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CONDITIONING OF STEEL SURFACES WITH VARIOUS ABRASIVE BLAST MEDIA AND EFFECT ON COATING PERFORMANCE

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ABSTRACT

There are various abrasive media available for blasting steel surfaces in preparation for protective coating application. Each of these abrasive materials provides not only a surface profile, but a different resulting steel surface condition either from direct embedment of particles and/or changing of the corrosion potential of the steel chemistry. This paper will provide an analysis of the steel surface after blasting with different abrasive media including garnet, coal slag, steel slag, and glass / silica. This analysis includes profile peak density measurements, XPS, polarization resistance, and soluble salt measurements prior to coating application. The scope of the work also includes the use of conditioning or cleaning agents to prepare the steel surface for optimum cleanliness after the blasting process. The coated panels will then be tested with elevated temperature deionized water immersions (NACE TM 0174) and corrosion cell. (Atlas cell) This work will provide insight into some of the variation seen in the field between using different abrasive blast medias that result in differences in coating performance.

INTRODUCTION

Over the past few decades surface preparation standards have been implemented to provide guidance on determining the necessary surface cleanliness for specific applications. Prior to such standards, surfaces were prepared as they saw fit at the time of application which created high variability in performance of the protective coating. Since the standards were developed, the resulting performance consistency has become increased significantly. Such standards discuss a visual inspection of the steel after an abrasive material has been used to remove scale, rust, and other discoloration soils. These standards classify these levels of cleanliness with the following general order starting with the cleanest; NACE 1/SSPC SP 5 - White metal, NACE 2/SSPC SP10 - Near white, NACE 3/SSPC SP6 - Commercial, NACE 8/SSPC SP 14 - Industrial, and NACE 4/SSPC SP 7 - Brush off. This standard focuses on visual inspection cleanliness, but do not address how this cleanliness is achieved. There are multiple methods of cleaning the surface of the steel using chemical and mechanical materials which include strong

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acid and metal-to-metal brushing. The focus of the surface preparation method for this work will be abrasive blasting media utilized in a high pressure dry blasting process.

Generally, the higher the performance requirements of the application with regard to temperature and liquid exposure. With these higher coating performance requirements comes increased scrutiny of the surface preparation of the steel surface. One of the most demanding application in the protective coatings market is the hydraulic fracturing (fracking) oil production which requires high temperature immersion in a very corrosive solution. This application provides the basis for this study.

EXPERIMENTAL PROCEDURE

Steel –

Steel typically used in tanks and vessels needs to be of high standard with regard to tensile properties so the integrity can support the contents or process. Much of the steel used in the fracking oil and water separators needs to be heat treated or normalized by slowly heating the steel to 1650°F and then slowly cooling. This process increases the strength and hardness of the steel, making it capable of withstanding the pressures that are involved in recovering oil and water from the wellhead which can be from 500 to 1000 psi depending on the depth of the well. With this normalizing process hardening the steel, it was added to the scope as a variable to determine if this difference in hardness keeps abrasive blast materials from embedding into the surface of the steel.

Normalized Steel (Norm), (N)

The process to normalizing the metal:

1. Preheat oven to 1650°F
2. Place metal in oven and bring to temperature.
- 3. Hold temp for 1 hr per 1" thickness of metal then air cool.**
4. Project panels at 3/16" thick metal are held at temp for 29 minutes. Then air cool.

Blast Media -

Blasting media use has been around for more than a century. With the industrial revolution occurring, an abundance of steel assets was created that needed cleaned of rust and scale. There is an abundance of different types of abrasive blasting media available for use in the market. These blasting media are typically the waste product or byproduct of another process such as steel production or coal burning for electricity generation. The efficacy of these materials lies in their composition which creates the hardness (Image 1.) which will dictate most of the profile efficiency when blasting steel surfaces. Also, these materials have different geometries and particle size which will provide for different achievable peak density and roughness.

Another key aspect of these abrasive media is how friable the materials are which means how brittle and easily pulverized they are. The blasting media impacts the surface to create peaks and valleys, but it can embed itself into the surface of the steel upon fragmentation. The residual material that is left on the surface of steel is assumed to be benign and largely blown

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off the surface with compressed air during the clean up process. The final inspection to determine cleanliness focuses on the appearance of iron oxide presence and not the degree of fine particle discoloration such as that from black particles of coal slag for example.

The 12 blast media reviewed in this study are shown in Image 2. The scope of work includes a range of particles sizes and compositions along with looking at the possibility of changing the potential of the steel surface with an alkaline material in sodium bicarbonate. When steel is exposed to a pH of 8-11 or so, the surface is passivated with a weak oxide layer shown by a Pourbaix diagram in Image 3.

The blasting process setup was adjusted by a third party NACE level III inspector to provide for the highest efficacy of each blast media.

Coatings –

Three different high performance, high solids epoxy linings were selected from the market for application over the blasted steel panels for performance testing. The three linings are typically utilized in the oil and gas market for storage tanks and oil / water separation vessels. They are of particular interest as they have established historical performance in the field. The applied average WFT ranged from 8-15 mils in one coat. Each of the following linings are leading products from 3 different major oil and gas linings suppliers.

Coating #1 - (Green) High solids, novolac epoxy tank lining typically used for ambient crude oil storage. Relative observed performance - **Medium**

Coating #2 – (Light blue) High solids, higher reactivity novolac epoxy lining for high pressure / high temperature service in oil and gas. Relative observed performance - **High**

Coating #3 – (Light blue) High solids, hybrid low viscosity novolac epoxy lining for high pressure / high temperature service in oil and gas. Relative observed performance – **High**

Steel –

The steel used in the study adheres to ASTM A36 grade steel which is a common standard grade. Large 3/16” thick sheets were cut into 3”x6” and 6”x6” panels. The A36 steel grade in comparison to another common grade in 1018 are shown in Image 3.

CHEMICAL PROPERTIES

A36 steel has similar chemical properties with differing mechanical properties.

	A36	1018
Iron (Fe)	99%	98.81-99.26%
Carbon (C)	0.26%	0.18%
Manganese (Mn)	0.75%	0.6-0.9%
Phosphorus (P) - max	0.04%	0.04%

	A36	1018
Sulfur (S) - max	0.05%	0.05%

MECHANICAL PROPERTIES

	A36	1018
Tensile Strength	58,000 psi	63,000 psi
Yield Strength	36,300 psi	53,700 psi
Elongation (50 mm)	20%	15%

Steel surface analysis -

Digital Profilometer and Surface Roughness –

The surface of the steel was analyzed with a B&H Laser Profilometer which provided a roughness and a peak density measurement. Roughness is an assessment of average peak height (**Sa**) and a deviation (**Sq**) was also measured which provides an idea of how consistent the surface roughness is. Lastly, the peak density was measured as the total number of peaks per a given area (**SHSC, peaks/mm²**). Digital pictures of a defined area are also taken for ease of visual comparison of roughness. It is intuitive that if the surface is rougher that the adhesion would be higher; however, if the roughness is from embedded abrasive material, the adhesion values may not be as high as expected with adhesion to “false” peaks created by embedded blast media.

Humidity Cabinet Flash Rust Relative Rates –

A fundamental difference between the different steel treatments that can easily be assessed is the rate of flash rusting after abrasive blast cleaning the surface. Slow flash rust formation is a highly desired property in the field for its financial impact on a project. If the steel flashes, the blasting process has to be repeated which increases the labor and materials cost for the project. There are ways to inhibit flash rust with an alkaline chemical treatment which passivates the metal surface; however, it is highly desirable to not utilize further chemistry if it can be avoided.

Surface Soluble Salt Titration – ISO 8502

Much of the abrasive blasting media are materials that could be exposed to or inherently contain soluble salts such as chlorides and sulfates. It has become standard practice to test the blast media after manufacturing to determine soluble salt content. These salt ions are very corrosive and invisible to the eye, so a chemical assessment with a titration is necessary. The titration test kit typical in the market is the ChlorTest CSN kit which uses a chemical reaction for ion concentration per a defined area with the units in micrograms per cm². The two salt ions of interest in this work are chlorides and sulfates which are typically present in oil and gas upstream applications. Nitrates which are less corrosive are another ion of interest but primarily in areas of agriculture and fertilization operations which is out of the scope of this work.

SEM / EDX –

Scanning electron microscopy was used to magnify the surface of the steel to be able to see structures that have been created by the different blasting medias. These structures are created from the impact of the abrasive media particles which have different density and geometry. The roughness and integrity of the profile on the surface can be assessed comparatively between the abrasive medias which provides an insight into the dry adhesion test data.

These structures can be created in two different ways with pitting and bending of the steel surface from impact and embedment of the impacting abrasive particles. SEM will show us the structure, but it won't tell us which type of structure it is. In order to determine the composition, EDX is utilized which provides for specific elemental energy emittance in the presence of X-ray wavelengths. The location and composition of the foreign material can then be analyzed. In this way, key elements of the known abrasive blast media can be identified in a defined surface area providing a profile of the composition on the surface.

Polarization Resistance (iCorr) –

A difference between blasting media observed in the field is that with similar humidity and temperature, certain blasted steel surfaces flash rust quicker than others. One of the reasons for this observation that can be evaluated is the surface potential of the steel changing per the blasting process. This change could come from embedded material providing a partial barrier to the oxygen and moisture in the environment which can be measured by applying a very low amount of direct current to a defined area and measuring the resistance to the oxidative or corrosion current. This methodology has been applied to anodized aluminum and stainless steel to observe the passivation chemistry on the surface of the metals. During the blasting process, it is possible to provide for a slight pH change of the surface which would promote this passivation or even disrupt it from forming. Polarization resistance is more experimental for this purpose, but there is enough related use and chemistry relevance to attempt it in this scope.

Protective Coating Performance –

Dry Adhesion Evaluation – ASTM D4541 / ISO 4624

The most basic evaluation of cleanliness and surface profile creation is applying a coating and upon drying / curing conducting an adhesion test to determine the mechanical bond to the surface. The interpretation of this test in the mode of failure is as important as the value in force of the pull-off process. A key focus is looking for correlation between surface contamination and adhesion along with comparison to the roughness factor. This analysis will provide insight into false structures existing on the surface that are not part of the steel material and the embedment strength of the foreign material.

Isothermal Immersions – TM 0174

Each of the three selected coatings was applied to both sides of a 3"x6" carbon steel panel. The edges of the panels for dipped in a novolac epoxy lining to inhibit excessive creep corrosion from the edges. The isothermal immersions were placed in containers with deionized water as the immersion solution with the volume level sufficient to leave a third of the panel exposed, out

of the liquid, and in the vapor phase of the test. The temperature for this immersion testing is set at 180°F which should be high enough to differentiate between poor and proper surface preparation from past experiences.

Corrocell / Atlas Cell – ASTM D 6943

The three coatings were also applied to 6"x6" Corrocell corrosion cell panels. This test method represents tank lining applications where one side of the steel substrate is not coated and there is a thermal gradient across the steel from front to back. This thermal gradient causes an effect called "Cold Wall" that enhances the corrosive environment by increasing the vapor pressure at the coating / steel interface. The Corrocell panels will be evaluated at 180°F with deionized water as the cargo material. The cell panel facing will have approximately 2/3 liquid phase and 1/3 vapor phase. Evaluation of performance was conducted per ASTM D 714 and pull-off adhesion per ASTM D 4541 in both the liquid and vapor phase.

RESULTS

Digital Profilometer –

Surface Roughness

Sample Name	Sa (μm)	Sq (μm)	SHSC pks/mm ²
Steel 40 Mesh (As Is)	97.1	210.6	106.0
Steel 40 Mesh (Norm)	103.1	223.9	114.8
Steel 50 Mesh (As Is)	46.2	140.5	130.2
Steel 50 Mesh (Norm)	49.4	139.2	122.9
Garnet 1 (As Is)	13.0	32.5	130.2
Garnet 1 (Norm)	13.8	34.1	127.1
Coal Slag (As Is)	46.5	115.1	94.8
Coal Slag (Norm)	44.1	112.4	91.9
Nickel Slag (As Is)	24.3	74.0	112.5
Nickel Slag (Norm)	29.4	84.9	104.7
Copper Slag (As Is)	7.6	18.5	137.8
Copper Slag (Norm)	8.7	19.5	130.4

Sample Name	Sa (μm)	Sq (μm)	SHSC pks/mm ²
Garnet 4 (As Is)	13.4	35.9	116.6
Garnet 4 (Norm)	16.8	51.2	114.6
Amorphous Silicate (As IS)	16.2	40.1	105.9
Amorphous Silicate (Norm)	20.3	54.5	98.3
Magnesium (As Is)	20.0	45.8	98.8
Magnesium (Norm)	26.1	63.1	89.9
Garnet 3 (As Is)	10.2	19.0	135.3
Garnet 3 (Norm)	11.9	27.6	129.9
Garnet 2 (As Is)	19.1	64.3	131.1
Garnet 2 (Norm)	21.0	69.1	126.1
Steel Grit / Sodium Bicarbonate (As Is)	11.2	32.7	131.4
Steel Grit / Sodium Bicarbonate (Norm)	13.1	30.1	114.5
Bare Metal	8.2	17.7	154.5

Surface Images





