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Review of Epoxy Coated Steel on Bond Strength of Concrete

Miss. Pooja V. Kalyani[1], Dr. Nandkumar K. Patil[2]

[1]P.G Scholar, S.S.D. G.C.T. Sanjay Ghodawat Group of Institutions, Atigre, Kolhapur, India
[2]Professor Dr. Dept. of Civil Engineering, S.S.D. G.C.T. Sanjay Ghodawat Group of Institutions, Atigre, Kolhapur, India

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Abstract – *Reinforced concrete is one of the most widely used construction materials in the world. It is a versatile and economical material that usually performs its intended use well over its service life. Reinforced concrete is used in numerous ways, some of the larger and better known uses including roadways, bridges, car parks, residential buildings and in industry. It is in general an outstanding construction material. Concrete alone is good in compression, but reinforced concrete greatly increases the scope for making structures required to withstand other forms of mechanical force. The coating, however, causes a decrease in bond strength between reinforcing bars and concrete. The main objective of this study was to study the bond strength of epoxy coated reinforcement and equivalent uncoated bars. The effectiveness of bond strength between reinforcing steel and concrete is the most important requirement of reinforced concrete as composite building material. The Present investigation, bond strength of the epoxy coated grey colour, green colour and uncoated steel bar with concrete was studied.*

1. INTRODUCTION

Epoxy coatings are used to increase the corrosion resistance of steel reinforcement used in reinforced concrete construction. The coating can bse applied either before or after the reinforcement is fabricated. In the former method, the epoxy coating is applied to straight reinforcing bars, which subsequently are bent (fabricated) into required shapes. Bars prepared using this procedure commonly is known as “green epoxy-coated bars” because of the green colour of the epoxy that is used. Sometimes the fabrication process can cause damage to the green epoxy coating, leading to reduced corrosion resistance. Prefabricated epoxy-coated reinforcement (typically either purple epoxy-coated or gray epoxy-coated) has been developed to reduce potential damage to the protective coating. The reinforcement is first fabricated into required shapes, and then it is hung from a conveyor system and moved through the coating process. The epoxy coating for prefabricated epoxy-coated reinforcement can be more rigid, as specifications do not permit bending the reinforcement after coating. Although excellent quality control in epoxy coating thickness is possible with either method, it is more difficult to control coating thickness for prefabricated reinforcement than it is for green epoxy-coated reinforcement.

Corrosion of steel reinforcement occurs gradually in RC structures exposed to marine environments or de-icing condition. As a result, the cross-sectional area reduction of the steel reinforcement occurs and the strength of the steel-concrete interface is influenced. Moreover, the volumetric expansion of the corrosion products generates additional stress in the concrete, and finally causes the cracking and even spalling of the concrete cover, inducing the loss of bond performance of the steel reinforcement in the corroded RC structures

2. LITERATURE REVIEW

2.1. Akram Jawdhari, Amir Fam and Issam Harik, "Bond Between CFRP Rod Panels And Concrete Using Cementitious Mortar" Construction and Building Materials Vol No - 235, 2020.

Carbon-FRP rod panels (CRPs), generated from small diameter rods mounted on a fiberglass mesh, are becoming a viable retrofit option. The gaps between rods enable full encapsulation by adhesive, thereby enhancing bond to existing concrete members, compared to flat plates. Existing studies focused on epoxy adhesive. In this study, 44 notched-beam bond tests, were carried out to investigate the efficiency of cementations mortar in bonding CRP to concrete and to examine the effects of a number of material and geometric parameters, comparing CRP to flat plates and mortar to epoxy. Results show that the mortar be able to achieve a comparable ultimate load (Pult.), 86% that of epoxy, and a much more ductile failure by gradual rod slippage from the mortar. Compared to an equivalent CFRP plate, Pult. of CRP was 1.17 and 7 times, respectively, for epoxy and cementations mortar. Brittle debonding failure dominated in CRP with epoxy and in CFRP plate with both epoxy and mortar. Pult was found to vary linearly with the bond length of CRP, up to a development length of 125 mm. A value of 460 kN/m can be assumed for bond strength. Rod axial stress (rf) increased by 42%, when CRP panel-to-concrete width (bf /bc) ratio increased from 0.25 to 0.5; decreased linearly by 13% when rod spacing-to-diameter (S/D) ratio increased from 3 to 8; decreased by 76% when rod diameter D increased from 2 to 4 mm. Sand coating the smooth rod resulted in a 45% increase in rf of the 4 mm rods but not the 2 mm rods, although failure shifted from gradual slippage to sudden debonding.

2.2. Jinfeng Chia, Guoliang Zhang, Qingyi Xie, Chunfeng Ma and Guangzhao Zhang, "High Performance Epoxy Coating with Cross-Linkable Solvent via Diels-Alder Reaction for Anti-Corrosion of Concrete" Progress in Organic Coatings, Pp. No - 139, 2020.

Protective coatings are effective to prevent concrete from corrosion and improve its durability. In this study, we report a novel epoxy coating with cross-linkable solvent via Diels-Alder reaction. Such a coating has a low viscosity so it can permeate into the pores or defects of concrete up to 1.5 mm, whereas the solvents cross-link with epoxy resin in-situ at higher temperature, forming a robust root-like coating/concrete composite. The concrete is significantly reinforced in the mechanical strength and corrosion resistance. Moreover, the crosslink able solvents allow the coating to have a low content of volatile organic compound (VOC) (< 2 wt%) so it exhibits less negative impact on environment. The high performance coating can find applications in protection of concrete.

2.3. **Jaesung Lee, Evan Sheesley, Yuxiang Jing, Yunping Xi And Kaspar Willam, "The Effect Of Heating and cooling on the Bond Strength Between Concrete and Steel Reinforcement Bars With and Without Epoxy Coating" Construction and Building Materials, Vol - 177, Pp. No - 230–236, 2018.**

The purpose of this study is to investigate the temperature effects on the bond strength between concrete and steel reinforcement bars. For two different steel bars (epoxy-coated and uncoated bars), three experimental parameters (heating rate, target temperature, and cooling condition) are examined. At a target temperature of 200 _C, the epoxy-coated rebar has much higher bond strength than the uncoated rebar. However, in the specimens exposed to target temperatures higher than 200o C, the test results show that the epoxy coated rebar has less bond strength than the uncoated rebar. Also, the test results demonstrated that as the heating rate and target temperature increase the bond strength decreases. The cooling method does not affect the ultimate bond stress of the specimens using uncoated rebar very much but can greatly affect specimens that contained epoxy coated rebar. A more in-depth study can be considered regarding the cooling effect on the bond strength.

2.4. Wenjun Zhu, Jian-Guo Dai and Chi-Sun Poon, "Prediction of the Bond Strength between Non-Uniformly Corroded Steel Reinforcement and Deteriorated Concrete" Construction and Building Materials Vol. No - 187, Pp. No - 1267–1276, 2018.

This paper investigates the influence of non-uniform corrosion on the bond strength of the steel reinforcement in concrete. To achieve the non-uniform corrosion, partial surface of the steel reinforcement was coated by an epoxy resin which could prevent effectively that part of steel from corrosion. Thus, corrosion only happened to the bare (un-protected) zone of the surface. A series of reinforced concrete (RC) specimens were cast and stored in a chloride environment. An impressed current was applied to accelerate the corrosion of the steel reinforcement. Pull-out tests were conducted on the specimens with different corrosion degrees. The experimental results show that the bond strength was higher than that of the control (non-corroded bar) when the corrosion degree was smaller than 0.8% and was the highest (1.6 times of the control) when the corrosion degree was about 0.2%. The bond strength started to decrease significantly with further increases in corrosion degree. By considering the corrosion of the steel reinforcement and the pressure induced by the expansion of the corrosion products, analytical models were proposed to predict the bond degradation due to pitting corrosion and uniform corrosion. The models were also validated by the test results from existing literature.

2.5. Zhidong Zhou and Pizhong Qiao, "Bond Behavior of Epoxy-Coated Rebar in Ultra-High Performance Concrete" Construction and Building Materials, Vol No - 182, Pp. No - 406–417, 2018.

The bond behavior of epoxy-coated rebar embedded in two different ultra-high performance concrete (UHPC) mixtures is experimentally investigated by a uniaxial pullout test, and the effect of embedment length, side cover, and mixture type on the bond stress-slip relationship is predicted using a double phase analytical model. The bond mechanism and failure modes of rebar in UHPC are similar to those observed in normal concrete. The embedment length and side cover have significant influence on the bond behavior of epoxy-coated rebar in UHPC, and more drastic bond stress hardening and softening are observed for the case of larger embedment length and side cover. Two UHPC mixtures exhibit comparable bond strength and critical development length because they have close mechanical properties gained at test age. The adopted analytical model matches well with the experimental bond-slip response of epoxy-coated rebar in UHPC, and both the characteristic parameters in the model show an increasing trend when more dramatic hardening and softening of bond stress exhibit.

2.6. Jaesung Lee, Evan Sheesley, Yunping Xi and Kaspar Wilam, "Bond Strength of Steel Bars in Concrete under High Temperatures" Fire and Structural Engineering, Pp. No - 11-15 June 2017.

This work investigated the temperature effects on bond strength between steel reinforcement (rebar) and concrete. Two different steel bars with epoxy coating and without coating were experimentally studied under different high temperature conditions (heating rates and target temperatures). The results showed that at 200º C, epoxy coated rebars have higher bond strength than that of uncoated bars; however, with the temperature higher than 200º C, the reduction of bond strength of epoxy coated rebars is higher than that of uncoated rebars.

2.7. K B Osifala, M A Salau and T H Obiyomi, "Effect of Waste Steel Shavings on Bond Strength between Concrete and Steel Reinforcement" IOP Conf. Series: Materials Science and Engineering Vol - 251, 2017.

The investigation was carried out to know the effect of waste steel shavings on the bond resistance between concrete and steel reinforcement using 16mm and 20mm diameter high-yield reinforcing bars. Eighty (80) RILEM specimens, made up of forty (40) cubes each of 160mm x 160mm x 160mm and 200mm x 200mm x 200mm were cast and tested with varying percentages of waste steel shavings, (0%, 1%, 1.5%, and 2%, by weight of concrete) using pull out arrangement. The normal concrete (with no steel shavings) which are ten (10) in number were used as reference. Also, twelve (12) 150mm concrete cubes were cast to monitor the compressive strength of concrete. The results showed that bond strength increased with the addition of 2%, (by weight of concrete), of waste steel shavings.

2.8. Joseph J. Assaad, Camille A. Issa, "Bond Strength of Epoxy-Coated Bars in Underwater Concrete" Construction and Building Materials, Vol. No - 30, Pp. No - 667–674, 2012.

A comprehensive research project was approved out to assess the effect of washout loss on bond between underwater concrete (UWC) and epoxy-coated reinforcing steel. Washout loss of investigated mixtures was evaluated using the CRD C61 test method. The compressive and bond strengths of UWC were determined using the same concrete samples that were used for washout loss dimension. Test results showed that the ultimate bond strengths of epoxy-coated bars embedded in UWC are affected by the level of washout loss. Compared to reference concrete sampled in dry condition, a decrease in bond varying from 15% to 25% was measured for UWC possessing washout loss in the range of 8% ± 3%. The bond stress vs. slip behavior of epoxy-coated bars is remarkably different than the one obtained using reference concrete. Mixtures subjected to some washout exhibited less stiffness together with a decrease in the ultimate bond strength and shifting of the slip towards lower values.

2.9. Can Chul Choi, Hossain Hadje-Ghaffari, David Darwin, and Steven L. Mccabe, "Bond of Epoxy-Coated Reinforcement: Bar Parameters" ACI Materials Journal, 1991.

The effects of coating thickness, deformation pattern, and bar size on the reduction in bond strength between reinforcing bars and concrete caused by epoxy coating are described. Tests include beam-end and splice specimens containing No.5, 6, 8, and 11 bars with standard coating thicknesses ranging from 3 to 17 mils (0.08 to 0.43 mm). Three deformation patterns are evaluated. All bars are bottom cast. Beam-end specimens have covers of two bar diameters, while splice specimens have covers that depend on bar size and are less than 2 bar diameters.

2.10. Lawrence H. Taber, Abdeldjelil Belarbi and David N. Richardson, "Effect of Reinforcing Bar Contamination on Steel-Concrete Bond During Concrete Construction"

During concrete construction, form oil, bond breaker, concrete splatter and other types of contaminants often contaminate reinforcement. Current specifications and quality control measures require the elimination and clean up of these contaminants before the placement of concrete due to a concern of a reduction in bonding capacity. This is costly, labor intensive, and may not be necessary. Currently, there is limited research on the effect of reinforcing bar contamination on the bond between the deformed steel reinforcing bar and concrete. Because of this lack of data, specifications are traditional and require the removal of the contaminant. Inspectors often cite ACI 301-96, Standard Specifications for Structural Concrete, which states, "When concrete is placed, all reinforcement shall be free of materials deleterious to bond." If it could be conclusively proven that this level of care is unnecessary, the construction industry would benefit greatly.

3. CONCLUSIONS

The structural behavior of reinforced concrete elements is significantly affected by the bond properties of the reinforcement. The bond properties are again directly related to the loading condition of the structural elements. Several parameters of the experiment were chosen in the present study, Experimental tests and finite element analyses conducted in this research program highlighted the effects of natural corrosion, confinement and repeated loading on bond strength between steel rebar and concrete. Different bond strength curves were observed from experimental tests. In some cases the presence of an effective confinement prevented the formation of splitting cracks and high peak values of bond stress were achieved. In other cases a marked deterioration of the concrete cover and considerable levels of longitudinal bar corrosion caused a sudden loss of bond strength and premature bond failure. The steel bar yielding was prevented and lower values of the slip corresponding to the peak bond stress were registered. Finite element models were developed on the basis of the results of the laboratory tests and parametric analyses were carried out to provide a better understanding of the experimental findings.

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