EXPERIMENTAL STUDY ON THE INFLUENCE OF CORROSION INHIBITOR ON BOND STRENGTH DEVELOPMENT BETWEEN STEEL AND CONCRETE

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ABSTRACT: **Bond strength is one among the important property of hardened concrete. Bond between the reinforcement and concrete influences the behavior of structural concrete in many respects. The quality and quantity of ingredients used for making the concrete affect the bond strength of concrete. The addition of mineral admixtures like fly ash, silica fume, rice husk ash etc. into the cement by means of replacing the cement content is nowadays considering as an important matter for protecting the environment against any hazardous situations and also recycling the waste by-products into an effective manner. But, the addition of mineral admixtures affects the structural system of cement and also in concrete. It also leads to the variations in the properties of concrete both fresh and hardened state. With these in mind, the bond strength variations of ternary blended concrete were examined in this experimental investigation and compared with the normal strength concrete. The class F type Fly Ash (FA) was used for making the binary blended concrete. In addition to that Silica Fume (SF) and Rice Husk Ash were (RHA) considered for developing the ternary blended concrete.**

I.INTRODUCTION

1.1 General

Reinforced concrete is one of the most widely used construction materials in the world. It is a versatile and economical material that generally performs its intended use well over its service life. Concrete is a construction material that is relatively easy to work with. But, it is weak in tension and this necessitates reinforcing steel bars in regions of tension in a concrete member. The combination of concrete and steel provides a relatively inexpensive and durable material that has become widely used in the construction of high-rise buildings, water tanks and bridges.

Concrete is a highly alkaline material that can easily deteriorate in acidic environments; most important and costly deterioration mechanism affecting the reinforced concrete structures is the corrosion of steel reinforcement. In good quality concrete, reinforcement steel is unlikely to corrode even if sufficient moisture and oxygen are available due to formation of a protective oxide film (passive film) in the highly alkaline environment. However, this passive film can be disrupted and corrosion initiated by carbonation, i.e., due to the penetration of carbon dioxide into the concrete, which lowers the alkalinity of the environment or by the presence of high concentrations of aggressive ions, mainly chlorides.

1.2 BOND BETWEEN REINFORCEMENT AND CONCRETE

Development of appreciable bond strength between steel and surrounding concrete is vital for effective performance of RCC structures. Bond strength is dependent on chemical adhesion along the peripheral surface of the rebar, bearing action of concrete against deformations of rebar and frictional resistance offered by concrete. In delayed construction projects, rust formation due to corrosion on the rebars that are kept exposed to atmosphere over a long period poses potential threat as rust affects the development of bond between steel and concrete.

Steel-reinforced concrete is a widely used structural material. The effectiveness of the steel reinforcement depends on the bond between the steel reinforcing bar (rebar) and the concrete. The basic concept of reinforced concrete is to take advantage of its constituents: i.e., the compression resistance from concrete and the tension resistance from reinforcing bars. The bond between reinforcement and concrete may be idealized as a shear force along the surface of reinforcement. The usefulness of reinforced concrete as a structural material depends on the strength and permanency of the bond between the concrete and the reinforcing metal, and for this reason bond resistance has received much attention from engineers and experimenters.

Bonding is essential for “reinforced concrete” it can directly influence the overall structural behaviour. Bonding between concrete and steel bars is primarily through adhesion. It is a physical phenomenon and absolutely no chemical reaction takes place between two materials. This bonding, however, is at the core of physical interaction between the two materials in so far as the strain and stress transfer is concerned. The adhesive strength gets affected with change of temperature as steel and concrete have slightly different coefficients of expansion. As a result, the two materials undergo relative displacements with the fluctuation in temperature.

At higher temperature the relative displacements may result in loss of physical bonding, thereby making the materials behave independently and hence the composite action of steel and concrete getting lost forever.

Bond studies have been actively conducted since the introduction of reinforced concrete into civil engineering. Many researchers have brought up various formulae to estimate the bond strength of deformed steel reinforcement. Bonding is determined by its constituents (concrete and reinforcement) and the interaction between them. Three primary mechanisms determine bond behaviour: chemical adhesion, mechanical interlock and friction resistance. Each component contributes to the overall bond performance in varying degrees depending on the type of reinforcing bar. The chemical bond can be lost at a very small slip between reinforcing bar and concrete. In the case of deformed reinforcement, the chemical bond can be broken at an even earlier stage: internal cracks (crack unnoticeable at the concrete surface) are apt to be created at very low load levels; the chemical adhesion has been lost at these portions. Typical bond mechanisms for deformed reinforcing bars at/near the ultimate are shown in Fig. 1.1

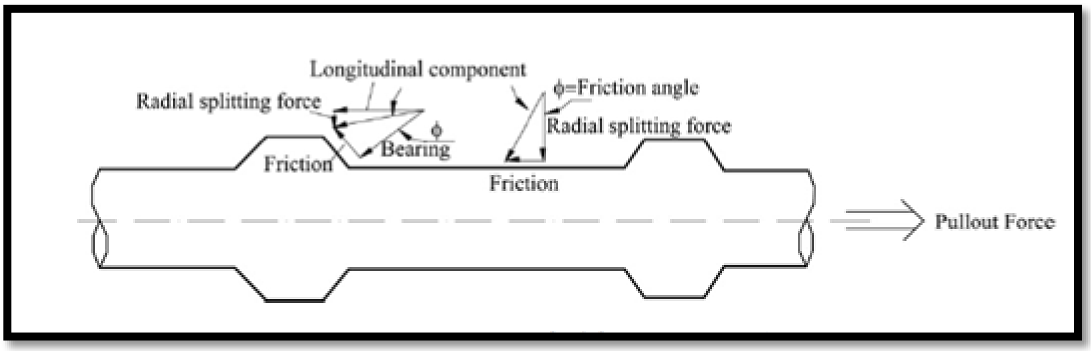


Fig. 1.1 Bond mechanism for deformed reinforcing bars

II. LITRATURE REVIEW

The research work carried out for the past twenty years on development of bond strength between steel and concrete is reviewed in this chapter. The literature pertaining to bond strength performance of uncoated rebar, rusted rebar and coated rebar with different rebar surface configurations, in control and inhibitor admixed concrete, carried out by the earlier researchers is presented in this chapter.

Kayyali and Yeomans (1995) evaluated the bond and slip of coated reinforcement in concrete. Galvanized, black and epoxy-coated rebar were embedded in reinforced concrete beams of size 1500 × 160 × 320 mm. The specimens were subjected to flexure test such that pure flexure occurred within the middle third of the beam. The test results revealed that ultimate capacity in flexure of beams reinforced with ribbed, galvanized or epoxy- coated bars was not statistically different to that of black steel reinforced beams. The results from load-slip measurements were indicative of the variation in bond for the different bar coatings. It was found that loads at a slip of 0.05mm was close to the ultimate load and accordingly loads at lower slip levels such as 0.01 mm and 0.02 mm were considered for analysis. The mean critical load at these slips values for the ribbed galvanized bars was not statistically different from black steel. But for epoxy-coated ribbed bars about 20% reduction in load was observed. It was concluded that there was no significant loss in bond strength for galvanized bars, whereas there was significant reduction in bond strength for epoxy-coated bars.

Thangavel et al. (1995) studied the behavior of protective coatings to steel reinforcement with respect to bond strength at the rebar concrete interface for the reliable performance of reinforced concrete structures. Pull-out tests were conducted on coated and uncoated rebar of 10mm diameter and 450mm in length, placed centrally in a 100mm concrete cube as per Indian standards. Bond behavior of the galvanized, inhibited cement slurry coated and fusion bonded epoxy-coated bars with two different coating thickness was assessed and compared. It was observed that the coated rebar improved the bond strength as compared to the plain mild steel bars. Galvanizing and epoxy coating reduced the bond strength at higher thickness of coatings. On the other hand for inhibited cement slurry coated rebar, the bond strength improved further at higher thickness of coatings.

Protasio Castro et al. (1996) analyzed the influence of protective coatings on the rebar-concrete bond. The value of the bar-friction co-efficient was obtained by testing a concrete tension strut reinforced with only one steel bar. The rebar include smooth and ribbed control bars, and bars manually coated with commercially available zinc based and epoxy resin coating to a thickness of 0.3 mm. The size of the concrete specimen was 820 x 54 x 54mm with centrally embedded rebar extended from both ends to a sufficient length to conduct tension test. The reinforcing bars were loaded in tension to 80% of its yield load and totally 72 tests were conducted. The average distance between cracks that form on concrete prisms was determined and bar-friction co-efficient was also obtained. It was concluded that application of epoxy coating on ribbed bars had an appreciable influence on the friction co-efficient as compared to smooth bars. The zinc coating on smooth and ribbed bars had a significant influence on the friction co-efficient as compared to control rebar.

Kumar et al. (1996) discussed the various aspects relating to the mechanization of cement-polymer composite coating system for corrosion protection of rebar. Chemical resistance test, bond strength test and macro cell corrosion tests were conducted on coated rebar. Stress corrosion cracking tests and field exposure tests were conducted on coated prestresing strands. It was concluded that cement polymer composite coating offered excellent protection to steel bars and prestressing strands. Due to passivation-cum-barrier-nature of coating, localized defects in coating may not lead to severe undercutting.

Effect of reinforcement corrosion on the bond strength between steel and concrete was investigated by **Abdullah A. Almusallam et al. (1996)**.The bond behavior of reinforced concrete elements, including the ultimate bond strength, free-end slip, and the modes of failure in precracking, cracking and post cracking stages were studied. The effect of different crack width and the rib profile degradation for various degrees of corrosion on the bond strength were also evaluated. The results indicated that in the precracking stage, (0 to 4% corrosion) the ultimate bond strength increased, whereas the slip at the ultimate bond strength decreased with an increase in the degree of corrosion. In the cracking stage (4 to 6% corrosion), the bond failure occurred suddenly at a very low free end slip. A large slip was noted as the ultimate failure of the bond occurred due to splitting of the specimens. Beyond 6% rebar corrosion, the bond failure resulted as a continuous slippage of the rebar. It was concluded that ultimate bond strength initially increased with an increase in the degree of corrosion up to 4% rebar corrosion after which there was a sharp reduction in the ultimate bond strength up to 6% rebar corrosion. Beyond 6% rebar corrosion the ultimate bond strength did not vary much even up to 80% corrosion. A crack width of 0.3 mm and a rib profile loss of 25% were observed beyond which a sharp reduction in bond strength occurred

III. DETAILS OF MATERIAL

Cement is the most important constituent of the concrete, in that it forms the binding medium for the discrete ingredients. Cement of 53 Grade Portland Pozzolana Cement (PPC) obtained from a single source is used. Locally available river sand confirming to Zone 1 and 20mm downgrade blue granite forms the fine and coarse aggregate. Potable water is used for mixing concrete and no other chemical mineral admixture is introduced in to the concrete. Reinforced comprise of 16mm and 20mm diameter commercially available TMT rebar with spiral rib configuration.

Mix design was carried out for M25 concrete as per IS: 10262-1982 and accordingly used in the casting of specimens involving rust free and coated rebars. The Steel comprises of 16mm and 20mm diameter deformed TMT rebar. The Cement polymer anticorrosive coating and nitrite based corrosion inhibitor which was developed by Dr. M.S. Haji Sheik Mohammed and available commercially is used.

IV. METHODOLOGY

4.1 Mix Design

Mix Proportion

S.No	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Water (litre)
1	340	695	1280	186
2	1	2.04	3.76	0.54

4.2 Cement polymer anticorrosive coating

There is a need to evolve effective user friendly corrosion prevention measures which may be based on preventing passivating film on the steel at all times. This can be achieved by giving a permanent anticorrosive polymeric cementious alkaline coating on the steel surface. The coating should have sufficient tensile strength, so that it does not develop cracks before yield stress. This can be a barrier-cum-passivating type of coating with a high capacity to retain alkalinity for a long time in spite of attacks from chlorides and carbonation. A blend of anticorrosive and polymers having good rust mingling properties were developed in recent time. This anticorrosive polymer solution is compatible with concrete or cement paste when uniformly mixed with fresh ordinary Portland cement.

This process involves removal of rust and scales from the steel rebars by hard wire brush cleaning or blasting and application of cement polymer coatings by brushing. This coating has excellent resistance to chemicals, corrosion and impact. Cement Polymer Anticorrosive Coating was developed by Dr. M.S. Haji Sheik Mohammed, Professor, Department of Civil Engineering, B.S. Abdur Rahman University. Figure 3.1 shows the view of Cement Polymer Anticorrosive Coated Rebars and Figure 3.2 shows the sequence of cement polymer anticorrosive coating process. The coating thickness for single coat is 200 ± 25 µm and for two coats is around 275 ± 25 µm.

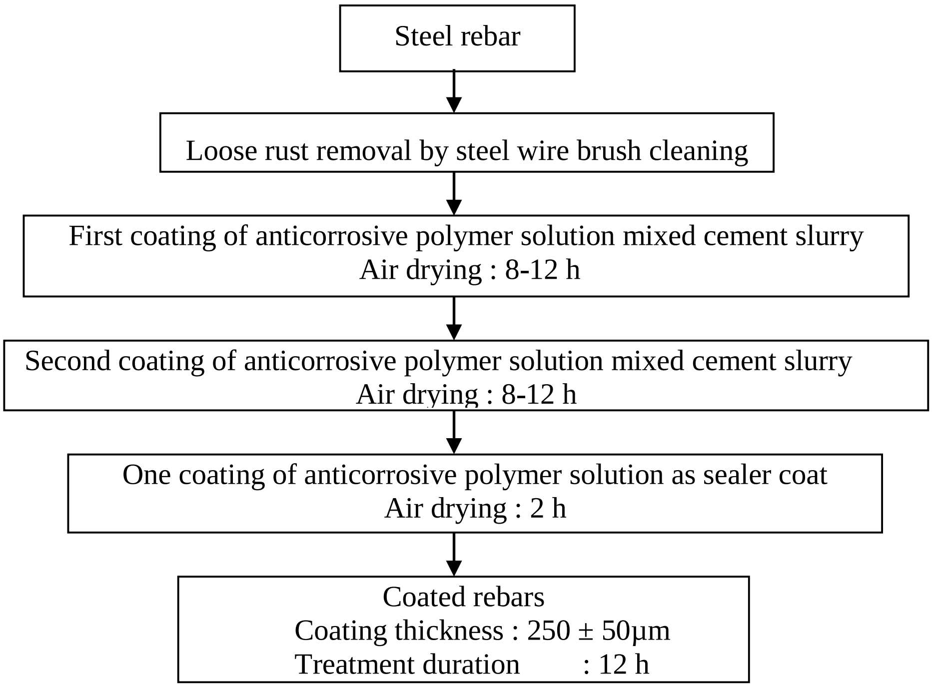


Fig 4.2 Sequence of cement polymer anticorrosive coating process

4.3 Nitrite based corrosion inhibitor

The use of inhibitors in concrete is a common phenomenon for preventing corrosion of steel in concrete. The effect of addition of corrosion inhibitors in concrete has been studied by many researchers (Omar S. Baghabra Al-Amoudi, Mohammed Maslehuddin, Lashari, A.N., and Abdullah A. Almusallam, 2003, Saraswathy, V., and Ha-Won Song, 2007). Corrosion inhibitors can either influence the anodic or cathodic reactions, or even both. Since the anodic and cathodic reactions should balance each other, a significant reduction in either or both will result significant reduction in the corrosion rate. Since anodic inhibitor is usually more effective than cathodic inhibitor, which enabled us to undertake anodic inhibitor for corrosion control. However, calcium nitrite was the first corrosion inhibitor used commercially on a large scale for reinforced concrete. A simple nitrite based anodic mixed inhibitor solution was developed by Dr. M.S. Haji Sheik Mohammed, Professor, Department of Civil Engineering, B. S. Abdur Rahman University in the recent time (Haji Sheik Mohammed, M.S., 2008). The colour of the corrosion inhibitor is dark brown with pH 11.10 and density 1.06 g/cc. The detrimental effects of nitrite in plastic or hardened properties of concrete such as strength reduction can be compensated by using other additives (Haji Sheik Mohammed, M.S., and Samuel Knight, G.M., 2008).

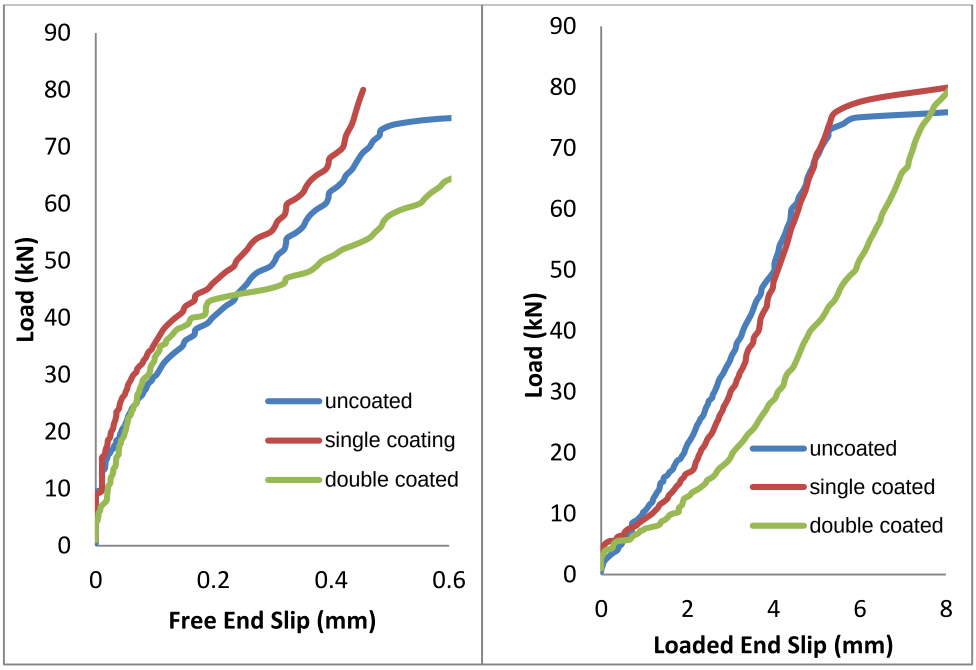
V. EXPERIMENTAL INVESTIGATION

5.1 Bond strength to concrete test

According to IS 456 - 2000, rebars used in the Reinforced cement concrete should be free from rust. The Bond strength results of rust free uncoated rebar are compared with cement polymer anticorrosive coated (single and double coating) for analysis.

Figure 5.1 shows the Load – Slip behavior of 16mm diameter uncoated and coated rebar in control concrete. It can be seen that uncoated rebar and cement polymer anticorrosive coated (CPAC) - single coat - rebar offered similar load - slip behaviour irrespective of the measurement location throughout the test period. CPAC double coated rebars offered increased slip level after 45 kN free end load and 15 kN loaded end load, but the slip at ultimate load level remains similar.

Figure 5.2 exhibits the load – slip behavior of 16mm diameter uncoated and cement polymer anticorrosive coated rebars in inhibitor admixed concrete. It can be visualized that there is a similar load-slip for uncoated and coated bars irrespective of coating thickness. Marginally improved bond strength behaviour for uncoated rebars as compared to coated rebars. Among coated rebars, load-slip behaviour of double coated CPAC bars are in line with single coated CPAC bars which is an appreciable aspect.



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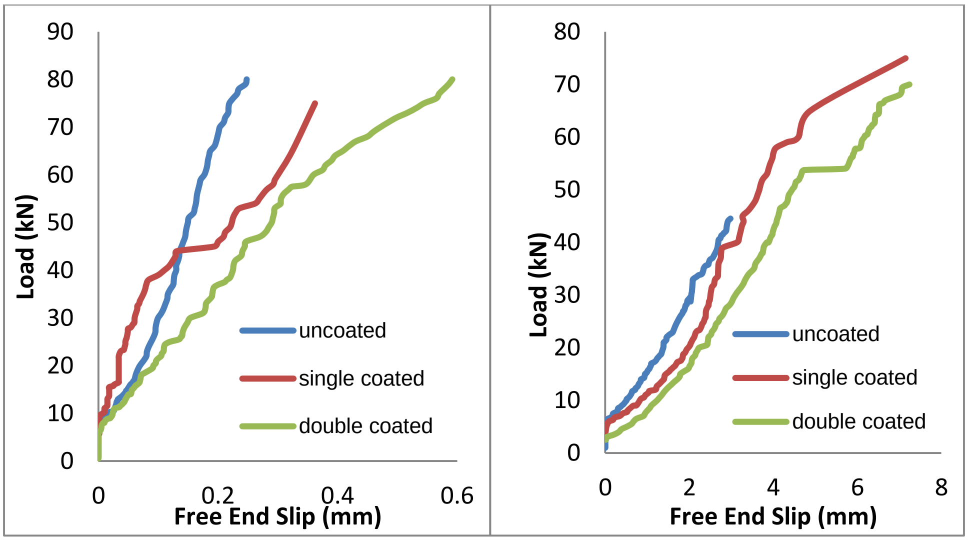
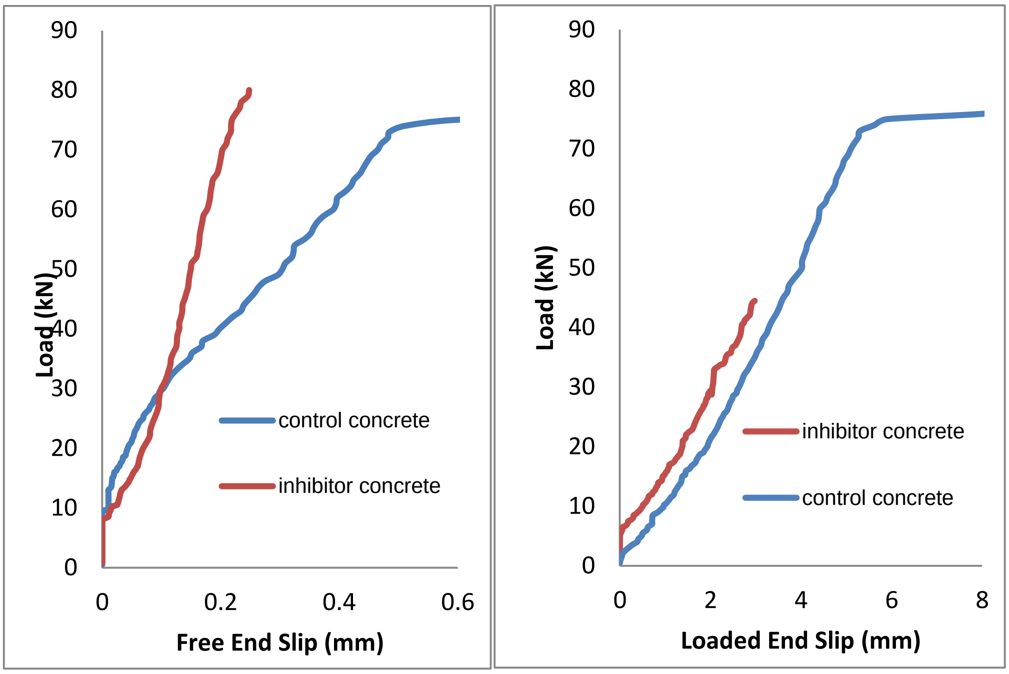
5.1.1 Load-Slip Behaviour of 16 mm diameter uncoated and Cement Polymer Anticorrosive Coated Rebars in Control Concrete

Figure 5.3 shows the load – slip behavior of 16mm diameter uncoated rebar in control and inhibitor admixed concrete. It can be seen that inhibitor admixed concrete offered improved bond strength to uncoated bars as compared to control concrete irrespective of the measurement locations. Figure 5.4 exhibits the load – slip behavior of 16mm diameter single coated CPAC rebars in control and inhibitor admixed concrete. There is a nearly



5.1.2 Load – Slip Behavior of 16mm diameter Uncoated and Cement Polymer Anticorrosive Coated Rebars in inhibitor Admixed concrete



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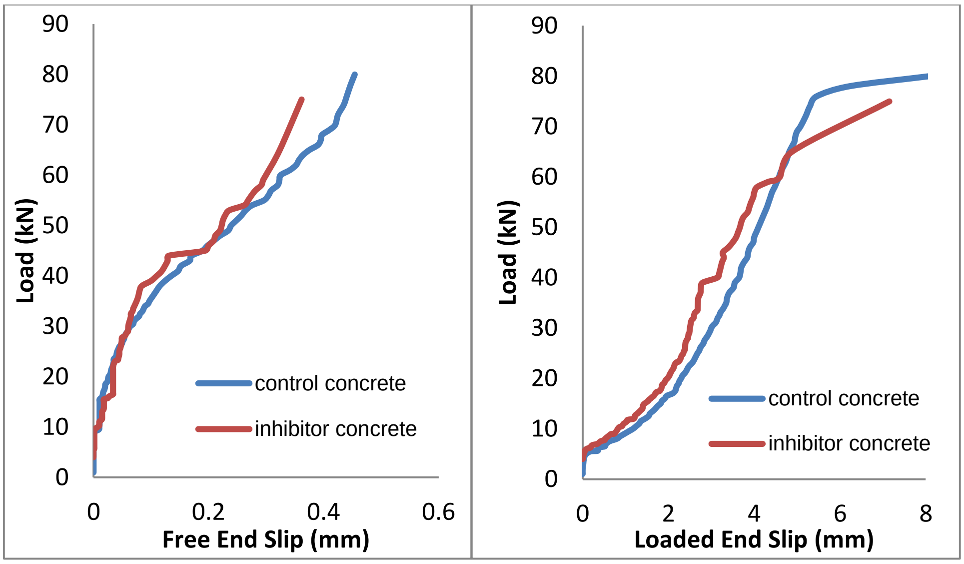
5.1.3 Load – Slip Behavior of 16mm Diameter Uncoated Rebar in Control and Inhibitor Admixed Concrete

Fig 5.4 similar load-slip behaviour for single coated CPAC rebars irrespective of type of concrete. This implies that inhibitor modification in concrete did not alter the bond strength development of coated rebars with concrete and explicit the good compatibility with coated rebars.



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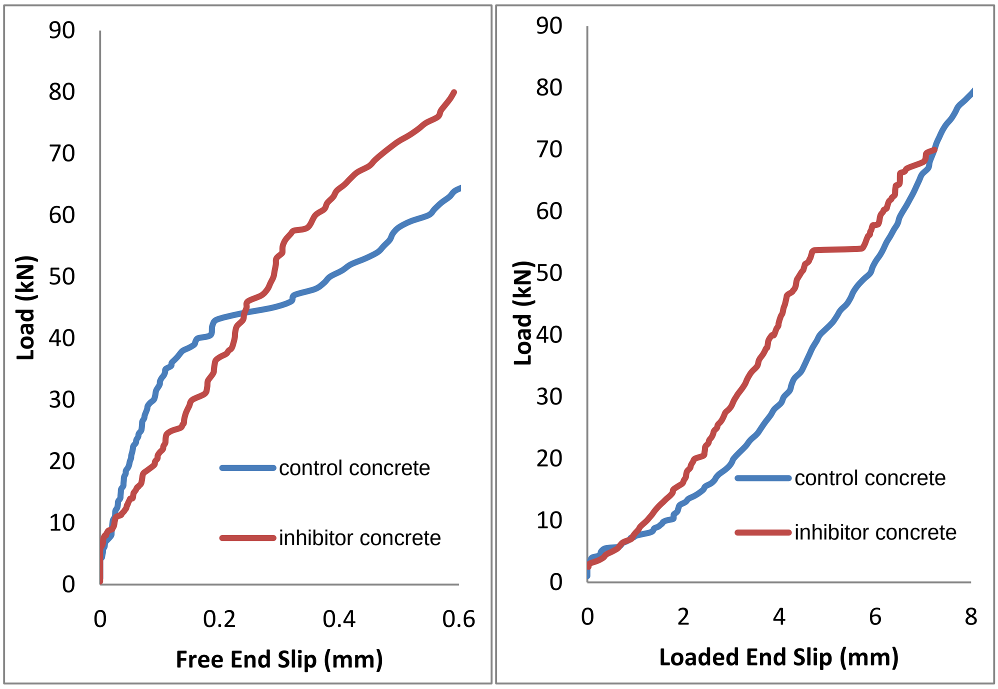
5.1.4 Load – Slip behavior of 16mm diameter single coated CPAC rebars in control and inhibitor admixed concrete

Figure 5.5 shows the load – slip behavior of 16mm diameter double coated rebar in control and inhibitor admixed concrete. It can be observed that irrespective of the measurement locations, double coated CPAC rebars exhibits similar usable bond strength values. Afterwards inconsistent load - slip behaviour until failure of specimens. But slip levels in ultimate load exhibits similarity irrespective of concrete type.

Figure 5.6 reveals the load – slip behavior of 16mm diameter uncoated and coated rebars in control and inhibitor admixed concrete. It can be seen that single coated CPAC rebars possess improved usable bond strength as compared to uncoated rebars in control and inhibitor admixed concrete irrespective of measurement location. Inhibitor modification in concrete improves the loaded end slip behaviour for uncoated rebars in the usable bond region but with similar load values in free end as compared to control



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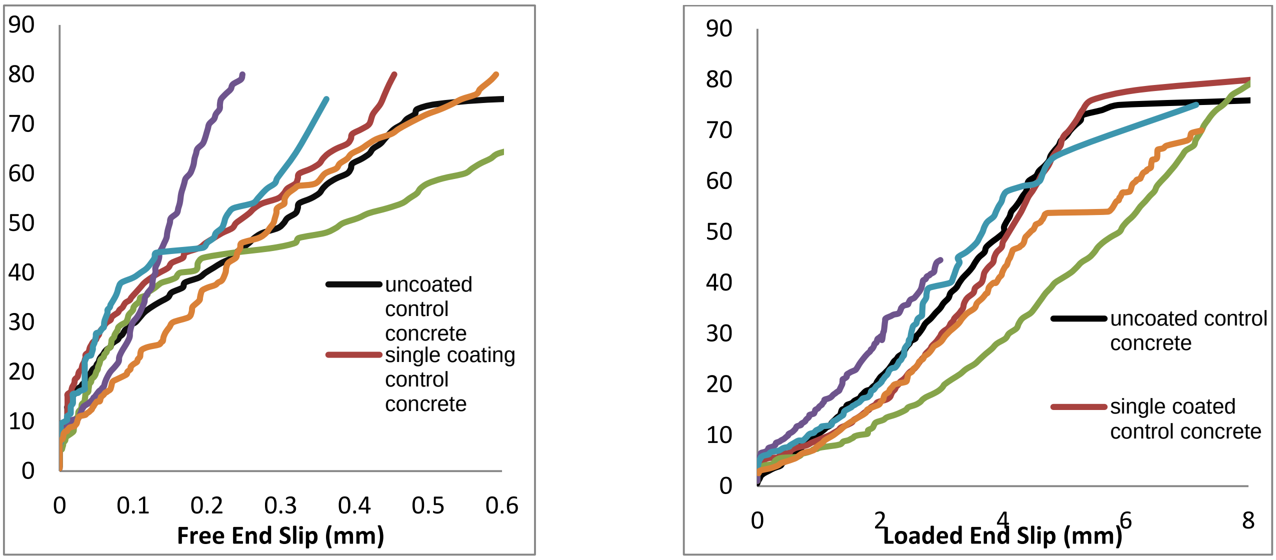
5.1.5 Load – Slip behavior of 16mm diameter double coated rebar in control and inhibitor concrete

concrete. Although the loaded end slip values in the usable bond region for double coated CPAC rebars is similar as compared to control concrete, marginal reduction in usable bond behaviour in the free end loading measurement.

Figure 5.7 shows the load – slip behavior of 20mm diameter uncoated and CPAC coated rebars in control concrete. Although uncoated and coated rebars exhibit similar load values in the usable bond region in free end slip, significant increase in load values for CPAC coated rebars irrespective of coating thickness in the loaded end as compared to uncoated rebars. This shows the improved chemical adhesion exhibited by coated rebars with concrete constituent materials due to material similarity.

Figure 5.8 explicit the load – slip behavior of 20mm diameter uncoated and CPAC coated rebars in inhibitor admixed concrete. It can be visualized that there is improved usable bond behaviour for uncoated rebars due to inhibitor modification in concrete as compared to coated rebars irrespective of measurement location. The usable bond strength slip behaviour reveals



5.1.6 Load – Slip behavior of 16mm diameter uncoated and CPAC coated rebars in control and inhibitor admixed concrete

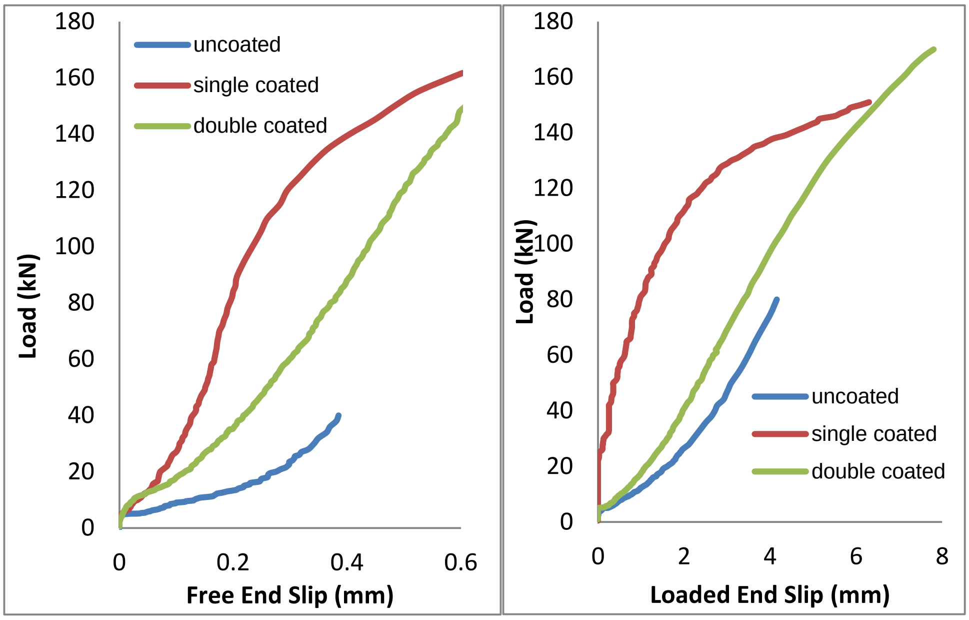


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Table 5.1 Observation on Bond Strength Test for 16mm Diameter Uncoated and CPAC Coated Rebars in Control and Inhibitor Admixed Concrete

Sl. No.	Type of Rebar				Usable Bond Strength (N/mm^2)	Variation (%)
		0.025mm FE slip	0.25mm LE slip	Ultimate Load (KN)		
1.	Uncoated rebar - CC	**16.5**	3.45	101	4.10	-
2.	Single Coated CPAC rebar - CC	**19.5**	5.55	107	4.85	+18.30
3.	Double Coated CPAC rebar - CC	**13.5**	4.35	107	3.36	-18.05
4.	Uncoated rebar - IAC	**10.5**	7.75	100	2.61	-
5.	Single Coated CPAC rebar - IAC	**15.75**	6.85	109	3.92	+50.20
6.	Double Coated CPAC rebar - IAC	**10.5**	3.65	93	2.61	-

CC - Control Concrete; IAC - Inhibitor Admixed Concrete; CPAC - Cement Polymer Anticorrosive Coating; FE – Free End; LE – Loaded End

Table 5.2 Ultimate Bond Strength and Failure Pattern for 16mm Diameter Uncoated and Coated Rebars in Control and Inhibitor Admixed Concrete

Sl. No.	Type of Rebar	Ultimate Load (KN)	Ultimate Bond Strength (N/mm^2)	Variation (%)	**Type of Failure**
1.	Uncoated rebar - CC	101	20.1	-	Pull out of rebar
2.	Single Coated CPAC rebar* - CC	107	21.3	+5.93	Yielding of rebar

3.	Double Coated CPAC rebar - CC	107	21.24	+5.93	Yield cum Pull out of rebar
4.	Uncoated rebar - IAC	100	19.93	-	Pull out of rebar
5.	Single Coated CPAC rebar - IAC	109	21.70	+9.00	Yielding of rebar
6.	Double Coated CPAC rebar - IAC	93	18.52	-7.00	Pull out of rebar

CC - Control Concrete; IAC - Inhibitor Admixed Concrete; CPAC - Cement Polymer Anticorrosive Coating

VII. CONCLUSION

There is a significant increase in usable bond strength of the order of 18- 60% for cement polymer anticorrosive coated rebars (single coating) as compared to uncoated rebars in control concrete. Inhibitor modification in concrete did not offer any appreciable influence in usable bond strength and ultimate bond strength for uncoated and coated rebars as compared to control concrete. There is a marginal increase in ultimate bond strength values for cement polymer anticorrosive coated rebars of the order of 6% as compared to uncoated rebars in control concrete. Whereas inhibitor admixed concrete exhibits marginal variation in ultimate bond strength for coated rebars.For cement polymer anticorrosive coated bars (single coat), yielding of rebar is observed instead of a typical pull-out failure which indicates improved bond strength offered by coated rebars in the interface.There is a similar bond strength values for uncoated and cement polymer anticorrosive coated rebars irrespective of the type of concrete. The cement polymer anticorrosive coating satisfy the codal provisions of Indian standards IS 2770-1967 with respect to Bond strength.It can be concluded that introduction of cement polymer anticorrosive coating in steel-concrete interface and incorporation of nitrite based corrosion inhibitor in concrete have no negative influence on bond strength development between steel and concrete.

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