Development of a coating system for high temperature corrosion protection

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Abstract, Corrosion protection is one of the important performance properties of organic coatings. In this study, an attempt has been made to develop a high temperature coating. Different compositions of silicone and polyester resins are taken and mixed well with the addition of a hardener. The binder system is applied on the pre-treated cold rolled steel panels. Physical and mechanical properties are evaluated. Thermal resistance of the coating system is done according to specification of ASTM D2485 standards. DSC and TGA analyses are carried out to study the glass transition temperature and temperature dependence of the sample prepared respectively. Corrosion protection ability of the system is evaluated by electrochemical impedance spectroscopy (EIS) and immersion studies. From the thermal studies, the coating containing 40% silicone and 60% polyester has withstood up to 498 K.

Introduction
Corrosion can be defined as the deterioration or the destruction and loss of material due to chemical attack. Different forms of corrosion can form on steel, and they differ in the size, nature, environment and effect [1]. High temperature corrosion is caused by the direct reaction of exposed metals to oxidising agents at elevated temperatures. Corrosion protection can take place through corrosion resistant coatings, alloying, cathodic protection and use of inhibitors. Corrosion protection is one of the important performance properties of organic coatings [2, 3]. The main function of a coating is to isolate, separate and protect the metal from an aggressive medium. Organic coatings the most popular form of corrosion protection compared to the other means because of the low cost, ease of application and suitability to various environments.
Various types of organic resins such as acrylic [4], alkyd [5], epoxy [6], polyurethane [7] polyester [8] and silicone [9] have been used for coating purposes in the past few decades. Among these, silicone resins have good resistance for corrosion in all kind of environments and better thermal stability owing to their exclusive organic – inorganic hybrid molecular formation [6]. Polyester resins have higher tensile and flexural strengths and can be cross-linked using different cross linking agents, become quite resistant to softening and deformation at high temperatures. So, polyester resin is selected, in this research, to develop a binder for the development of a coating system for high temperature atmosphere. From the binder system formulated in this study, a detailed analysis which required a perfect coating system for the better protection of corrosion in all kinds of adverse environments has been done.

Experimental
Different compositions of silicone and polyester resins (varying from 20% to 80% and vice versa) were mixed with the addition of a hardener and coated on the degreased steel panels of 5cm x 7cm in size. The mechanical properties were measured such as impact resistance was measured by tubular impact resistance tester, in which a known weight of a tub is allowed to fall over the coated specimen from different heights. Thermo gravimetric analysis (TGA) was done to study the dependency of degradation in terms of weight change as a function of temperature. The glass transition temperature was determined in order to study the cross linking between the polymer
resins and curing kinetics. Coating deterioration was evaluated by Electrochemical Impedance Spectroscopy (EIS)[10]. The details of the method have been explained elsewhere [11, 12]. The test panels were exposed to 3% NaCl solution and impedance measurements were carried out for 30 days at regular intervals. Heat resistance property studies of the coating system were carried out as per ASTM D2485 standards [6]. The panels were also kept in a furnace and heated to different temperatures for 24 hours and allowed to cool at room temperature. They were tested to verify for the occurrence of cracks, chalking and colour changes.

**Results and Discussions**

The samples were prepared by varying the compositions of silicone and polyester resins where transparent coatings were obtained. Initial increase in the concentration of silicone in the polyester matrix improved the film property and made the coating harder, and further increases in the concentration above 60% could make the coating much harder. It was very hard to coat or highly brittle coatings were obtained for 100% silicone. The addition of polyester resin enhanced the formation of thin film. This may be due to the hydroxyl end groups of the polyester that contribute to the network formation [8]. The adhesion of the binder on the solid surface was tested by cross hatch method. The adhesion can be related to the roughness and hardness of the coating. This may be attributed to the formation of cross linking network between the resins and resulted to a good adhesion in the interface of the solid surface [13]. All the specimens prepared in the study had good adhesion properties. The coating contains contained high silicone resin showed little peel off from the substrate. The coating failure was evaluated using impact resistance test and presented in terms of impact energy. The maximum impact resistance had been offered by the coating materials containing silicone 50% and 40%. Fig. 1 shows the variation in the impact energy levels at which the coating starts to deform, or crack. It is noticed from the graph that both sides of the peak performance bars decrease for a smaller extent. The left side may be due to the more flexibility offered by polyester resin. The composition that is more than 60% silicone developed some small cracks on the surface. From the cross hatch test and impact test, it is observed that the coatings have good attraction between molecules as well as with the substrate. This may be due to the fact that the network density would have increased, and hence, leads to a beginning in the increase in the brittleness.

![Fig. 1: Effect of Silicone Concentration on Impact Resistance](image)

The samples were heated in a furnace at different high temperatures. The maximum temperature that the coating could withstand was found by identifying cracks, chalking and colour changes. The coating consists of 40 % silicone and 60 % polyester could withstand temperatures up to 498 K. The effect of silicone composition on the ability to withstand for higher temperature is shown in Fig. 2. This high temperature withstand have been achieved due to the formation of a stronger
network between the molecules by cross-linking [6]. The samples tested in different corrosive atmosphere have showed good resistance to corrosion in 3% NaCl, 3% KCl and diluted HCl solutions for 30 days.

![Fig. 2: Effect of Silicone on Heat Resistance](image1)

Electrochemical impedance spectroscopy (EIS) studies were carried out by immersing the samples in 3% NaCl solution. Fig. 3 shows the changes in resistance with time for different compositions. Resistance remains constant for the first 5 days of immersion. This is because the coating film does not allow water molecules to enter or penetrate the substrate. Once the ions begin entering resistance will decrease. It is bad if the coating contains pores. The quality of the coating must be examined before the test. The number and the size of pores increase which lead to further decrease in resistance. During the 30 days of immersion, the values of coating resistance are in the range of $10^9$ - $10^7$ (ohm) which is the range for a high performing coating system [7, 15].

![Fig. 3: Variation of Corrosion Resistance with Time](image2)

The glass transition temperature ($T_g$) of the coatings was determined using DSC for all the samples prepared. $T_g$ increases with increasing silicon content. The increase in hardness and $T_g$ for the polyester – silicone system can be explained by increasing network density, caused by silica cluster formation around the end groups of the polyesters [8]. In the combination of polyester and silicone resin a Si – O – C bond could be formed by a condensation reaction [9, 16]. When the silicone concentration increases in the polyester matrix, the silica concentration increases, which in turn increases the $T_g$. This cross-linking network is highly achieved by the addition of the hardener. From the thermo gravimetric analysis, it is observed that the degradation of the polyester matrix has
been delayed by the addition of silicone resin. This confirms that occurrence of cross-linking reaction between the polymer matrices [4].

Conclusions

In this current study, the silicone – polyester hybrid systems were formulated with varying compositions to find out an optimum composition for high temperature applications. For the purpose of this study different types of physical, mechanical, thermal and electrochemical studies were done. From this work it shows that coating mixture of 40% silicone and 60% polyester is the best performing composition to produce high performance coating. The coating formulated by this composition possesses good adhesion properties, high impact resistance, and high coating resistance and can withstand high temperatures up to 498 K.

Reference