Polymer Linings for Restoration & Corrosion Protection of Steel Surfaces: Crude Oil Storage Tank Repair and Reline in New Zealand

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Introduction

When Marsden Point Oil Refinery in New Zealand needed to reline 3 steel crude oil storage tanks, Figure 1, the engineers began a search for a lining with the necessary properties to provide a long-term solution. Figure 2 is a schematic of a typical crude oil storage tank at the facility. The existing liners had failed in many areas, allowing severe corrosion of the carbon steel tanker, Figure 3. Magnetic Flux Leakage (MFL) scans of the steel showed a significant loss of steel thickness due to corrosion, in some areas greater than 25%. The internal linings that had been previously installed ranged in age from 12 to 15 years old and had failed over the entire floor area and 1 meter (~3.281 feet) up the sidewall. One of the 3 tanks was heated as it stored heavy crude.

Discussion

The severe loss of plate thickness placed additional performance requirements on any replacement coating chosen. Not only would excellent chemical resistance and very low permeance be required, but excellent flexural and bond adhesion became equally important considerations. Test plates were made of a particular lining, based upon an analysis of published coating properties vis a vis actual stresses due to plate movement from maximum to minimum fill levels. Deflection, adhesion, hardness and crack-resistance of the test plates were then back-checked against actual tank movement.

A life cycle cost analysis was taken into account, including application cost savings against other products under consideration, including the two coatings previously applied.

An analysis of the two failed coatings applied previously showed that a high permeance of the coatings and the presence of pinholes in the coating were the primary cause of the failures. The two linings were made by two different coatings manufacturers. Both were approximately 65% solids by volume bisphenol A epoxies which had been applied in 3 coats to a total film thickness of 15 to 16 mils (400 microns). The high solvent content is the primary reason for the high permeance and likely contributed to pinhole formations as well due to entrapped solvent in the cured coatings

To avoid these issues, an ultra-high solids coating, greater than 98% weight solids, with a very low permeance was investigated. This particular coating is a fiber-reinforced epoxy with a blend of discrete fibers. The fibers not only aid in physical reinforcement, especially in the critical flexural properties and crack resistance, but also greatly reduce permeance. Independent lab tests show a permeance reduction of more than 100-fold when the coating incorporates these particular fiber blends. To further ensure maximum chemical-resistance and minimum permeance, New Zealand Refining Company (NZRC) chose a novolak epoxy. Novolak epoxies have inherently better physical properties, lower permeance and generally better chemical resistance then other types of epoxies. Figure 4 is a Scanning Electron Microscope (SEM) of a cross-section of this lining material. Note how the fiber strands overlap and stack. The average number of layers of fiber per mil of coating exceeds 100 layers. This results in a highly tortuous path for any corrosive media, gas or liquid, to penetrate.

Corrosion protection afforded by protective coatings is, among other factors, a function of the efficiency of the barrier provided. There are several factors involved in the performance of these coatings and linings. The first factor is the lack of a chemical reaction between the coating material and the media. If a given chemical will deleteriously react with one or more of the coating's components, then that coating is by definition corroded by that chemical and is not chemically resistant to it. Take for example a furan resin exposed to 50% nitric acid. The resin itself is destroyed by the nitric acid. Regardless of other properties, the furan resin is not resistant to this specific environment.

Permeance is another critically important factor. All materials are permeable to some extent, depending upon the chemical(s) to which they are exposed. Steel for example, is permeable to molecular hydrogen and coatings are often permeable to solvents and other compounds. The key is to find coatings with very low permeance. Permeance, which is calculated from the measured Water Vapor Transmission (WVT) rate, is a performance property. The lower the permeance, the lower the penetration of the coatings, and the better the corrosion protection.

Sometimes certain specific mechanical properties are of importance to the lining selection process. In this case flexural properties, tensile properties, adhesion and abrasion resistance were all considered to be critical to the lining's long-term performance. The tanks' floors and walls flex as the fill level changes. To resist cracking, the lining required high flexural strength, high tensile strength and a low flexural modulus of elasticity. To ensure against disbondment, the linings must also exhibit a high level of adhesion. When a lining disbonds from a substrate, it forms a blister or a bubble. These will grow with time and with multiple cycles of stress. The blisters will reach a critical diameter and crack under stress, allowing corrodents direct access to the substrate, resulting in under-cutting of the coating, further disbondment and greater substrate corrosion.

The previously applied linings were 65% volume solids bisphenol A epoxies (often called bis A epoxies for convenience). This high level of solvent can result in problems in the cured film. If the solvent is not completely removed before cure, the entrapped solvent will cause blistering and a significantly higher permeability. Both endanger corrosion protection. These coatings were applied in 3 coats of 5 mils (127 microns) each, building to 15 to 16 mils dry film thickness (381 to 407 microns) (DFT). While this coating thickness may work for occasional atmospheric corrosion protection, it will not work in an aggressive immersion environment. A DFT of 15 to 16 mils (381 to 407 microns) also does not afford the necessary abrasion resistance or flexural properties.

The selected coating for the reline for these 3 tanks, which totaled 5062 square meters (54,488 square feet), was a novolak epoxy, reinforced with discrete fibers and other selected corrosion-resistant fillers and reinforcing materials. A novolak resin is not strictly required for chemical resistance to crude oil, water, salts, and sulfur. A good quality bis A epoxy, properly formulated, will chemically withstand this environment. However, the novalak epoxy has superior permeance, better abrasion resistance, and significantly better mechanical properties. As NZRC does not want to reline these tanks for many years and since all of the tanks had lost a significant thickness of steel to corrosion, it was decided to use the novolak epoxy to extend service life. Further, to provide maximum abrasion protection and to provide an even lower permeability, the thickness of the applied lining was increased to 40 to 50 mils (1016-1270 microns). The installed lining was also tested for holidays by ASTM D5162, when cured, over 100% of the area. All pinholes were repaired before exposure. Only the repairs were retested for pinholes. Retesting of the entire coating is not done as it could cause disbondment and create additional voids.

The permeability of the installed lining is obtained by multiplying the thickness expressed in inches, by the permeance expressed in perms. The resulting permeability, expressed in perm-inches (gr/m²/24 hr/mmHg/cm) should be as low as possible. A permeability of 1 x 10^9 perm-inches or less has been found to be the point at which good corrosion protection begins. The installed lining has a permeability of 1.14 x (1 x 10^10) perm-inches (1.45 x (1 x 10^-18) gm/Pa·s·m). Permeability, permeance, and water vapor transmission rates were determined in accordance with ASTM D-1653, method A.

The flexural, tensile, abrasion resistance, and bond strength are shown in Table I below:

Table I.

Flexural strength, ASTM C-580	3100 psi (217.9 kg/cm²)
Flexural MOE, ASTM C-580	10.5 x 100000 psi (7.4 x 10000 kg/cm²)
Tensile strength, ASTM C-307	2300 psi (161.7 kg/cm²)
Abrasion resistance, ASTM D-4060	<100 mgm weight loss

Based upon the results of test panels made up from the actual material to be used on the reline project, the engineers at NZRC were convinced that this fiber-reinforced lining would provide the physical properties needed to withstand expected mechanical stresses with an acceptable safety margin. The chemical resistance is assured due to the extremely low permeance and permeability and the use of the novolak epoxy resin.

The surface was cleaned by ultra-high pressure (UHP) water blast to remove oil, contaminates, and to prepare the area for inspection and steel repair. The surface was blasted using garnet to SSPC-SP5 cleanliness and a steel grit sweep blast to a 2.5-4 mil (63.5-101.6 microns) angular profile prior to priming. After surface preparation the fiber-reinforced topcoat was applied in one coat, building to 40-50 mils (1016-1270 microns). This resulted in a permeability of 1.14 x (1 x 10^-10) perm-inches (1.65 x (1 x 10^-18) gm/ Pa·s·m), a very low value and one that will give excellent long-term penetration protection. Following a cure of 2 days the tanks were placed back in service. This lining is expected to provide 12 to 15 years of service, see Figure 5 (completed lining).

The technical requirements of the proposed new linings were specified by NZRC and a conforming specification was prepared by Pacific Concrete Protection Ltd. (PCP) of New Zealand, who called for continuous onsite technical service to ensure that the coating was correctly applied and tested before placing the tanks into service. This onsite inspection, also provided by PCP, was vital to the overall success of the project as potential problems were prevented at the outset. In this manner, compromised coatings were prevented from going into service.

The application contractor, TBS Group Ltd, New Zealand, commented that once the correct equipment was setup and a means found to keep the material at a constant 30 C (86 F), the lining material was “ a breeze to apply”. Once again having onsite technical service helped in this regard as well.

Summary

Even though not required by the chemical environment, NZRC chose a particular novolak epoxy liner to refurbish 3 carbon steel crude oil storage tanks. The novolak epoxy provided other properties vital to the long-term success of the lining system. In this instance, physical performance parameters were as critical as chemical resistance. The physical properties deemed most critical were permeance, flexural strength, flexural MOE, tensile strength, bond adhesion, crack resistance and abrasion resistance. Novolak epoxies are generally better in these properties than are bis A or bis F epoxies.

Permeance, a performance property, is inherently better in a novolak epoxy than in a bis A epoxy. The chosen lining system, in addition, incorporates a blend of discrete blended fibers of varying aspect rations to further enhance certain properties such as crack-resistance, tensile strength, flexural strength, flexural MOE and permeance. The fiber-reinforced lining is able to achieve a very low permeance of less than 1 x 10^-9perm-inches and an installed permeability of 1 x 10^-10 perm-inches (1 x 10^-18gm/ Pa·s·m).

A final assurance in the lining's installed integrity was obtained by testing 100% of the coated surface for holidays per ASTM D-5162. Once tested, the owner, specifier, installer and coating manufacturer have a high degree of confidence that pinholes will not be able to initiate a coating failure.

References

1. ASTM Annual Book of Standards, Volume 04.05, Standard Test Method for Water Vapor Permeability of Organic Films, Method D-1653.
2. ASTM Annual Book of Standards, Volume 06.02, Practice for Discontinuity (Holiday) Testing of Nonconductive Protective Coatings on Metallic Substrates, Method D-5162.
3. ASTM Annual Book of Standards, Volume 04.05, Test Method for Flexural Strength and Modulus of Elasticity of Chemical-Resistant Mortars, Grouts, Monolithic Surfacings and Polymer Concretes, Method C-580.
4. ASTM Annual Book of Standards, Volume 04.05, Test Method for Tensile Strength of Chemical-Resistant Mortar, Grouts and Monolithic Surfacings, Method C-307.
5. ASTM Annual Book of Standards, Volume 06.01, Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser, Method D-4060.

Figure 1

Exterior View of Crude Oil Storage Tank

Figure 2

Floating Roof Tank Maintenance Summary Sheet

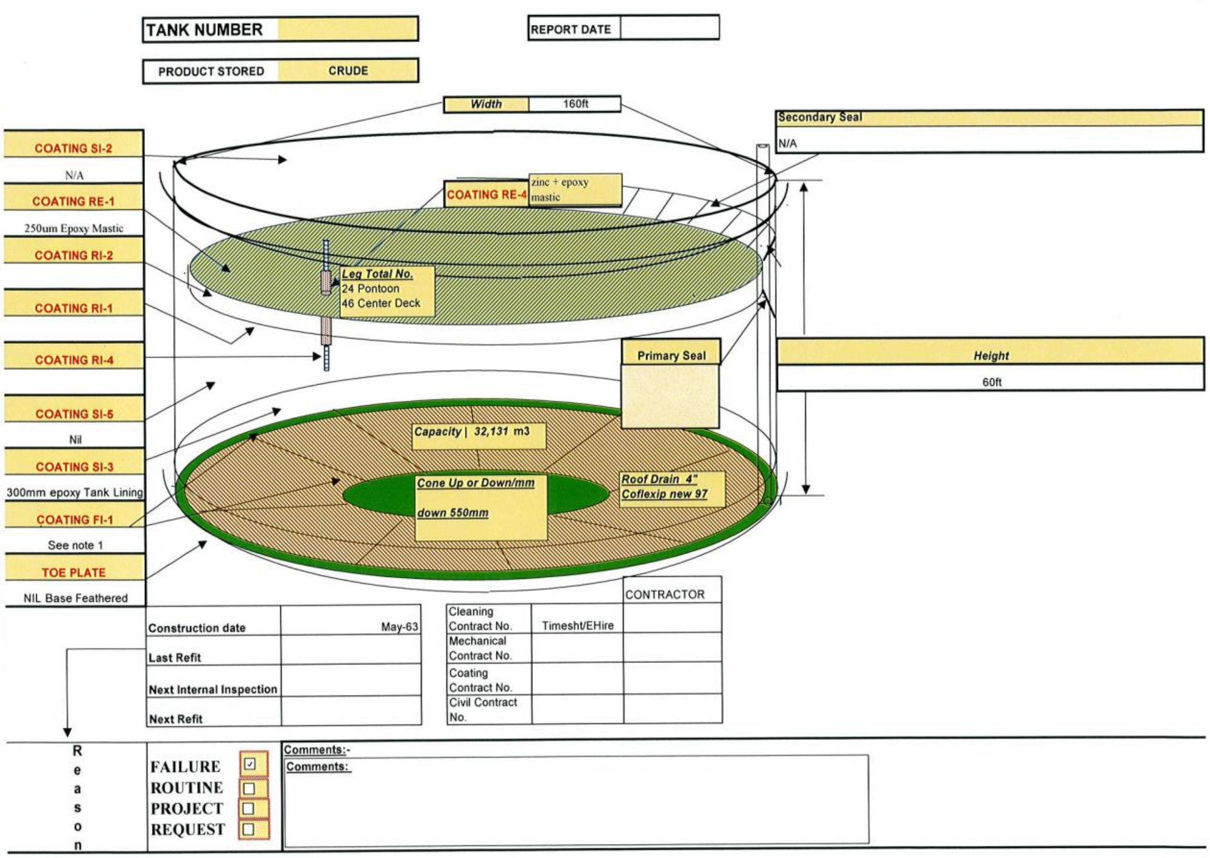

Figure 3

Corrosion of carbon steel

Figure 4

Scanning Electron Microscope (SEM) of Cross-section of interlocking fiber network

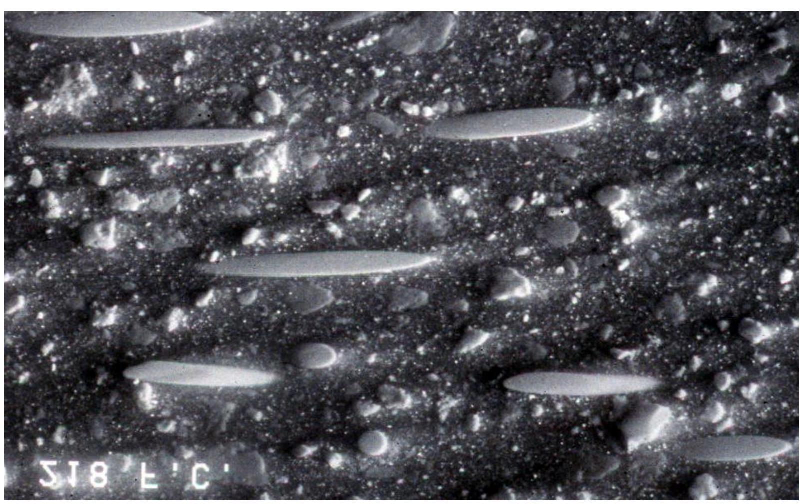

Table 1

Flexural Strength, ASTM C-580	**3100 psi (217.9 kg/cm^2)**
Flexural MOE, ASTM C-580	**10.5 x 100,000 psi (7.4 x 10,000 kg/cm^2)**
Tensile Strength, ASTM C-307	**2,300 psi (161.7 kg/cm^2)**
Abrasion Resistance, ASTM D-4060	**<100 mgm weight loss**

Figure 5
Completed Lining