Fourth Conference on Aerospace Materials, Processes, and Environmental Technology

Evaluation of Various Depainting Processes on Mechanical Properties of 2024-T3 Aluminum Substrate

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September 19, 2000

Interagency Depainting Agreement

Participants

- National Aeronautics and Space Administration
- Environmental Protection Agency
- United States Air Force
- Industry Partners

Objective

Evaluate effects of alternative depainting technologies on aluminum substrate.

Depainting Operations

Media Stripping

- Plastic Media Blast
- Sodium Bicarbonate Wet Stripping
- High Pressure Water Blast
- Wheat Starch Blast
- Xenon Flashlamp/CO_2

Chemical Stripping

- Eight environmentally advantaged chemicals
- Two methylene chloride chemicals

Metallurgical Evaluations by Depainting Process

Depainting Process	Corrosion Potential[1]			Fatigue[2]		Crack Detectability[3]		Tensile[4]	
	Total Immersion	Sandwich Corrosion	Hydrogen Embrittlement	Clad	Non-Clad	Clad	Non-Clad	Clad	Non-Clad
Chemical Stripping	x	x	x						
Xenon Flashlamp/CO_2					x				x
CO_2 Laser Stripping[5]									
Plastic Media Blasting				x	x	x	x	x	x
Sodium Bicarbonate Wet Stripping							x		
High-Pressure Water Blasting					x		x		
Wheat Starch Blasting					x		x		

Notes:

1. Corrosion potential evaluations were conducted in accordance with ASTM F483-90, *Standard Test Method for Total Immersion Corrosion Test for Aircraft Maintenance Chemicals*; ASTM F1110-90, *Standard Test Method for Sandwich Corrosion Test*; and ASTM F519-93, *Standard Test Method for Mechanical Hydrogen Embrittlement Testing of Plating Processes and Aircraft Maintenance Chemicals*.
2. Fatigue evaluations were conducted in accordance with ISO/SAE MA4872 (draft 4).
3. Crack detectability evaluations were conducted in accordance with ISO/SAE MA4872 (draft 4).
4. Tensile evaluations were conducted in accordance with ASTM E8, *Standard Test Methods for Tension Testing of Metallic Materials*.
5. A processing anomaly during the final sequence of depainting prevented the metallurgic evaluation of the panels stripped with the CO_2 laser.

Corrosion Testing

SAE MA4872
Immersion Corrosion
Sandwich Corrosion
Hydrogen Embrittlement

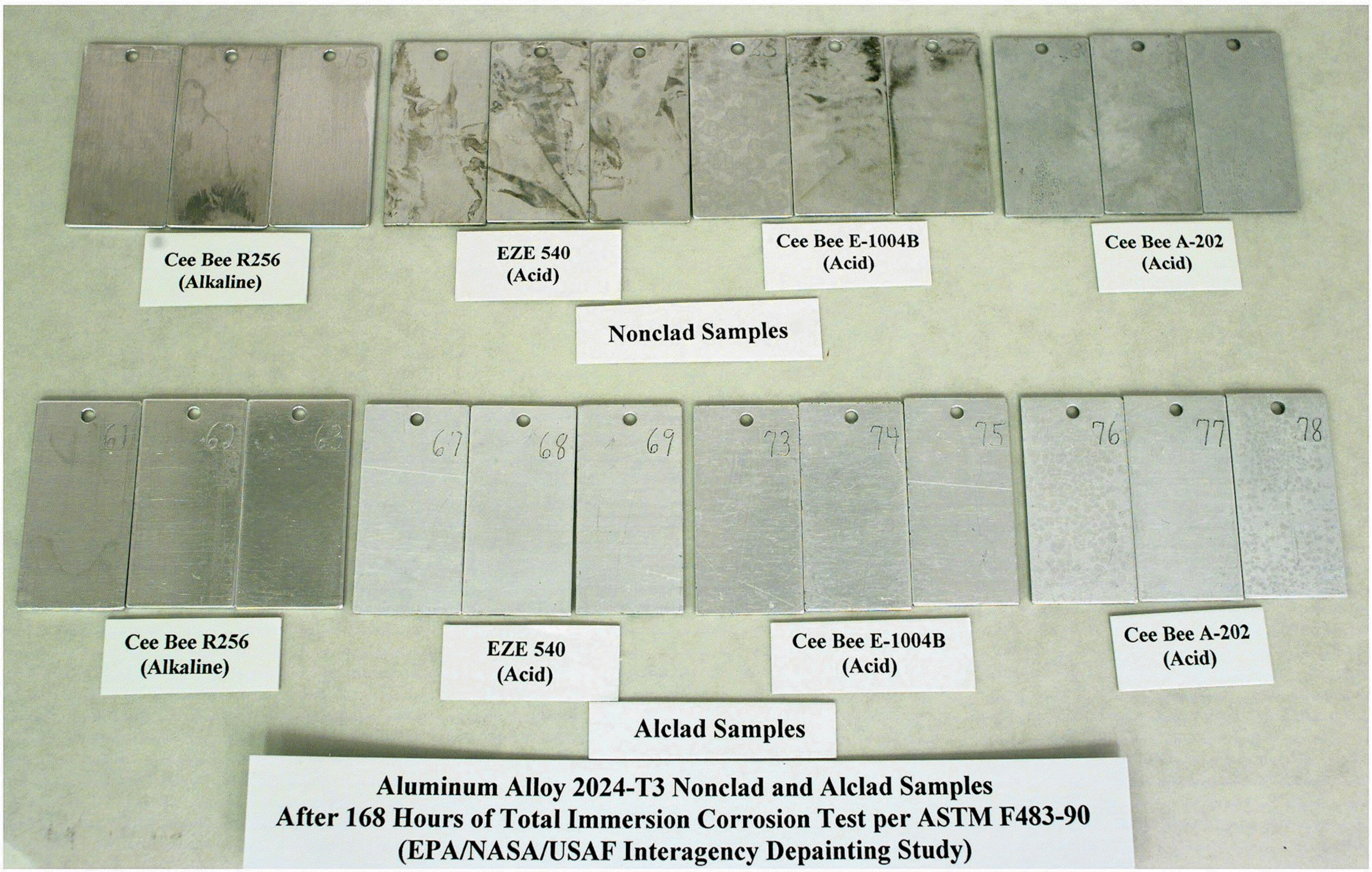
Total Immersion Corrosion

Test: ASTM F483-90 Standard Test Method for Total Immersion Corrosion Test for Aircraft Maintenance Chemicals

Objective: Determine corrosiveness of chemical on substrate.

Material: Clad and Non-Clad 2024-T3 Aluminum

Methodology: Immerse substrate in chemical, measure weight change and note visual change after seven days.



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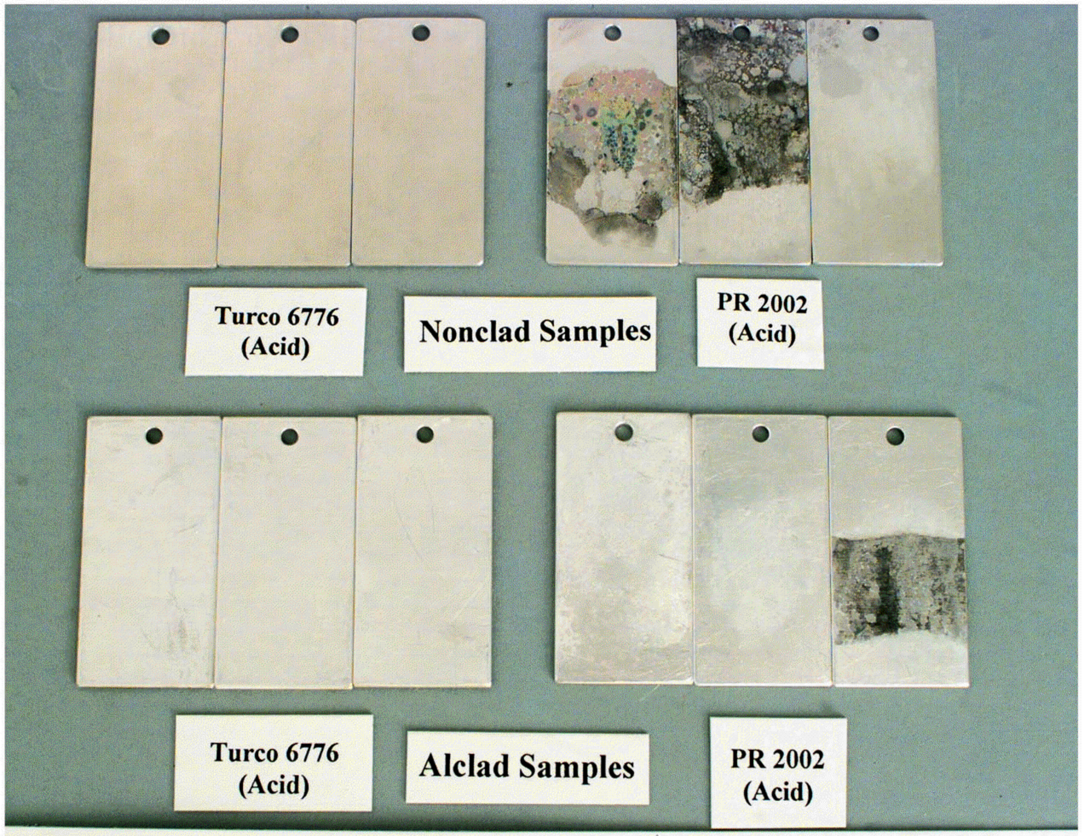

Aluminum Alloy 2024-T3 Nonclad and Alclad Samples
After 168 Hours of Total Immersion Corrosion Test per ASTM F483-90
(EPA/NASA/USAF Interagency Depainting Study)

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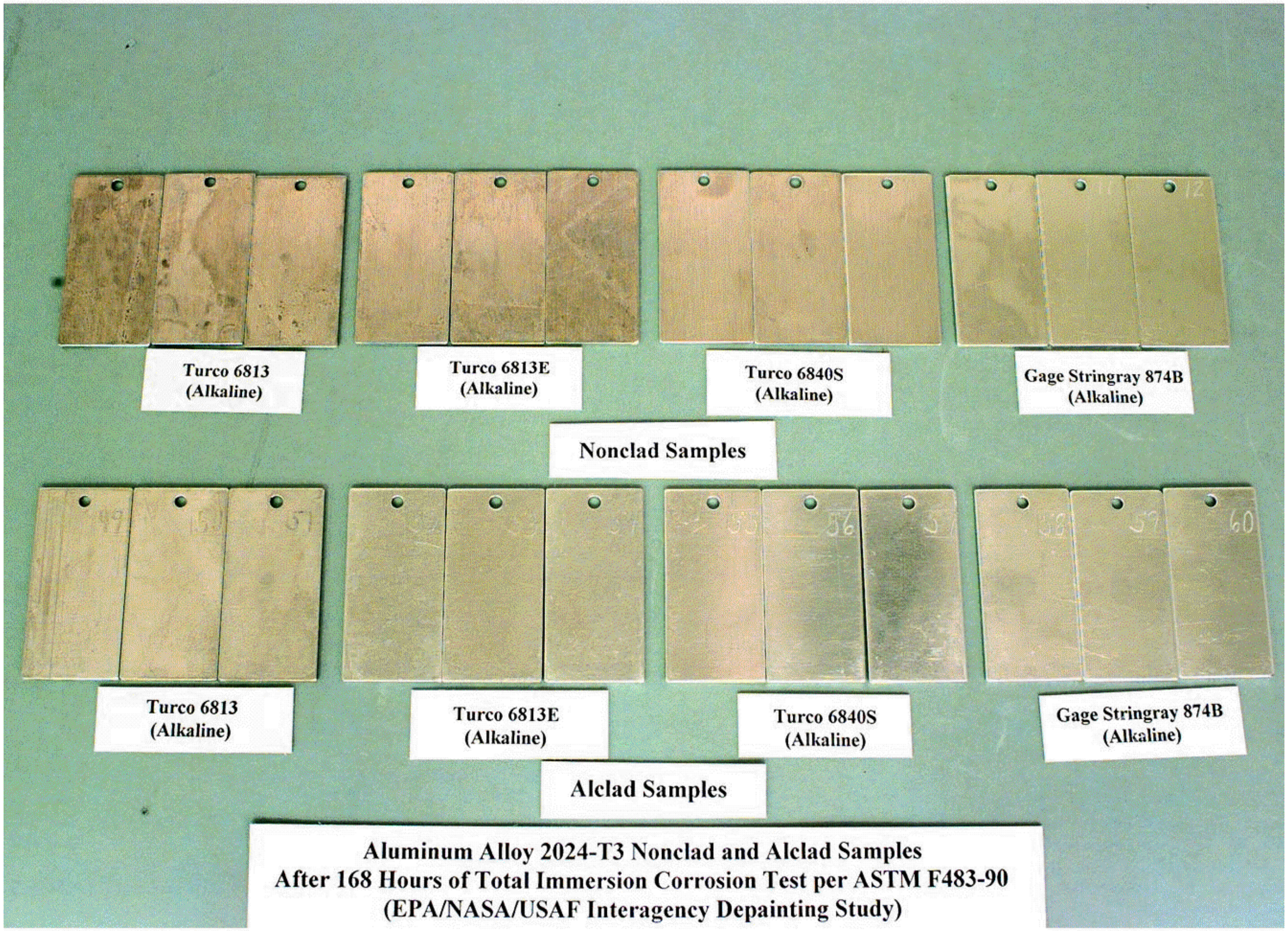

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Total Immersion Corrosion Test Results

Chemical Tested	Weight Loss Rate (mg/cm^2/24 hr)			
	Non-Clad 2024-T3		Clad 2024-T3	
	24-hr Exposure	168-hr Exposure	24-hr Exposure	168-hr Exposure
Turco 6813 (Alkaline)	0.0035	-0.0005	0.0000	-0.0025
Turco 6813-E (Alkaline)	0.0071	-0.0015	0.0000	-0.0020
Turco 6840-S (Alkaline)	0.0000	-0.0010	-0.0071	-0.0020
Stingray 874B (Neutral)	0.0000	-0.0005	0.0000	-0.0010
Cee-Bee R-256 (Alkaline baseline)	0.0000	0.0015	0.0000	-0.0015
Turco 6776 (Acidic)	0.3121	0.4189	0.2092	0.3440
EZE 540 (Acidic)	0.2943	0.2771	0.2624	0.2036
PR-2002 (Acidic)	0.0319	0.0709	0.0000	0.1054
Cee-Bee E-1004B (Acidic)	0.1986	0.1717	0.1773	0.1327
Cee-Bee A-202 (Acidic baseline)	0.2979	0.2594	0.1950	0.1753

Chemical Tested	Coupon Number	Discoloration or Dulling	Etching	Accretions Present and Relative Amounts	Pitting	Selective or Localized Attack
Turco 6813 (Alkaline)	1 2 3	yes	no	no	no	no
Turco 6813-E (Alkaline)	4 5 6	yes	no	no	no	no
Turco 6840-S (Alkaline)	7 8 9	no small spots no	no	no	no	no
Stingray 874B (Neutral)	10 11 12	very little a little no	no	no	no	no
Cee-Bee R-256 (Alkaline baseline)	13 14 15	very little very little no	no	no	no	no
Turco 6776 (Acidic)	16 17 18	yes (coupons whitened)	yes	no	no	no
EZE 540 (Acidic)	19 20 21	yes	yes	no	yes	yes
PR-2002 (Acidic)	22 23 24	yes (many spots)	yes	no	yes	yes
Cee-Bee E-1004B (Acidic)	25 26 27	yes	yes	no	yes	yes
Cee-Bee A-202 (Acidic baseline)	28 29 30	yes	yes	no	yes	yes

Total Immersion Corrosion Test Conclusions

Alkaline and Neutral Chemicals -
Little to no weight loss during exposure.
Well below acceptable weight loss rates.
No visible etching, pitting or accretions.

Acid Chemicals -
Non-clad - Three of five, including baseline, exhibited weight loss rates above acceptable rate (0.2mg/cm^2/24 hr).
Etching occurred from all chemicals.
No accretions on any samples.
Pitting and localized attack from all but one chemical.
Clad - One of five exhibited weight loss rates above acceptable rate (0.3 mg/cm^2/24 hr).
Etching occurred from all chemicals.
No accretions on any samples.
Pitting and localized attack from all but two chemicals.

Sandwich Corrosion Testing

Test: ASTM F1110-90 Standard Test Method for Sandwich Corrosion Test

Objective: Determine corrosiveness of chemical on substrate

Material: Clad and Non-Clad 2024-T3 Aluminum

Methodology: Immerse filter paper in chemical, sandwich filter paper between substrate panels and rate visual change per ASTM scale after seven days.

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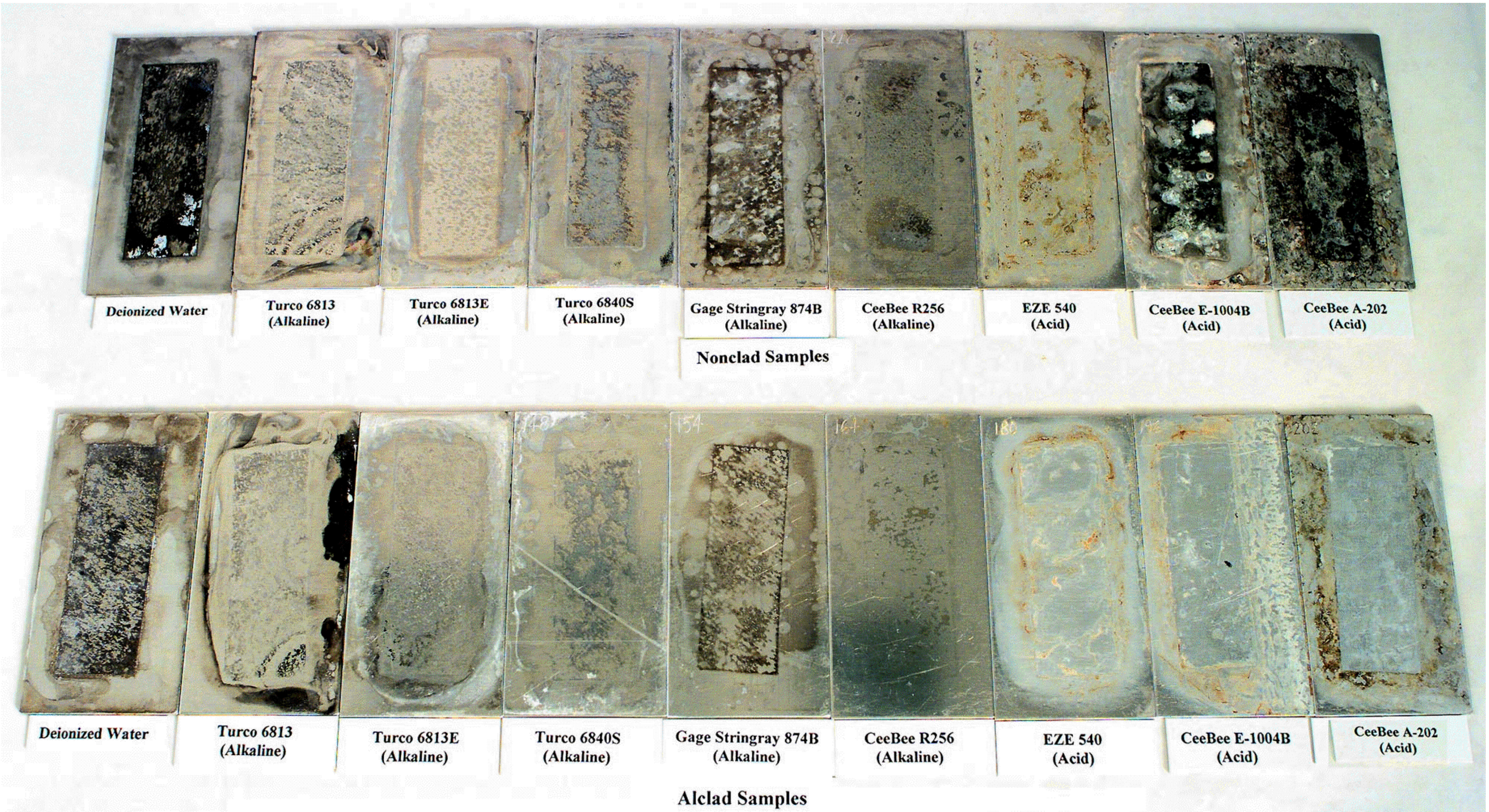

Representative Aluminum Alloy 2024-T3 Nonclad and Alclad Samples After Sandwich Corrosion Test per ASTM F1110-90 (EPA/NASA/USAF Interagency Depainting Study)

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Rating	Condition
0	No visible corrosion
1	Very slight corrosion or discoloration (up to 5% of the surface area corroded)
2	Slight corrosion (5 to10% of the surface area corroded)
3	Moderate corrosion (10 to 25% of the surface area corroded)
4	Extensive corrosion or pitting (25% or more of the surface area corroded)

Chemical Tested	Non-Clad 2024-T3		Clad 2024-T3	
	Sandwich Number	Rating	Sandwich Number	Rating
Deionized Water (per ASTM D1193, Type IV)	1	3	121	3
	3	3	123	3
	5	3	125	3
	7	3	127	3
Turco 6813 (Alkaline)	9	1	129	3
	11	2	131	3
	13	2	133	3
	15	3	135	3
Turco 6813-E (Alkaline)	17	2	137	2
	19	2	139	3
	21	2	141	2
	23	2	143	3
Turco 6840-S (Alkaline)	25	3	145	2
	27	3	147	3
	29	2	149	2
	31	2	151	3
Stingray 874B (Neutral)	33	3	153	3
	35	3	155	3
	37	3	157	3
	39	3	159	3
Cee-Bee R-256 (Alkaline baseline)	41	2	161	1
	43	3	163	2
	45	2	165	2
	47	3	167	1
Turco 6776 (Acidic)	49	4	169	3
	51	4	171	3
	53	4	173	3
	55	4	175	3
EZE 540 (Acidic)	57	4	177	3
	59	4	179	4
	61	4	181	3
	63	4	183	3
PR-2002 (Acidic)	65	4	185	3
	67	4	187	3
	69	4	189	3
	71	4	191	3
Cee-Bee E-1004B (Acidic)	73	4	193	3
	75	4	195	2
	77	4	197	3
	79	4	199	2
Cee-Bee A-202 (Acidic baseline)	81	4	201	3
	83	4	203	2
	85	4	205	2
	87	4	207	3

Sandwich Corrosion Test Conclusions

Alkaline and Neutral Chemicals -

Non-clad -

All chemicals performed equal to or better than deionized water.

Three alkaline alternate chemicals performed equal to or better than methylene chloride baseline.

The neutral chemical did not perform as well as the methylene chloride baseline.

Clad -

All chemicals performed equal to or better than deionized water.

Methylene chloride baseline performed better than alternate chemicals.

Acid Chemicals -

Non-clad -

All chemicals performed worse than deionized water.

Alternate chemicals performed the same as the methylene chloride baseline.

Clad-

Four of five chemicals (including the baseline) performed as well or better than deionized water.

Three of four alternate chemicals performed worse than methylene chloride baseline.

Hydrogen Embrittlement Testing

Test: ASTM F519-93 Standard Test Method for Mechanical Hydrogen Embrittlement Testing of Plating Processes and Aircraft Maintenance Chemicals

Objective: Determine hydrogen embrittlement potential of chemical

Material: Cadmium plated 4340 steel

Methodology: Immerse preloaded specimen in chemical for 150 hours, check for failure of specimen

Hydrogen Embrittlement Test Results

Chemical Tested	pH Values (as tested)	Failure Ratio	Time to Failure (hr or time interval)
Turco 6813 (Alkaline)	9.8	0/3	No Failures
Turco 6813-E (Alkaline)	9.9	0/3	No Failures
Turco 6840-S (Alkaline)	9.3	0/3	No Failures
Stingray 874B – Group 1 (Neutral)	5.7	2/3	98-145 128-143
Stingray 874B – Group 2 (Neutral)	5.7	1/3 (See note.)	191-198
Cee-Bee R-256 (Alkaline baseline)	8.0	0/3	No Failures
Turco 6776 (Acidic)	2.0	3/3	4.5 6 28-48
EZE 540 (Acidic)	2.5	3/3	0.5 8-24 8-24
PR-2002 (Acidic)	2.5	3/3	0.5 7-23 31-47
Cee-Bee E-1004B (Acidic)	2.4	3/3	1.75 1.75 1.75
Cee-Bee A-202 (Acidic baseline)	1.3	3/3	0.5 0.5 0.5

Note: Exposure time for the Group 2 specimens was extended to 200 hours.

Hydrogen Embrittlement Test Conclusions

Alkaline and Neutral Chemicals -

All alkaline chemicals (including the methylene chloride baseline) passed.
Failing neutral chemical exhibited two failures in six days (after 102 hours).
Failed specimens exhibited a region of intergranular fracture.
Failing neutral chemical was repeated and passed with no failures in 8 days (200 hours)
pH level of neutral chemical below levels reported by manufacturer.

Acid Chemicals -

All specimens failed within two days.
Failed specimens exhibited a region of intergranular fracture.
Methylene chloride baseline specimens failed in 0.5 hour.
Average failure times for alternative chemicals exceeded methylene chloride failure time.

Summary

Alternate alkaline and neutral chemical paint strippers have been identified that, with respect to corrosion requirements, perform as well or better then a methylene chloride baseline. These chemicals also, in general, meet corrosion acceptance criteria as specified in SAE MA 4872.

Alternate acid chemical paint strippers have been identified that, with respect to corrosion requirements, perform as well or better than a methylene chloride baseline. However, these chemicals do not generally meet corrosion acceptance criteria as specified in SAE MA 4872, especially in the areas of non-clad material performance and hydrogen embrittlement.

Mechanical Testing

SAE MA4872
Tensile
Fatigue
Crack Detectability
Clad Penetration

Tensile Testing

Test: ASTM E8

Objective: Determine tensile properties of substrate

Material: Clad and Non-Clad 2024-T3 Aluminum

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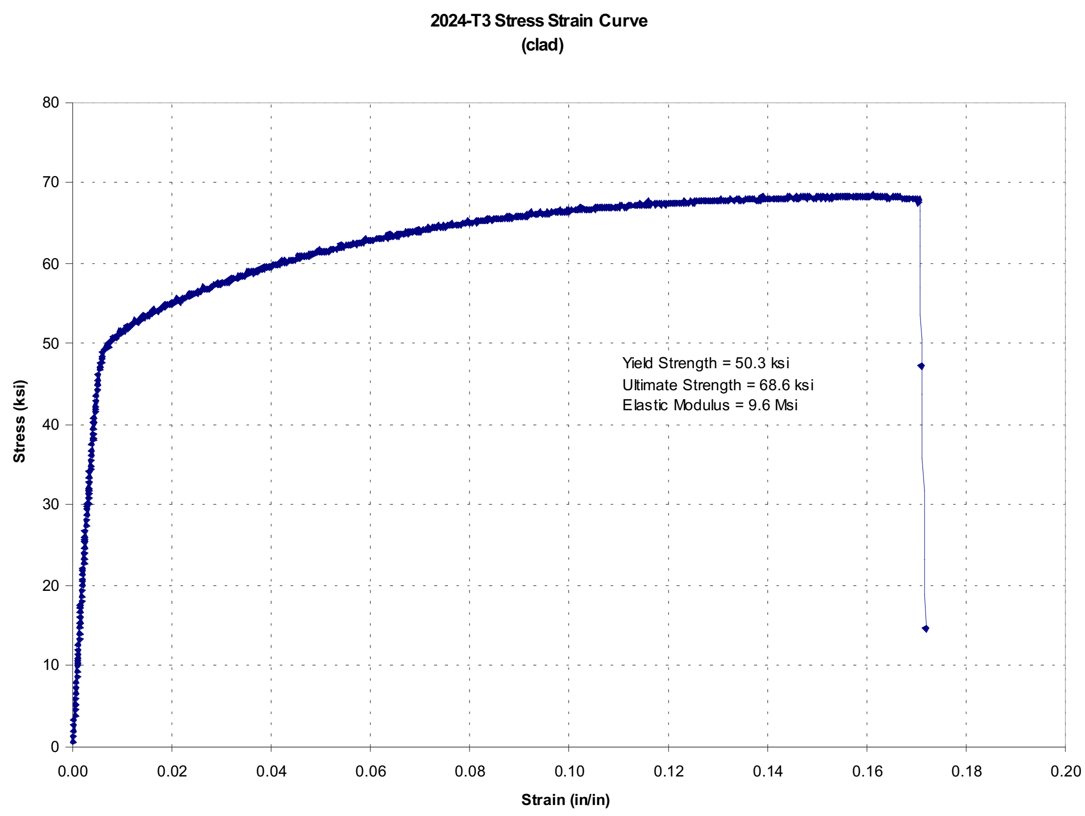
Tensile Stress-Strain Curve for 2024-T3 Aluminum (clad)



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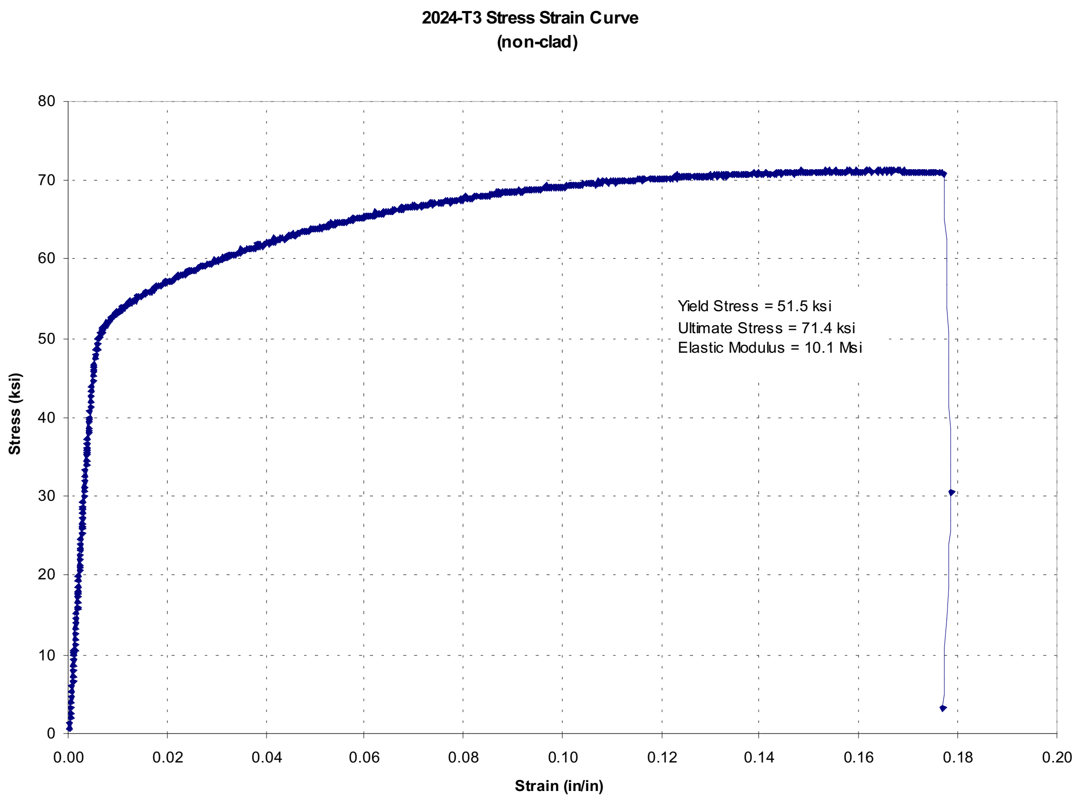
Tensile Stress-Strain Curve for 2024-T3 Aluminum (non-clad)



Tensile Test Data Summary (2024-T3 Aluminum, Longitudinal Direction)

Depainting Process	Clad/ Non-Clad	Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (%)
Baseline	non-clad	70.6	51.7	18.4
Xenon Flashlamp/CO_2				
Panel IV-15.7	non-clad	71.0	51.1	15.7
Panel IV-15.10	non-clad	67.3	45.6	14.7
Plastic Media Blasting				
Panel VII-VIII 29.16	non-clad	71.9	52.1	15.9
Panel VII-21.28	non-clad	71.4	51.5	17.7
MIL-HDBK-5G	non-clad	64	47	(See note.)
Baseline	clad	67.8	49.1	16.3
Plastic Media Blasting				
Panel VII-40.4	clad	68.2	49.8	16.9
Panel VII-40.2	clad	68.6	50.3	17.1
MIL-HDBK-5G	clad	60	44	(See note.)

Note: Elongation data are not provided in MIL-HDBK-5G.

Fatigue Testing

Test: SAE MA4872 (Type II Specimens)

Objective: Assess effects of depainting process on fatigue performance of substrate.

Material: Clad and Non-Clad 2024-T3 Aluminum
Baseline
Processed Panels

Methodology: Maximum stress 45 ksi
R Ratio of 0.1
Cyclic load frequency of 10 Hz.

Fatigue Test Configuration

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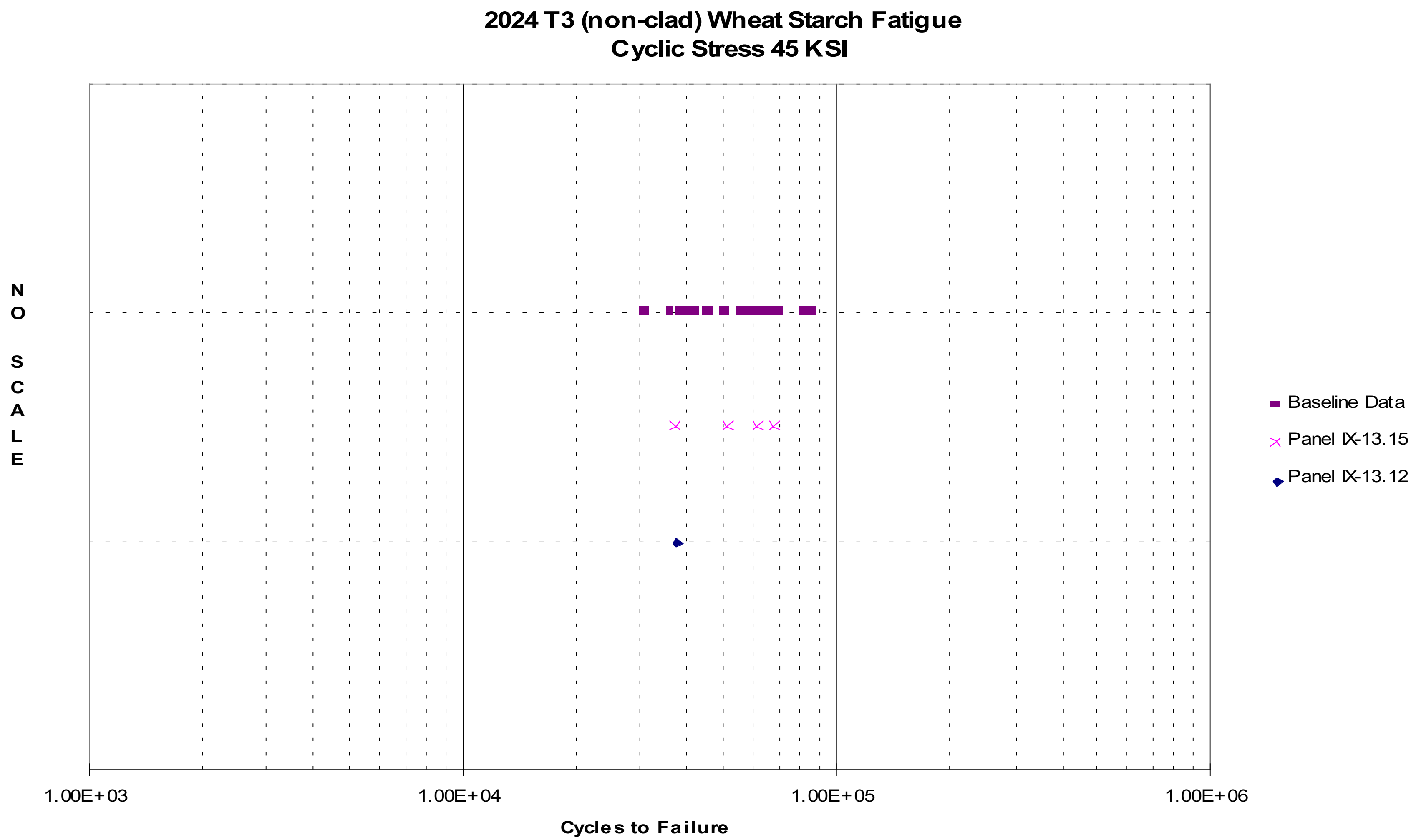
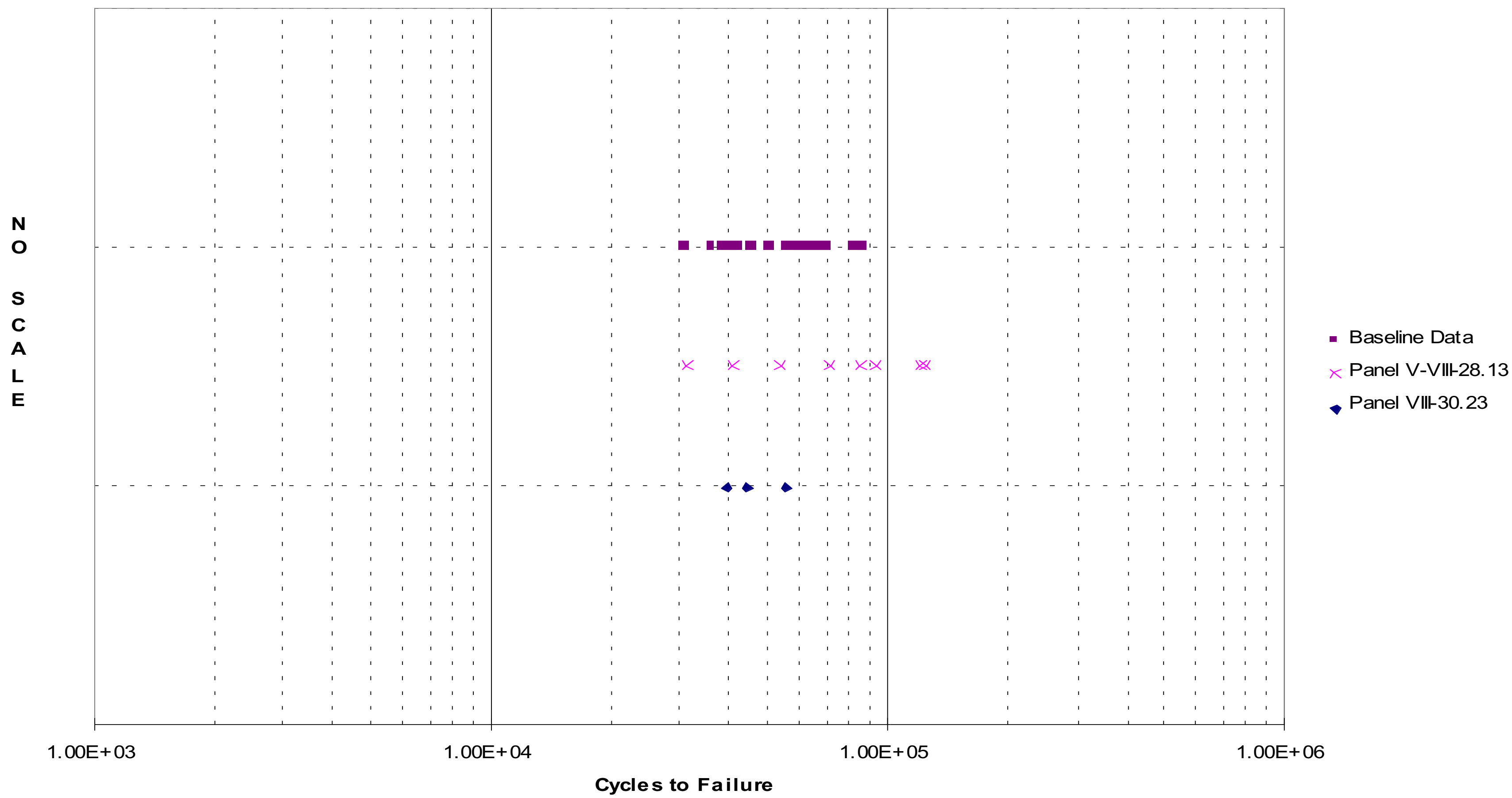


2024 T3 (non-clad) Water Blast Fatigue
Cyclic Stress 45 KSI



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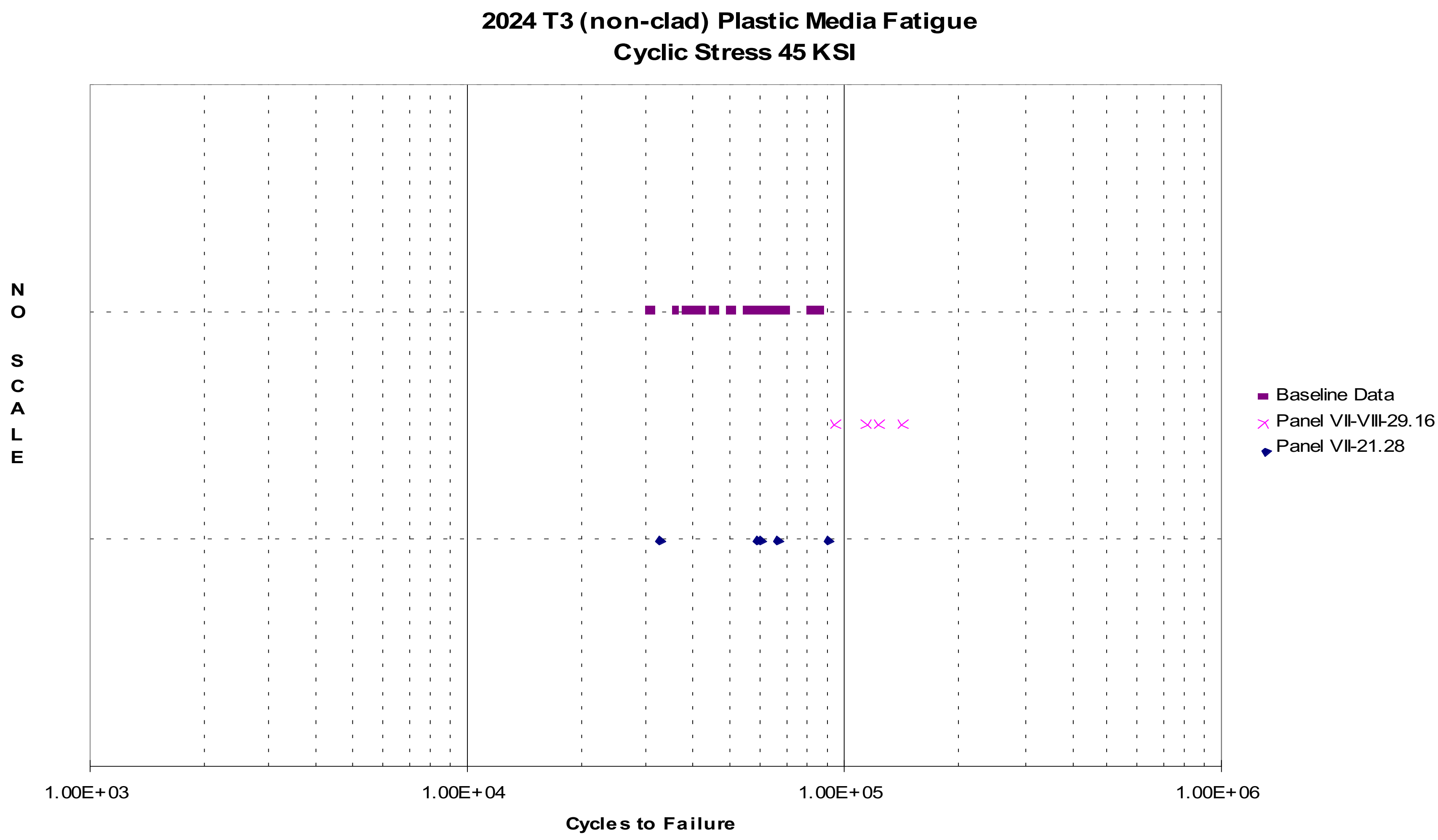

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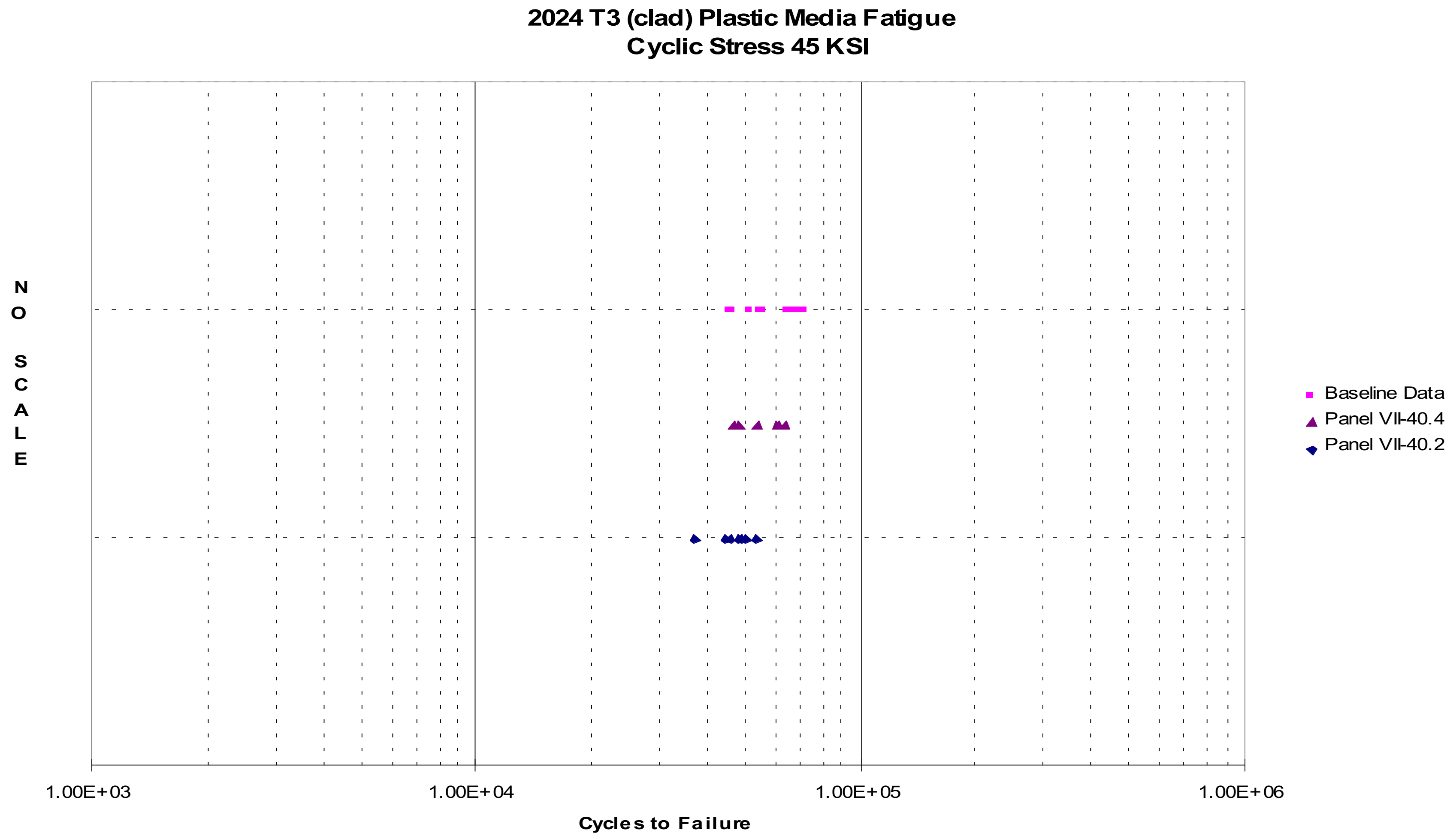
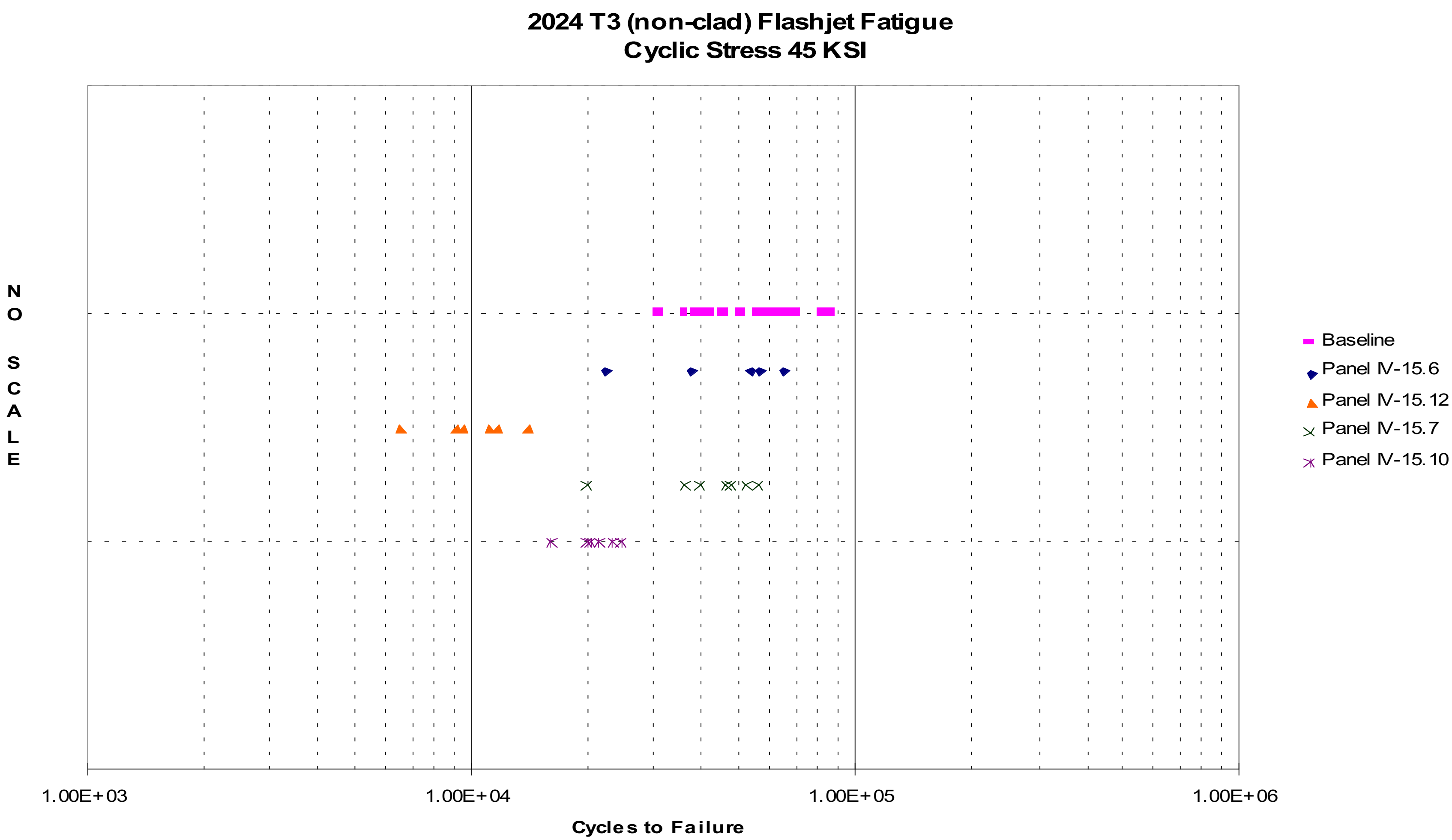



2024 T3 (non-clad) Flashjet Fatigue
Cyclic Stress 45 KSI
NO SCALE
1.00E+03
1.00E+04
1.00E+05
1.00E+06
Cycles to Failure
Baseline
Panel IV-15.6
Panel IV-15.12
Panel IV-15.7
Panel IV-15.10

Depainting Process	Clad or Non-clad	Number of Samples	Mean Fatigue Life (cycles)	Standard Deviation (cycles)	95% Confidence Intervals for Mean Fatigue Life (cycles)	
					Lower	Higher
Baseline	Non-clad	22	54,118	15,231	47,753	60,482
Xenon Flashlamp/CO_2						
Panel IV-15.6	Non-clad	5	47,804	21,478	28,978	66,630
Panel IV-15.7	Non-clad	7	43,058	15,298	31,725	54,390
Panel IV-15.10	Non-clad	6	21,048	3,124	18,549	23,548
Panel IV-15.12	Non-clad	6	10,351	2,779	8,128	12,575
Plastic Media Blasting						
Panel VII-VIII-29.16	Non-clad	4	119,249	20,852	98,815	139,683
Panel VII-21.28	Non-clad	5	62,173	23,901	41,224	83,123
High-Pressure Water Blasting						
Panel V-VIII-28.13	Non-clad	8	79,457	42,735	49,843	109,070
Panel VIII-30.23	Non-clad	3	46,112	8,038	37,016	55,208
Wheat Starch Blasting						
Panel IX-13.12	Non-clad	1	37048[1]	Note 2	Note 2	Note 2
Panel IX-13.15	Non-clad	4	54,827	14,704	40,418	69,238
Baseline	Clad	8	57,488	9,967	50,582	64,395
Plastic Media Blasting						
Panel VII-40.4	Clad	6	55,396	7,333	49,529	61,264
Panel VII-40.2	Clad	7	46,579	5,575	42,450	50,709

Notes:
1. Only one specimen from wheat starch blasting panel IX-13.12 failed in the gauge section; this figure is the actual number of cycles performed to fatigue the specimen.
2. No data are available for these categories since only one specimen from this panel failed in the gauge section.

Fatigue Test Conclusions

Small Sample Size

Xenon Flashlamp/CO_2 (non-clad)

- Overlap in mean life for two sets of panel specimens
- Reduction in mean life for two sets of panel specimens
  - Surface condition
  - Low strength material

Plastic Media (clad and non-clad)

- Increase in mean life for one set of non-clad panel specimens
- Overlap in mean life for one set of non-clad panel specimens
- Overlap in mean life for two sets of clad panel specimens

Wheat Starch (non-clad)

- Overlap in mean life for one set of panel specimens

Water Blast (non-clad)

- Overlap in mean life for two sets of panel specimens

Crack Detectability Testing

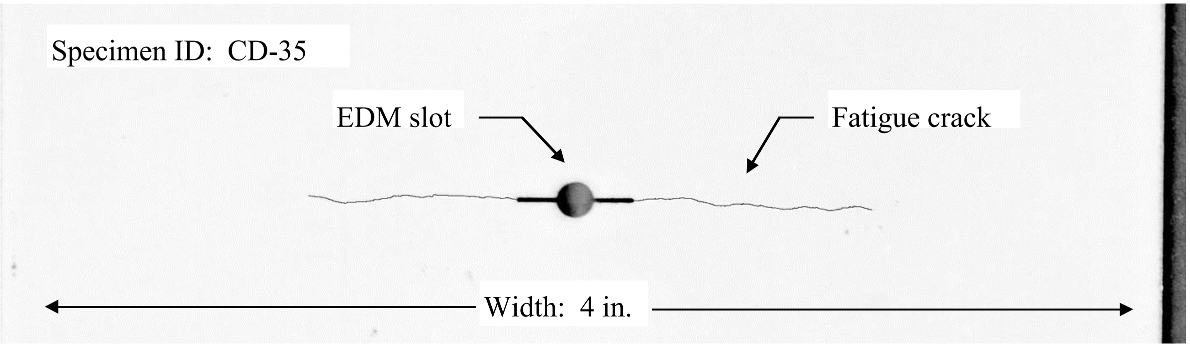
Test: SAE MA4872 - Crack Detectability

Objective: Assess effect of depainting process on detection of substrate cracks.

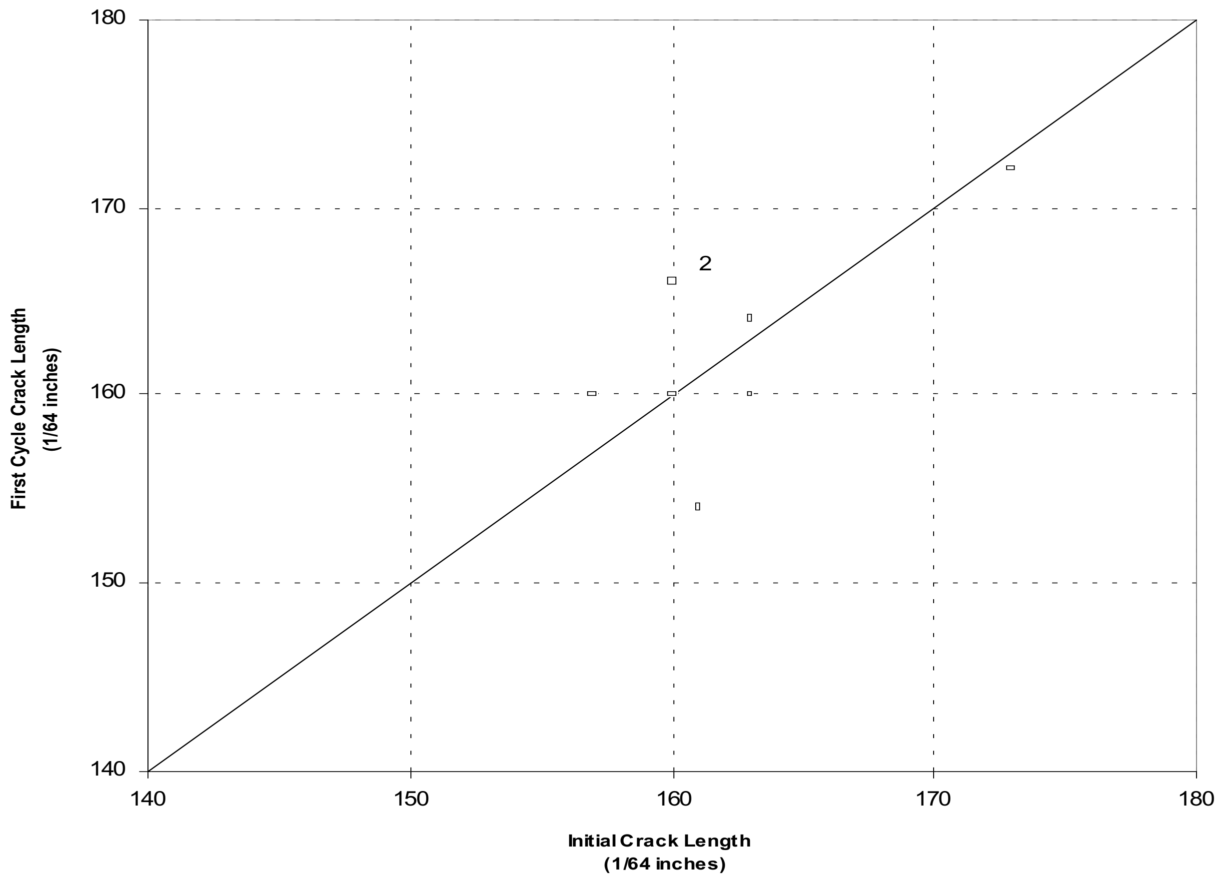
Material: Clad and Non-Clad 2024-T3 Aluminum

Methodology:
- Painted and Cured
- Notched and Precracked
- Crack lengths measured (eddy current)
- Depainted
- Crack lengths measured (eddy current)

Crack Detectability Specimen



Initial vs First Cycle Crack Length Measurements
Envirostrip Wheat Starch



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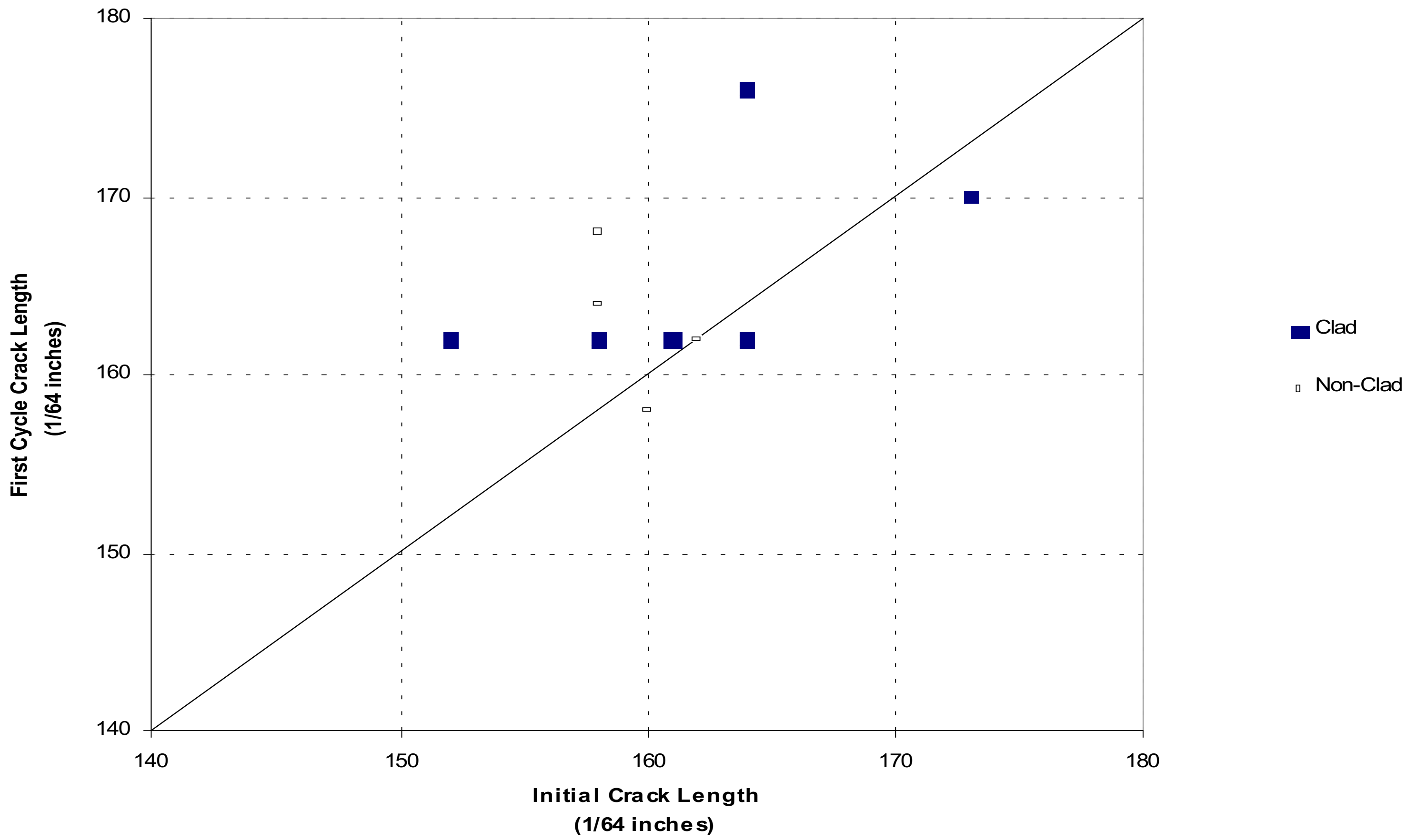
Initial vs First Cycle Crack Length Measurements
Plastic Media Blast



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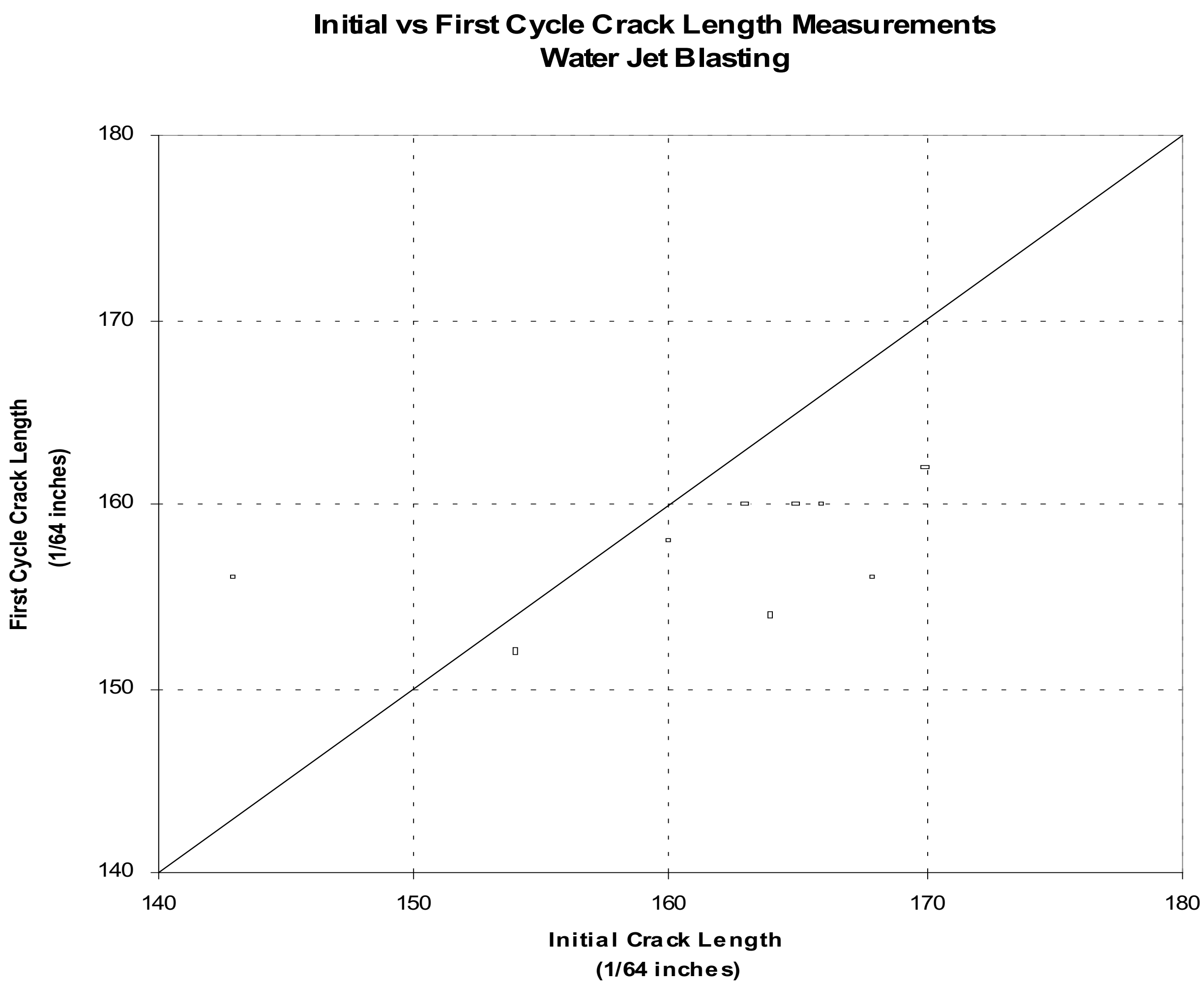

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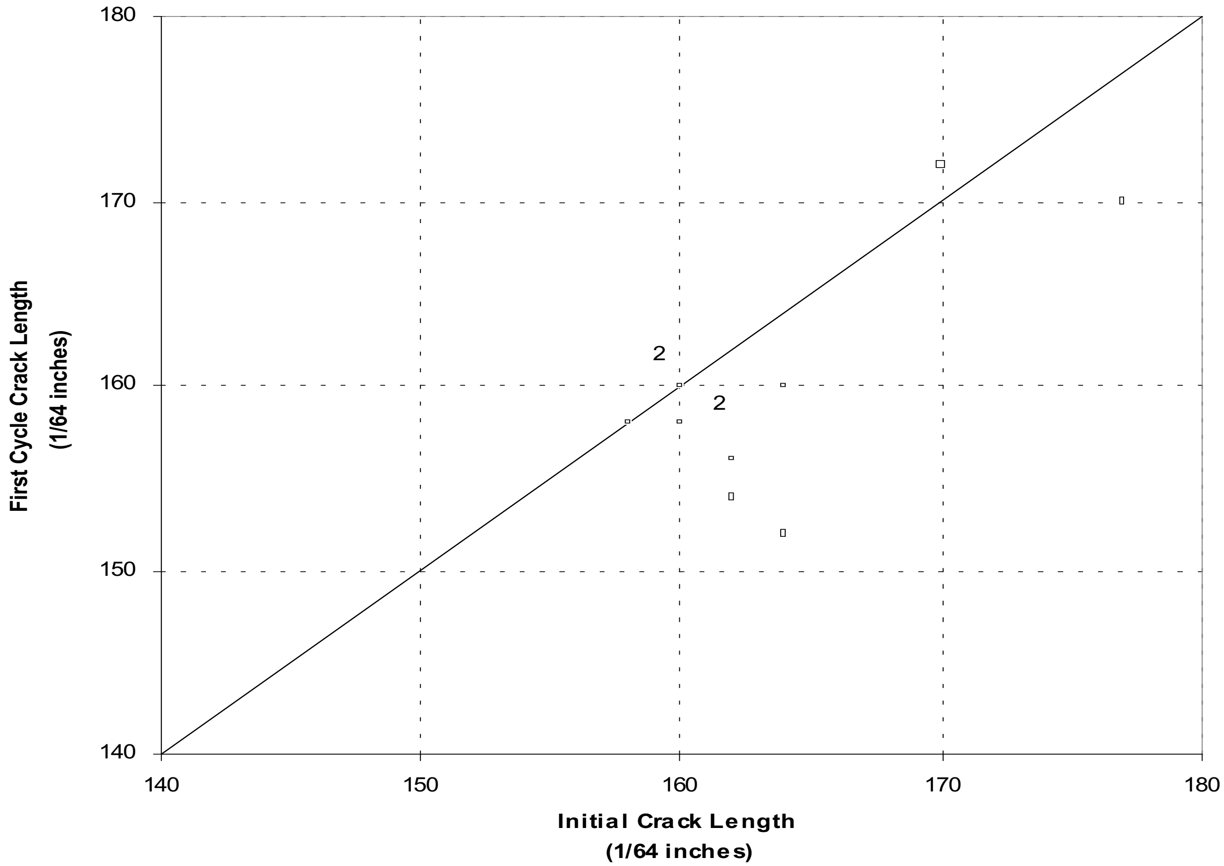
Initial vs First Cycle Crack Length Measurements
Sodium Bicarbonate Wet Stripping



Summary of Crack Detectability Test Results

Process	Specimen Number	Clad (y/n)	Crack Length (1/64 in.)		Process	Specimen Number	Clad (y/n)	Crack Length (1/64 in.)	
			Initial	Cycle 1				Initial	Cycle 1
Plastic Media Blasting	CD-10	n	158	164	Sodium Bicarbonate Wet Stripping	CD-2	n	162	154
	CD-11	n	158	168		CD-3	n	164	152
	CD-13	n	160	158		CD-20	n	177	170
	CD-15	n	162	162		CD-21	n	164	160
	CD-12	y	164	162		CD-22	n	160	158
	CD-14	y	164	176		CD-24	n	158	158
	CD-16	y	152	162		CD-25	n	160	160
	CD-17	y	161	162		CD-26	n	162	156
	CD-18	y	158	162		CD-27	n	160	158
	CD-19	y	173	170		CD-28	n	160	160
WaterJet Blasting	CD-30	n	166	160		CD-29	n	170	172
	CD-31	n	168	156	EnviroStrip® Wheat Starch Blasting	CD-40	n	160	166
	CD-32	n	143	156		CD-41	n	161	154
	CD-33	n	165	160		CD-42	n	160	160
	CD-34	n	170	162		CD-43	n	160	166
	CD-36	n	164	154		CD-44	n	163	164
	CD-37	n	160	158		CD-45	n	163	160
	CD-38	n	163	160		CD-46	n	157	160
	CD-39	n	154	152		CD-47	n	173	172

Summary of Pre- and Post-Processed Panel Crack Lengths

Process	Clad (y/n)	Average Difference (1/64 in.) (Cycle 1 - Initial)	Standard Deviation	Sample Size	95% Confidence Interval for Mean of the Difference	
Plastic Media Blasting	n	3.5	5.51	4	-1.9	8.9
	y	3.67	6.22	6	-1.31	8.64
Sodium Bicarbonate Wet Stripping	n	-3.55	4.27	11	-6.07	-1.02
WaterJet Blasting	n	-3.89	7.24	9	-8.62	0.84
EnviroStrip® Wheat Starch Blasting	n	0.63	4.44	8	-2.45	3.7

Crack Detectability Test Conclusions

Small Sample Size

Plastic Media (clad and non-clad)

Zero mean difference falls in 95% confidence interval.

Water Blast (non-clad)

Zero mean difference falls in 95% confidence interval.

Wheat Starch (non-clad)

Zero mean difference falls in 95% confidence interval.

Sodium Bicarbonate Wet Stripping (non-clad)

Zero mean difference does not fall in 95% confidence interval.

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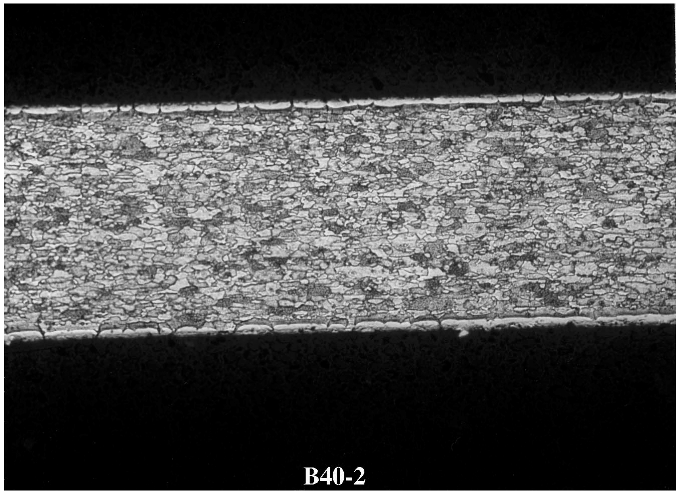
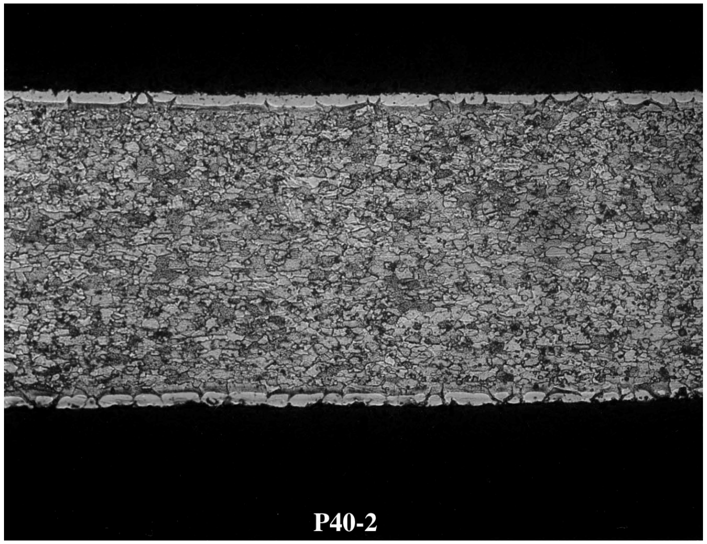
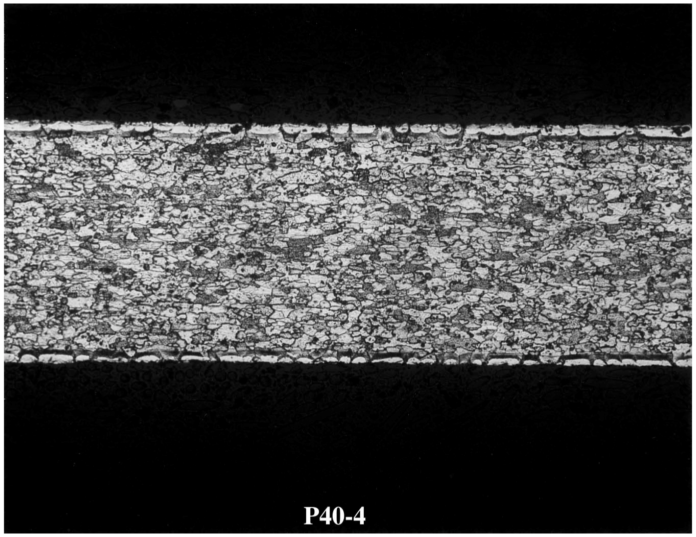
Clad Penetration Evaluation

Baseline







Plastic Media Blast

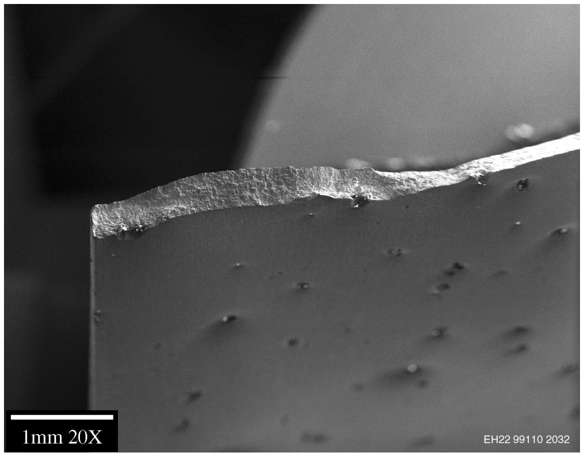
Summary

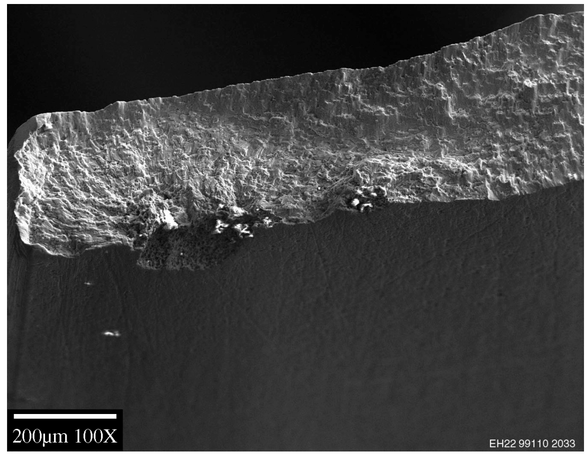
Alternate alkaline and neutral chemical paint strippers have been identified that, with respect to corrosion requirements, perform as well or better then a methylene chloride baseline. These chemicals also, in general, meet corrosion acceptance criteria as specified in SAE MA 4872.

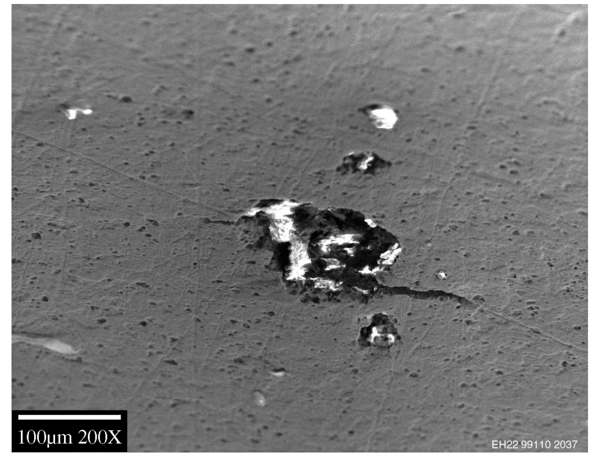
Alternate acid chemical paint strippers have been identified that, with respect to corrosion requirements, perform as well or better than a methylene chloride baseline. However, these chemicals do not generally meet corrosion acceptance criteria as specified in SAE MA 4872, especially in the areas of non-clad material performance and hydrogen embrittlement.

Media blast methods reviewed in the study do not, in general, adversely affect fatigue performance or crack detectability of 2024-T3 substrate. Sodium bi-carbonate stripping exhibited a tendency towards inhibiting crack detectability. These generalizations are based on a limited sample size and additional testing should be performed to characterize the response of specific substrates to specific processes.

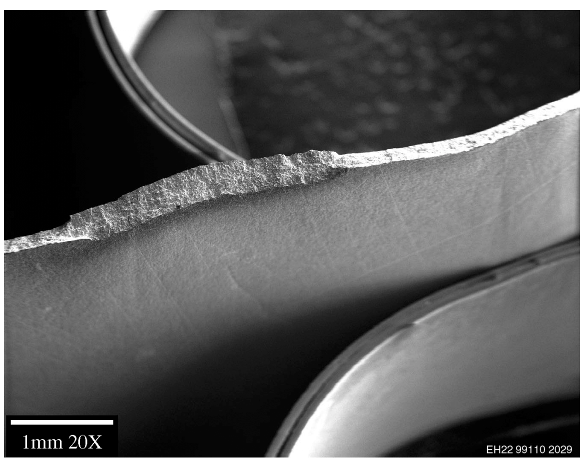
Flashjet Panel IV-15.12



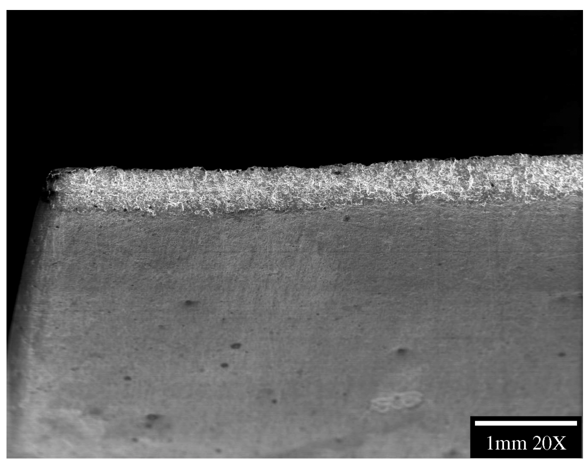




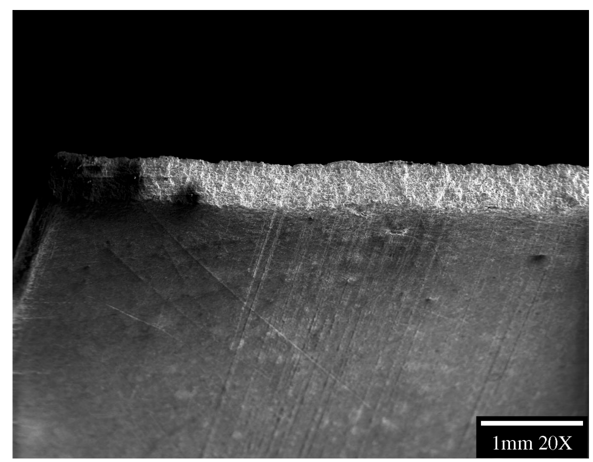
Panel IV-15.6

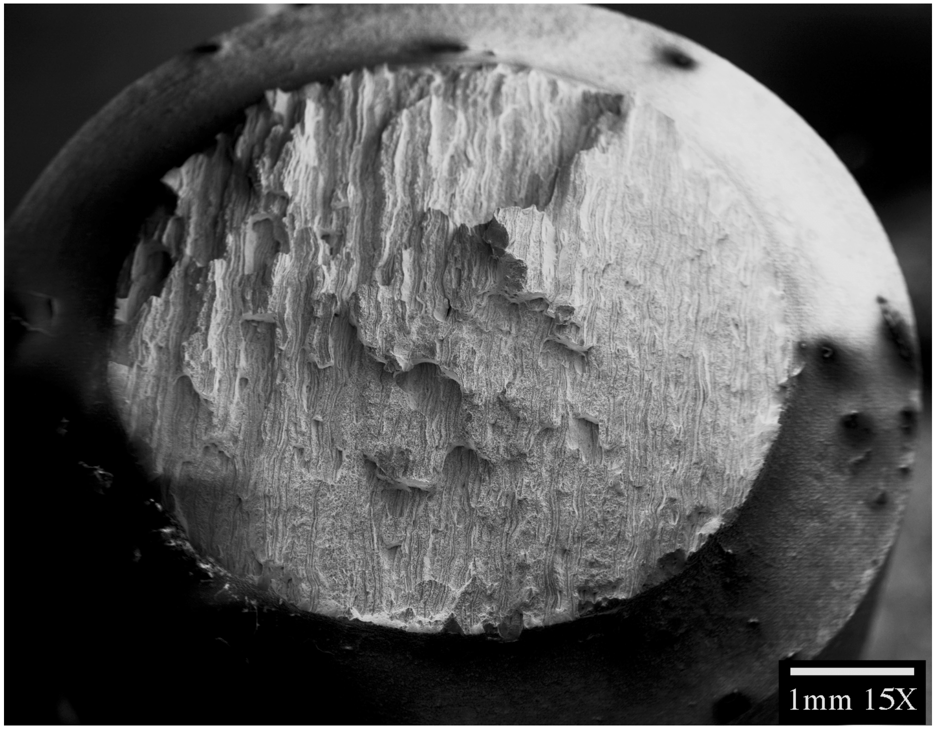


Panel IV-15.7



Panel IV-15.10




1mm 15X