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An Experimental Study On The Bond Strength Between Reinforcement Bars And Concrete As A Function Of Silan And Siloxane Basedcoating And Corrosion Level

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ABSTRACT:*Studies have been carried out to investigate the performance of silane-siloxane based hydrophobic emulsioncoating (SS)on reinforcement corrosion and bond strength. The SS is an emulsion which is silane / siloxane combination based.The coated and uncoated concrete specimens were subjected to accelerated corrosion to determine the time-to- corrosion initiation.The accelerated corrosion test results clearly showed that the specimens coated withSS performed very well against reinforcement corrosion and better than uncoated specimens.Pull out test results showed that the positive effects of SS coating on the bond strength are negligible according to uncoated specimens before accelerated corrosiontest.On the other hand, the experimental results indicated that the coated specimens exhibit higher bond strength as compared to uncoated specimens after accelerated corrosion test.*

KEYWORDS:*Corrosion,steel, coating,chloride, concrete, reinforcement.*

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I INTRODUCTION

Concrete structures in environments with adverse geomorphic and climatic conditions such as severe ground and ambient salinity and high temperature-humidity regimes are prone to early deterioration. Such aggressive environments induce several deterioration problems, and the most frequent and damaging one is the corrosion of reinforcing steel, which causes early deterioration of concrete structures. [1].

During the long term service life of RC structures the deterioration of bond often takes place. Due to the chloride contamination or carbonation the steel bar embedded in the concretecan corrode. The corrosion products have higher volume than the steel and can cause damage of concrete cover and influence bond properties. When the steel bar is only slightly corroded the bond property is improved, however, once the concrete cover is cracked due to the expansive corrosion products, the bond properties become seriously deteriorated [2].

Several measures have been tried to combat this problem and extend the service life of concrete structures. One such measure is the application of a waterproofing coating on the external surface of concrete structure. The main function of a waterproofing system is to prohibit water and any soluble salts from penetrating the concrete to cause corrosion, leaking, and other problems. In addition, waterproofing materials can be very effective in minimizing the rate of corrosion once it has initiated by preventing access of moisture and oxygen to the steel surface [1].

Silane and siloxane sealers are silica-based materials that function as hydrophobic agents. Silane and siloxane sealers do not block the pores of the concrete like most oil based sealers, but react chemically with the concrete surface to form a hydrophobic layer under the surface that repels water and chloride ions while allowing water vapor to pass through [3].

The advantage of silane and siloxane sealers is that they are easy to apply, can be applied to any part of a structure, and can be applied at any time, during or after construction [3].

The study conducted by Tittarelli and Moriconi, sound or deliberately pre-cracked concrete specimens, with 0.5 or 1 mm wide crack, were manufacturedwith water to cement ratios (w/c) of 0.45 and 0.75, both in the presence and in the absence of a silaneadmixture. The specimens were exposed to wet–dry cycles in a 10% NaCl aqueous solution. The results,in terms of electrochemical measurements, and visual and metallographic observations carried out on thegalvanized steel reinforcement removed from the specimens, showed that the hydrophobic concrete isable to protect galvanized steel reinforcement from corrosion even in the presence of cracks in the concretecover, especially when a high w/c is used[4].

The study conducted by Tittarelli and Moriconi, the influence of a hydrophobic admixture based on silane on the corrosion resistance of steel reinforcementin concrete was studied. Sound or deliberately pre-cracked concrete specimens were manufactured with w/cof 0.45 and 0.80, both in the presence and in the absence of silane. The specimens were fully immersed in a3.5% NaCl aqueous solution. The results, in terms of electrochemical measurements, visual observations, and weight loss measurementsof steel reinforcement, show that silane blocked corrosion process in uncracked concrete specimens[5].

The study conducted by Yalçıner,Eren and Şensoy,on the bond strength between reinforcement bars and concrete as a function of concrete cover, strength and corrosion level was studied. An accelerated corrosion method was used to corrode the reinforcement bars embedded in concrete specimens. Pullout tests were performed to develop an empirical model for the ultimate bond strength by evaluating bond strengths in two different concrete mixes, three concrete cover depths and different mass losses of reinforcement bars after corrosion. Bond-slip relationships for the different corrosion levels were compared. It was found that the relationship between bond strength and concrete strength in uncorroded specimens differed from that of corroded specimens set in high-strength concrete because of brittleness in the corroded specimens, which caused a sudden loss of bond strength. The results revealed that specimens with higher concrete strength levels and corroded reinforcements showed a higher percentage of bond strength degradation due to concrete cracking during the pullout tests[6].

An experimental investigation was conducted by Wu, Lv, Zhou and Fang to explore the degradation model of bond stress between concrete and deformed steel bars with four different diameters (12,16,20 and 25 mm) to determine the couplingeffects onthe bondbetweendeterioratedconcrete andcorroded steelbars. Theresultsindicated that the failure mode of the specimens was primarily splitting failure; however, the marks of the steel bars at the interface between the deteriorated concrete and corroded steel bars became unclear as the corrosion ratio increased. The ultimate bond strength of the two specimens with the smaller diameters increased withdeterioration before acrack appearedand thenitdecreased, whereasthatof thetwo specimens with the larger diameters continuously decreased due to smaller protective concrete thickness [7].

The bond tests were carried out on 18 beam specimensby Lin and Zhao to investigate the bond behavior between concrete and corroded steel bars, with corrosion and stirrups being the principal parameters. Through systematical analysis of the test results and extensive test data from the literature, the confinements were found to have significant influence on the bond strength. Considering the effects of concrete cover, stirrups and corrosion current density, empirical model for the degradation of bond strength was established[8].

In this study, the formation of corrosion in concrete structures and the results of a study concerning withthe corrosion and bond strength behavior of reinforced concrete in presenceof silane - siloxane based hydrophobic emulsion coating in chlorinated environment have been described.

II EXPERIMENTAL PROCEDURES

The reinforced concrete specimens were used to evaluate the effectiveness of coating materials were 70x140 mm concretecylinders in which a 10mm diameter steel bar was centrallyembedded.

Theselected reinforcing steel was a 10 mm-diameter ribbed barand complied with TS 708. TS EN 197-1 CEM I 42.5 R Portland cement, manufactured by Aslan (OYAK) Cement Manufacturing Co. was used in all reinforced concrete specimens. The concrete cover was 30 mm.The concrete mixtures were proportioned for an effectivewater to cement ratio of 0.80.Themixture proportion of concrete is given below in Table 1.Compressive and tensile strength at 28 days were measured by 150 mm-cubic samples. Strength measurements are given in Table 2.

Table1. Mixture Proportion of Concrete in kg/m^3

Materials	kg/m^3	Tolerances(± %3)	
		Max.	Min.
CEM I 42.5 R	300	309	291
Coarse aggregate	806	827	779
Fine aggregate (0-4 mm)	432	445	419
Stone Powder	525	541	509
Water	263	271	255
Total	2323	2392	2253

Table 2. Compressive and tensile strength at 28 days (MPa)

Compressivestrength	28,5
Tensile strength	2,9

After 24 h of setting, the samples were removed fromthe molds and air cured underlaboratory conditions at 23 ± 2 ºC temperature for 28 days.In this study, the following coating materials were examined.Silane-siloxane based hydrophobic emulsioncoating (SS): SS is a coating material,silane - siloxane combination based. It has strong water repellent capability. SS was applied on the concretespecimens according to the suppliers' recommendations as 200 gr/m^2 by brush.Two groups of concrete specimens were prepared.Concrete specimens are given below in Fig 1.First group consists of uncoated control concrete specimens andthe other group represent concrete specimenscoated with the selected coating material described above after air cured for 28 days.

Fig. 1. Lollipop Cylindrical Samples

At the end of the curing period, each concrete test specimenwas partially immersed in 50 gr Cl- / liter NaCl solution and subjected to acceleratedcorrosion in a sodium chloride solution for 3 months.

The goal of concrete samples partially immersed is to provide needed moisture and agressive chloride ions for reinforcement steel corrosion.The purpose of accelerated corrosion test to determine the effectiveness of selected coating materials protecting steel against the entry of harmful ions.Corrosion current density measurements were made regularly for three months.

The corrosion rate(Ikor = $\mu A/cm^2$) of steel reinforcement embedded in concrete was measured GECOR 8 named device that could measure linear polarization method.

In order to determine the bond strength, as shown in Fig. 1,concrete cylinders with dimensions of 70 x 140 mm, in which a 10 mm diameter steel bar was centrally embedded were used.The ribbed steel is placed in the sample with a clamping length of 110 mm.

Pullout tests were performed for all specimens based on ASTM C234-91a. The bond tests were performed with an universal testing machine. The setup of the pullout testing system is shown in Fig.2.

Fig. 2. Setup of the pullout testing system.

None of the reinforcement bars reached the yield point during the pullout tests, and the maximum pullout forces were recorded to calculate the ultimate bond strength (τbu) according to Eq (1) :

$$\tau bu = \frac{Pmax}{\pi DL}(\text{MPa}) \qquad (1)$$

where Pmax is the ultimate pullout load and D and L are the diameter and bond length of the reinforcement bars, respectively.The diameter of the reinforcement bar is 10 mm and the total length is 200 mm and the length in the concrete is 110 mm.

III RESULTS AND DISCUSSION

Corrosion rates (Icorr = µA/cm^2) of steel reinforcement embedded in the concrete measured with the device GECOR 8 according to the ASTM G59 (2014) standard.Interpretation criteria of the LPR measurements are given in Table 3.

Table 3Interpretation Criteria of the LPR Measurements

Corrosion Current Density	Corrosion Level
Icor <0,1 µA/cm^2	Negligible
0,1 µA/cm^2<Icor< 0,5 µA/cm^2	Low to moderate corrosion
0,5 µA/cm^2<Icor< 1,0 µA/cm^2	Moderate to high corrosion
Icor> 1 µA/cm^2	High corrosion rate

Corrosion current density average values measured for concrete specimens coated with SSSilane - siloxanebased hydrophobic as 0.20 µA/cm^{2}at the end of ninetieth day.This average value is slightly exceeded the limit of passive corrosion and remains in the region showing the presence of very low reinforcement corrosion.
Besides several researchers have considered values of currentdensity greater than 0.3 µA/cm^{2}to be indicative of active.[9]

According to this result it couldn't detected a danger in terms of durability of SSSilane - siloxanebased hydrophobic coated reinforced concrete even if 90 days exposure to aggressive conditions.So this condition shows that SS coating can protectthe reinforced concrete against aggressive chloride ions and oxygen which penetrates the pores of the concrete and that is absolutely necessary for the formation of corrosion and water which acts as the electrolyte.Consequently this situation shows thatSS coating can protectthe reinforced concrete structure long term compared to control samples.

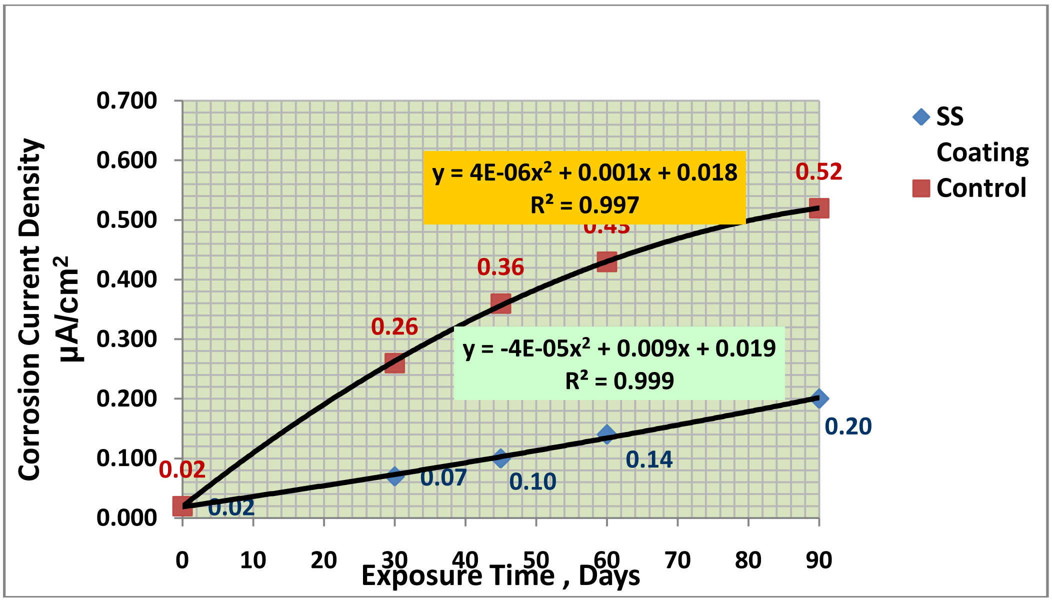

Fig. 3.SS Silane - siloxanebased hydrophobic coated samples and control samples corrosion current density -time curves

After 28 days curing, bond strengths of coated and uncoated samples were measuredand presented in Figure 4. The adherence strength of coated and uncoated specimens were measured as 5.30 MPa and 5.25 MPa, respectively.According to the results obtained, SS coating did not change the adherence strength of reinforced concrete specimens but it was found that this coating did not adversely affect to the adherence strength of reinforcement while acting as corrosion inhibitor.

After 28 days curing, bond strengths of coated and uncoated samples were measuredand presented in Figure 4. The adherence strength of coated and uncoated specimens were measured as 5.30 MPa and 5.25 MPa, respectively.

After 90 days of accelerated corrosion,bond strengths of coated and uncoated samples were measuredand presented in Figure 4. The adherence strength of coated and uncoated specimens were measured as 5.29 MPa and 4.03 MPa, respectively.

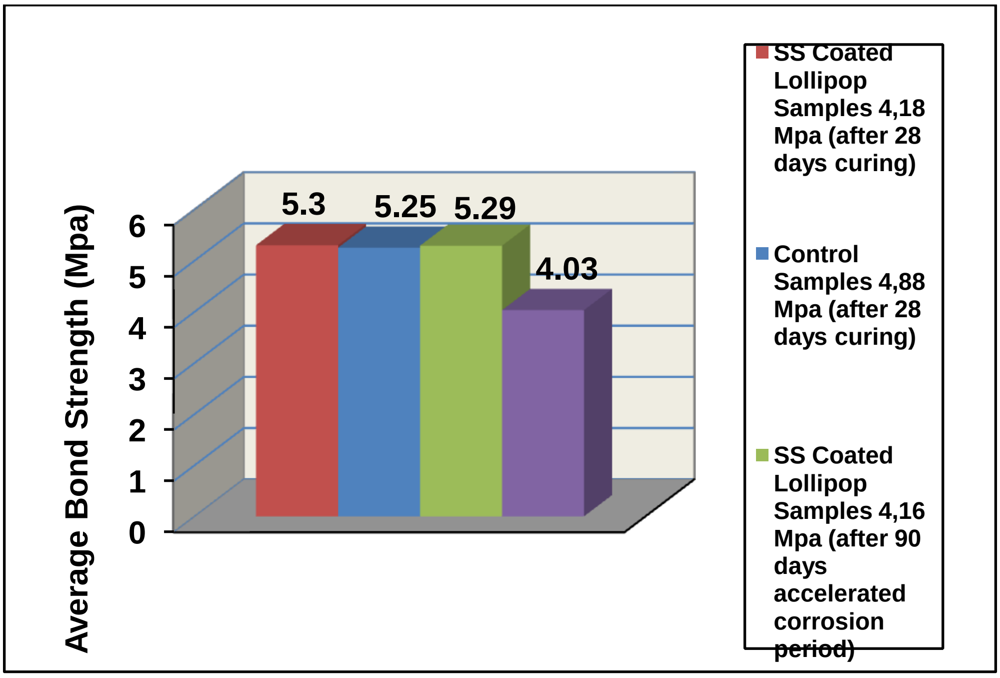

Fig. 4.Bond strength of Silane - siloxanebased hydrophobic coated samples and control samples

According to the results obtained, no significant change in adherence strength of the coated sample was observed at the end of 90 days accelerated corrosion.However, the adherence strength of uncoated samples decreased.

IV CONCLUSIONS

This investigation was conducted to assess the effectivenessof concrete exterior surface coating on bond strength between steel and concrete and in mitigating reinforcementcorrosion in the concrete specimens.Based on the resultsobtained within the time frame of this study, the followingconclusions can be drawn:

(1) SSSilane - siloxanebased hydrophobic exterior surface coating were effective in delaying the initiation of reinforcement corrosion.

(2) The Icorr data indicated that the steel bars in the concrete specimens incorporating Silane - siloxanebased hydrophobic coating investigated in this study were in a passive state, even after 90 days of exposure. However, corrosion activation was indicated on the steel bars in all the concrete specimens without coating after 45 days of exposure.

(3) According to calculated ultimate bond strength data, no significant change was observed in adherence strength of the coated sample at the end of 90 days accelerated corrosion. This confirms that the SS coating prevents the decrease in adherence strengthdue to corrosion layer formation. However, the adherence strength of uncoated samples decreased. It is expected that the bond strength between the concrete and the steel reinforcement is weakened due to the corrosion formation of the reinforcement detected in the corrosion current measurements.

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