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Next Generation Coatings for Erosion-Corrosion Protection

Sprayable protection in extreme erosion environments

The erosion-corrosion environments found in fluid conveying components such as pipelines, pumps, agitators and chutes have important implications for both service life and maintenance cost. The destructive synergy wrought when corrosion occurs in combination with erosion can be many times greater than the sum of each mechanism acting in isolation. A factory applied coating, if present, will have a finite lifetime and wear resistant alloys can be prohibitively expensive or promote galvanic corrosion on adjoining surfaces. To extend service life and prevent catastrophic failure, the in-situ application of cold cure liquid epoxy coatings is recommended.

Ceramic filled epoxy coatings are an established technology for protection against erosive environments found in process industries. These coatings incorporate hard ceramic particles within an epoxy binder creating a ceramic composite with excellent adhesion and chemical resistance. The approach relies on the difference in hardness between ceramic filler particulates embedded within the coating and the entrained solids suspended in the conveyed fluid. The hard ceramic filler acts as armour protecting the coating from the softer entrained solids.

Ceramic filled coatings are, however, unsuitable for spray application. The hard angular nature of ceramic filler can cause extensive damage to the piston ball valves, packing seals and nozzle tips of spray equipment. In practice, ceramic filled epoxy coatings are recommended for brush application only. The authors are aware of several 'sprayable' ceramic filled epoxy coatings on the market but these have compromised performance and never truly allow low maintenance spray application.

Belzona 1331 and Belzona 1381 are new generation erosion resistant coatings based on novel filler-free polymer alloy technology. The polymer alloy contains an immiscible blend of a tough ductile phase within a hard epoxy matrix. These coatings have superior erosion resistance yet cause negligible wear to spray equipment when compared to conventional ceramic filled epoxy coatings. Belzona 1331 is specified for use at ambient service temperature while Belzona 1381 is the elevated temperature equivalent.

Novel technology provides superior performance

The superior erosion resistance of the polymer alloy is understood by considering the mechanisms of erosion acting on a coating surface. Erosion due to impingement of entrained solids in the conveyed fluid is categorized into ductile and brittle mechanisms. Ductile erosion involves material removal due to cutting or ploughing via sliding abrasion (e.g. along pipeline straights and risers). The angle of impingement is small, typically less than 30^0. Brittle erosion involves material removal due to radial crack formation via impact abrasion (e.g. pipeline elbows, bends and protrusions), this occurs at angles of impingement near normal to the surface.

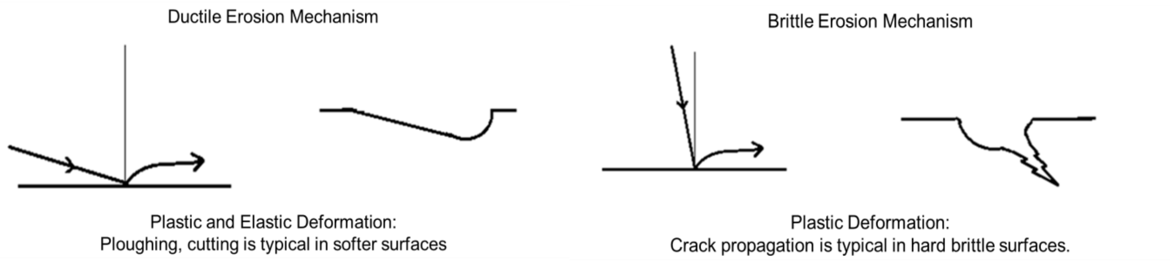

Figure 1: Diagrams of Ductile Erosion Mechanism and Brittle Erosion Mechanism demonstrate the mechanisms of erosion acting on a coating surface.

Hard ceramic filled coatings resist ductile erosion mechanisms but suffer from brittle erosion at impingement angles above 60^0 due to their low fracture toughness. The tough ductile phase of the polymer alloy is capable of elastic deformation and is therefore resilient to brittle erosion mechanisms and due to a low co-efficient of friction, also resists ductile erosion mechanisms.

In addition to their inherent erosion resistance, Belzona 1331 and Belzona 1381 can be applied at wet film thickness up to 2000 micron without sagging as opposed to a maximum of about 700 micron for conventional epoxy coatings. This is due to the coatings' low density combined with their pseudoplastic rheology.

'Spray friendly' provides economic benefits

Belzona 1331 and Belzona 1381 can be applied in one or more coats using off-the-shelf heated airless spray equipment. The volume mixing ratio is compatible with single and plural component spray units.

As 'spray-friendly' coatings (which do not wear or damage spray equipment) Belzona 1331 and Belzona 1381 offer important benefits. They can be specified on large areas or spin sprayed on pipeline internals where application by brush or roller is not practical. The service life of consumables such as nozzle tips as well as piston ball valves and packing seals is extended and less downtime is spent on maintenance such as stripping the piston to replace worn packing seals.

Wear to the nozzle tip will cause the orifice and internal flow passages to enlarge. The flow of product therefore increases and the fan angle reduces resulting in a narrower applied band width and reduced coverage per pass. The time taken to complete a job is therefore increased and excessive product application results.

Application trials were carried out to demonstrate the 'spray-friendly' characteristics of this technology. A Graco King 65:1 heated airless spray unit was used to apply both a ‘sprayable’ ceramic epoxy coating and Belzona 1331. A Graco XHD523 nozzle tip was used with a 23 thou orifice.

On application of the ceramic filled epoxy coating, the fan angle halved within 10 minutes of continuous spray. When Belzona 1331 was applied under identical conditions, the fan angle remained consistent. After 45 minutes continuous spray without observable deterioration to the fan angle, the test was stopped with the conclusion that erosion on the tip due to Belzona 1331 is negligible.

Damage to ball valves and packing seals in the positive displacement pump was also assessed after 6 hours of continuous spray application. Belzona 1331 and a ‘sprayable’ ceramic epoxy coating were tested. The volume of product displaced by the piston after 6 hours was approximately 1000 litres; equivalent to a coverage area of over 2000m^2. Three hours into the test, the ceramic filled epoxy coating was observed to leak from the piston resulting in catastrophic failure. No problems were observed with the Belzona product during the 6 hour procedure. On completion, the piston was stripped down and the packing seals and ball valves recovered, cleaned, weighed and examined for visual signs of wear.

Figure 2: The packing seals and ball valves recovered from the piston exhibit a marked difference in the extent of wear resulting from the use of Belzona 1331 (top) and a ‘sprayable’ ceramic epoxy coating (bottom)

The Tuff-Stack O-ring packing seals were not found to erode regardless of the coating used. Visual inspection of the ball valves however exhibited marked differences between Belzona 1331 and the ‘sprayable’ ceramic epoxy coating. The ball valves exposed to the Belzona coating were still glossy and as good as new save a few isolated marks. The ball valves exposed to the ceramic filled epoxy coating were matted and evidently well worn. When weighed, the ceramic filled epoxy coating was found to cause 100 times greater erosion to the ball valves than the Belzona product. The test demonstrates that large volumes of Belzona 1331 can be applied without damaging spray equipment.

Superior erosion resistance

A test program employing a number of abrasion mechanisms allows approximation of field conditions and is a necessary step in validating product quality. Several test methods were therefore employed to benchmark the erosion resistance of Belzona 1331 and Belzona 1381. Table 1 lists the coatings tested.

	Dry Taber Abrasion ASTM D4060	**Wet Taber Abrasion** ASTM D4060	**Slurry Drum Abrasion** ASTM G6	**50 Hrs. Jet Erosion** Leeds University
Belzona 1331	0.013	0.046	0.117	0.061
Belzona 1381	0.009	0.047	0.116	0.046
Non-sprayable Ceramic Filled Epoxy	0.015	0.127	0.142	0.195
Competitor 'Sprayable' Ceramic Filled Epoxy	0.027	0.208	0.288	Not Tested

Table 1: Volume loss (cm^3) due to erosion of epoxy coatings subjected to abrasion testing.

Slurry Drum Abrasion

‘Modified test method for abrasion resistance of pipeline coatings (ASTM G6)’ was employed. Coated specimen rods are pre-weighed and inserted into a drum containing abrasive slurry (3.5 kg each of coarse quartz sand and bauxite in 6 kg of water). The assembled drum is then rotated at 100 rpm for 100 hours exposing the coated rods to abrasive wear. On completion, the drum is disassembled and the coated rods inspected. Erosion resistance is determined from the calculated volume loss.

This test mimics the environment experienced by pipeline internals exposed to highly abrasive slurries where the entrained solid slides and cascades against the coating. The results demonstrate the superior performance of the polymer alloy technology versus conventional ceramic filled epoxy coatings which experienced 20% greater volume loss.

Taber Abrasion

The degree of erosion to a pre-weighed cast disc of cured epoxy is determined by ‘Wet Taber Abrasion (ASTM D4060)’. The specimen disc is placed on the turntable tray of a Taber Abraser. The tray is filled with water to simulate abrasion associated with the transport of fluids. The tray is rotated perpendicular against a pair of H-10 abrasive wheels under a 1 kg load. A circular track is worn into the specimen disc by the action of the abrasive wheels. Erosion resistance is determined by volume loss per 1000 cycles. Ceramic filled epoxy coatings perform well against sliding abrasion as measured by the Taber Abraser but these results show that the polymer alloy technology performance is even better.

Jet Impingement Erosion

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‘Jet Impingement Erosion’ was carried out by the School of Mechanical Engineering, University of Leeds, UK on behalf of Belzona Polymerics Ltd. A cast specimen disc of cured epoxy coating is pre-weighed and submerged in a jet impingement tank. A jet of salt water solution containing quartz sand at 2100-2300 mg/L loading is directed from a nozzle tip to the submerged specimen disc at a velocity of 20 m/s. The angle of impingement is 90°. The temperature of the fluid jet was 20°C for Belzona 1331 and 70°C for Belzona 1381. The test is carried out over 50 hours and volume lost to erosion was an impressive three to four times less than the ceramic filled epoxy coatings.

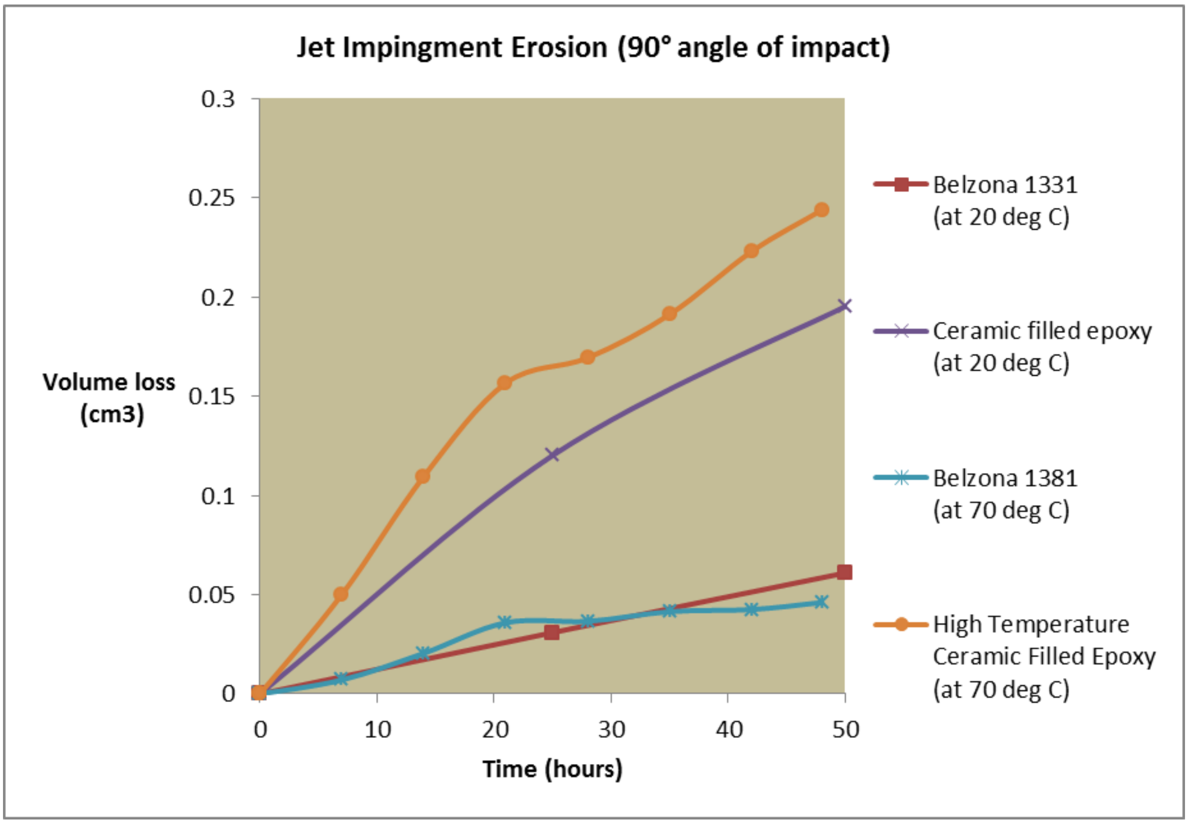

Figure 3: Belzona 1331 and 1381 jet impingement erosion versus ceramic filled epoxy coatings

Erosion-corrosion in heat exchanger tube sheets

The combined effects of erosion-corrosion are most damaging in fluid flow equipment. Metal loss is exacerbated as the corroded layer is eroded away by fluid flow exposing new metal underneath. Elevated temperatures, high flow rates and entrained solids lead to increased metal loss. Corrosion rates increase where chloride ions are present such as in salt water immersion. These conditions can be found in cooling water systems and affect pipes, valves, pumps and heat exchangers.

Heat exchanger tube sheets are particularly susceptible. The effect described combine with increased risk of galvanic corrosion at the tube / sheet interface due to differing construction materials such as steel and copper. Other areas such as division bars can also deteriorate and if left unprotected will result in recirculation of cooling water and efficiency losses.

Belzona in Canada were recently contacted by a local nuclear power facility. They required a solution for heavily damaged tube sheets which had suffered from the effects of erosion-corrosion following the breakdown of the existing protective lining which had eroded rapidly allowing severe corrosion to occur at the tube / sheet interface and between the water box and the tube sheet. The cooling media was seawater which contained some entrained solids. The customer required a rapidly applied, erosion-corrosion resistant coating.

A two coat application of the newly developed Belzona 1331 was recommended. Following preparation by grit blasting, the tubes were temporarily plugged and sealed. Metal loss was restored using the paste grade Belzona 1111 (Super Metal) epoxy composite before applying the Belzona 1331 to provide overall erosion-corrosion protection. Spray application resulted in minimal downtime.

Internal field joint protection

Spin spray techniques allow internal protection of pipelines against erosion-corrosion and the associated cost of environmental clean-up and lost production revenue. Pipeline parts particularly subject to internal erosion include elbows, bends, and protrusions such as the internal girth welds of field joints.

Using these coatings, wet film thickness up to 2000 micron are achievable without sagging and full coverage of the girth weld bead achievable in a single coat; an important requirement in pipeline field assembly.

In application trials using a Hodge Clemco R9003 Rormaster II spin spray unit, Belzona 1331 was applied at 1800 micron wet film thickness to the internal wall of a 60 cm diameter test pipe with a 1.5 mm high internal girth weld bead. A smooth coat was applied without sagging and single coat coverage of the girth weld achieved. In contrast, conventional solvent free epoxy coatings fail to cover most weld beads as they tend to drip and sag when applied at film thickness greater than 700 micron.

Figure 4: Single coat application of Belzona 1331 achieves full coverage of a 1.5mm high weld bead. The masking tape was removed to reveal the weld bead.

Due to the ductile phase of the polymer alloy, these coatings exhibit flexibility and impact resistance much greater than conventional ceramic or mineral filled epoxy coatings and can tolerate greater stress during pipeline field assembly and in-service soil movement. When tested, these coatings achieve 2.5 degrees per pipe diameter for 'Flexibility of coating for field bending (NACE RP0394)'.

The coatings excel when used for the spin spray technique and are robust within a wide range of operational variables such as boom speed, pipe diameter and spin rate. Wet film thickness from 500 to 2000 micron is achievable even when coating pitted areas.

Submarine snort tube interiors which were previously difficult to coat due to internal pitting, small diameter and aggressive service conditions are now enjoying successful service following protection using Belzona 1331 applied using spin spray techniques. Here the versatility and ease of use of the material were apparent. Simple mixing ratios and ample working life allowed the product to be delivered using heated single airless spray equipment to a spinning head pipe coating machine. The pipe coater applied the product using centrifugal force across internal protrusions and pitting. All areas were coated in one pass allowing the product to be delivered to the customer in excellent time.

High velocity abrasion and cavitation

Kort nozzles, turbines and pumps are employed in highly erosive environments where centrifugal forces are transferred by rotating blades to fluid containing entrained solids. The casing and blades are subject to a range of high velocity impingement angles and the wear mechanism varies from mostly sliding erosion on casing walls and trailing edges to impact erosion at the leading edge of the blade and on cutwater parts. Pumps may be gravity fed from hoppers or feed tanks on the intake side then discharged under pressure to pipe work or other process equipment.

Cavitation resulting from the formation and collapse of low-pressure bubbles in fluids is a common mode of erosion on propellers/impellers and can reduce component service life dramatically. The polymer alloy technology offers the adhesion of an epoxy coating in combination with elastomeric character and therefore exhibits excellent cavitation resistance. When tested in accordance with 'Cavitation Erosion Testing (ASTM G32-92)' at 20 kHz frequency and 50 micron amplitude for 20 hours; Belzona 1331 was superior to the other flexible epoxy coatings tested.
This technology has also proved useful in casting and machining nozzle inserts. These are 'tubes' of cured product which have been manufactured to set diameters and are used to protect small bore nozzles on process equipment where hand application is difficult and inspection of coating integrity is hampered by access. The process involves applying layers of the product to a mandrel and then machining the cured material to the specified thickness. Once manufactured, the nozzle inserts are bonded in place on site. This innovative application technique ensures complete protection of the nozzle bore. Previously manufactured from ceramic filled epoxies, these were difficult to machine and required specialist tooling. The machinability of the polymer alloy allows easier manufacture yet creating nozzle inserts with increased erosion resistance.

Mechanical, thermal and chemical resistance

Slurry tanks, agitators and process vessels may require erosion protection from suspended solids in the process fluid. In these systems, energy is transferred from the stirring shaft to the vessel walls resulting in vibration, bending moments, downward load and pressure thrust. The polymer alloy imparts excellent flexural toughness. In a three point bend test, when applied to grit blasted 3mm thick steel strips and cured at 20°C (68^{0}F) for 7 days, Belzona 1331 and Belzona 1381 were found to bend at a 60° angle from the horizontal (the maximum for the gauge). Conventional epoxy coatings typically achieve a 30° bend angle from the horizontal before cracking failure occurs. The 'Product Specification Sheets' for Belzona 1331 and Belzona 1381 are available from Belzona Polymerics Ltd. with a comprehensive list of mechanical properties tested to industry standards.

High temperature immersion and chemical resistance are also important considerations in these applications. The immersion resistance of these coatings was assessed by Atlas cell in accordance with NACE TM0174 for 6 months continuous immersion in deionised water under cold wall conditions. Belzona 1331 was found to be suitable for immersion at temperature up to 50^{0}C (122^{0}F). Belzona 1381 is suitable for immersion at temperatures up to 95^{0}C (203^{0}F). In common with other epoxy coatings, the polymer alloy technology is resistant to a broad range of chemicals. A comprehensive 'Chemical Resistance Chart' is available from Belzona Polymerics Ltd.

Complex vessel geometries require brush application of a stripe coat on internal tank furniture such as lips, fins, supports etc. These coatings are easily applied by brush and have excellent edge retention. On NACE TM0304 test Belzona 1331 and Belzona 1381 achieved the required 0.5 peak to flat coating thickness ratio over a ridge radius curvature of 0.7mm demonstrating excellent edge retention for protection of sharp edges. The polymer alloy technology is also electrically insulating and as a result the cured film can be inspected using a high voltage 'spark tester'.

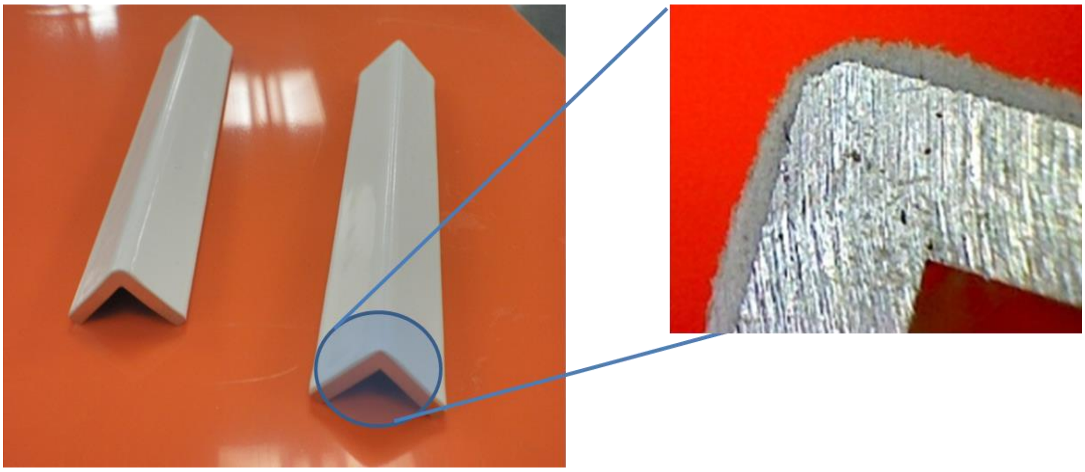

Figure 5: Excellent edge retention - NACE TM0304 specified 90° angle aluminium specimen with ridge radius curvature of 0.7mm. The peak to flat coating thickness ratio of 0.5 is achieved

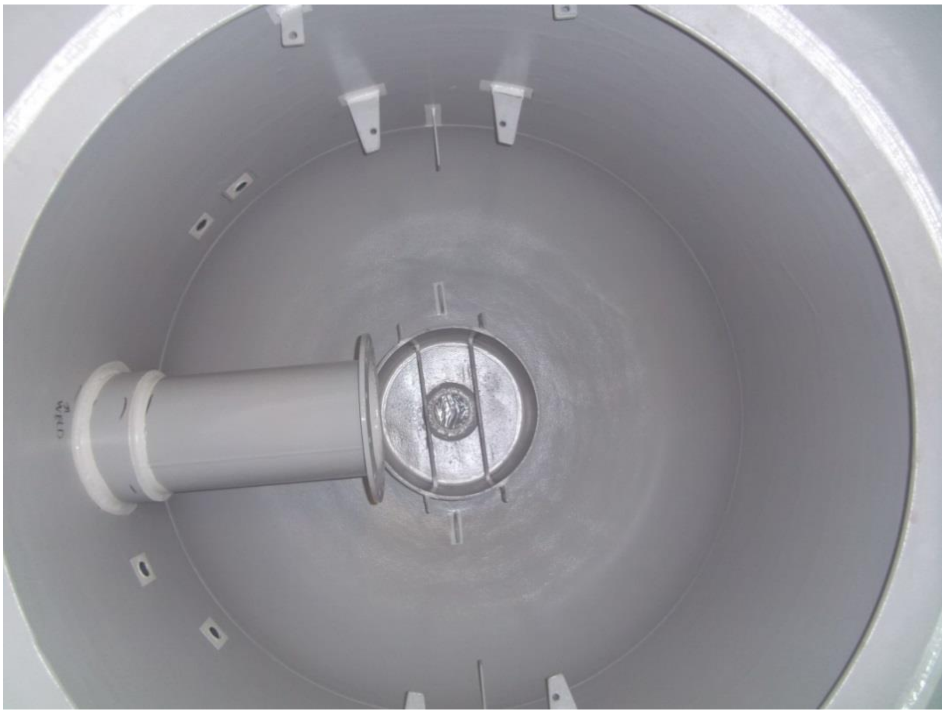

Figure 6: Belzona 1331 spray applied to a process tower in the UK North Sea for a major Oil and Gas client. The high build capacity meant that internal furniture and welds are coated resulting in minimal remedial work and faster job completion.

Concluding remarks

These coatings represent a novel class of erosion resistant and 'spray friendly' epoxy coatings utilising a filler-free polymer alloy technology rather than conventional ceramic fillers. Unlike some ceramic filled epoxy coatings which claim to be sprayable, these erosion resistant coatings do not wear or damage spray equipment.

When compared to conventional ceramic filled epoxies, laboratory testing demonstrates superior resistance to sliding and impact abrasion, excellent flexibility and single coat application at film thickness up to 2000 micron. The coatings have excellent edge retention, are machinable and spark testable.

Belzona 1331 and Belzona 1381 can therefore be specified for spray application in a wide range of erosive environments where brush or roller application is not practical.

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