

Atmospheric Plasma: One-Step Precision Process to Remove Coating and Promote Chemical Adhesion

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ABSTRACT

Removal of coatings around thin-walled ligaments or potentially defective structures require a precision tool that does not impact the structure leading to failure. The removal of any metal or damage to the surface must be avoided in these scenarios, which disqualifies highly abrasive removal methods such as blast cleaning and water-jetting. Atmospheric plasma coating removal (APCR) is a precision tool that can remove the layers of the original coating and modify the surface properties of the bare metal surface to promote chemical adhesion by increasing surface energy. Presented in this work will be our results on the removal efficiency of the original coating, change in water contact angle (adhesion promotion) before and after plasma treatment, and the increased adhesion strength shown by standard adhesion tests. Multiple metal surfaces and adhesives will be presented that represent the commonly used materials for naval and infrastructure industries.

Key words: Chemical adhesion, coating removal, adhesion promotion, water contact angle, wettability, plasma

INTRODUCTION

This paper details a precision process for removal of coatings and preparation of the metal surface underneath for optimal chemical adhesion without damaging the metal surface or the surface profile. A precision process is required for removal of coatings around corroded surfaces, potentially defective structures, or thin-walled ligaments where abrasive removal procedures will damage the substrate. In these cases, removing metal will worsen or cause a defect where replacement is expensive. A precision tool that can safely remove the coating, allow for inspection, and enhance adhesion for recoating is

needed. This type of tool would enhance existing repair technologies and eliminate the immediate need for replacement.

EXPERIMENTAL PROCEDURE

Atmospheric Plasma Coating Removal (APCR) Overview

The atmospheric coating removal technology was developed from surface modification plasma technology typically used at vacuum pressures. The atmospheric air plasma is generated using a compressed air source (70-100 psi, 80-100 slm flow rate) and electricity (208-240 volt). Inside the plasma applicator, a pulsed electric field is applied over a small gap distance with high velocity air flowing through it. The plasma is generated in this gap distance and directed through the applicator to a nozzle that concentrates the plasma flow into a beam. This creates a highly reactive environment that is delivered to the substrate for coating removal. Once the plasma is in contact with the coating, the organic components are oxidized, and a significant portion is converted into water vapor and carbon dioxide. This process then blows these molecules away via the compressed air flow and leave behind mostly inorganic pigments and fillers that are able to be collected by a HEPA vacuum. This process can be done both handheld and integrated with robotic platforms for automated coating removal. Shown in Figure 1 below are the APCR system's plasma generator with the handheld applicator and the robotic stage with a mounted plasma applicator.

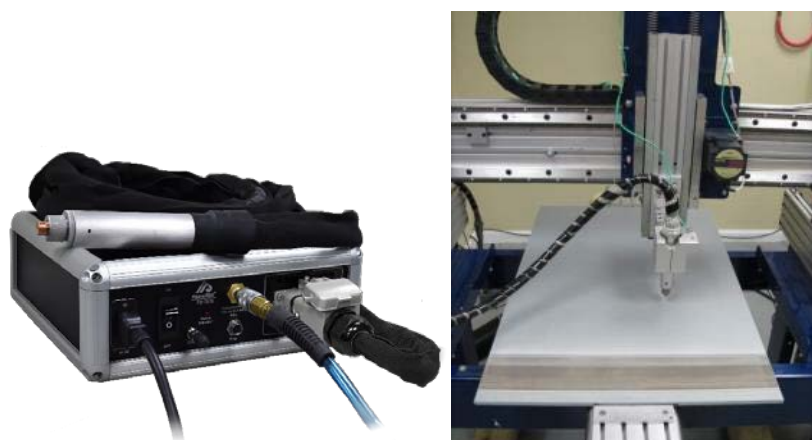


Figure 1. The APCR system as a hand-held device (left) and mounted onto a 3-axis robot (right).

APCR Treatment

Plasma treatment was done on an in-house robotic setup. For coating removal, the plasma beam was applied at 500 inches per minute (ipm) at 2200W. The applicator was fixed to be at a 9-degree angle from normal and was set to variable heights above the surface of the coating: 0.1", 0.2", and 0.4". Remaining coating thickness was measured using a micrometer.

For adhesion promotion, the gap distance between the nozzle and the treated surface was varied from 0.15" to 0.6". The speed was also varied from 200 - 600 in/min at a 9-degree angle from normal. Immediately before and after treatment, five water contact angles were recorded in an X formation. The BTG Labs surface analyst was used for all water contact angle measurements.

Sample Preparation for HY80 Steel for Coating Removal

HY80 Steel samples were procured already coated in Fast Clad UHS or Duraplate UHS Epoxy. Samples were cut to 4"x6" coupons and prepped for treatment by cleaning off the surfaces.

Sample Preparation for DH36 Plates for Adhesion Promotion

DH36 steel plates were received with SW24441 paint on them. The paint was removed, sanded with an orbital sander at 180 grit, and cleaned with acetone prior to plasma treatment. Water contact angle (WCA) was measured and recorded using the Surface Analyst 3001 (BTG Labs, Cincinnati, USA) both before and after treatment. Analysis of the WCA was done according to the ASTM D7334-08.

Sample Preparation for A709 Plates for Testing Adhesion Strength and the WCA Effect on Corrosion

A709 plates were cut to 4"x6" coupons and grit blasted to a NACE-10 profile. These surfaces were cleaned with acetone to remove any contamination prior to coating with a zinc-rich epoxy primer according to the manufacturer's instructions. There are four conditions tested for adhesion promotion due to plasma treatment: (1) untreated – polished surface, (2) NACE-10 grit blasted surface, (3) plasma treatment – polished surface, (4) plasma treatment – NACE-10 surface. For the cases with the polished surface, grit-blasted A709 plates were then sanded with 180 grit paper to remove the NACE-10 profile. The water contact angle was measured before and after plasma treatment, or before coating for the conditions without plasma to correlate with adhesion strength. Plates were painted with the SW Organic Zinc-Rich Epoxy shortly after water contact angle measurement. After they were cured, 10 plates per group were scribed according to ASTM D1654-08 prior to exposure to a 5% salt fog (ASTM B117-19). Additionally, ten other plates per group were tested using ASTM D4541-17 (PATTI) for adhesion strength using 14 mm dollies as well as using the crosshatch test (ASTM D3359-17) and pressure sensitive tape. The dolly pulls and cross-hatch tests were done in triplicate across ten plates, 30 tests total. The samples for corrosion testing were exposed to the salt fog for 1500 hours.

RESULTS

Surface Removal of Two Coatings on HY80 Steel

Removal of both Fast Clad UHS and Duraplate UHS Epoxy from HY80 steel was measured. Plasma treatment was done using a 3-axis robot for reproducibility. The plasma beam rastered across the small width of the plate at a speed of 500 in/s and at a 8-degree angle from normal. As shown in Figure 2, the coating of the plates was removed with subsequent rasters across the plate along the same raster path. The effectiveness of the removal is dependent on the height between the plasma pen and the surface of the substrate for removal. This is due to the higher delivery of plasma-generated species to the surface when the pen output is closer to the surface. At higher concentrations, these species react with the organics in the coating and remove more layers of coating. The same can be seen in Figure 3, for Fast Clad UHS, showing this is not dependent on the coating being removed. Once the full coating stack is removed, then the plasma-generated species can increase the surface energy of the substrate to promote adhesion.

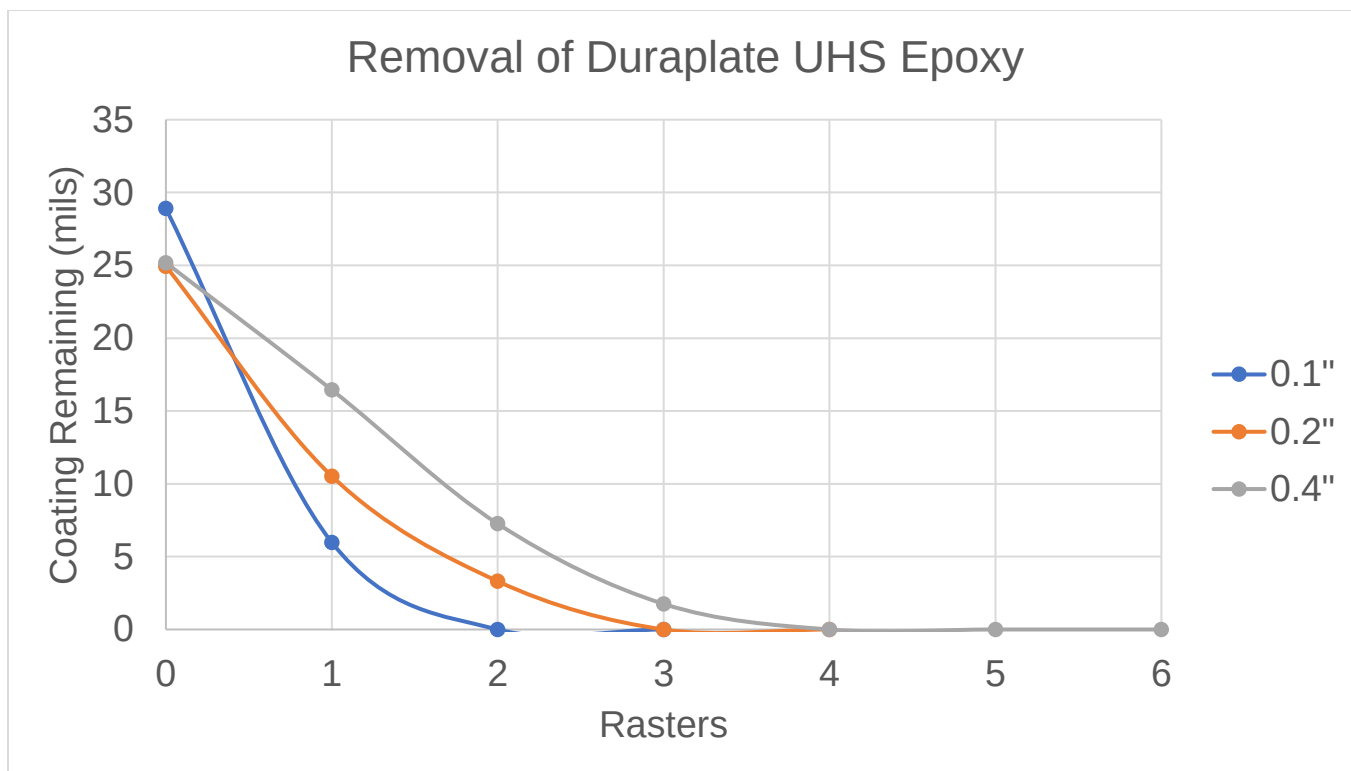


Figure 2. Removal of Duraplate UHS Epoxy using APCR.

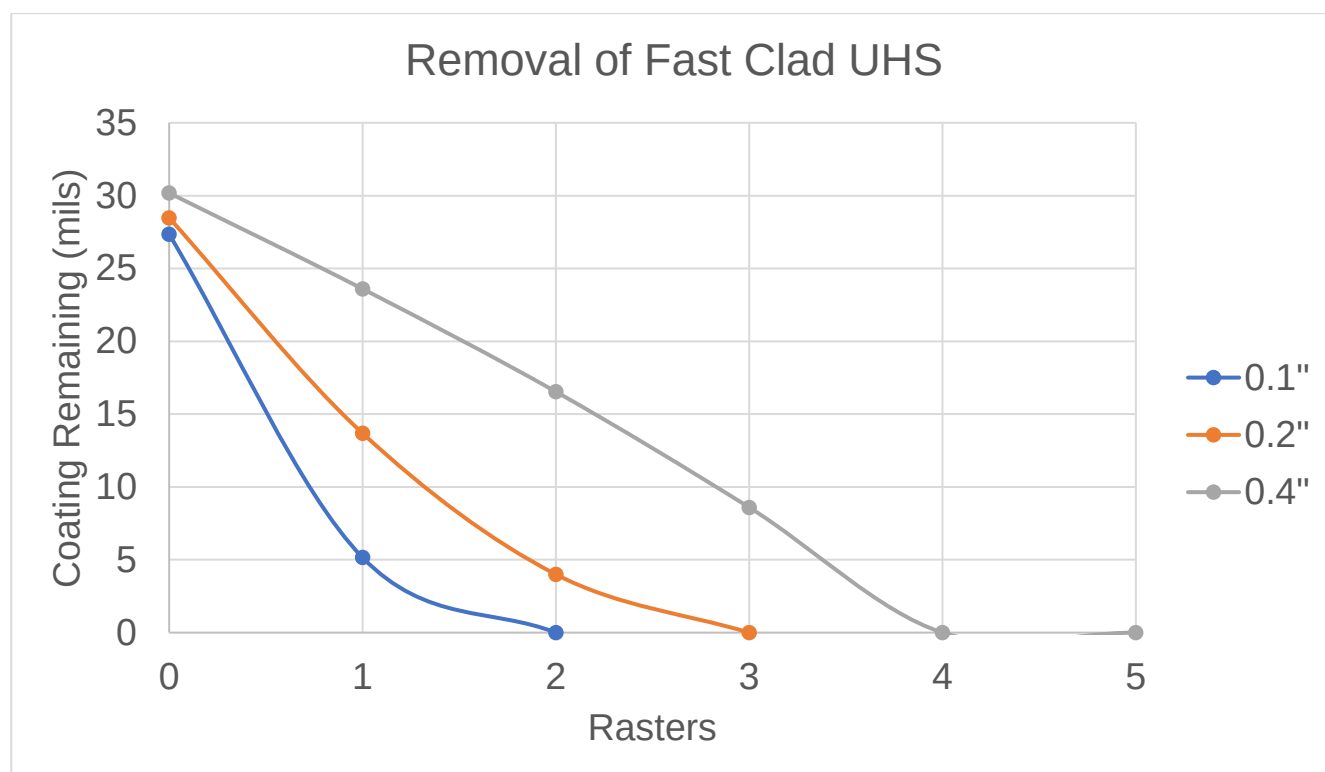


Figure 3. Removal of Fast Clad UHS using APCR.

Adhesion Promotion on DH36 Steel

Water contact angle was measured to assess the wettability of the metal post plasma treatment.

Wettability is correlated to surface energy with lower water contact angles indicating a substrate with high

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