only occurred in areas where the overcoat had been performed. The left most end of each sample where the CTE had been left uncoated showed no damage. This would seem to indicate that overcoating the coal tar can cause changes to the material resulting in a decreased service life.

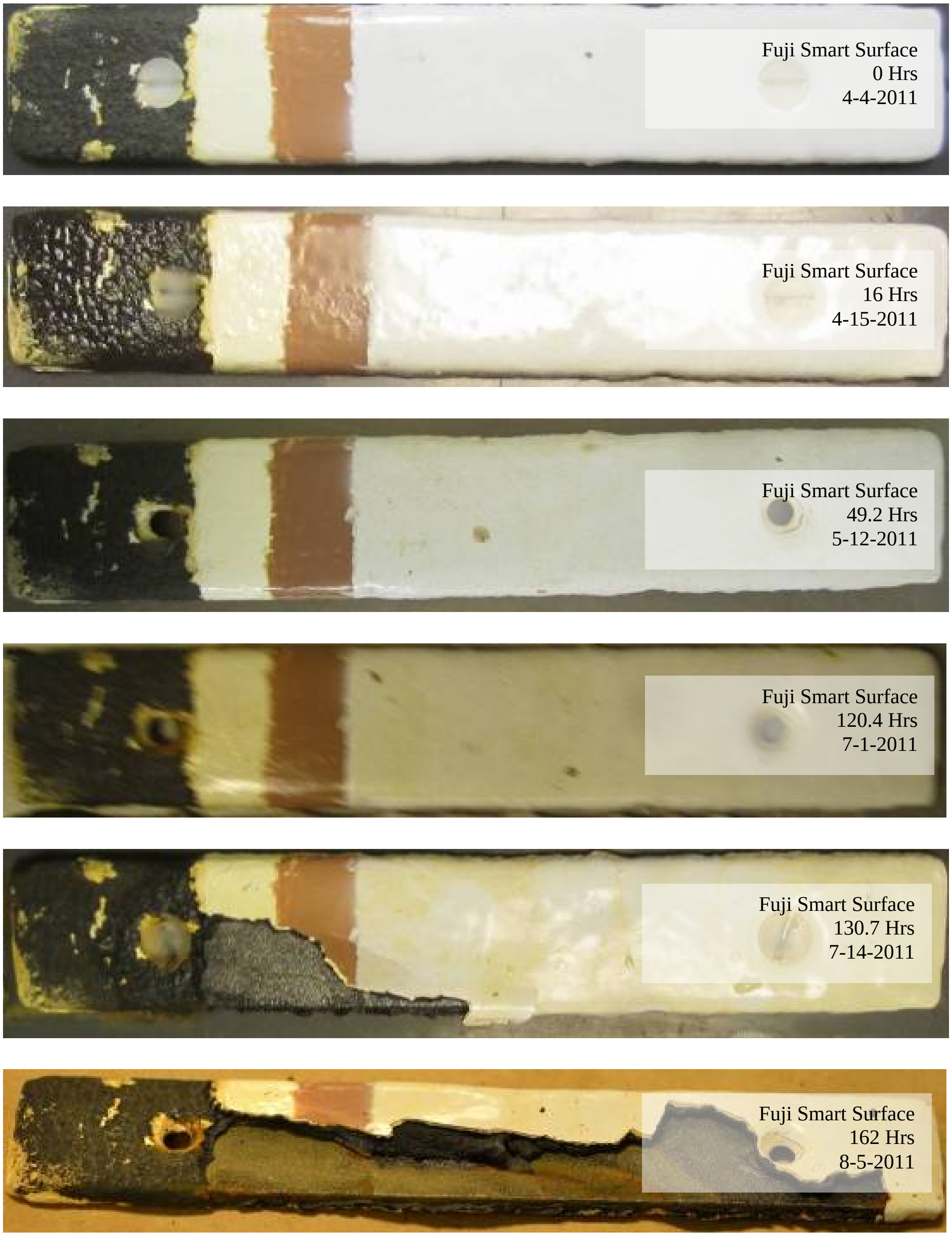


Figure 9: Photo-documentation of High Flow Immersion Test: Fuji Smart Surface, sample A.

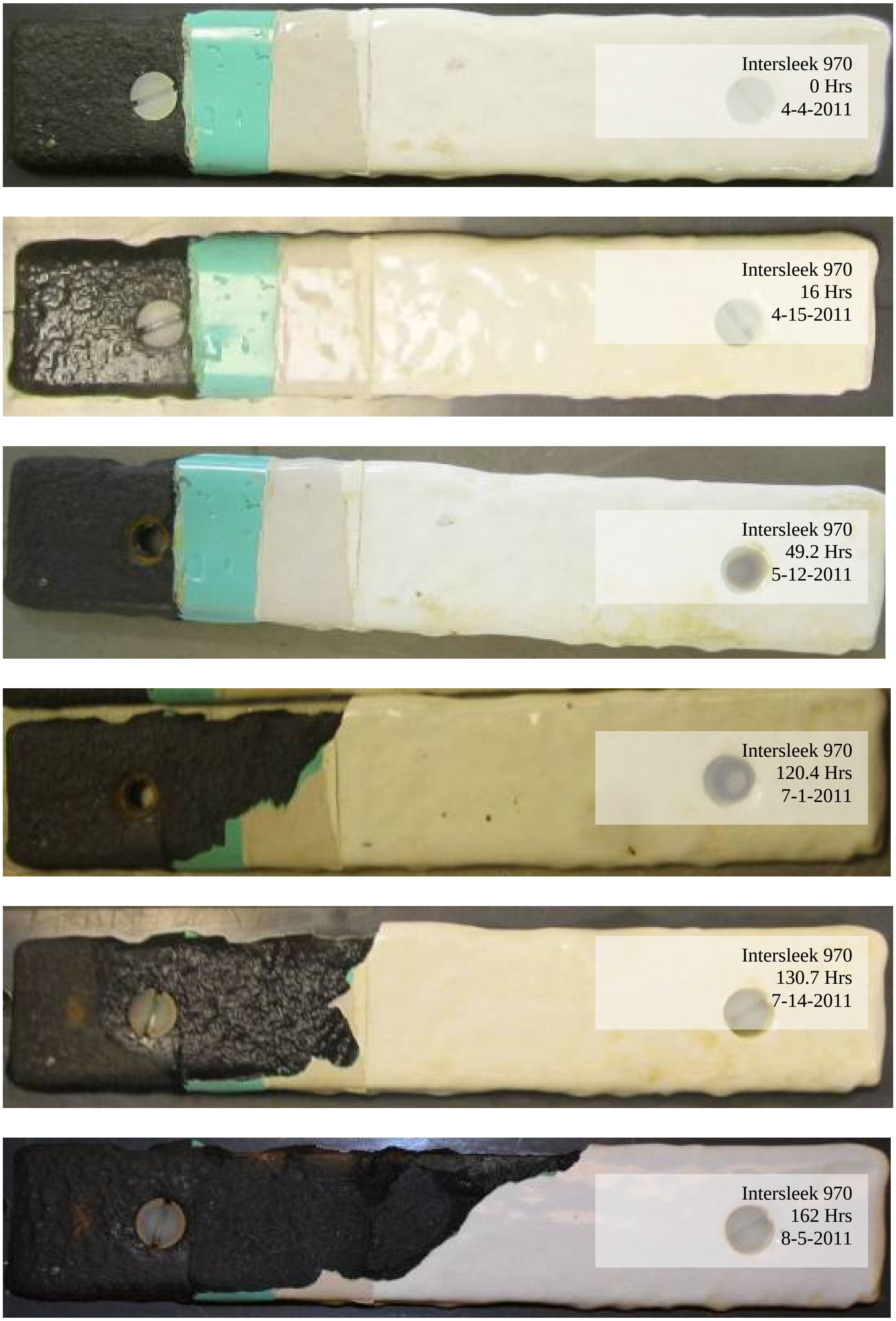


Figure 10: Photo-documentation of High Flow Immersion Test: Intersleek 970, sample A.

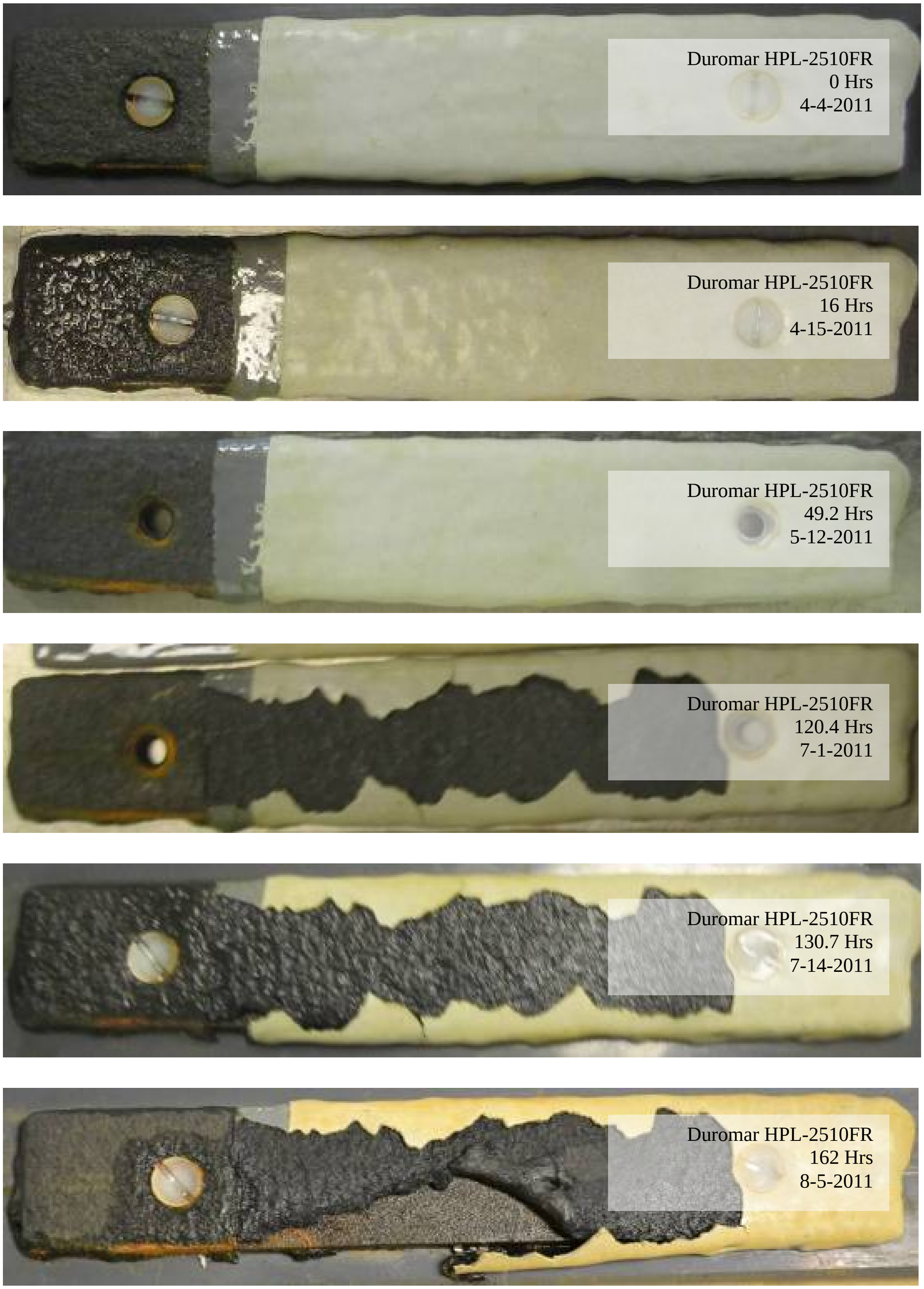


Figure 11: Photo-documentation of High Flow Immersion Test: Duromar HPL-2510FR, sample A.

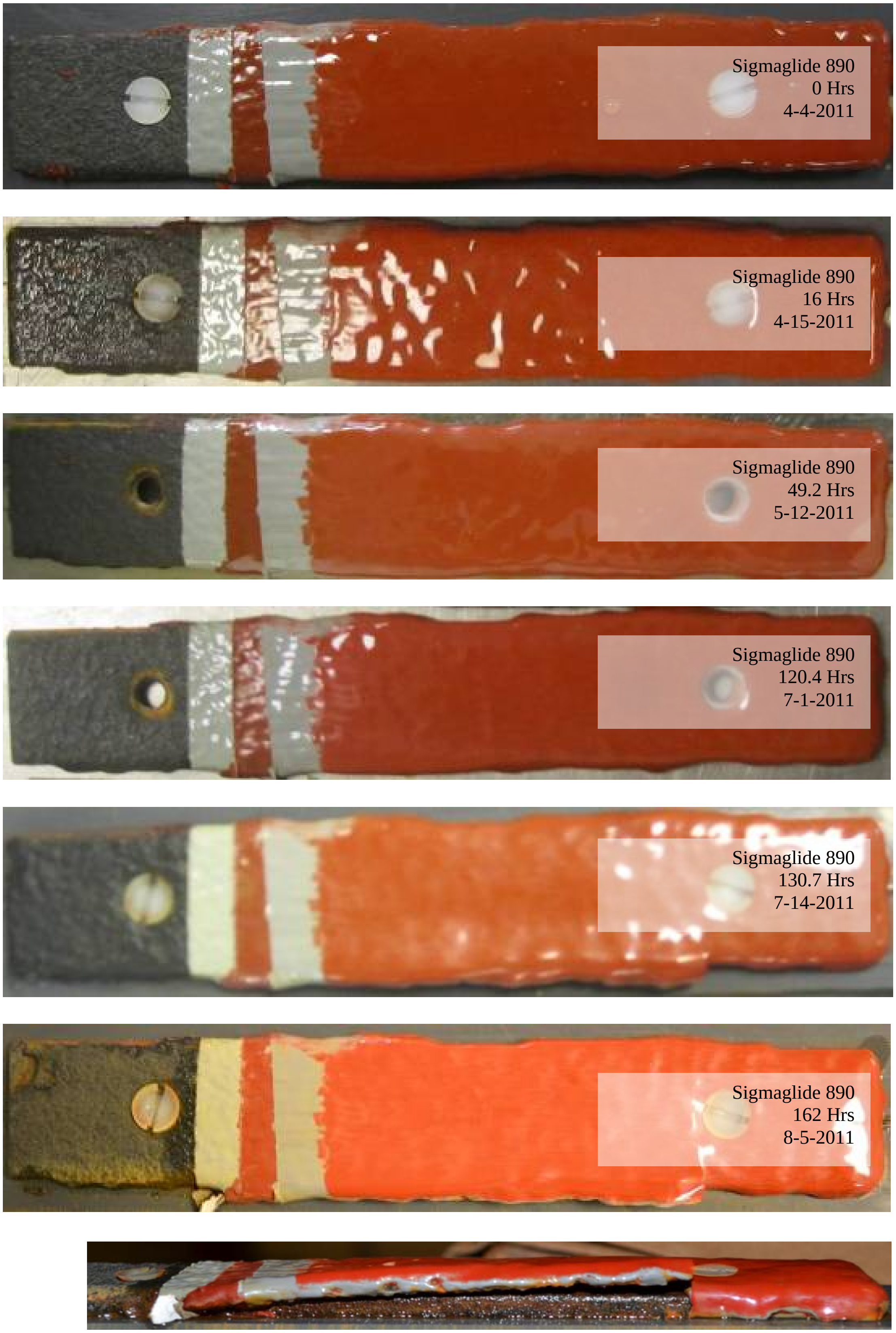


Figure 12: Photo-documentation of High Flow Immersion Test: Sigmaglide 890, sample A.

Waterjetting Test Results

Results for the waterjet test are shown in Table 4. The waterjet test was able to cause failure in all of the coating systems but there was a difference in the amount of pump pressure required to cause damage. The damage at various pressures is shown in Figure 13 through Figure 16. The Fuji topcoat was the most easily damaged system requiring only 300 psi to cause pitting in the topcoat. The two other silicone systems experienced damage at 400 psi. All of the silicone systems failed at much lower pressures than their respective primers. The Euronavy primer in the Fuji system sustained 800 psi with no damage (850 psi caused a complete failure). Enviroline (Intersleek 970 system) sustained 700 psi and Amercoat 240 (Sigmaglide 890) sustained 600 psi. The best system overall was the Duromar HPL-2510FR which sustained 800 psi with no damage to the topcoat or primer. 850 psi cause a complete disbondment between the primer and coal tar enamel but the size of the failure was relatively small compared to the other systems.

Table 4: Waterjet Test Results

Waterjet Pressure (psi)	Fuji Smart Surface	International Intersleek 970	Duromar HPL-2510FR	PPG Sigmaglide 890
200	No Damage	No Damage	No Damage	No Damage
300	Pitting on topcoat	No Damage	No Damage	No Damage
400	More damage to topcoat	Pitting on topcoat	No Damage	Damage to topcoat (hole)
500	More damage to topcoat	More severe damage to top coat, delamination of tie coat (Enviroline primer is visible)	No Damage	More damage: complete striping of topcoat with hole down to CTE
600	More damage to topcoat, slight damage to tie coat	Pitting damage to tie coat, more damage to topcoat	No Damage	No additional damage
700	More damage to topcoat, more damage to tie coat	Incrementally more damage to tie coat and topcoat. Primer is undamaged	No Damage	When jet hit the tie coat (790), it penetrated a hole into the coating and disbanded a large piece from CTE
800	More damage to topcoat, more damage to tie coat (pitting on tie coat). Primer and interface are undamaged.	Complete removal to coating system down to CTE	No Damage	Complete removal down to CTE
850	Complete removal to coating system down to CTE	N/A	Complete removal to coating system down to CTE (1” long piece)	N/A

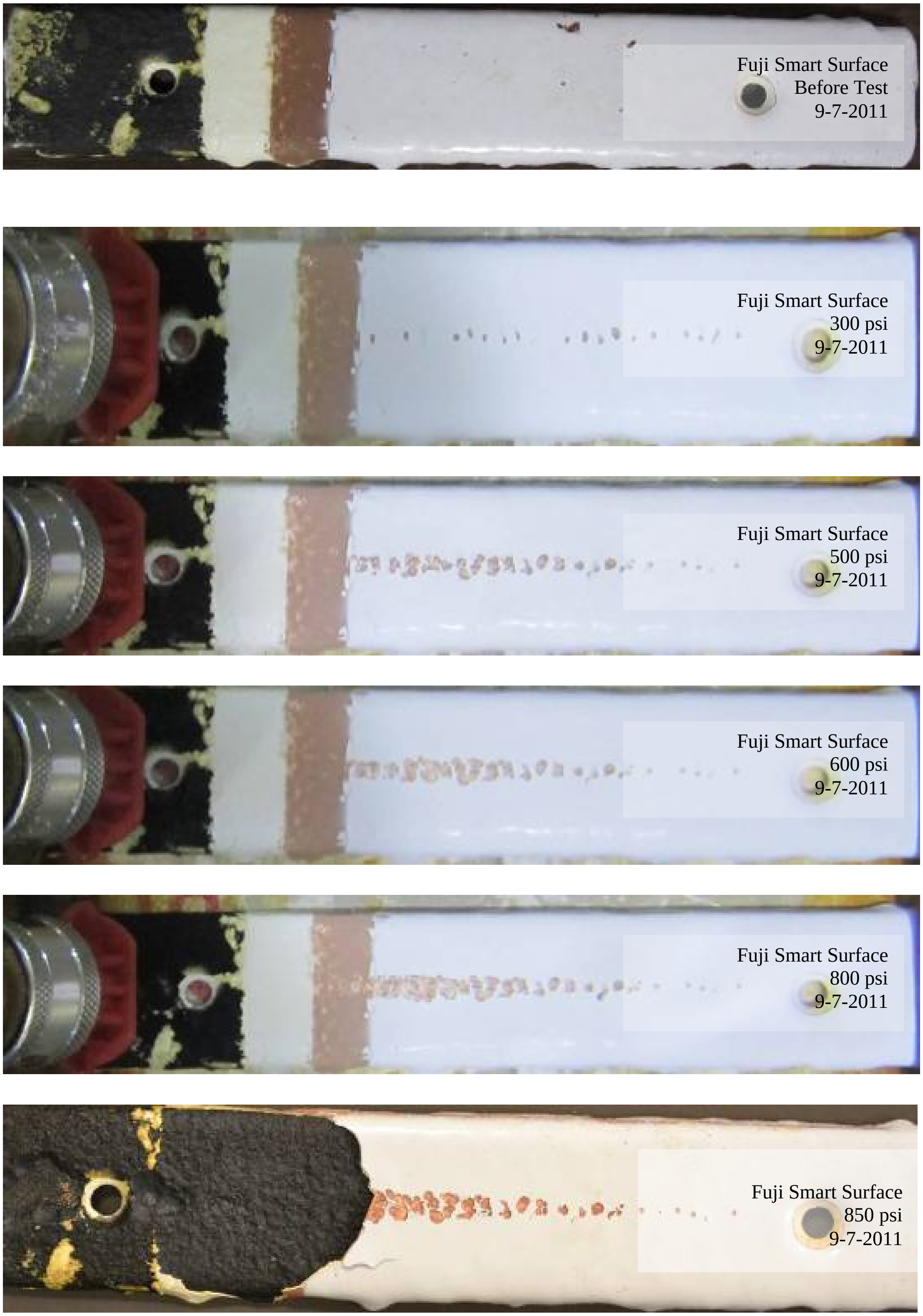


Figure 13: Photo-documentation of Waterjet Test: Fuji Smart Surface

Figure 14: Photo-documentation of Waterjet Test: Intersleek 970

Figure 15: Photo-documentation of Waterjet Test: Duromar HPL-2510FR

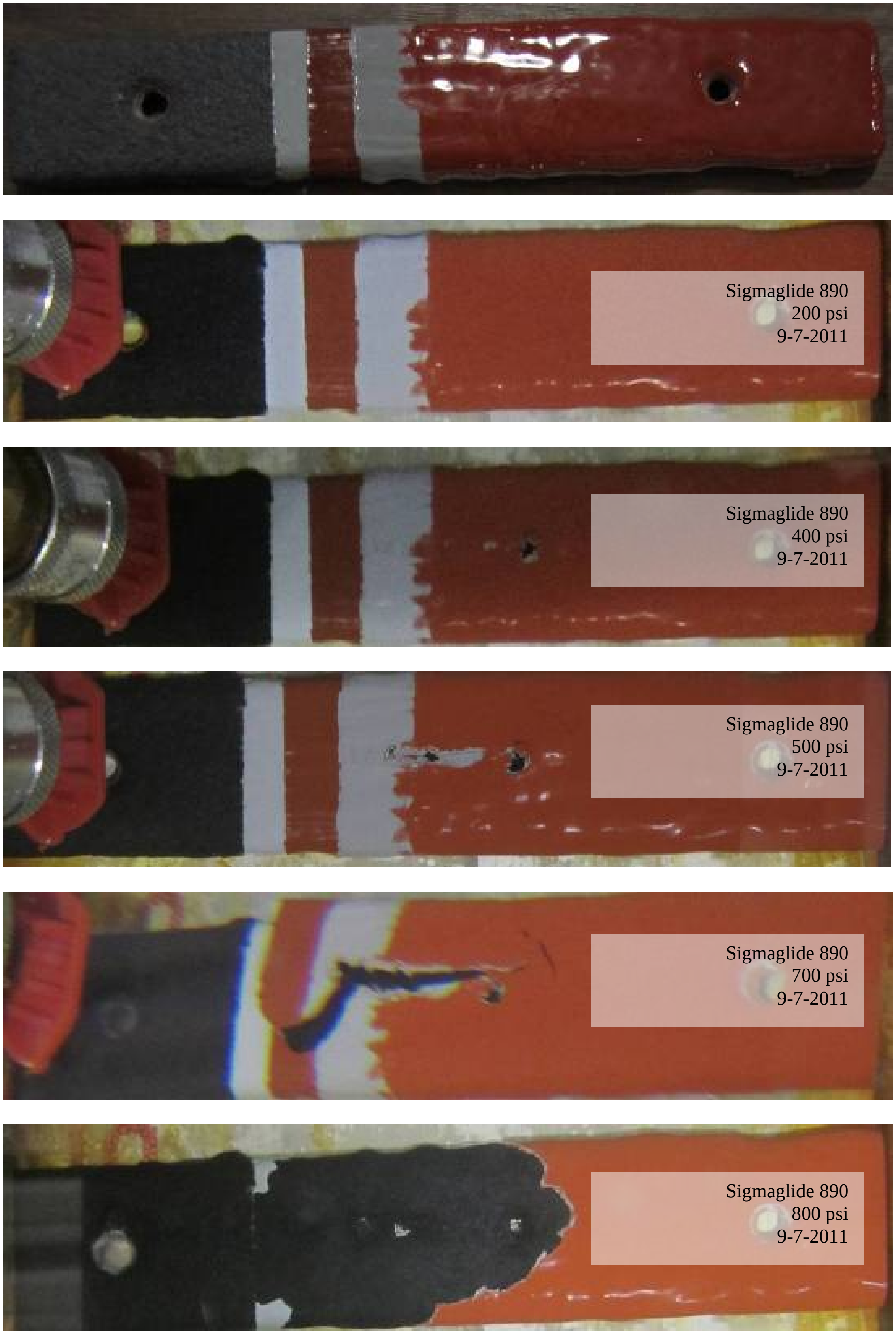


Figure 16: Photo-documentation of Waterjet Test: Sigmaglide 890

Adhesion Test Results

Table 5: Adhesion test results

Sample	Test Material	Test Number	HAR Immersion		Refrigeration (No Immersion)	
			Adhesion Strength	Failure Mode	Adhesion Strength	Failure Mode
Fuji Smart Surface	Coal Tar	1	400	Coal Tar	412	Coal Tar
	Coal Tar	2	358	Coal Tar	444	Coal Tar
	Primer + CTE	1	392	Coal Tar	414	Coal Tar
	Primer + CTE	2	432	Coal Tar	436	Coal Tar
	Primer + CTE	3	250	Coal Tar	240	Coal Tar
International Intersleek 970	Coal Tar	1	366	Coal Tar	380	Coal Tar
	Coal Tar	2	362	Coal Tar	370	Coal Tar
	Primer + CTE	1	498	Coal Tar	470	Coal Tar
	Primer + CTE	2	462	Coal Tar	Broke	Coal Tar
	Primer + CTE	3	492	Coal Tar	Broke	Coal Tar

Sample	Test Material	Test Number	HAR Immersion		Refrigeration (No Immersion)	
			Adhesion Strength	Failure Mode	Adhesion Strength	Failure Mode
Duromar HPL-2510FR	Primer + CTE	1	360	Coal Tar	444	Coal Tar
	Primer + CTE	2	370	Coal Tar	428	Coal Tar
	Primer + CTE	3	400	Coal Tar	490	Coal Tar
PPG/ Sigma	Coal Tar	1	380	Coal Tar	384	Coal Tar
Sigmaglide 890	Coal Tar	2	382	Coal Tar	358	Coal Tar
	Primer + CTE	1	270	Coal Tar	258	Coal Tar
	Primer + CTE	2	260	Coal Tar	260	Coal Tar
	Primer + CTE	3	240	Coal Tar	236	Coal Tar

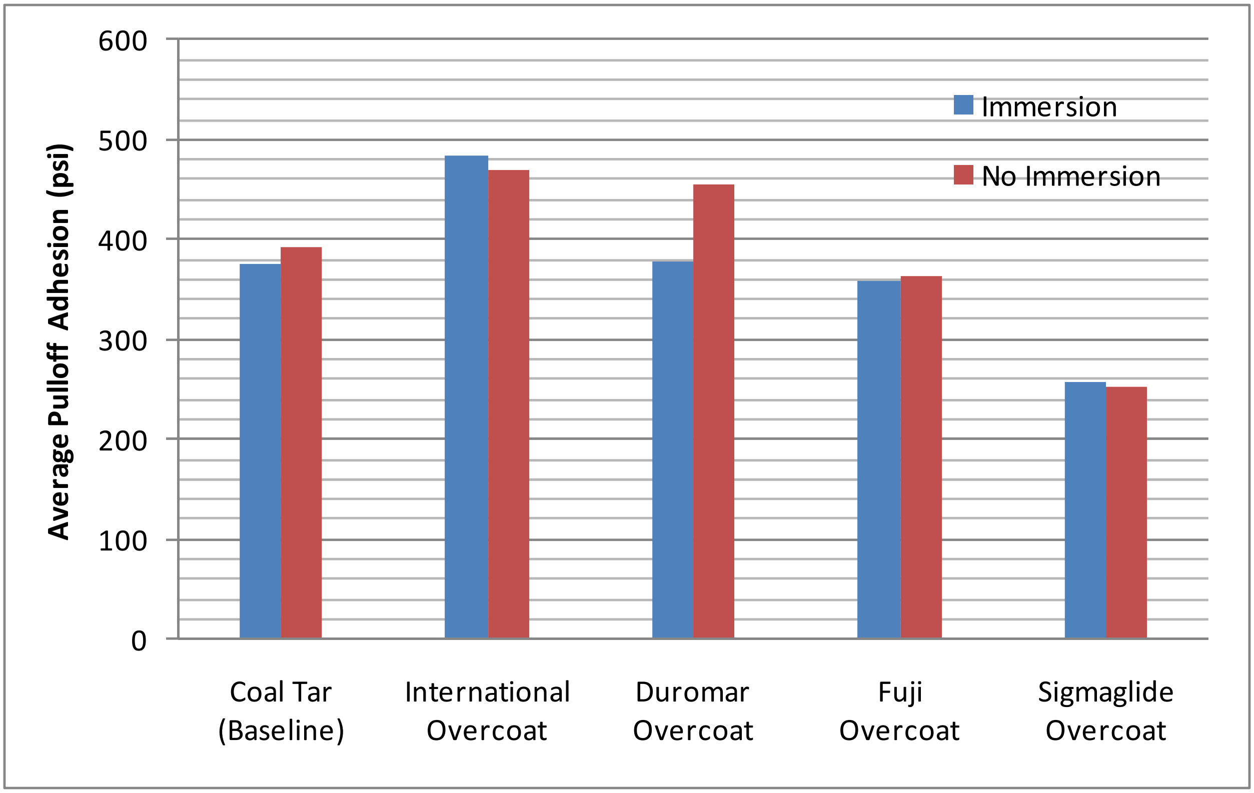


Figure 17: Average pulloff adhesion strength

The adhesion test results are given in Table 5 and summarized in Figure 17. Note that in all of the systems, the test failed within the coal tar enamel. In most systems, immersion did not appear to lower the coal tar strength significantly. The results show no significant decrease in adhesion for the two coating systems that used a 100% solids epoxy primer and actually may be slightly higher. The solvent borne epoxy primers used with Sigmaglide and Fuji caused slight decreases in adhesion due to the solvents dissolving the coal tar enamel. The effect was greater in the Sigmaglide sample which contained a higher amount of solvent (13% vs 3%). There was no significant change between the exposed samples and the controls that were in the refrigerator for the entire testing period.

Refrigerated control group

The samples which were not placed in immersion showed no signs of deterioration (cracking, coating disbondment etc). This would indicate that the immersion process is responsible for the cracking observed. However, it may also be possible that the low storage temperatures help to preserve the coating.

Discussion

Evaluation of the results from each test conducted suggests that overcoating coal tar enamel with a foul release coating will likely cause a decrease in the expected service life of the coating system. There was no significant difference in the results of static immersion in Harrison solution or deionized water. Immersion in either solution resulted in the development of cracks at the border between the coal tar enamel and overcoated portion of the sample. On panels where the coal tar was completely coated, the cracks developed along the panel edge whereas on the striped panels, the cracks were found on the front of the panel at the primer – CTE interface. In contrast, the overcoated refrigerated control samples which were not exposed to an immersion environment experienced no cracking. The cracks are likely a result of residual stresses that are developed within the coating system due to a differential in expansion / contraction following water uptake. CTE is a relatively soft material and is unable to support large tensile stresses which causes cracking to occur.

Cracking which was similar in nature to the static immersion samples was also present on the high flow immersion test samples. In addition, the high flow immersion test caused catastrophic failures. The International and Duromar systems which each used a 100% solids primer experienced delamination of the overcoated material from the coal tar. In these samples, the delaminated material contained a thin layer of coal tar enamel but the majority remained intact with the steel substrate. In contrast, the Fuji and Sigmaglide systems, which each used a primer that contained solvent (3% and 13% respectively), experienced failure in which the entire system delaminated from the metal substrate. The underlying coal tar became damaged as well sometimes after disbondment of the overcoat material. Damage to the CTE was restricted to the portions that were overcoated indicating that overcoating weakens the underlying material. Adhesion testing seems to support the conclusion that solvent borne primers weaken the coal tar enamel. The average pull off strength of the coal tar enamel was reduced in both the Fuji and the Sigmaglide samples where overcoating was present.

While the immersion tests were both long term tests that were conducted over a period of several months, the waterjetting test requires 30-45 minutes. In the waterjet test, the softer silicone products failed at lower impact pressures that their respective primers. The Duromar fared the best in the waterjet test owing to its durable, abrasion resistant topcoat and the strong adhesion of the primer system. The Enviroline primer also performed well. At 850 psi, the CTE also experienced severe damage which undermined the overcoat primer.

The fact that systems were foul release meant that additional coats were required over the primer which likely has the compounding effect of adding additional residual stress to the primer – CTE interface. The high flow test essentially accelerated the failure process by subjecting the coatings to boundary layer stresses due to the fluid flow. Elevated temperatures most likely accelerated the failure process as well. Where insipient damage was evident in the static immersion tests, the high flow samples experienced catastrophic failures. Therefore, the high flow test appears to be a useful tool in evaluating coating systems which subject to an immersion service environment.

The coal tar enamel appears to be the weakest link for all of the systems present. In general, the presence of solvent in the overcoating material appears to have a detrimental effect on the integrity of the CTE which further weakens the system. Finally, subjecting the material to immersion or high flow immersion creates stresses in the coating system which ultimately led to failure. The results suggest that one possible solution to increase the probability of a successful overcoat application would be to use a 100% solids primer system. In it is desirable to select a system that minimizes the number of total coats. Another approach would be to key the overcoat material in to the coal tar enamel by scoring a notch into the material. This would increase the surface area for the bonded interface at the leading edge thereby potentially lowering the stresses acting to remove the overcoat material. This approach was not investigated in this study.

Summary and Recommendations

- It is desirable to be able to overcoat the coal tar enamel which is ubiquitous on existing Reclamation equipment with an effective foul release coating system to prevent the attachment of zebra and quagga mussels.
- Four candidate foul release systems were identified through an ongoing research study being performed by Reclamation at Parker Dam.
- Steel samples were coated with coal tar enamel (CTE) and then with one of the four systems prior to undergoing laboratory evaluation which included static immersion in a Harrison solution or deionized water, high flow immersion testing (deionized water), waterjet testing, and adhesion testing.
- High flow immersion testing and waterjet testing produced catastrophic failures in all four systems. Insipient damage was also evident in HAR and DI immersion.
- The coal tar itself appears to be compromised by the overcoating process especially when solvent containing materials are used in the overcoat system directly over the coal tar.
- As a result of the failures observed none of the systems tested are recommended for overcoating coal tar enamel.

Appendix

Photo- Documentation: Post Harrison Immersion

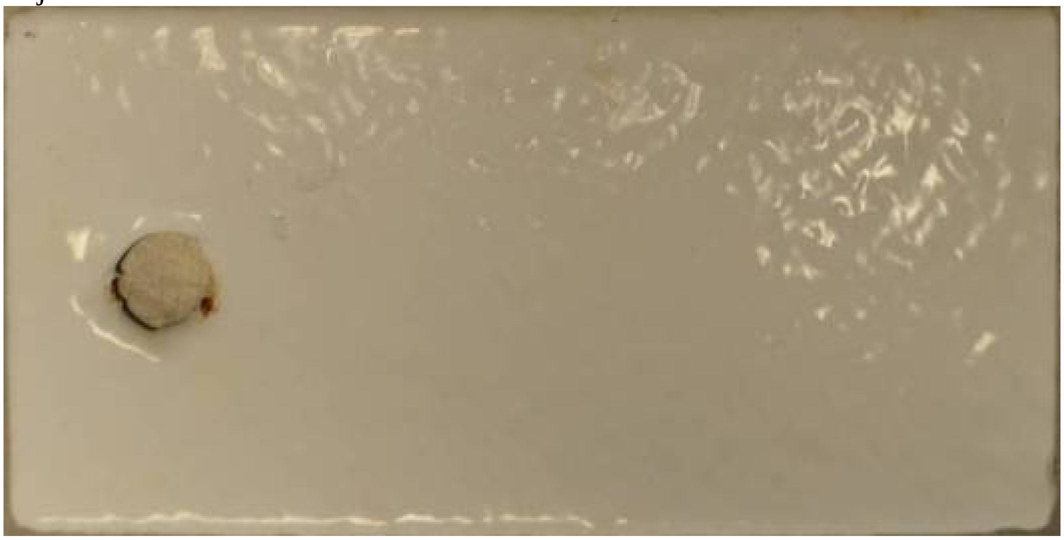
Duromar HPL-2510FR

Fuji Smart Surface

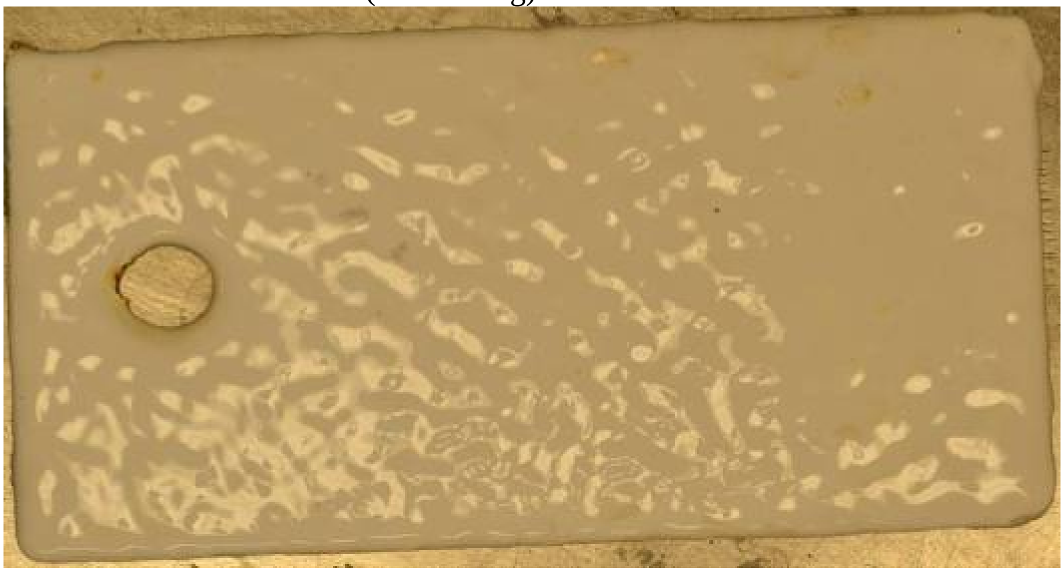
Sigmaglide 890

Intersleek 970

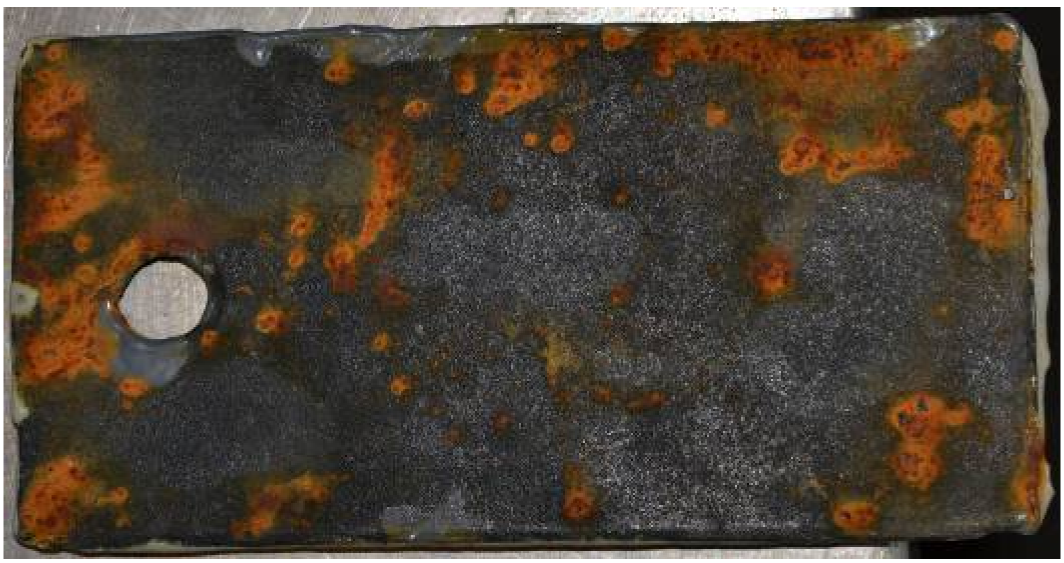
Photo- Documentation: Post Deionized Immersion
Fuji Smart Surface



International Intersleek 970 (no cracking)



Duromar HPL-2510FR



Sigmaglide 890