Bond Strength of Epoxy-Coated Reinforcement in Concrete

Anik Naha[1], G.M. Sadiqul Islam[2], Md. Ariful Islam Chowdhury[3]

[1]*BSRM GROUP, Ali Mansion, Corporate Office, Chattogram, BANGLADESH (Email:naha.anik25@gmail.com)*
[2]*Professor, Department of Civil Engineering, CUET, Chattogram, BANGLADESH (Email: gmsislam@cuet.ac.bd)*
[3]*DEVCON Consultant Ltd, Karnafully Tunnel Project, Chattogram, BANGLADESH (Email: mdarifulislamrafi@yahoo.com)*

Abstract

Reinforcement in concrete is deteriorated due to carbonation and chloride induced corrosion in highway bridge and marine exposure conditions. The epoxy-coated rebar can extend the service life of a reinforced concrete structure. However, researches indicated the bond performance between concrete and epoxy coated rebar might be reduced from uncoated bars. The pullout test was conducted to evaluate the bond performance of rebars in concrete. Cylindrical specimens using different concrete grades viz. C15, C28, C35, and C41 using 10 mm rebar with different embedded length (viz. 67mm, 100mm and 134mm) with the coated and uncoated condition has been prepared. The tensile load was applied to the rebars to obtain the bond strength between the concrete and the embedded bar. Results indicate that the bond ratio with the increase of embedded length. Furthermore, the bond strength increases with concrete strength. However, the bond ratio between coated and uncoated bars decreased for the same. Due to the epoxy coating on the bars, the bond strength reduced approximately 18% for splitting failure and 25% for pullout failure. Therefore, to protect the rebars from adverse environmental action, epoxy would require compromising a portion of its bond strength.

Keywords: *Epoxy-coated bar; Embedded Length; Concrete Strength; pullout; Bond Strength.*

1. Introduction

Reinforced concrete (RC) is the composition of concrete and steel to counteract compressive and tensile stress by concrete and steel, respectively, to withstand the working load of infrastructures. This solidarity reduces significantly due to corrosion of reinforcing steel. The process begins with rapid oxidation of the rebar embedded in the concrete when exposed to a saline environment. The corroded rebar can expand up to 3-6 times than the original volume. This causes cracking and spalling due to the radial pressure on the cover concrete by the expansion of steel (Treece & Jirsa, 1989). Preventing the rebar in concrete from coming in contact with moisture, oxygen, and chloride ion could be one solution.

Coating the bars with an inert polymer resin such as epoxy coating could create a barrier to contact with adverse chemicals. (ASTM, 2019) gives a standard specification for epoxy-coated bars to use in concrete. However, the coating might affects the bond behavior between the reinforcing bar and concrete (Pandurangan & Rao, 2013). Several studies worked on the performance of epoxy coated bar. A few of them focused on the bond strength of epoxy coated bar in concrete (Cleary & Ramirez, 1991; Clifton & Mathey, 1983; El-Hakeem, Abd El-Aziz, & El-Reedi, 1997; Treece & Jirsa, 1989). (De Anda, Courtier, & Moehle, 2006) worked with prefabricated epoxy bars while (El-Hakeem et al., 1997) determined the bond strength of epoxy coated bar by analytical calculation. In addition (Clifton & Mathey, 1983) studied the creep performance of coated bars. (Nie et al., 2020) studies bond performance of epoxy-coated reinforcement using coral aggregate concrete at sea environment. This study evaluates the bond behavior of epoxy coated bar when used instead of the uncoated (black) bar. This was examined considering several factors such as the coating thickness, bar size and embedded length with position, properties of concrete and bond ratio.

2. Materials

2.1 Concrete

CEM I Cement of 52.5 kN strength category with well-graded coarse aggregate (nominal size ¾ inch) and fine aggregate (FM=2.62) was used for concrete preparation. High range water reducing admixture was used to maintain the desired workability with target compressive strength of 15 MPa, 28MPa, 35 MPa and 41 MPa.

2.2 Reinforcing Steel

The reinforcement steel was a 10 mm rebar with a yield strength of 60 ksi. This was used both in epoxy coated and uncoated condition. Figure 1 shows the epoxy resin which was prepared by mixing the Base (A) and Hardener (B) at an equal ratio. The mixture was then applied on the 10 mm deformed rebar by maintaining an approximate coating thickness of 175-300µm. Figure 2 shows the bar which has been epoxy coated at different length to be placed in concrete.

Figure 1. Epoxy Coated resin

Figure 2. Epoxy Coated Bar

3. Experimental Program

Mix design was conducted as per (ACI 211.1-91, 2009), and the different trial mix has been adopted to get the target strength of 15 MPa, 28 MPa, 35 MPa and 41 MPa. The mix design is given in Table 1. The concrete sample was made by mixing all the ingredients properly to get the desired slump. After the slump test, the fresh concrete was poured into the cubical and cylindrical mold to prepare the sample for compressive strength and pull out test. After underwater curing, for 28 days, the cube specimen were crushed to obtain the compressive strength. The pullout test was conducted to evaluate the bond performances of the coated reinforcement relative to control reinforcement (without coating) in concrete. The pullout specimens were ϕ100×200mm cylindrical concrete prisms with ϕ10 mm bar with a total length of 0.9 m. The bars were embedded 76mm (1/3L), 100mm (1/2L) and 134mm (2/3L) in the different cylindrical prism. All the pull out the test was carried out using a 1000 kN Universal Testing Machine (UTM). Figure 3 shows that the prism specimen placed in the testing machine. The bond test was carried out as per (ASTM, 2015). The pullout test was originally used to estimate concrete in situ strength (Krenchel & Shah, 1985).

Table 1. Mix proportion for 1 m^3 fresh concrete

Target Strength, MPa	w/c ratio	Materials required (SSD where applicable)					Total, kg
		Water, kg	Cement, kg	Sand, kg	Stone, kg	Plasticizer kg	
15	0.46	130	280	900	1030	2.5	2343
28	0.42	135	320	860	1030	3.0	2348
35	0.40	150	380	780	1030	3.0	2343
41	0.38	165	430	735	1015	3.3	2348

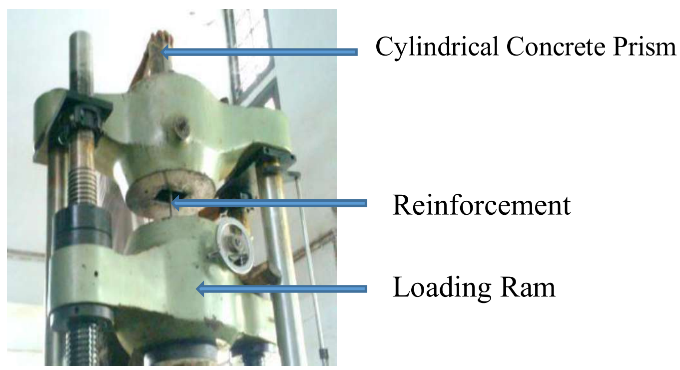

Figure 3. Sample placed on UTM for Pullout test

4. Result and Discussion

4.1 Compressive strength

The cube compressive strength of concrete samples was converted into cylinder strength as written in Equation 1 (Mansur & Islam, 2002). Table 2 shows the target and obtained compressive strength in a different format. In general, the test samples' compressive strength was close to the target strength.

$$(fcu)_{150} = (f'c)_{100\times200} + 6.41 \quad (1)$$

Where, $(f'c)_{150}$ and $(f'c)_{100\times200}$ are the cube and cylindrical strength, respectively.

Table 2. Compressive strength of ϕ100mm×200mm specimen

Target strength, MPa	Compressive strength of cube, MPa	Compressive strength cylindrical specimen, MPa
15	18.2	12
28	33.5	27
35	43.4	37
41	47.0	41

4.2 *Pullout Test with Different Concrete Strength*

The pullout test result of ϕ10 mm rebar with different embedded length inside 15 MPa concrete is shown in Figure 4. The general mode of failure for all cylindrical prism specimens was pullout for both coated and uncoated bar. The bond ratio between coated and uncoated bar for 67 mm, 100mm and 134 mm embedded length was found to be 0.63, 0.76 and 0.93, respectively. This indicates with the increased embedded length, the bond strength also increased. Figure 5 shows the pullout test result for 28 MPa cylindrical prisms. With the increase in compressive strength of concrete, the failure mode changed. Splitting type failure was noted for all uncoated bars, while this was generally pullout for coated bars. This indicates a reduction in bond performance for coated bars. The bond ratio is 0.87, 0.82 and 0.95 for 67 mm, 100 mm and 134 mm embedded length, respectively, indicating a reduction from 67 mm to 100 mm and then an increase for 134 mm embedded length.

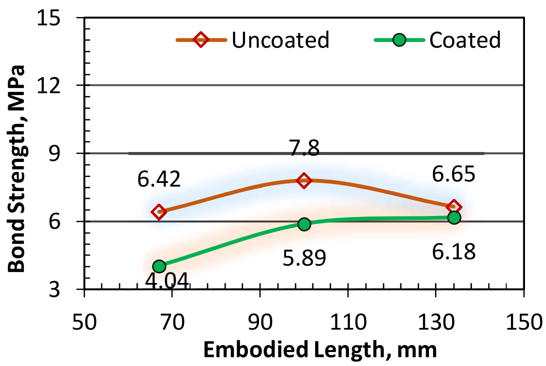

Figure 4. Bond strength variation of C15

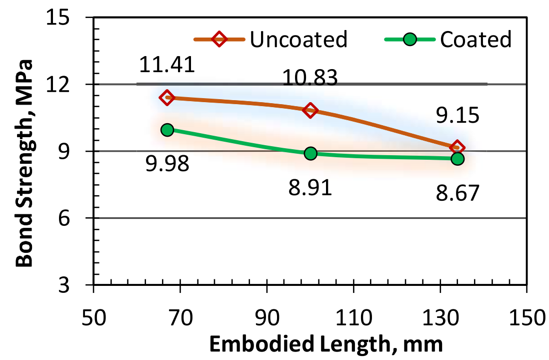

Figure 5. Bond strength variation of C28

As shown in Fig. 6, overall, the bond strength increased slightly for 35 MPa cylindrical prisms than for the 28 MPa strength sample. The failure mode entirely shifted to the splitting type for each sample tested. The bond ratio between coated and uncoated bars at 67mm, 100mm and 134 mm embedded length was found to be 0.72, 0.86 and 0.88, respectively, indicating a continuous rise in bond strength with embedded length. The common mode of failure remained splitting for both uncoated and coated bar inside the highest 41 MPa concrete (Fig. 7). Although the bond strength was increased with concrete compressive strength, an opposite trend in bond strength was noted with an increase in embedded length. The bond ratio between coated and uncoated bars for 67mm, 100 mm 134mm embedded length was found to be 0.85, 0.84 and 0.80, respectively. In general, the bond ratio decreases with the increase of embedded length and strength of concrete.

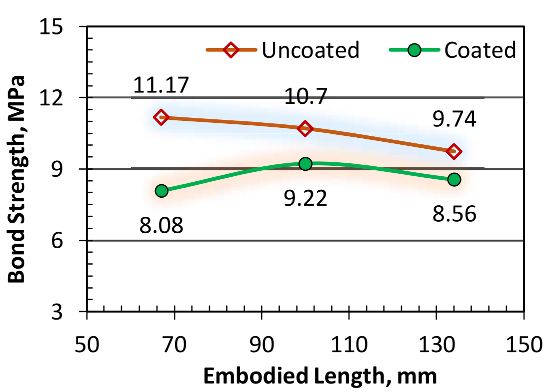

Figure 6. Bond strength variation of C35

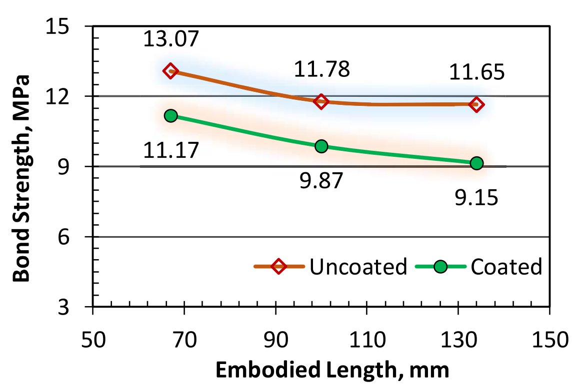

Figure 7. Bond strength variation of C41

Overall two failure type has been observed as shown in Figure 8. Pullout type dominated for lowest compressive strength concrete and splitting failure for 28 MPa, 35 MPa and 41 MPa. This failure was not only dependent on the concrete strength but also on the embedded length.

(a) Pullout Failure

(b) Splitting Failure

Figure 8. Pullout test failure mode

4.3 *Pullout Test – effect of embedded length*

Table 3 shows the summary of the bond strength ratio between the coated and uncoated bars. With a 100mm embedded length, the bond strength varies from 0.76 to 0.86. The bond strength ratio increased with concrete compressive strength up to 35 MPa and then dropped slightly for 41 MPa. An opposite trend was noted for 67 mm and 134 mm embedded length. Generally, the bond strength ratios are higher with higher embedded length, meaning less impact of coating on bond strength. However, this could be severe for lower embedded length in strength concrete. Only 63% bond strength was obtained for coated reinforcement at 15 MPa concrete of uncoated reinforcement. In general, the bond strength of epoxy coated bar in concrete depends not only on the concrete compressive strength but also on embedded length.

Table 3. The bond ratio of 10mm bar in Ø100x200 concrete cylinder

Strength, MPa	**Embedded Length**		
	67 mm	**100 mm**	**134 mm**
15	0.63	0.76	0.93
28	0.87	0.82	0.95
35	0.72	0.86	0.88
41	0.85	0.84	0.85

5. Conclusion

a) Pullout failure observed in the concrete with lower compressive strength, and splitting failure occurred in concrete with higher compressive strength. In splitting failure, the bond strength reduced by 18% for the epoxy-coated bar compared to the uncoated bar, and the pullout failure reduction was approximately 25%.
b) A higher bond ratio (0.80-0.95) was noted for 134mm embedded length. This was reduced gradually for 100mm (0.76-.087) and 67 mm (0.63-0.87) embedded length. With the highest compressive strength (41 MPa), the bond ratio was found similar between each embedded length indicating its less effect on bond strength.

c) The reduction in bond strength depends on the embedded length and concrete strength. The reduction in bond strength for the epoxy-coated bar can be minimized by applying some modification factors in design aid, such as increasing the splice length, development length, and maintaining a proper site fabrication.

6. Acknowledgement

The authors acknowledge the kind assistant of the laboratory team from Department of Civil Engineering, CUET. Thanks extended to Bharal Chemical and Confidence Group for material support.

7. References

ACI 211.1-91. (2009). Standard practice for selecting proportions for normal, heavy weight, and mass concrete (Reapproved 2009). Retrieved April 16, 2021, from https://www.concrete.org/store/productdetail.aspx?ItemID=211191&Language=English&Units=US_Units

ASTM. A994-Standard test method for comparing bond strength of steel reinforcement bars to concrete using beam-end specimens (2015). West Conshohocken, PA, USA.

ASTM. A775-Standard specification for epoxy-coated steel reinforcing bars (2019). West Conshohcken, PA, USA.

Cleary, D. B., & Ramirez, J. A. (1991). Bond strength of epoxy-coated reinforcement. *ACI Materials Journal*, *88*(2), 146–149. https://doi.org/10.14359/1909

Clifton, J. R., & Mathey, R. G. (1983). Bond and creep characteristics of coated reinforcing bars in concrete. *Journal of the American Concrete Institute*, *80*(4), 288–293. https://doi.org/10.14359/10848

De Anda, L., Courtier, C., & Moehle, J. P. (2006). Bond strength of prefabricated epoxy-coated reinforcement. *ACI Structural Journal*, *103*(2), 226–234. https://doi.org/10.14359/15180

El-Hakeem, Abd El-Aziz, F. A., & El-Reedi, M. A. (1997). Calculating bond strength of coated and uncoated steel bars using an analytical model. In *Proceedings of the Seventh Arab Structural Engineering Conference* (pp. 247–256.). Kuwait.

Krenchel, H., & Shah, S. P. (1985). Fracture analysis of the pullout test. *Materials and Structures*, *18*(6), 439–446. https://doi.org/10.1007/BF02498746

Mansur, M. A., & Islam, M. M. (2002). Interpretation of Concrete Strength for Nonstandard Specimens. *Journal of Materials in Civil Engineering*, *14*(2), 151–155. https://doi.org/10.1061/(ASCE)0899-1561(2002)14:2(151)

Nie, R., Huang, Y., Li, X., Sun, H., Li, D., & Ying, J. (2020). Bond of epoxy-coated reinforcement to seawater coral aggregate concrete. *Ocean Engineering*, *208*, 107350. https://doi.org/10.1016/j.oceaneng.2020.107350