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the sheet linings on a side wall and bottom of a tank or pit so that they meet at the 90-degree joint, the sheet linings are shortened to leave a small gap at the joint. This allows the molten thermoplastic weld material to flow into and fill the gap between the lining sheets and penetrate the joint to the substrate. An infused weld area is created that eliminates channels behind the weld seams, reduces the probability of leaks, and increases the service life of the tank or pit. Should a leak happen, the weld blocks solution from flowing behind the lining.

Inner bottom corners, where three intersecting lining sheets must be joined, are typical problem areas and a frequent source of early leaks and premature lining failures, Goad says. "It is difficult to perform a high-quality weld in a corner. You need perfect speed, temperature, and pressure as you move the welding machine along the joint; but when you come to a corner, you can't preheat the lining sheets because the machine stops," he notes. To address this problem, the company has devised molded thermoplastic corner inserts that enable the machine to weld continuously in the corners.

Goad comments that the extruded welding machine technique with plasticized PVC also can be used with rigid PVC and chlorinated PVC (CPVC) fabrications. Although steel and concrete are the major substrates used for processing tanks and pits, the PVC linings and machine welding technique can be used with wood, fiberglass, and other substrates that require corrosion protection.

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Inorganic ceramic coating shows resistance to corrosion

A new inorganic spray-on protective coating technology, developed by scientists with EonCoat, LLC (Wilson, North Carolina), provides corrosion protection to metal through a chemically bonded phosphate ceramic (CBPC) that bonds with the surface of a substrate to form an impenetrable ceramic coating that will flex with the underlying metal.

The coating technology utilizes two components—a food grade acid phosphate and a water-based slurry that contains base minerals and metal oxides (such as magnesium oxide [MgO])—that are combined and sprayed onto a metal surface. An acid-base exothermic reaction occurs at the surface of the metal that forms a hard, two-layer ceramic coating that is chemically bonded to the metal in about 5 min. Unlike polymer paints that mechanically bond with a substrate, the CBPC coating essentially forms an alloy with the substrate surface, says NACE International member Tony Collins, CEO of EonCoat.

Collins explains that the acid phosphate and oxides in the slurry interact with the metal ions in the substrate to form a covalent bond (where the atoms are bound by shared electrons). The result is an insoluble, 20-μm thick passivation layer of stable oxides that contains ~60% iron with phosphate, potassium, magnesium, silicon, hydrogen, and oxygen. This inert, alloyed passivation layer does not support the oxidation process and protects the underlying metal from corrosion. On top of the alloy layer, a tough, dense, ceramic outer layer forms simultaneously, which resists abrasion and protects the passivation layer beneath it. The thickness of the ceramic outer layer is determined by the amount of slurry material applied to the substrate. The high pH of the ceramic outer layer, around 10 or 11, also protects the underlying metal from corrosion, Collins says.

"We originally thought the ceramic top layer was the primary method of corrosion protection," Collins comments. However, he says, the underlying steel did not corrode during corrosion tests that EonCoat conducted with portions of the ceramic layer pulled off a coated metal sample. "That was the biggest surprise," he adds, noting that the company's scientists used scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) to further evaluate the coated samples, and learned that the surface alloy is a passivation layer, which is actually the coating's principal means of corrosion protection.

The coating is based on a CBPC material initially developed in the 1990s by researchers with Argonne National Laboratory and the University of Chicago to encapsulate radioactive nuclear waste. The dense ceramic cement, known as Ceramicrete[†], is also formed by acid-base reactions between an acid phosphate and a metal oxide, and possesses physical properties that led to its use in commercial applications such as building materials, drilling cement for the oil and gas industry, and dental and bone cements.

Several years ago, Collins realized the CBPC's potential as a corrosion-resistant protective coating. He was initially interested in the ceramic cement as a building material. "We put Ceramicrete on a metal plate as part of an experiment. The cement didn't bond, fell off, and we threw the plate in the scrap bin," Collins writes in his company blog. "That would have been the end of the story, except several

[†]Trade name.

months later my wife, Sandy, and I drove in the back gate at our facility and she asked, 'What is the story with that piece of metal in the scrap bin?' Unlike other metal scraps in the bin, the one that had been touched with the Ceramicrete was not rusted," he says.

Arun Wagh, a consultant to EonCoat who is a former materials engineer at Argonne National Lab and the lead developer of the CBPC technology, confirms the occurrence of the chemical reaction and creation of a passivation layer when the coating's two components are spray-applied to steel. "A hand-held thermometer indicates a 10 to 12 °F temperature rise, as iron becomes a corrosion-resistant passivation layer of iron oxyhydroxide. Because the passivation layer is electrochemically stable, like gold and platinum, it does not react with corrosion promoters such as water and oxygen," he says.

The photos show a steel sample coated with the protective CBPC coating on the first day of a NASA-developed seawater corrosion test (left) and after 170 days of continuous exposure (right). Photo courtesy of EonCoat.

Wagh observes that history suggests the passivation layer on a metal surface formed by the CBPC coating may resist corrosion indefinitely, as demonstrated by the Iron Pillar of Delhi. The Iron Pillar, a 7-m high, 6-ton (5,443-kg) Indian artifact, which has resisted corrosion for 1,600 years with its original inscriptions still legible, has a passivation layer virtually identical to the one formed by the CBPC technology, he says.

According to Collins, the CBPC coating has undergone thousands of hours without corroding in an ASTM B117[1] salt spray test. To determine how the coating would perform under a more aggressive corrosion test, EonCoat tested a CBPC-coated steel sample, gouged down the center with a scribe, for corrosion resistance using a seawater corrosion test developed by NASA. The test consists of continuous cycles of four hours of exposure to seawater spray (an average of 14 gal of seawater are sprayed on the samples) followed by four hours of exposure to simulated sunlight (426-nm light waves) in a test chamber. "Currently this is the most aggressive corrosion test we've been able to find at ambient temperatures," notes Collins. After 170 days of exposure, the CBPC-coated sample showed no signs of corrosion failure, he says.

Because the coating's exothermic reaction creates a heat rise of only 7 to 40 °F (4 to 22 °C), the company says a wide range of materials can be used to enhance the coating's performance. Fibers and fillers with an acicular (needle-like) microstructure create additional ductility as well as toughness. The CBPC coating has many times the ductility needed to accommodate the typical amount of flexing, expanding, or contracting that a steel substrate would experience, says Collins, adding that steel typically flexes ~1% before it permanently deforms and flexes 7 to 38% before it breaks. Independent bend tests conducted according to ASTM D522[2] at Weldon Labs indicate that the standard CBPC coating can flex up to 19% before it will fracture.

Additionally, the CBPC coating is non-flammable. While the ceramic outer layer will withstand temperatures up to 1,500 °F (816 °C), the alloy passivation layer, the coating's primary means of corrosion protection, is a hydrate that expels water at temperatures above 200 °F (93 °C), which can diminish its corrosion protection at higher temperatures, Collins says. The coating is not resistant to strong acids, such as hydrochloric acid (HCl) and sulfuric acid (H_2SO_4). Although it can withstand short-term exposure to milder acids, the CBPC coating isn't recommended for continual exposure or immersion in acids below pH 4.

Tests indicate the CBPC coating will bond chemically to aluminum and nonmetals such as Portland cement and gypsum as well as steel. It does not chemically bond to polymers but will mechanically bond to expanded polystyrene (EPS).

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References

1 ASTM B117, "Standard Practice for Operating Salt Spray (Fog) Apparatus" (West Conshohocken, PA: ASTM International).

2 ASTM D522, "Standard Test Methods for Mandrel Bend Test of Attached Organic Coatings" (West Conshohocken, PA: ASTM). MP