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EXTENDED PERFORMANCE ASSESSMENT IN ACCELERATED CORROSION AND ADHESION OF CARC PREPARED ALUMINUM ALLOY 5059-H131 FOR THREE DIFFERENT PRETREATMENT METHODS

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ABSTRACT

Aluminum alloy 5059-H131 panels rolled to 0.25" thickness were prepared using Chemical Agent Resistant Coating (CARC) for evaluation under three different pretreatment conditions. The pretreatment conditions were abrasive blasted, a nonchromate pretreatment (NCP)[1], and a commercial trivalent chromate pretreatment (TCP)[2]. The primer used was MIL-P-53022[3] and the topcoat was MIL-DTL-53039[4]. Corrosion resistance was evaluated under GM 9540P[5] and ASTM B 117[6] neutral salt fog (NSF) methods. Adhesion was assessed under dry conditions using ASTM D 4541[7] pull-off and under wet conditions using ASTM D3359A[8]. Prior to coating, the conversion coated surfaces were compared for uniformity and color versus identically prepared AA5083 samples to determine whether or not the alloy differences will warrant modifications to current pretreatment processes.

Keywords: Corrosion, Aluminum, 5059-H131, Cyclic, GM 9540P, Salt fog, Adhesion, Pull-off

INTRODUCTION

Current U.S. Army and Marine Corps vehicle deployments require improved survivability and light weight armor designs to maintain mission performance. Historically, AA5083-H131 has been used in armor systems such as the M113, the M109, and the USMC Amphibious Assault Vehicle (AAV) in accordance with the MIL-DTL-46027J[9] for its combination of desirable traits such as lighter weight, ease of manufacturing via welds, excellent performance against fragmentation based threats, and excellent corrosion resistance. As threat levels have increased, more recently designed aluminum armor based systems such as the M2 Bradley

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and the USMC Expeditionary Fighting Vehicle (EFV) have migrated to higher strength Al alloys such as AA7039[10], AA2219[11], and AA2519[12]. These higher strength alloys provide better ballistic protection versus armor piercing threats and can also derive lighter weight hull designs from their increased yield and tensile strengths. Unfortunately, corrosion resistance for these alloys significantly decreases versus AA5083-H131 whether by stress corrosion cracking in AA7039 or from pitting and exfoliation in AA2519. This decrease in corrosion resistance has had profound effects on maintenance, the application of coatings, as well as environmental implications from the need to compensate for corrosion deficiencies through the use of hexavalent chromium based protection schemes.

Aluminum alloy 5083-H131 has many desirable traits but is lacking higher strength, thus imparting decreased survivability versus armor piercing AP threats. An alternate aluminum alloy that delivered the positive characteristics of AA5083-H131 with increased mechanical properties and improved performance against AP threats would represent an ideal choice for consideration as an aluminum armor material for production and repair of new and existing systems.

One possible alloy that could fulfill this role is AA5059-H131, an alloy that is produced by Aleris International Inc.[13] in Koblenz, Germany. As with AA5083, AA5059 is a magnesium based non heat treatable aluminum alloy that is strengthened via mechanical strain hardening. As a result of the strain hardening process, the 5000 series alloys receive the “H” designation rather than the “T” designation that is typical for heat treatable Al alloys. The 5059 alloy contains greater amounts of Mg than 5083 as well as some additions of Zn and Zr for grain refinement. Tables 1 and 2 compare the compositional and mechanical properties of AA5083, AA5059, and other military specification aluminum armors. Marine grade tempers of AA5059 such as H116 and H321 have been commercially available and in use for many years on yachts, ferries, and catamarans. However, limited information was known in regards to the hard H131 temper that would be applicable for armor plate.

A Foreign Comparative Test (FCT) proposal was submitted in 2004 to the Office of the Secretary of Defense (OSD) to examine and verify AA5059-H131 for possible use as an armor repair material for battle damaged or cracked armor plate sections on the M2 Bradley hull. Although the project was approved, it was initially unfunded for FY05 but eventually funded for FY06. The project goals were to verify the material performance in ballistics[14], blast resistance, weldability, corrosion due to sensitization, general corrosion and CARC coatings compatibility, and to update or create a military specification to include the alloy if proven successful.

All of the evaluations to date have been highly successful with the lone exception being decreased resistance to sensitization. A recent study by NAVSEA[15] found the AA5059 to be more susceptible to sensitization than AA5083. However, AA5059 was no more susceptible than AA5456, an armor alloy that in addition to AA5083 is fully compliant under the MIL-DTL-46027 armor specification. As a result of easily meeting or exceeding the balance of the remaining project goals, AA5059 was included in a revised edition of the armor military specification, MIL-DTL-46027K[16], effective July 31, 2007.

EXPERIMENTAL PROCEDURE

The purpose of this study was to verify the performance and compatibility of the AA5059 alloy when coated with variations of CARC coating systems most likely to be used at original equipment manufacturer (OEM) production facilities, and to determine what differences or unforeseen issues may exist when 5059 is used. The focus areas for these evaluations include ASTM B 117 neutral saltfog corrosion, GM 9540P cyclic corrosion, ASTM D 4541 pull-off adhesion, and ASTM D 3359A wet adhesion. Test panels of AA5059-H131 measuring 4.0” X 6.0” were machined from 0.25” thick plate. Based upon feedback from Project Manager Heavy Brigade Combat Team[17] (PM-HBCT) and BAE

Systems[18], a coatings matrix based upon likely production line scenarios was devised. The matrix consisted of three different surface preparations: Abrasive Blast, a nonchromate pretreatment (NCP), and a commercial trivalent chromate pretreatment (TCP) with one primer/topcoat combination. The TCP pretreatment is a variant of the NAVAIR developed formulation and fully complies with both MIL-DTL-5541F[19] and MIL-DTL-81706B[20] as a type II nonhexchrome variation. It is listed on the MIL-DTL-81706B Qualified Products List[21] (QPL). The abrasive blast media was 85 grit almandite garnet applied at 110 psi. Prior to applying the conversion coating, test panels were cleaned using a non-silicated, non-chromated, mildly alkaline aluminum cleaner and deoxidized using a non-chromated ferrous sulfate/nitric acid based desmutter. TCP (50%) and NCP were spray applied for 10 minutes at ambient conditions. All test panels were given a final deionized water rinse following completion of conversion coating application. The process flow diagram used for NCP and TCP is illustrated in Figure 1. The primer and topcoat combination used was manufactured by Hentzen[22] and consisted of the solvent based MIL-DTL-0053022 primer and a 1 lb/gal volatile organic compound (VOC) 686 tan pigmented topcoat formulation compliant with the new class of Type II low VOC and polymeric bead flattened topcoats described under MIL-DTL-53039B.

After 2 weeks of cure time, test panels for neutral salt fog (ASTM B 117) and cyclic accelerated corrosion (GM 9540P) were scribed with an “X” using a carbide tipped hardened steel scribe and placed into their respective chambers. A Harshaw Model 22 test chamber was used for neutral salt fog testing and an Attotech Model CCT-NC-20 was used for cyclic testing. The neutral salt fog operating parameters were in accordance with ASTM B 117, 95ºF with saturated humidity and atomized fog of 5% NaCl solution. The cyclic accelerated corrosion test was in accordance with GM 9540P consisting of 18 separate stages that include the following: saltwater spray, humidity, drying, ambient, and heated drying. The environmental conditions and duration of each stage for one complete cycle are provided in Table 3. The standard 0.9% NaCl, 0.1% $CaCl_2$, 0.25% $NaHCO_3$ test solution was used. In addition the cyclic chamber was calibrated with standard steel mass loss calibration coupons as described in the GM 9540P test specification.

In order to quantify the corrosion, all panels were numerically rated for scribe corrosion creepback damage at scheduled intervals in accordance with method ASTM D 1654.[23] The neutral salt fog panels were rated weekly for the first 3 weeks (504 hours) and then every three weeks henceforth until conclusion at 4032 hours. The cyclic panels were rated after 10 cycles, 20 cycles, and then every 20 cycles thereafter until conclusion of testing at 200 cycles. To facilitate easier viewing, color codes were assigned based upon ranges of ASTM D 1654 ratings. Table 4 depicts the ASTM D 1654 rating parameters and also defines the colors and their respective rating ranges. Upon measurements of scribe creepback ratings of 8 or less, accompanying images were obtained via 600 dpi digital flatbed scans and then subsequently rescanned at every remaining inspection interval until the conclusion of the experiment.

Wet adhesion was performed in accordance with Method 6301 of Federal Test Method Standard 141[24] and rated in accordance with ASTM D 3359A. Previous studies[25] on similar systems had indicated good performance from the conversion coatings in this study, therefore a more severe form of the wet adhesion procedure was chosen. Two replicates of each coating system were immersed in deionized water undisturbed for 1 week at 150ºF. After one week, the panels each were removed from the bath, patted dry with a lint-free wipe, then scribed and tested for wet tape adhesion. The rating system for ASTM D 3359A is described in Table 5.

Pull-off adhesion measurements assessing the performance of the coating system, surface preparation and/or pretreatments were performed in accordance with ASTM D 4541. An Elcometer Model 108 Hydraulic Adhesion Test Equipment (HATE) was used for this procedure. In addition to being a more quantitative test method, pull-off adhesion is also less prone to inevitable human influences in testing such as variations in pressure applied during scribing as well as interpretation and perception of results. For the pull-off adhesion test, a loading fixture commonly referred to as a “dolly” is secured normal to the coating surface using an adhesive. The first adhesives used were several different brands of standard cyanoacrylate in a variety of viscosities. After allowing the adhesive to cure for 24 hours at 25ºC and 65% RH (Table 6), the attached dolly was inserted into the test apparatus. The load applied by the apparatus was gradually increased and monitored on the gauge until a plug of coating was detached. Though it is not common practice to vary adhesives, the multitude of cyanoacrylate formulations were used due to repeated bonding difficulties to the steel surface of the test dollies. Due to these unforeseen adhesion problems with the standard cyanoacrylates, an alphacyanoacrylate ester formulation[26] was chosen and successfully substituted. Coating failure tensions (in psi) were then recorded with the accompanying failure modes characterized. The pull-off test apparatus and dolly configuration are illustrated in Figure 2. For pull-off data to be valid, the specimen substrate must be of sufficient thickness to ensure that the coaxial load applied during the removal stage does not distort the substrate material and cause a bulging or “trampoline effect.” If a thin specimen is used, the resultant bulge causes the coating to radially peel away outwards from the center instead of being uniformly pulled away in pure tension. Thus, the use of a thinner substrate results in significantly lower and erroneous readings than for identically prepared specimens at greater substrate thickness. At 0.25 inches, all of the 5059-H131 armor panels evaluated had adequate thickness for valid pull-off test results. In order to capture a statistically meaningful numerical assessment of coating adhesion, a minimum of 30 pull-off data points each were collected for each of the three coating systems.

RESULTS

Processing and Coating Application

An additional goal of this study was to assess the AA5059 alloy from a processing standpoint with the ultimate goal of production in mind. The abrasive blast and conversion coatings process steps were found to be identical to AA5083 from a processing standpoint. For the TCP there was even the added bonus of a more distinct color change to the substrate produced by the conversion coating. The TCP formed a significantly darker blue gray coating on AA5059 vs. AA5083 as seen in Figure 3. This more obvious color change is advantageous for production lines from a quality control standpoint and will directly translate to improved assurance of complete conversion coating coverage prior to application of the primer.

Accelerated Corrosion

As in previous studies with similar coatings on AA5083[27,28], the AA5059 panels exposed to neutral salt fog and cyclic corrosion testing exhibited excellent performance under accelerated corrosion conditions. After 4032 hours of neutral salt fog exposure, the only apparent creepback damage occurred on the abrasive blast prepared panels. After 200 cycles of cyclic testing, there was no visible creepback damage whatsoever across all replicates. As evident in Table 7, the bulk of the damage to the abrasive blast prepared neutral salt fog panels appeared within the first week via rapid nucleation and growth of blisters along the scribe. These blisters then progressed at a much slower rate after the initial one week observation. Scans depicting the relative progress of blisters for the same panels at 168 hours and at 4032 hours are shown in Figure 4. The conversion coated panels had no coating creepback whatsoever under the full durations of both neutral salt fog and cyclic exposures. The “9” ratings that appeared after

2016 hours were solely the result of inevitable discoloration and dulling from oxidation of the bare 5059 substrate exposed within the scribe. Interestingly, while the abrasive blast prepared panels performed significantly worse than the conversion coated counterparts under salt fog, they performed just as well as the conversion coated panels under cyclic testing with ratings of 9 across all 5 replicates at 200 cycles as listed in Table 8 and shown in Figure 5.

Adhesion

As mentioned in the procedure, a much more rigorous form of wet adhesion testing was conducted. After a full week of immersion in deionized water at 150ºF there was no coating removal produced for any of the panels when the tape was removed. All of the panels were rated at 5, a perfect rating and fully compliant with the performance level set for military applications. The wet adhesion data are listed in Table 9 and representative scans of the successful results are presented in Figure 6.

The pull-off adhesion evaluations proved more complex than with previous efforts. In addition to evaluating the new 5059-H131 substrate, the MIL-DTL-53039, Type II topcoat being used was also previously untested. As mentioned in the procedure, it became necessary to use an alphacyanoacrylate ester based formulation rather than the common commercial off the shelf cyanoacrylate formulas more typically used for pull-off adhesion testing. The use of this alternate adhesive was necessitated due to insufficient bonding strength between the metallic surface of the test dolly itself and the cured adhesive. For every measurement attempt, the dolly would separate at the metal-adhesive interface with a very low reading well under 1000 psi. Several different brands and viscosities of cyanoacrylate were evaluated in addition to grinding fresh surfaces onto the dollies in an attempt to improve the mechanical bond strength. In many years of performing this procedure and taking tens of thousands of individual measurements, this behavior had never previously been observed. In order to promote better adhesion to metallic surfaces, alphacyanoacrylate ester, a formulation promoted for its performance when bonded to metals was selected as a substitute for standard cyanoacrylate and was found to perform satisfactorily.

Thus, when the pull-off measurements were successfully taken, the results also proved interesting in regards to the new MIL-DTL-53039 formulation. In every measurement obtained for the panel sets, the failure locations were not at the substrate but instead were located within the primer and topcoat layers. For the NCP and TCP conversion coated panels, the pull-off results were all characterized as cohesive within the topcoat layer. This meant that the cohesive strength of the primer layer, the adhesive strength of the topcoat to the primer layer, as well as the adhesive strength of the primer to the conversion coated substrate surface were all in excess of the cohesive strength of the topcoat. The actual average pull-off values measured between the NCP prepared panels and the TCP panels, 2012 psi and 1974 psi respectively, differed only slightly. This was to be expected as the primer and topcoat layers were identically prepared and failed in identical modes. For the abrasive blast prepared panels the pull-off values measured were consistently lower averaging 1694 psi. Correspondingly, the failure mode differed versus the conversion coated panels and was characterized as adhesive at the topcoat-primer interface. This meant that the weakest link in the coating system occurred between the topcoat and the primer and thus the pull-off tensions were correspondingly lower as would be expected versus the conversion coated panels that failed cohesively. While all failure tensions measured individually were high enough to justify a good coating, it also meant that it was not possible to ascertain any differences between the different coating types at the primer-substrate interface. While no exact measurement at the primer-substrate layer was possible, it can be stated that the performance was in excess of the adhesive strength of the topcoat to the primer for the blast prepared panels and in excess of the cohesive strength of the topcoat for the conversion coated panels and therefore satisfactory. All pull-off adhesion data with accompanying representative pictures of the pull-off failure modes are listed in Tables 10-12. Correspondingly, the pull-off data are plotted as histograms in Figures 7-9.

DISCUSSION

The goal of this study was to evaluate the compatibility of the AA5059-H131 substrate with CARC coating systems that are relevant to current and future weapon systems. The excellent corrosion resistance inherent to the AA5059 alloy necessitated the longer exposure durations versus the shorter intervals normally relevant to the more corrosion prone alloys among the 2000 and 7000 series aluminums. Even after the longer exposure durations, the AA5059 showed little or no damage from corrosion with the sole exception being the abrasive blast prepared samples under neutral salt fog. It can be definitively stated that either NCP or the TCP would qualify as an excellent spray based hexavalent chromium-free pretreatment step on any repair or production line. The TCP is fully compliant as a Type II, hexavalent chromate free conversion coating under MIL-DTL-5541. The previously referenced studies that also examined less corrosion resistant Al alloys such as 2024-T3 and 7075-T6, determined the performance of NAVAIR based TCP variants to be greatest among any of the hexavalent chromate free conversion coatings.

If a situation arises where absolutely no chromium containing compounds are permitted then the NCP will function very well but only as part of a complete coating system. It should be noted that unlike TCP and other accepted TCP based products, the NCP does not meet the MIL-DTL-5541 specification due to its poor bare corrosion resistance. Previous studies have shown that the NCP while indeed a very good conversion coating, only works well as part of a complete coating system as was the case in this study. Trivalent chromium pretreatments such as TCP must provide additional bare corrosion resistance performance in order to qualify under MIL-DTL-5541 and MIL-DTL-81706. It is important to distinguish this difference for the purpose of highlighting possible performance differences if a coating system were to be damaged or omitted.

In the specific case of AA5059 and other 5000 series alloys where bare corrosion resistance is excellent, the impact from the absence of a primer and topcoat would likely be minimal and the temptation to even omit the pretreatment may exist. In this particular study, the only corrosion damage observed was on the abrasive blasted panels with no conversion coating. In addition, the corresponding pull-off adhesion values were lowest on the abrasive blast prepared set. Keeping the experimental results in mind, based upon its compliance with the conversion coating military specifications and its ability to sustain performance under bare conditions, one would logically conclude that the best overall system to use would be the TCP. It can be mentioned that while the abrasive blast method certainly works, it is certainly not optimum and is not recommended other than perhaps for field repairs where conversion coatings are not always available or practical.

A secondary goal of this study was to obtain more data on the new class of low VOC single component topcoats specified under MIL-DTL-53039B. In all of the corrosion and adhesion evaluations it is evident that no detrimental effects were observed. The only real anomalous behavior observed was the significant decrease in bonding performance of standard cyanoacrylate adhesives to the steel pull-off dollies when bonded to the new coating. Ultimately it was rationalized that some component unique to the new MIL-DTL-53039B, Type II topcoat formulation with the polymeric beads interacted with the adhesive and thus degraded the bonding strength of standard cyanoacrylate formulas to the steel surfaces. Whether or not this interaction is specific to all MIL-DTL-53039, Type II coatings, MIL-DTL-53039, Type II coatings containing polymeric beads for flattening, or MIL-DTL-53039, Type II coatings from the particular manufacturer used has not been determined.

CONCLUSIONS

1. AA5059-H131 did not display any negative compatibility problems with any of the CARC coating components, processes, or the complete coating systems.

2. The performance of the coating systems on the AA5059 was exemplary under extended accelerated corrosion durations of 4032 hours in neutral salt fog and 200 cycles in GM 9540P cyclic.

3. Based upon excellent performance, the trivalent chromate pretreatment formulation evaluated in this study as well as any other NAVAIR based TCP variant listed on the MIL-DTL-81706 QPL would be recommended as the pretreatment of choice based upon its qualification with the conversion coating MIL-DTL-5541 and MIL-DTL-81706 and its ability to sustain performance under bare conditions.

4. The nonchromate pretreatment examined in this study exhibited excellent performance as part of a complete coating system and would be ideal for situations in which any chromium containing compounds hexavalent or otherwise are completely banned.

5. All coating systems exhibited superior extended 150ºF wet adhesion performance in ASTM D 3359A with perfect ratings of 5.

6. Adhesion problems with cyanoacrylate bonding to the pull-off test dollies were likely caused by absorption of a component or additive within the MIL-DTL-53039B, Type II topcoat and subsequent interaction and degradation of the adhesive.

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TABLES

TABLE 1
CHEMICAL COMPOSITION REQUIREMENTS FOR QUALIFIED MILITARY SPECIFICATION ALUMINUM ARMOR ALLOYS (%)

Element	**5083**	**5456**	**5059**	**7039**	**2219**	**2519**
Silicon	0.40 max	0.25 max	0.50 max	0.30 max	0.20 max	0.25 max
Iron	0.40 max	0.40 max	0.50 max	0.40 max	0.30 max	0.30 max
Copper	0.10 max	0.10 max	0.40 max	0.10 max	5.8 Š 6.8	5.3 Š 6.4
Manganese	0.4 Š 1.0	0.5 Š 1.0	0.60 Š 1.2	0.10 Š 0.40	0.20 Š 0.40	0.10 Š 0.50
Magnesium	4.0 Š 4.9	4.7 Š 5.5	5.0 Š 6.0	2.3 Š 3.3	0.02 max	0.05 Š 0.40
Chromium	0.05 Š 0.25	0.05 Š 0.20	0.30 max	0.15 Š 0.25	Š	Š
Zinc	0.25 max	0.25 max	0.40 Š1.5	3.5 Š 4.5	0.10 max	0.10 max
Titanium	0.15 max	0.20 max	0.20 max	0.10 max	0.02 Š 0.10	0.02 Š 0.10
Zirconium	Š	Š	0.05 Š 0.25	Š	0.10 Š 0.25	0.10 Š 0.25
Vanadium	Š	Š	Š	Š	0.05 Š 0.15	0.05 Š 0.15
Others (each)	0.05 max	0.05 max	0.05 max	0.05 max	0.05 max	0.05 max
Others (max)	0.15 max	0.15 max	0.15 max	0.15 max	0.15 max	0.15 max
Aluminum	Remainder	Remainder	Remainder	Remainder	Remainder	Remainder

TABLE 2
MINIMUM MECHANICAL REQUIREMENTS FOR MILITARY SPECIFICATION ALUMINUM ARMOR ALLOYS

Property	**5083**	**5456**	**5059**	**7039**	**2219**	**2519**
Yield Stress (ksi) (0.2% offset min.)	35.0	35.0	44.0	51.0	46	58.0
Ultimate Stress (ksi)	45.0	45.0	57.0	60.0	62.0	68.0
Percent Elongation	8	8	8	9	7	7

TABLE 3
GM 9540P CYCLIC CORROSION TEST DETAILS

Interval	Description	Time (min)	Temperature (±3C)
1	Ramp to Salt Mist	15	25
2	Salt Mist Cycle	1	25
3	Dry Cycle	15	30
4	Ramp to Salt Mist	70	25
5	Salt Mist Cycle	1	25
6	Dry Cycle	15	30
7	Ramp to Salt Mist	70	25
8	Salt Mist Cycle	1	25
9	Dry Cycle	15	30
10	Ramp to Salt Mist	70	25
11	Salt Mist Cycle	1	25
12	Dry Cycle	15	30
13	Ramp to Humidity	15	49
14	Humidity Cycle	480	49
15	Ramp to Dry	15	60
16	Dry Cycle	480	60
17	Ramp to Ambient	15	25
18	Ambient Cycle	480	25

TABLE 4
EVALUATION AND COLOR CODING OF SCRIBED COATED SPECIMENS SUBJECTED TO CORROSIVE ENVIRONMENTS (ASTM D 1654)

Rating of Failure at Scribe (Procedure A)		
Representative Mean Creepage From Scribe		Rating Number
(Millimeters)	(Inches)	
0	0	10
Over 0 to 0.5	0 to 1/64	9
Over 0.5 to 1.0	1/64 to 1/32	8
Over 1.0 to 2.0	1/32 to 1/16	7
Over 2.0 to 3.0	1/16 to 1/8	6
Over 3.0 to 5.0	1/8 to 3/16	5
Over 5.0 to 7.0	3/16 to 1/4	4
Over 7.0 to 10.0	1/4 to 3/8	3
Over 10.0 to 13.0	3/8 to 1/2	2
Over 13.0 to 16.0	1/2 to 5/8	1
Over 16.0 to more	5/8 to more	0

TABLE 5
WET ADHESION RATING – METHOD ASTM D 3359A

Rating	Description of Coating After Tape Removal
Method A - Wet Adhesion	
5*	No peeling or removal. (*Passes Military Performance Criteria)
4	Trace peeling or removal along scribes.
3	Jagged removal along scribes up to 1/16 in. (1.6 mm) on either side.
2	Jagged removal along most of the scribes up to 1/8 in. (3.2 mm) on either side.
1	Removal from most of the area between the scribes under the tape.
0	Removal beyond the area of the scribes.

TABLE 6
LABORATORY CONDITIONS FOR PULL-OFF ADHESION ASTM D 4541

Adhesive Type Used	alphacyanoacrylate ester
Cure time (hours)	24
Temperature (C)	25
Percent Relative Humidity	65
Substrate Material	AA5059-H131
Substrate Thickness (in)	0.25
Pretreatment Types	Abrasive Blast Nonchromate Pretreatment (NCP) Trivalent Chromate Pretreatment (TCP)
Primer Used	MIL-DTL-0053022
Topcoat Used	MIL-DTL-53039B (Type II)
Total Coating Thickness (mils)	Abrasive Blast ~3.1 Conversion Coated ~2.5

TABLE 7
ASTM D 1654 CREEPBACK RATINGS FOR ASTM B 117 NEUTRAL SALT FOG

Panel Designation	Pretreatment	Surface Finish	ASTM B 117 Hours									
			24	168	336	504	1512	2016	2520	3024	3528	4032
A1	NCP	Mill Finish	10	10	10	10	10	10	9	9	9	9
A2	NCP	Mill Finish	10	10	10	10	10	10	9	9	9	9
A3	NCP	Mill Finish	10	10	10	10	10	10	9	9	9	9
A4	NCP	Mill Finish	10	10	10	10	10	10	9	9	9	9
A5	NCP	Mill Finish	10	10	10	10	10	10	9	9	9	9
T1	TCP	Mill Finish	10	10	10	10	10	10	9	9	9	9
T2	TCP	Mill Finish	10	10	10	10	10	10	9	9	9	9
T3	TCP	Mill Finish	10	10	10	10	10	10	9	9	9	9
T4	TCP	Mill Finish	10	10	10	10	10	10	9	9	9	9
T5	TCP	Mill Finish	10	10	10	10	10	10	9	9	9	9
GB1	None - DTM	Abrasive Blasted	10	6	6	6	6	5	5	5	5	5
GB2	None - DTM	Abrasive Blasted	10	7	7	6	6	6	6	6	6	6
GB3	None - DTM	Abrasive Blasted	10	6	6	6	6	6	6	6	6	6
GB4	None - DTM	Abrasive Blasted	10	7	7	7	7	7	7	7	7	7
GB5	None - DTM	Abrasive Blasted	10	6	6	6	6	6	5	5	5	5

TABLE 8
ASTM D 1654 CREEPBACK RATINGS FOR GM 9540P CYCLIC CORROSION

Panel Designation	Pretreatment	Surface Finish	GM 9540P Cycles										
			10	20	40	60	80	100	120	140	160	180	200
A1	NCP	Mill Finish	10	10	10	10	10	10	9	9	9	9	9
A2	NCP	Mill Finish	10	10	10	10	10	10	9	9	9	9	9
A3	NCP	Mill Finish	10	10	10	10	10	10	9	9	9	9	9
A4	NCP	Mill Finish	10	10	10	10	10	10	9	9	9	9	9
A5	NCP	Mill Finish	10	10	10	10	10	10	9	9	9	9	9
T1	TCP	Mill Finish	10	10	10	10	10	10	9	9	9	9	9
T2	TCP	Mill Finish	10	10	10	10	10	10	9	9	9	9	9
T3	TCP	Mill Finish	10	10	10	10	10	10	9	9	9	9	9
T4	TCP	Mill Finish	10	10	10	10	10	10	9	9	9	9	9
T5	TCP	Mill Finish	10	10	10	10	10	10	9	9	9	9	9
GB1	None - DTM	Abrasive Blasted	10	10	10	10	10	10	9	9	9	9	9
GB2	None - DTM	Abrasive Blasted	10	10	10	10	10	10	9	9	9	9	9
GB3	None - DTM	Abrasive Blasted	10	10	10	10	10	10	9	9	9	9	9
GB4	None - DTM	Abrasive Blasted	10	10	10	10	10	10	9	9	9	9	9
GB5	None - DTM	Abrasive Blasted	10	10	10	10	10	10	9	9	9	9	9

TABLE 9
150°F EXTENDED WET ADHESION RESULTS FOR COATED AA5059 PANELS

Panel Designation	Measurement	Surface Type/Pretreatment	Rating
A19	1	Mill Finish/NCP	5A
A19	2	Mill Finish/NCP	5A
A20	1	Mill Finish/NCP	5A
A20	2	Mill Finish/NCP	5A
T19	1	Mill Finish/TCP	5A
T19	2	Mill Finish/TCP	5A
T20	1	Mill Finish/TCP	5A
T20	2	Mill Finish/TCP	5A
GB19	1	Abrasive Blasted/None	5A
GB19	2	Abrasive Blasted/None	5A
GB20	1	Abrasive Blasted/None	5A
GB20	2	Abrasive Blasted/None	5A

TABLE 10
PULL-OFF RESULTS FOR NCP CONVERSION COATED AA5059 PANELS

Pretreatment	Adhesion (psi)	Failure/Mode
NCP	2000	Topcoat/Cohesive
NCP	1880	Topcoat/Cohesive
NCP	2380	Topcoat/Cohesive
NCP	2380	Topcoat/Cohesive
NCP	2110	Topcoat/Cohesive
NCP	2070	Topcoat/Cohesive
NCP	2020	Topcoat/Cohesive
NCP	2240	Topcoat/Cohesive
NCP	2120	Topcoat/Cohesive
NCP	1800	Topcoat/Cohesive
NCP	1900	Topcoat/Cohesive
NCP	1890	Topcoat/Cohesive
NCP	1800	Topcoat/Cohesive
NCP	2390	Topcoat/Cohesive
NCP	2240	Topcoat/Cohesive
NCP	1790	Topcoat/Cohesive
NCP	2090	Topcoat/Cohesive
NCP	1750	Topcoat/Cohesive
NCP	1640	Topcoat/Cohesive
NCP	1820	Topcoat/Cohesive
NCP	1820	Topcoat/Cohesive
NCP	1800	Topcoat/Cohesive
NCP	1900	Topcoat/Cohesive
NCP	2480	Topcoat/Cohesive
NCP	2690	Topcoat/Cohesive
NCP	1900	Topcoat/Cohesive
NCP	1900	Topcoat/Cohesive
NCP	2230	Topcoat/Cohesive
NCP	1970	Topcoat/Cohesive
NCP	1800	Topcoat/Cohesive
NCP	1810	Topcoat/Cohesive
NCP	1910	Topcoat/Cohesive
NCP	1880	Topcoat/Cohesive
Average	2012.12	
STD DEV	246.07	
Geometric Mean	1998.41	
Median	1900.00	
95% Confidence	83.95	
MAX	2690.00	
MIN	1640.00	

TABLE 11
PULL-OFF RESULTS FOR TCP CONVERSION COATED AA5059 PANELS

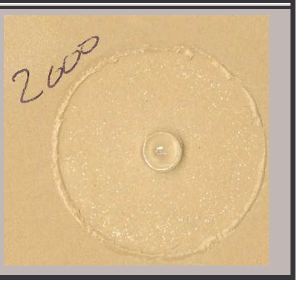
Pretreatment	Adhesion (psi)	Failure/Mode
TCP	1970	Topcoat/Cohesive
TCP	1860	Topcoat/Cohesive
TCP	1960	Topcoat/Cohesive
TCP	2170	Topcoat/Cohesive
TCP	1920	Topcoat/Cohesive
TCP	1980	Topcoat/Cohesive
TCP	2120	Topcoat/Cohesive
TCP	1860	Topcoat/Cohesive
TCP	1710	Topcoat/Cohesive
TCP	1750	Topcoat/Cohesive
TCP	2240	Topcoat/Cohesive
TCP	1770	Topcoat/Cohesive
TCP	1940	Topcoat/Cohesive
TCP	2140	Topcoat/Cohesive
TCP	2010	Topcoat/Cohesive
TCP	2310	Topcoat/Cohesive
TCP	1890	Topcoat/Cohesive
TCP	2090	Topcoat/Cohesive
TCP	1930	Topcoat/Cohesive
TCP	1800	Topcoat/Cohesive
TCP	2200	Topcoat/Cohesive
TCP	1920	Topcoat/Cohesive
TCP	2120	Topcoat/Cohesive
TCP	2030	Topcoat/Cohesive
TCP	2000	Topcoat/Cohesive
TCP	2080	Topcoat/Cohesive
TCP	1910	Topcoat/Cohesive
TCP	1980	Topcoat/Cohesive
TCP	1700	Topcoat/Cohesive
TCP	1880	Topcoat/Cohesive
Average	1974.67	
STD DEV	154.82	
Geometric Mean	1968.82	
Median	1965.00	
95% Confidence	55.40	
MAX	2310.00	
MIN	1700.00	

TABLE 12
PULL-OFF RESULTS FOR ABRASIVE BLAST PREPARED AA5059 PANELS

Preparation	Adhesion (psi)	Failure/Mode
Abrasive Blast	2020	Topcoat/Adhesive
Abrasive Blast	1800	Topcoat/Adhesive
Abrasive Blast	1790	Topcoat/Adhesive
Abrasive Blast	1870	Topcoat/Adhesive
Abrasive Blast	1800	Topcoat/Adhesive
Abrasive Blast	1600	Topcoat/Adhesive
Abrasive Blast	1780	Topcoat/Adhesive
Abrasive Blast	1630	Topcoat/Adhesive
Abrasive Blast	1390	Topcoat/Adhesive
Abrasive Blast	1520	Topcoat/Adhesive
Abrasive Blast	2000	Topcoat/Adhesive
Abrasive Blast	1650	Topcoat/Adhesive
Abrasive Blast	1450	Topcoat/Adhesive
Abrasive Blast	1800	Topcoat/Adhesive
Abrasive Blast	1730	Topcoat/Adhesive
Abrasive Blast	1520	Topcoat/Adhesive
Abrasive Blast	1420	Topcoat/Adhesive
Abrasive Blast	1510	Topcoat/Adhesive
Abrasive Blast	1630	Topcoat/Adhesive
Abrasive Blast	1250	Topcoat/Adhesive
Abrasive Blast	1870	Topcoat/Adhesive
Abrasive Blast	1990	Topcoat/Adhesive
Abrasive Blast	1860	Topcoat/Adhesive
Abrasive Blast	1720	Topcoat/Adhesive
Abrasive Blast	2000	Topcoat/Adhesive
Abrasive Blast	1790	Topcoat/Adhesive
Abrasive Blast	1800	Topcoat/Adhesive
Abrasive Blast	1860	Topcoat/Adhesive
Abrasive Blast	1610	Topcoat/Adhesive
Abrasive Blast	1590	Topcoat/Adhesive
Abrasive Blast	1540	Topcoat/Adhesive
Abrasive Blast	1420	Topcoat/Adhesive
Average	1694.06	
STD DEV	198.80	
Geometric Mean	1682.43	
Median	1725.00	
95% Confidence	68.88	
MAX	2020.00	
MIN	1250.00	

FIGURES

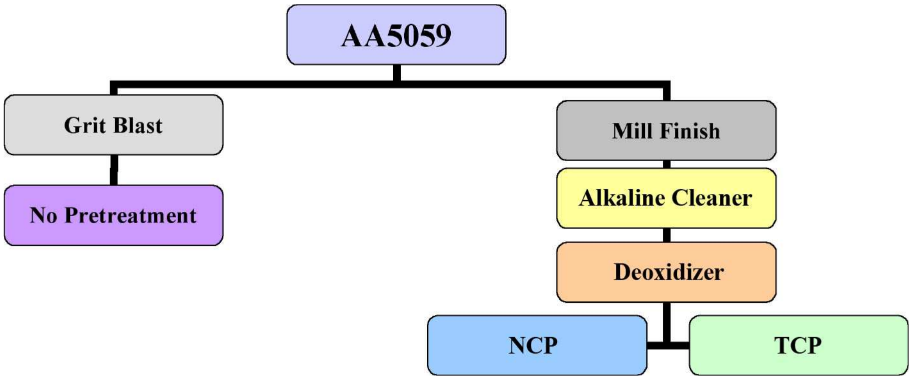


FIGURE 1: AA5059 Test Panel Conversion Coating Processing Flowchart

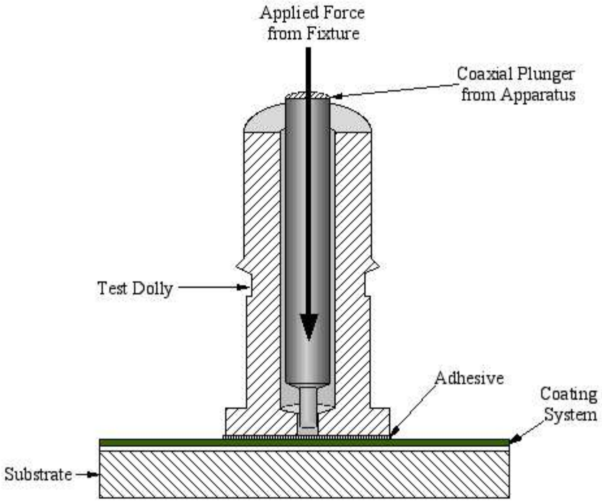
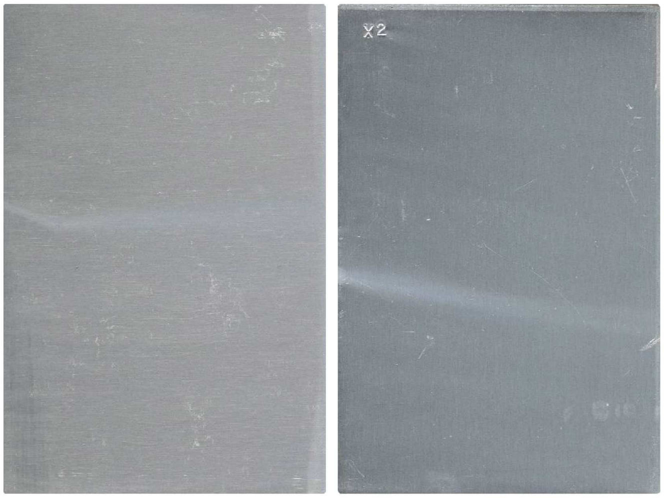
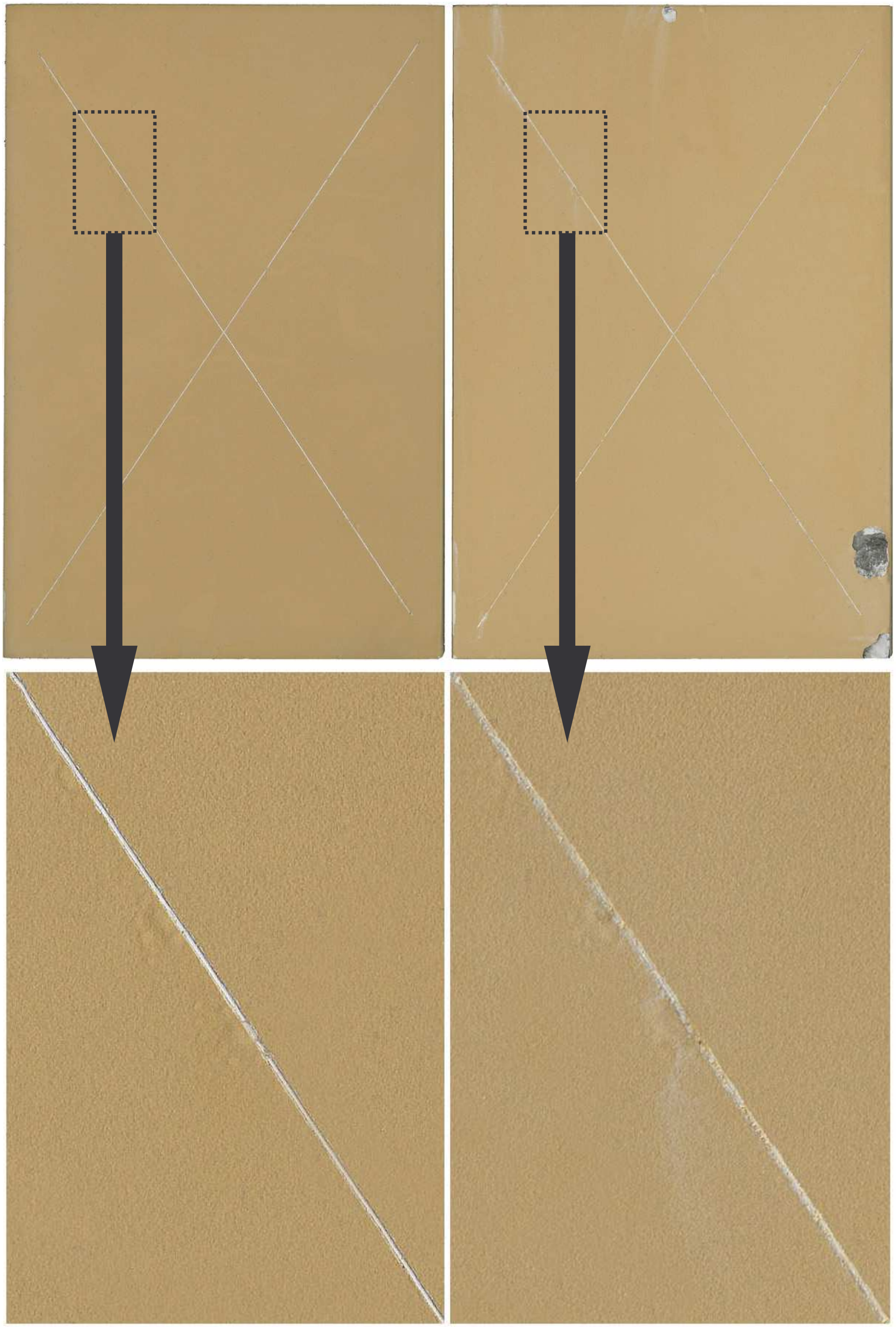


FIGURE 2: Pull-Off Hydraulic Adhesion Test (ASTM D 4541)



(a) (b)

FIGURE 3: TCP Color Change on (a) AA5083 and (b) AA5059



(a) (b)

FIGURE 4: Blistering Comparison Between Abrasive Blast Prepared Panel at (a) 168 Hours and (b) 4032 Hours of Salt Fog Exposure. (5.5X for lower images)

(a) (b) (c)

FIGURE 5: 200 Cycle GM 9540P Panels (a) NCP, (b) TCP, (c) Grit Blast

(a) (b) (c)

Figure 6: 1 Week 150°F Immersed Wet Adhesion Panels Representative Scans Showing Coating Surface Incisions and Corresponding Test Tape Back Sides, All Rated at 5A per ASTM D 3359A (a) NCP, (b) TCP, (c) Grit Blast

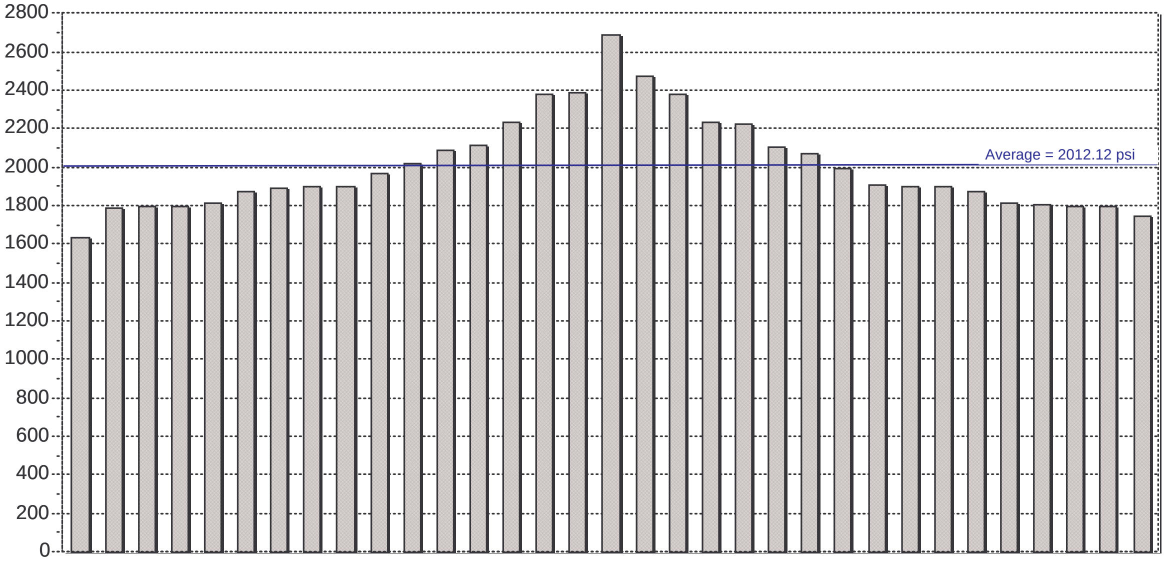


FIGURE 7: Pull-off Data Distribution for NCP Conversion Coated AA5059

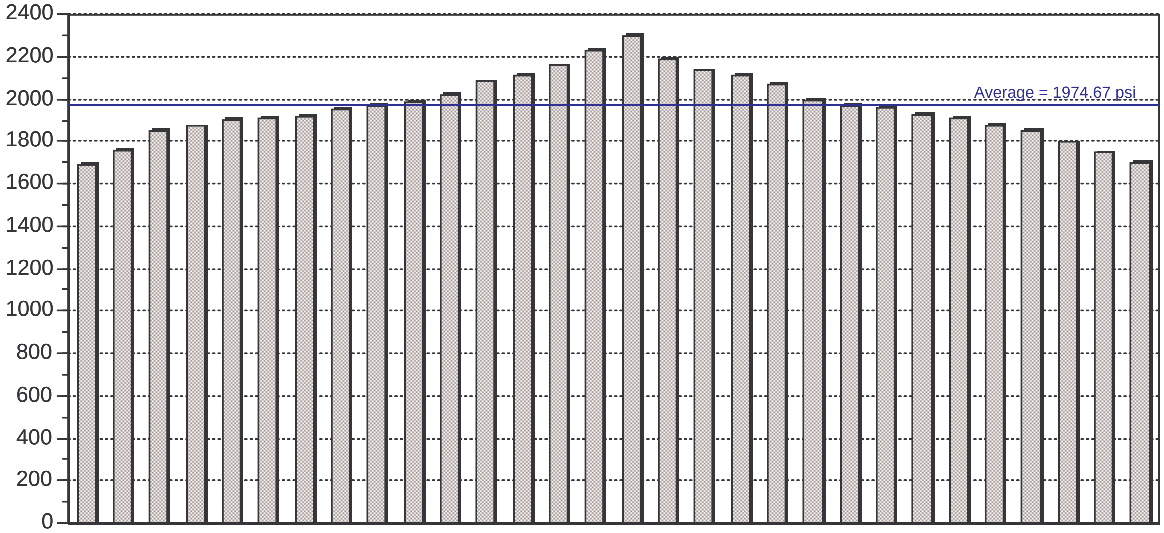


FIGURE 8: Pull-off Data Distribution for TCP Conversion Coated AA5059

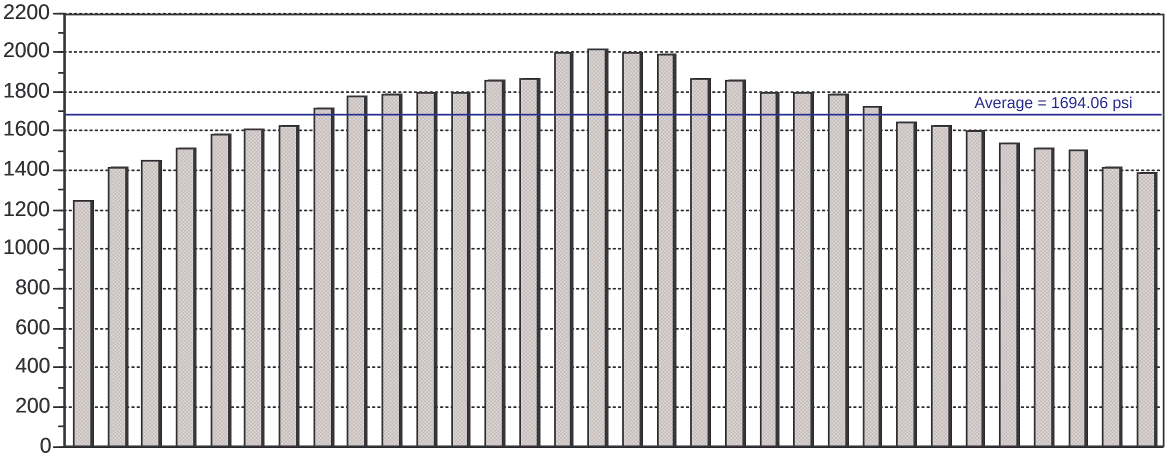


FIGURE 9: Pull-off Data Distribution for Abrasive Blast Prepared AA5059