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Multi-Functional New Coating System for Rehabilitation and Maintenance of Onshore and Offshore Infrastructure

Kaveh Sarikhani
Canusa-CPS a ShawCor Ltd.
Company 25 Bethridge Rd.
Etobicoke, Ontario, M9W 1M7 Canada

ABSTRACT

In recent years, there has been great focus on the preservation of aging infrastructure and extending the service life of assets in oil and gas, marine, power generation, water, and other corrosion affected industries. There has been increasing demand for surface tolerant and easy-to-apply rehabilitation coatings that will meet the most stringent industrial requirements and standards. Most existing anti-corrosion coating solutions have high standard surface treatment and application requirements which are not suitable for in-service assets. In addition, most commercial offerings require the complete removal of the previous coating system, some of which, require special disposal procedures due to HSE concerns and regulations. To address the need for an innovative solution to satisfy this industry demand, a multi-functional polymeric coating has been developed. The new corrosion protection system is easy-to-apply requires minimum surface preparation, and is able to encapsulate its residual coatings. This coating system has been engineered for the additional functionalities of UV light resistivity for environmentally exposed assets and vibration absorption resulting in sound dampening, reducing noise pollution. A comprehensive study was conducted using conventional and non-conventional test methods based on current industrial standards and performance specifications to evaluate the value proposition of this new coating system. Environmental and thermal shock results show excellent protection against corrosion and durability under changes in temperature. Salt spray results according to ISO 9227 and ISO 12944-2 successfully passed 720 hours of testing at category C4 (high) in the durability scale with the coating remaining intact with no corrosion creep observed at the edges of coated panels. Furthermore, thermal aging of this coating system has demonstrated a calculated lifetime of over 25 years.

This new coating system was engineered through software-guided mixture design-of-experiments (DOE) followed by extensive evaluation under simulated field conditions with the detailed results for this novel cold applied coating system presented herein.

Key words: Anti-corrosion Coatings, Viscoelastic Coatings, Rehabilitation, Aging Infrastructure

INTRODUCTION

Corrosion is costly for many industries that have exposed infrastructure. A proper selection of rehabilitation coatings will extend the lifetime of aging infrastructure and minimize the annual global cost of corrosion. Especially in the face of decreased investment in recent years in new infrastructure construction combined with worldwide economic challenges, rehabilitation coatings have gained more recognition and importance for maintaining current in-service infrastructure ¹.

Replacing, maintaining, and rehabilitating aging pipelines require continuous investment in innovative technologies for the oil and gas, power generation, utility, water, and industrial sectors. In North America 62 percent of existing onshore pipelines are older than 21 years, 46 percent internationally. In the United States, approximately half of the 2.5 million miles of U.S. steel pipeline infrastructure is at least 50 years old ². Cast iron and wrought iron pipelines have been used since the late 1800s to transport wet gas before converting to dry gas. The repurposing of these lines resulted in costly repair and rehabilitation of bell-and-spigot joints due to the protective sealant having been dried out³. The usage of bare-steel pipes continued until the 1960s for natural gas and hazardous liquid⁴ to which point protective coatings began to come into fashion. Without a barrier to mitigate the corrosion to these bare pipelines, they often had short service lives and were liable to failure creating a risk to environmental and public safety. To prevent corrosion, tape wraps and coal tar were the early technology used for pipeline coatings; however, these materials were limited in performance and were not designed with a long service life in mind. These shortcomings along with poor resistance to key corrosion phenomena and poor coating application, led to failures when faced with uncontrolled environmental conditions. Critical factors vital to the prevention of corrosion include: good surface preparation, strong adhesion of the coating to the substrate, the lack of salts present, and the role of osmosis. As technology advanced through the 1960s, 3-layer high-density polyethylene (HDPE) and fusion bonded epoxy (FBE) factory applied coatings were developed and began to take over as the industry norm. This advancement along with controlled application environments and procedures mitigated many risks associated with corrosion development. FBE has been applied on more than 100,000 km of pipe around the world and is the most widely used coating system today in the United States with a typical service life of up to 30 years⁵. Considering that 62 percent of pipelines in North America are over 21 years old, see Figure 1, and the designed life of factory coatings is approximately 30 years, it can be concluded that the majority of coated pipelines are due for inspection and evaluation to determine if rehabilitation or replacement is required in order to prevent pipeline failures and to extend the service life of these in-service assets. Most existing field-applied anti-corrosion coating solutions require complicated and expensive near white SPPC.SP10 (Sa 2 ½) surface treatment and application conditions which are not suitable for in-service assets. This makes many rehabilitation and repair projects impractical, thus the demand for surface tolerant and easy-to-apply rehabilitation coatings that will meet stringent industry requirements and standards.

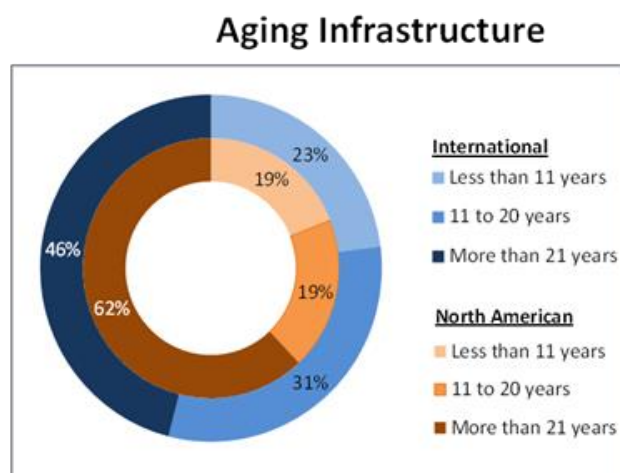


Figure 1: Distribution of ageing pipelines by age grouping from investor report⁶

There has been little research completed on rehabilitation coatings with few applicator-friendly options designed for cold and hot climates. These environmental conditions demand minimum surface preparation and little to no additional installation equipment to rehabilitate in-service infrastructure compatible with various surfaces as the removal of previous coating(s) is challenging and undesired. Our extensive research into this problem has resulted in the development of an unconventional anti-corrosion protection system under viscoelastic category of coatings which is easy-to-apply, has little HSE concerns, provides protection from extreme conditions, requires minimum surface preparation while having a long lifetime. This new coating system can satisfy the immediate need in the corrosion industry for a multi-functional cold-applied onshore and offshore solution for extending the lifetime of infrastructure assets with minimum capital expenditure while allowing continued operations during its rehabilitation.

Viscoelastic Coating Systems for the Repair & Rehab Market

Although all the polymers are viscoelastic materials, the time-scale desired for features such as self-healing and impact resistance for viscoelastic coating systems demands unconventional mechanical properties other than those of typical anti-corrosion coatings. A viscoelastic coating has viscous properties that resist shear flow and strain linearly with time under stress and elastic properties that strain when stretched while returning to the original state once the stress is removed. A viscoelastic materials exhibit element of both properties providing time-dependent strain. As a result of viscoelastic properties happening in a desired time scale, the coating can reflow into damaged areas, if the damaged area is not significantly large, providing self-healing characteristics until a repair can be completed. Viscoelastic coatings are required to be chemically engineered to provide very good wetting properties and instant bonding (tackiness) to substrates with minimal surface preparation, while still acting as a barrier to water and oxygen. These coatings are typically applied as a spiral wrap onto a pipeline without need for preheating or a curing period. In general, these coatings require additional mechanical (or environmental) protection which can be provided in various forms depending on environmental and project requirements. Examples of additional layers are UV resistant outer wraps, glass-fibre reinforced polyurethane coatings, polyvinyl chloride (PVC) outer wraps, heat-shrinkable sleeves (HSS), as well as other compatible paints can be added to provide the right custom solution to the specific problem.

Current viscoelastic coatings within the market can provide instant bond to a minimum SSPC, SP2 prepared steel, PE, or PP substrates. Another advantages of this category of coatings is retaining of their wetting properties even after installation due to being amorphous and inert, allowing the adhesive compound to flow into empty crevasses and pores of the substrate, increasing the contact surface area over time.

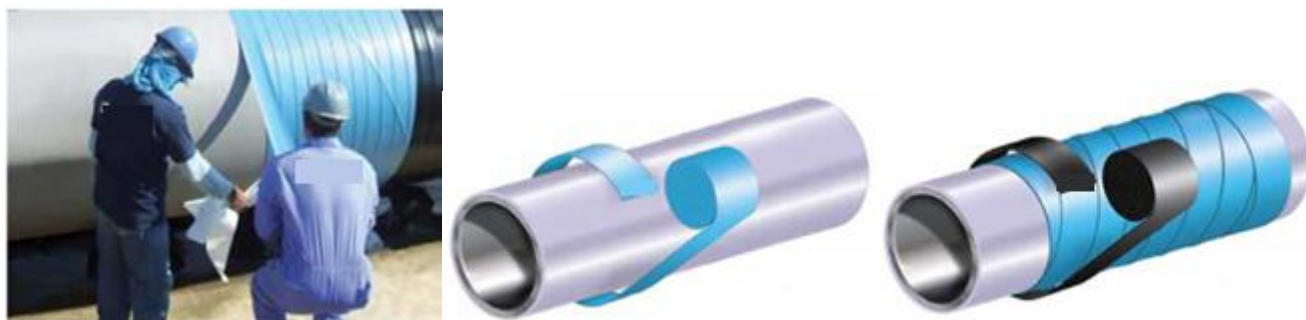


Figure 2: Representative field application conditions and procedure; in the field photo (left), schematic for viscoelastic base layer (middle), and outer coat system (right) applied in spiral fashion

Figure 2 shows actual in-field installation and schematics on how to install the viscoelastic coating system onto a steel substrate. The lack of preheat, cure time, heavy equipment, and low complexity is evident when compared to paint-based and other coating systems. Chemically, viscoelastic coatings are generally formulated with a non-polar chemical foundation which repels water, displaying very low

permeability and in turn, eradicating osmotic pressure. The combined properties of the instant bond, self-healing, and water resistance limits aggressive rust creep, commonly experience at areas of visually minor damage. In terms of health, safety, and environment (HSE), formulating a non-hazardous and inert compound helps reduce safety risks to field personnel, often associated with exposure to field mixing of multi-component coatings and fumes from high temperature cured products. No special personal protective equipment (PPE) such as face-shields, respirator masks, or full body protective suits are required for the application of this coating and there are no volatile organic compounds (VOCs) to be concerned with. Furthermore, no additional measures are needed to protect the environment from uncured/unstable residuals, as there is no risk of chemical side reactions post application, thus eliminating the risk of soil leaching and contamination to the surrounding environment.

In this paper all the above-mentioned design/selection criteria have been considered to develop a suitable rehabilitation coating system through a software-guided mixture design-of-experiments (DOE) followed by extensive evaluation under simulated field conditions with the detailed results.

EXPERIMENTAL PROCEDURE

Materials

Generally, performance testing was completed on steel pipe or panel segments at various levels of surface preparation included SP1 (solvent cleaned), St2 or St3 (power tool cleaning), Sa 2½ (near white blast). For non-standard tests, like coating on previous residual material, SP1 and/or St3 was used. On PE and PP substrates, solvent cleaning and roughening of the surface with 40 grit sandpaper was completed. Thus, the surface profiles of these substrates range from smooth (as received from supplier) to uniformly grit blasted on curved (pipe) or flat (panels) segments.

The coating system includes a base coat that consists of three components: the viscoelastic adhesive compound surrounding a plastic mesh laminated on a carrier film. Generally, a PVC outer wrap would be supplied as a mechanical protective barrier and the coating layers are spirally wrapped around a pipe or laid onto a flat surface as a single layer as needed. However, we will show several compatible outer wraps can be selected for various exposure and operating conditions.

The viscoelastic adhesive itself is soft to-the-touch at room temperature and is extremely tacky to the substrate surfaces. This allows for good adhesive compliance to various rough and smooth surfaces alike with the use of a J-roller or from the hoop stress upon installation. The adhesive backing and mesh are present to provide mechanical support for the anti-corrosion compound.

Methods

The experimental procedure used to support the performance claims of this viscoelastic coating system is based on the ISO 21809-3:2016 "Petroleum and natural gas industries - External coatings for buried or submerged pipelines used in pipeline transportation systems: Field Joint Coatings"⁷. The main test methods include adhesion testing (with cohesive failure) at ambient and coating rated temperatures, determining non-crystallinity, hot water immersion (HWI) and thermal ageing (for determining lifetime performance), and impact resistance. Some non-standard (not traditional for these coating systems) and in-house designed tests were completed to determine the level of protection against corrosion and the durability of the coating in adverse conditions. Direct salt exposure was tested as we purposely left the viscoelastic coating in the presence of chlorides and water by salt (3% NaCl) water immersion for 28 and 100 days followed by manual peel adhesion test based on ASTM D3330- Test Method F⁸. Samples were also tested at a third-party facility under salt spray according to ISO 9227⁹, passing an exposure rating of 720 h. To evaluate the ease-of-coating to which we will determine with the adhesive compound's instant tackiness, loop tack ASTM D 6195-03¹⁰ was measured.

Coating assembly and installation

The viscoelastic coating is supplied at various widths in tape form and is delaminated from its release foil prior to being applied with the pressure of the hand and then with a J-roller on the substrate. Installation occurs at ambient temperature (approximately 23 +/- 5C) and conditions to which we define as “cold-applied”, no preheat or post cure needed. Further, there is no need to wait for cure as the adhesive compound will remain amorphous for the life of the coating. This simplifies the coating process and requires less space, equipment, and setup required to apply the system. This reduction in complexity and potential for improper coating along with decreased coating time helps provide more consistent and repeatable coatings regardless of different application conditions.

RESULTS

The following sections will present summaries of the testing to convey the performance of viscoelastic coating systems.

Non-crystallinity and Low-Temperature Performance

First, in order to verify the self-healing behaviour and high performance even at low temperatures DSC was performed on the adhesive compound, see Figure 3. The DSC plot shows a glass transition (T_g) of approximately -60 C with no visible crystalline in the curve as per ISO 11357-211, thus is classified by the standard as a viscoelastic coating.

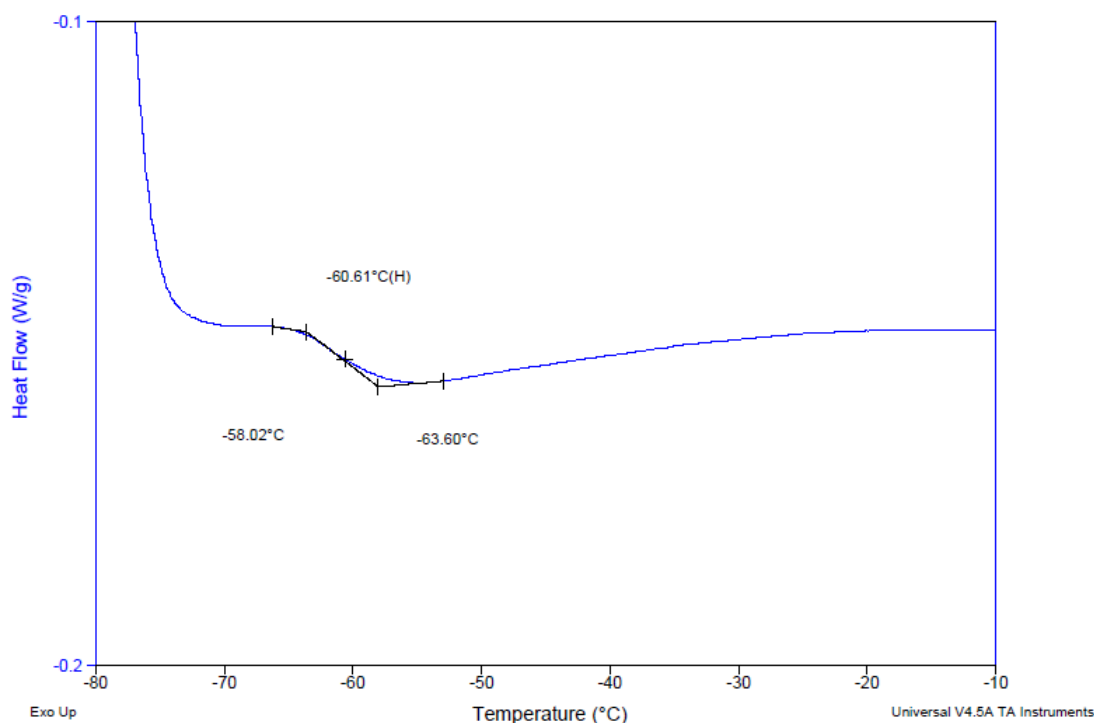


Figure 3: DSC (heat-cool-heat, 5C/min) of adhesive compound to show amorphous material and its low T_g (glass transition) as per ISO 21809-3:2016 definition and requirements magnified at lower temperatures for better visibility of T_g

Immediate tackiness

Loop tack was used to determine how quickly adhesion is initiated on a surface, see Figure 4 and Figure 5. With just the weight of coating itself, no pressure needed, the adhesive compound begins