

**The Effects of Different Blast Abrasives on the
Performance of Liquid-Applied Epoxy Pipeline Coatings**

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ABSTRACT

The importance of surface preparation on the successful performance of protective coatings is well-recognized. Typically, abrasive blast cleaning is routinely used to achieve the required surface conditions prior to the application of a coating. Despite having been utilized for about 150 years, a literature review revealed that little attention was given to the effects of different blast abrasives on coating performance. It is accepted by most professionals that all abrasives would provide similarly optimized surfaces, as long as the right size of abrasive is selected and the proper surface preparation technique is implemented. Consequently, research has focused primarily on characterizing surface roughness and identifying effective profile parameters prior to coating application.

This paper summarizes the results of a comprehensive study carried out on two representative liquid-applied epoxy pipeline coatings that were applied over 15 different surfaces that all met the requirements of NACE No. 2/SSPC-SP10. Ten different blast media were used to prepare the surfaces that included metallic, glass, garnet, coal slags, mineral slag, and mineral blend abrasives. For certain abrasives, two different sizes were deliberately chosen to confirm whether proper abrasive size can further improve performance or whether the selection of compatible abrasive is more critical. In this work, the levels of dust and embedment as well as soluble salt contamination for the 15 prepared surfaces were examined to assist in data analysis. Replica tape, stylus surface roughness tester, and 3D replica tape imaging methods were employed to characterize the prepared surfaces and the performance test program included pull-off and X-cut adhesion techniques to evaluate the initial coating/substrate interfacial adhesion strengths, and hot water immersion, and cathodic disbondment tests to investigate the effects of the different abrasive prepared surfaces on protective efficiency of the two coatings.

Key words: protective coatings, surface preparation

INTRODUCTION

Proper surface preparation to create sufficient adhesion of a coating over the substrate is fundamentally important in the long-life performance of a protective coating. Abrasive blast cleaning provides a fast and well-established method of surface preparation, which utilizes energy generated by an air supply to deliver a mass of abrasive particles at certain speeds and volumes to impact the steel resulting in a cleaned surface.^{1,2} The method not only cleans the surface to remove rust, scale, paint, and similar contaminations, but also roughens the surface to produce mechanical and chemical adhesion for a coating. Therefore, abrasive blasting is the preferred method for preparing steel for the application of high-performance coatings³ and routinely used for achieving the required surface conditions prior to a coating work.

Various abrasives are available for the blast cleaning process, from metallic shots and grits to non-metallic types of naturally occurring sands or minerals, by-products, and synthetic abrasives.^{4,5} Each type of abrasive possess its own physical attributes (hardness, shape, density, and size), which makes the selection of the right abrasive for a particular job vitally important. Since each abrasive is supplied with a range of sizes to serve different blasting purposes, it is anecdotally believed that all abrasives would provide similarly optimized surfaces, as long as the right size of abrasive is selected and the proper surface preparation technique is implemented. This is self-evident, when reviewing the international and national standards. For instance, the surface preparation as per ISO 21809-3:2016 section 18.3⁶ for liquid-applied coatings states “to a minimum cleanliness of Sa 2 1/2. The surface profile attained shall be between 50 µm and 100 µm as measured in accordance with the requirements of ISO 8503--5”, while CSA Z245.30-18 Section 6.2.2⁷ refers to the Manufacturer's Qualified Application Procedures (MQAP). Most MQAP and coating product data sheets also recommend minimum surface texture requirements (typically peak height) on the abrasively cleaned surface for good coating adhesion and performance. Typically, the type of abrasive and size to be used for a given job are left to the discretion of application companies or operators.

A previous study on a viscoelastic coating material for pipeline coating repairs by the authors⁸ revealed the significant impact of different blast abrasives on coating performance. The viscoelastic coating system demonstrated superior resistance in cathodic disbondment (CD) test with rather small amount of disbondment, when it was applied to a NACE No. 2/SSPC-SP10 steel surface that was prepared with steel grit. Surprisingly, the same coating system failed in the same test with excessively large disbondment, when it was applied on another NACE No. 2/SSPC-SP10 surface produced using magnesium orthosilicate mineral slag. The observation suggests blast cleaning surface by different abrasives are not equal, and some coatings are selective to the surfaces to be applied.

A thorough literature review was conducted to collect publicly available research on abrasives. The review revealed that for the selection of the right blast abrasives, much attention has been given by the industry on the improvement of abrasive blasting productivity and optimizing operation parameters, so as to achieve economic efficiency.^{9,10} To attain performance benefits, the literature is replete with references to understand the relationship between surface profiles and coating bonding strengths, to characterize surface pattern and assess anchor profile, and to identify primary variables/profile parameters affecting the surface performance, etc.¹¹⁻¹⁷ There is a limited number of relevant publications¹⁸⁻²⁰ that specifically investigate the variability of the surfaces prepared by different abrasives and its effect on coating performance. Additionally, the performance evaluation for most works used long-term outdoor exposure and/or neutral salt fog tests, which are applicable for atmospheric paint systems rather than below-ground pipeline coatings. One SSPC publication in 1991¹⁸ carried out a sophisticated experimental design to determine the performances of six coating systems on 24 prepared surface finishes using 12 abrasive types and six levels of cleaning. This study specifically examined the relative performance of the coatings applied over various mineral or metallic abrasives, with an intent to answer the following three questions:

- 1) Are metallic abrasives superior to mineral abrasives?
- 2) Which is better - steel shot or steel grit?
- 3) Is one mineral abrasive better than the rest?

The SSPC long-term outdoor exposure data led to the following responses:

- It cannot conclude that mineral abrasives are significantly better or worse than metallic abrasives. On average, a coating system's life over a surface prepared to a NACE No. 2/SSPC-SP 10 finish with S-280 shot is at least one and a half years less than a coating system over surfaces prepared with mineral abrasives. The only mineral abrasive that is significantly better than steel grit in promoting coating performance is silica sand.
- Steel grit always gave a numerical improvement in performance over steel shot, but this trend is statistically significant across different grades of surface preparation. For NACE No. 2/SSPC-SP 10 surfaces, grit is superior to shot. For NACE No. 1/SSPC-SP 5, NACE No. 3/SSPC-SP 6, and NACE No. 4/SSPC-SP 7 surfaces, grit is nearly equal to shot.
- Silica sand results in longer mean times to failure than all other abrasives. However, several other mineral abrasives, including coal slag, staurolite, and alumina, that are statistically indistinguishable from silica sand, though all provide worse performance on a simple numerical basis.

Since the data of the SSPC work were obtained from testing of different coating types (alkyd, acrylic emulsion, vinyl, and water-borne alkali silicate) in the atmospheric exposure and silica sand is no longer used in the field (due to the adverse health effects), it is apparent that the conclusions from SSPC work cannot be used to make prediction for modern-day, 100% solid liquid-applied epoxy pipeline coatings. Nevertheless, our literature review confirmed that effects of different abrasives on coating performance is a critical area that warrants further research.

A comprehensive experiment was consequently designed by the authors, involving two representative liquid-applied epoxy pipeline coatings and 15 different surfaces that were prepared using 10 different abrasives with eight of the surfaces produced by four abrasives with two different grit sizes. To characterize and differentiate the surfaces, replica tape, stylus surface roughness tester, and 3D replica tape imaging method were employed, along with the examination of levels of dust and embedment to assist in data analysis. The steel surfaces were also tested for soluble salt contaminations imparted from the abrasives. In terms of the performance comparison, both pull-off and X-cut adhesion techniques were included to evaluate the initial coating/substrate interfacial adhesion strengths. Both hot water immersion (HWI) and CD tests were utilized to reveal the effects of differently prepared surfaces on protective efficiency of the two coatings. Some traditional points of view are inevitably challenged as they are not able to give sensible explanations for certain observations. The main purpose of this paper is to present the results and raise awareness that the influence of different types of abrasives on coating performances is far-reaching. Further research is on-going to determine the source of the performance differentials, and this will be published in the following year.

MATERIALS SELECTION

Abrasives and Blasted Surfaces

Typically, the surface cleanliness requirements within the product data sheets and MQAPs for most oil and gas pipelines establish a minimum cleanliness of NACE No. 2/SSPC-SP 10. As for the anchor profile requirement, it mainly depends on the coating systems to be applied. For liquid-applied epoxy pipeline coatings, the anchor profile requirement of 64 – 127 μm (2.5 – 5 mils) range is common. In this study, NACE No. 2/SSPC-SP 10 with anchor profile of 76 – 114 μm (3 – 4.5 mils) were selected for preparing the steel surfaces.

There are a variety of abrasive types in the market and each type has various brands from different manufacturers. Most abrasives with proper mesh sizes can achieve the above surface cleanliness and anchor profile requirements. The selection of the abrasives and the mesh sizes for the present work was based on the following considerations and endeavors:

- The abrasives are approved for use by the pipeline company and comply with health, safety, and environmental regulation requirements
- The abrasives are capable of providing the required surface cleanliness
- The abrasives are frequently used by the pipeline company's contractors
- The abrasives represent at least one abrasive from each generic type
- The performance of steel grit was compared to steel shot to confirm the better performance of the steel grit
- The economic benefit of steel abrasives is due to its recyclability, often being recycled 100 times or more. The forementioned literature review indicated that steel abrasives were one type of blast materials broadly examined, but most studies were carried out on the surfaces prepared with new steel grits not recycled. In this work, beside a set of the new steel grit LG40 prepared surface, an additional set of coupons was sent to a local blast facility using recycling steel grit LG40, so the set could be blasted by the shop in the middle of their job. Note that to control proper work mix, the shop daily adds about 200 pounds of new LG40 steel grit into a 15-barrel reservoir containing about 1700 pounds recycling used steel grit. From a practical standpoint, the comparison of the performance data from the two sets of steel abrasive LG40 prepared surfaces will be interesting and informative
- The abrasives' mesh sizes for the test abrasives were as per the recommendations from abrasive suppliers/distributors or product data sheets to ensure peak heights within the range of 76 – 114 μm (3 – 4.5 mils)

In total, six generic categories of abrasives were studied, including steel abrasives (grit and shot), glass grits, garnet, coal slags, mineral slag, and mineral blend. The 15 surfaces were produced using 11 abrasive products: one steel shot S-280, one steel grit LG40, one recycled steel grit LG40, two glass grits, one garnet, three mineral slags with two of them tested with two mesh sizes, one mineral slag tested with two mesh sizes, and one mineral blend tested with two mesh sizes. The rationale for the selection of two different mesh sizes for certain abrasives was to demonstrate that a coating's interaction with surfaces produced by different types of abrasives has more impact on the coating performance than the controlling of anchor profiles by adjusting mesh sizes of the same abrasive.

Coating Systems for Performance Comparison

100% solids coatings are one type of the trending coating technologies that resulted from the industry solutions to reduce volatile organic compound (VOC) emissions and worker/health safety concerns. Nowadays, 100% solids liquid-applied epoxy coatings are often utilized as girth weld coatings and for maintenance repairs to provide corrosion protection for large diameter, below ground pipe in North America. One of the main purposes for solvents is to lower coatings' viscosity and increase wettability. It is recognized that for high-viscosity or low-flow liquid coatings, the liquid droplets might have difficulty in penetrating and displacing air entrapped in the valleys of a surface profile, so it is highly possible that no distinctive relationship can be found between the roughness depth of the substrate and the coating adhesion strength value for the type of coatings.²¹ 100% solids liquid-applied epoxy coatings are sprayed using a plural-component sprayer and the coating components are normally heated to specific temperatures to reduce the product's viscosity. As a matter of fact, the interaction of 100% solids liquid-applied epoxy pipeline coatings with different surfaces produced by various abrasives has not been studied or publicly reported.

The type of adhesion bonding mechanisms depends on both the substrate and the applied coating. Three well-accepted basic adhesion mechanisms are: (1) chemical bonding (primary valence bonding); (2) polar

adhesion (secondary valence bonding); and (3) mechanical bonding. The adhesion of most organic coatings relies on polar bonding with significant contributions of mechanical interaction.^{3, 21} Coatings are complex compounds that are made of a variety of interacting materials, such as: resins, catalyst conversion, pigments, solvents, plasticizers, and extenders.³ The variation in formulation makes each coating unique. In this work, two commercially available 100% solids liquid-applied epoxy coatings, labelled as “Coating A” and “Coating B”, were examined. Based on some preliminary empirical observations, the adhesion of Coating A might benefit from both polar bonding and mechanical bonding, while Coating B probably relies more on mechanical adhesion. Both coatings were selected for the study to determine if variation in abrasives would have a similar impact on their overall performances.

EXPERIMENTAL PROCEDURE

Surface Preparation and Coating Application

15 sets of the hot-rolled carbon steel panels with dimension of 100 x 100 x 6.35 mm (4 x 4 x 0.25 in.) were purchased from the same supplier (45 panels per set, total 675 panels). The selected 14 abrasives with the defined sizes, three 50 pounds bags per abrasive, were also sourced and delivered to the contract blasting facility in Red Deer, Alberta, that was equipped for open nozzle dry abrasive blast cleaning operations.

All panels were first solvent cleaned using acetone as per SSPC-SP 1, labelled with a unique ID at the backside of each panel, and each set was then properly packed in individual boxes. One set of panels was taken to a local blasting facility and blasted using recycling steel grit LG40. The other 14 sets were sent to the contract shop for blasting. All 14 sets were prepared using the same abrasive blast cleaning equipment by an experienced operator. For all 15 sets, the degree of cleanliness met the minimum requirements of NACE No. 2/SSPC-SP 10. The operating nozzle pressure was set at 100 psi. Slight pressure adjustment (± 10 psi) was made during blasting for different abrasives to ensure the obtained anchor profile was within the targeted range of 76 – 114 μm (3 – 4.5 mils) when measured using replica tape. The ordered size for garnet was GX3, but a finer size of GX2 was received. For the set of panels, only 51 – 56 μm (2.0 – 2.2 mils) anchor profile was achieved, and the set of panels was included to ascertain the effect of lower anchor profiles on the performance testing results. Table 1 details the selected abrasives and the 15 blasted surfaces for this study along with the abbreviated naming system.

Table 1. The Selected Abrasives and the Fifteen Blasted Surfaces

#	Abrasives (Size)	Surfaces	#	Abrasives (Size)	Surfaces	#	Abrasives (Size)	Surfaces
1	Steel Shot (S280)	SS	7	Coal Slag-1 (16/40)	CS1	12	Mineral Slag (20/50)	MS(L)
2	Steel Grit (LG40)	SG	8	Coal Slag-2 (16/30)	CS2(L)	13	Mineral Slag (16/36)	MS(H)
3	Recycled Steel Grit (LG40)	SG-R	9	Coal Slag-2 (12/40)	CS2(H)	14	Mineral Blend (32-B4)	MB(L)
4	Glass Grit-1 (10/30)	GG1	10	Coal Slag-3 (20/40)	CS3(L)	15	Mineral Blend (30/60)	MB(H)
5	Glass Grit-2 (12/20)	GG2	11	Coal Slag-3 (12/40)	CS3(H)			
6	Garnet (GX2)	GN						

Each panel was cleaned using compressed air to remove abrasive residue and dust. After cleaning, each set of panels was sorted and divided into three groups: 18 panels for group 1 to be coated with “Coating A”, 18 panels for group 2 to be coated with “Coating B”, and the remaining nine panels for group 3 were used for surface characterization. The grouped panels of each set were immediately vacuum sealed in plastic bags with a desiccant bag placed inside each bag to ensure no flash rusting.

Coating A and Coating B were sprayed using plural-component sprayers by experienced applicators. For Coating A, 15 sets of vacuum sealed panels were shipped to the product manufacturer's facility and coated by their in-house applicator. The application of Coating B was completed by a qualified local facility that was selected and approved by the product manufacturer. As per the requirement of this protocol, both coatings were cured at ambient temperature ($22 \pm 3^\circ\text{C}$) until a Shore D (ASTM D2240) ≥ 80 was achieved.

Characterization of Blasted Surfaces

The resultant surfaces are composed of complex roughness patterns of peaks and valleys, and, possibly, residual dust and abrasive embedment. To accurately assess and differentiate the 15 prepared surfaces, replica tape, stylus surface roughness tester, and 3D replica tape imaging method were employed to measure various roughness parameters. The dust level, embedment, and salt contamination were also examined to assist in the data analysis.

Measurement of Surface Roughness Parameters

1) *Replica Tape*

Replica tape is the most popular field method for measuring the height of surface profile due to its simplicity and relatively inexpensive cost. The test was conducted according to method C of ASTM D 4417²². For each prepared surface, the measurements were completed on five panels and five individual readings were collected.

2) *Stylus Profilometers*

A stylus roughness instrument makes direct contact with a sample and traces the up and down movements of a stylus across the surface. The tests were carried out according to ASTM D 7127²³ and ISO 4287²⁴ using a Times 3220 portable stylus instrument with a tip radius of 5 μm diamond stylus. The cut-off length and evaluation length were set to 2.5 mm and 12.5 mm, respectively, and a Gaussian filter was used. For each prepared surface, the surface roughness parameters were measured on five panels with two measurements per panel (total 10 measurements were completed). The portable stylus unit provides digital readout of results for a significant number of surface texture parameters. In this work, the two commonly applied parameters^{17,23} were reported: Rz (average maximum height of the profile) and Rpc (peak count). Some researchers showed that tortuosity has better correlation to cathodic delamination.²⁴ Tortuosity (T) is the ratio of the actual distance (L) divided by the straight-line distance. In this work, the parameter was calculated from the extracted stylus profilometer data using the formula^{24,25} below:

$$L = \sum_{n=1}^N \sqrt{\left(\frac{L_r}{N}\right)^2 + (r_{i+1} - r_i)^2} \quad (1)$$

Where L_r is the evaluation length, N is the number of measurements along the trace, and r_i is the recorded heights of the surface profile (1 μm interval for Times 3220 unit).

3) *3D Replica Tape Imaging Method*

It is a relatively new approach to use a digital replica tape reader (RTR-P probe) for measuring and recording 2D/3D surface profile parameters from burnished optical grade replica tape. The measurements were carried out as per the manufacturer's instruction using a PosiTector® RTR 3D instrument. The surface roughness parameters were collected on five panels per blasted surface type. The RTR 3D unit also supplies a significant number of surface texture parameters. In this work, the commonly reported parameters¹⁷ of H (average maximum peak-to-valley height) and Spd (area peak density) were selected for comparison.