

Surface And Defect Preparation Using Atmospheric Plasma For Non-Metallic Pipe Repair

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ABSTRACT

Atmospheric Plasma Solutions Inc. (APS) partnered with ADV Integrity, Inc. to conduct a testing program to evaluate the impact of atmospheric plasma surface preparation on the performance of composite systems used to repair defects in transmission pipelines. The APS surface treatment system provides a portable solution for coating removal and functionalizes surfaces to increase adhesion of resins/epoxy/coatings to the underlying substrate. Composite repair systems' performance relies heavily on the levels of adhesion between the initial layer of the composite system and the substrate. Enhanced adhesion translates to improved performance of composite systems due to increased bonding (mechanical and chemical) which improves the load transfer from the substrate to the composite

layers. Atmospheric plasma treated surfaces were compared to industry standard surface preparation (NACE-2) and flash-rusted surfaces on commercially available composite repairs systems. All groups were tested to ASTM standards for contact angle wettability; lap shear testing; full-scale leak repair pressure testing; and mechanical testing (tensile and fracture toughness (Charpy V-notch)). Plasma treated surfaces displayed over a 300% increase in pressure cyclic performance compared to industry standard solutions. Additionally, utilizing this solution did not affect the bulk material properties of the metal substrates as shown in tensile and Charpy tests.

Key words: Metallurgical failures; Materials performance, Maintenance; Preservation; Surface preparation; Non-metallic Repair; Adhesion

INTRODUCTION

Composite repair systems' performance relies heavily on the levels of adhesion between the initial layer of the composite system and the substrate. Enhanced adhesion translates to improved performance of the composite system since better bonding (whether mechanical or chemical) enhances the load transfer from the substrate to the composite layers as well as limit the porosity that would allow liquid or gas molecules to flow through. The aim of this study was to prove quantitatively how the APS atmospheric plasma surface preparation can improve the performance of composite repair systems whether on leaking or nonleaking defects.

The PlasmaBlast™ 7000-M (PB 7000M) system uses a low pressure (70-100 psi) compressed air source and electricity (208- 240 volt) to produce a special form of atmospheric pressure air plasma (as shown in Figure 1). This atmospheric air plasma is highly chemically activated and oxidizes any organic components in paints and other coating materials. The APCR process converts a significant portion of the removed organic coating into water vapor and carbon dioxide, leaving behind a lower volume of solids of mostly inorganic pigments and fillers that can be safely collected with a suitable HEPA vacuum.

The reactive species created by the plasma flows into the surface's fissures and irregularities, which allows any adhesive applied to not only mechanical bond but also functionalizes the surface to enhance chemical adhesion. Traditional surface preparation methods typically rely solely on mechanical bonding. For example, in surface preparations such as sandblasting where the surface is abrasively roughened, the adhesive mechanically bonds to the surface due to the defects that are introduced at the surface which results in anchoring of the adhesive molecules into the peaks and valleys created. Albeit, that mechanical bonding alone is effective, it is reversible. Contrarily, chemical bonding requires a chemical process to reverse it, and thus is harder to disbond. The main benefit of the atmospheric plasma preparation shown in this study is the significant reduction on the measured contact angle and subsequent increase in bond strength for commercially available composite repair systems which offers an alternative technology to increase the longevity of repaired assets.



Figure Error! No text of specified style in document.: PB 7000-M Applied on a Pipe Sample

EXPERIMENTAL PROCEDURE

The purpose of this research was to compare the effect of different surface preparations on the properties of the adhesive used on metallic substrates. Specific experimental tests were implemented to highlight the effects of using atmospheric plasma to enhance surface functionalization, adhesion to the underlying metal substrate, and increase the longevity of the repair.

Lap Shear Testing

Lap shear testing is a small-scale test where two steel plates are bonded using an adhesive then loaded in axial tension until failure occurs, which is characterized by the adhesive disbondment. The testing methods were governed by ASTM D1002 and included multiple samples with various surface preparations such as: unprepared, flash rust, NACE 2, PB 7000-M and PB 7000-M + NACE 2. The lap shear samples were bonded using an epoxy resin mixture provided by the manufacturer (CSNRI). Five (5) lap shear plates were prepared from 0.5-inch [12.7 mm] thick A572 Grade 50 steel plate. Each plate set was prepared using different surface preparations resulting in approximately eight (8) test specimens. According to ASTM D1002, at least five (5) test coupons are required to quantify the variability in the results. Table 1 describes the test samples.

Sample ID	Description	Adhesive
100225-LS-NP-Atlas	No Surface Preparation	CSNRI Two-Part Epoxy Resin
100225-LS-FR-Atlas	Flash Rust	
100225-LS-NACE-Atlas	NACE 2	
100225-LS-APS-Atlas	APS PB 7000-M	
100225-LS-NACE-APS-Atlas	NACE 2 + APS PB 7000-M	

Table 1: Lap Shear Sample Summary

All five (5) samples were machined from A572 Grade 50 steel plate. The samples were made thicker (0.5-inch [12.7 mm]) outside the lap joint location to prevent out-of-plane bending. The lap joint thickness was 0.25-inch [6.35 mm]. The 1.25-inch [31.75 mm] machined region was the location where the different surface preparations were applied. The following steps describe how each sample was surface prepared and assembled (steps are represented in Figure 2):



Figure Error! No text of specified style in document.: Lap Shear Samples Surface Preparation and Assembly

- Contact angles were measured using the Surface Analyst (BTG Labs) on all the plates before and after any surface preparation was completed. Contact angles were measured at four (4) equally spaced locations on each plate. The contact angles on the flash rust samples were not measured due to the significant variation from one location to the other.
- CSNRI's epoxy-based resin was applied to the prepared surface. Samples that were prepared with the PB 7000-M cooled for 5-minutes before applying the epoxy as the prepared surface. The CSNRI adhesive used is a 2-part epoxy primer that was specifically designed for adhesion to steel pipelines and is part of CSNRI's ASME PCC-2-2018 (ASME PCC-2: Repair of Pressure Equipment and Piping) certified repair systems. A 0.25-inch [6.35 mm] square bar was placed on the prepared surface prior to mating the plates. This resulted in a shear area of approximately 1.0 inch² [645 mm²] after the specimens were cut. The shear strength is calculated based on the load to failure divided by the shear area. If the shear area is maintained at 1.0 inch² [645 mm²], the load values can be directly used as the shear strength values in psi units.
- Plates were clamped and allowed to cure for a minimum of 48-hours. Plates were water jet cut into 1-inch [25.4 mm] wide specimens. Water jet cutting prevents heating of the plates which can affect the chemical composition of the adhesive as well as minimizes the material wasted. Additionally, the water jetting is typically considered as finished cut where no additional surface finishing such as grinding, or polishing is required. The lap shear samples were tested on a 100-kips [0.4 MN] load capacity Tinius Olsen load frame that was controlled hydraulically and

equipped with 10-kips [0.04 MN] load cell calibrated in the data acquisition system to ensure the readings were accurate. The system had built-in software that controlled the displacement rate and measured the resulting load from the load cell. The specimens' lap shear areas were measured prior to each test. Both length and width were recorded to calculate the lap shear area, which was approximately 1.0 inch² [645 mm²]. The specimens were marked to ensure the length in the grips was consistent throughout all tests as specified by ASTM D1002. All samples were aligned to ensure the load path is straight along the longitudinal axis of the specimen. The loading was adjusted to a displacement rate of 0.05-inch/min [1.27 mm/min] as specified by ASTM D1002.

Leak Repair Testing

The purpose of this phase was to compare the effect of different surface preparations on the leak repair performance of a composite system when subjected to pressure cycling. This portion of work included multiple samples with various surface preparations such as: flash rust, NACE 2, PB 7000-M and PB 7000-M + NACE 2. Testing included four (4) pipe samples that were 6.625-inch [168 mm] OD x 0.280-inch [7.1 mm] WT, Grade X52. All samples included a machined feature that represented a severe corrosion defect. The corrosion patch was 2.5-inch [63.5 mm] L x 1.5-inch [38.1 mm] W x 85% deep (0.238-inch [6 mm]), which meant the remaining material ligament in the corrosion patch was 0.042-inch [1 mm]. A 0.125-inch [3.2 mm] hole was drilled at the center of the corrosion feature to represent a through-wall defect. Table 2 shows a summary of the pipe samples, and Figure 3 shows a graphic of the corrosion patch feature.

Sample ID	Description	Size	Reinforcement
100225-P-NACE-APS-CS	PB 7000-M + NACE 2	6.625-inch OD 0.280-inch WT Grade X52	Western Specialties ComposiSleeve™
100225-P-FR-CS	Flash Rust		
100225-P-NACE-CS	NACE 2		
100225-P-APS-CS	PB 7000-M		

Table 2: Leak Repair Sample Summary