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FP-based formulations as protective coatings in oil/gas pipelines

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ABSTRACT

Corrosion in the interior of pipelines is a major and costly problem encountered in the oil and gas industry. In this context, a fluoropolymer and a hybrid epoxy/fluoropolymer resin were studied for their potential use to prevent corrosion. The fluoropolymer coating required the use of a primer layer. The coatings were formulated to maintain the excellent abrasion and chemical resistance properties of fluoropolymers, while enhancing adhesion to the substrates. Standard corrosion experiments, including chemical immersion, adhesion, and salt fog tests, were used for preliminary evaluation. Coatings were characterized using scanning electron microscopy and energy-dispersive X-ray spectroscopy before and after exposure to corrosive environments. Electrochemical properties were studied with electrochemical impedance spectroscopy, by monitoring the resistance and capacitance of the coatings over time. The results obtained in this work will fill a knowledge gap and will aid in the selection of the proper composition and thickness of anticorrosion coatings for use in a highly corrosive media.

1. Introduction

Corrosion is a significant industrial problem. Its mitigation and the replacement of corroded parts with new ones are costly endeavors. In the oil and gas industry, corrosion is encountered in the downhole and surface equipment of the oilfield, including wells, pipelines, tanks, heat exchangers, and separators. The annual cost of corrosion is estimated to be $1.4 billion, with $600 million for surface pipeline and facility costs, $500 million for downhole tubing expenses, and $300 million for capital expenditures [1].

Crude oil is a very corrosive fluid. It contains organic acids, salt water, and dissolved gases, such as oxygen (O_2), carbon dioxide (CO_2), and hydrogen sulfide (H_2S). This composition increases the conductivity and enhances corrosion. The CO_2 and H_2S have a tendency to deionize, decreasing the pH of the fluid and further increasing corrosion. Particulate matter (asphaltene and inorganic materials, like barium sulfate) in the fluid may cause chemical deposition on the surface and abrasion due to shear as the fluid is transported. All of these aspects, combined with environmental conditions, intensify corrosion [2].

Pipelines used in the petroleum industry are mostly made of low-carbon steel, which is prone to corrosion and requires periodic replacement. To alleviate replacement costs, corrosion-resistant alloys can be used in place of carbon steel. However, these alloys are much more expensive than low-carbon steel; hence, their use is limited to special parts [3].

One way to mitigate corrosion is to use a barrier coating to protect the inner surface of the petroleum pipeline from corrosive materials and conditions. Requirements for corrosion-resistant coatings include good adhesion to low-carbon steel but low surface energy (to prevent deposition on the steel surface), resistance to high operational temperatures and pressures, resistance to corrosive chemicals, flexibility, ease of application, and low cost [3,4]. Various materials have been researched for this purpose. Diamond-like carbon coatings have high wear and corrosion resistance, and they have shown good barrier and anticorrosion properties [5]. Ni-P/SiC composite coatings also show good wear and corrosion resistance [6,7]. However, both of these materials are expensive and require special application techniques, like chemical vapor deposition. Hence, they are not practical to apply or repair.

Polymeric coatings are good candidates to prevent corrosion, as they are low cost and can be applied or repaired easily. Epoxy and phenolic resins known for their excellent adhesion and resistance to chemicals have been evaluated in petroleum transport [3]. However, the glass transition temperature of epoxies is lower than the production temperature of crude oil [8]. Also, epoxies have low resistance to some chemicals that are commonly encountered during petroleum production [3,9].

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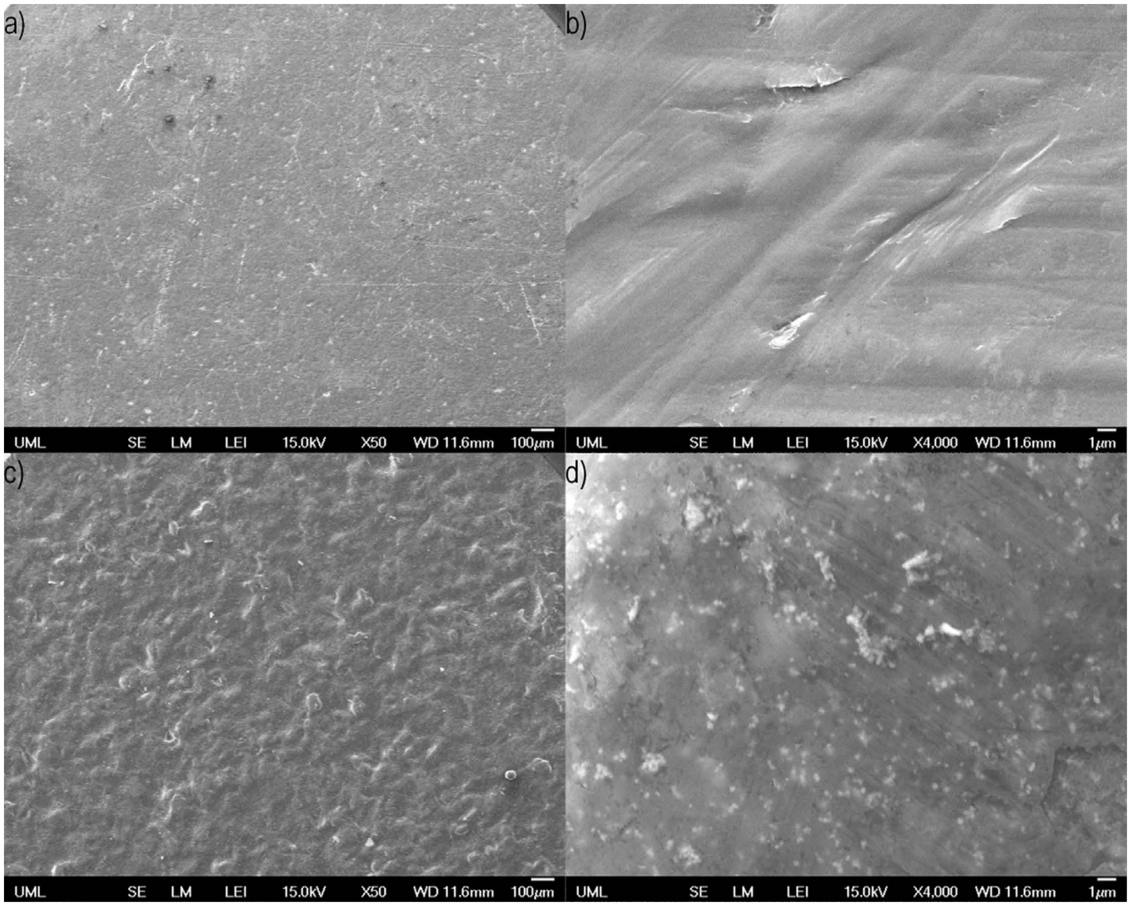

Fig. 1. SEM images of the surface of the coatings as received: (a and b) coating C1, (c and d) coating C2.

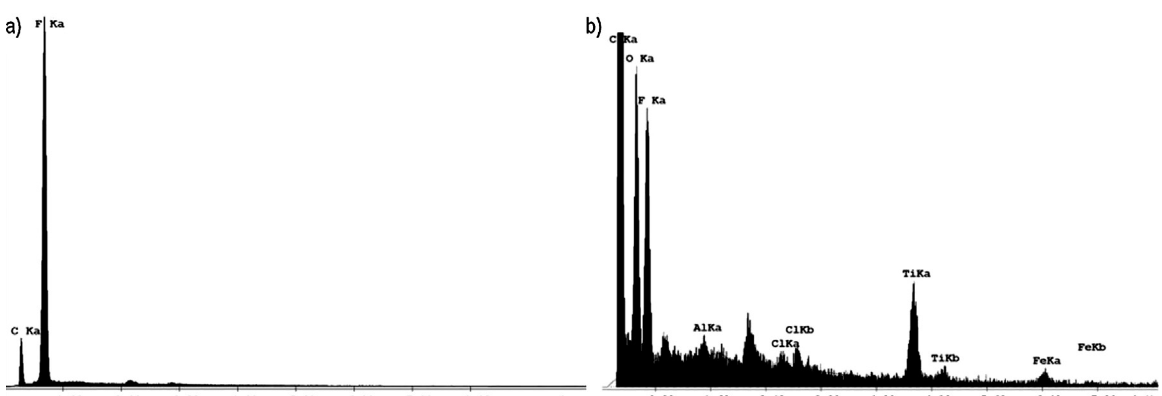

Fig. 2. EDS spectra of the surface of the coatings as received: (a) coating C1, (b) coating C2.

Fully fluorinated polymers (FPs) are currently used in many high-tech fields of industry, such as aeronautics, microelectronics, engineering, chemical, and automotive industries, optics, textile finishing, and military use [10]. Brady [11,12] used FP based formulations with CF_3 terminated perfluoroalkyl groups on the surface as foul-release coatings and showed that these coatings provided adequate corrosion protection in the marine environment. Asahi Glass Co. has developed and commercialized FP resins, known as fluoroethylene vinyl ether (FEVE) as topcoats for bridges [13,14]. These formulations have excellent durability, weatherability and corrosion resistance. The high resistance to a wide range of chemicals, high thermal stability, high abrasion resistance, flexibility, and low surface energy make FP coatings promising candidates for anticorrosion coatings in the petroleum industry [3]. However, the low surface energy of FPs, while desirable in terms of preventing fouling or chemical deposition on the inside of the pipeline, can adversely affect adhesion to the substrate. McKeen et al. [3,4] evaluated FP coatings for applications in the oilfield using autoclave tests at high temperature and high pressure in sweet and sour environments. The coatings passed the experiments successfully, and no inorganic deposition or scaling was observed [4,15].

In the present work, we studied the properties of a perfluoroalkoxy (PFA) fluoropolymer and a hybrid epoxy/FP resin in corrosive media typically encountered in oil-gas pipelines. These coatings were not specifically developed for the oil industry; however, because of their chemical structure and the high fluorine