Investigation on Bond Behavior and Debonding Characteristics for CFRP Strengthening Metal and Concrete Structural Sections

S. M. Z. Islam[1*], B. Ahmed[2], S. Alam[3], T. Ahmed[4], M. A. Sayed[5], T. S. Abrar[6], and M. M. Rahman[7]

[1]*Professor, Department of Civil Engineering, RUET, Bangladesh (zahurul90@gmail.com)*
[2]*Assistant Professor, Department of Civil Engineering, RUET, Bangladesh (bulbulruet@gmail.com)*
[3,4,5 &6]*Student, Department of Civil Engineering, RUET, Bangladesh, (shahalamruet4@gmail.com)*
[7]*Chairman and CEO, Nutech Construction Chemicals Company Limited, BUET, Dhaka, Bangladesh (mostafizur.rahman@live.com)*

Abstract

Carbon fibre reinforced polymer (CFRP) has significant application and is widely used for strengthening of metal and concrete structural sections. The bond behavior and debonding characteristics is a key issue for strengthening of metal and concrete structural sections. Previous research revealed that debonding between CFRP and adhesive as well as steel, stainless steel, aluminum and concrete is one of the main failure modes in CFRP-strengthening of structures. The aim of this study is to develop a better understanding of bond behavior and debonding characteristics, bonding mechanisms and reliable analytical models for CFRP-strengthening structures. The objective of the research is to investigate the bond behavior and debonding characteristics of CFRP strengthening metal and concrete structural sections. A series of Butt joint coupon tests are conducted on steel, stainless steel and aluminum. A series of pull out tests are also conducted between CFRP and concrete surface. A comparative study is performed between the bond behavior and debonding characteristics of CFRP and steel, stainless steel and aluminum as well as concrete. The effect of different parameters such as bond length, adhesive thickness, surface treatment and adhesive strain have been identified and investigated. The failure modes found in CFRP strengthening is steel-adhesive interface debonding and CFRP delimitations. This paper highlights the importance of bond behavior which is an important parameter for the performance of CFRP strengthening of steel, stainless steel and aluminum as well as concrete structures. Finally, based on the experimental observations and results, a bilinear bond-slip models have been proposed for CFRP-to-steel, stainless steel, aluminum and concrete interfaces.

Keywords: *Bond Behavior, CFRP, Debonding characteristics, Metal and concrete sections, Strengthening.*

1. Introduction

Innovative structural strengthening schemes of external bonding using Carbon Fibre-reinforced Polymer (CFRP) plates or sheets has emerged as a popular method for the concrete and steel structures. Recently, CFRP has attained great importance for strengthening, repair and rehabilitation work due to some outstanding mechanical properties such as high strength, high elastic modulus, light weight and good durability (Islam and Young 2011; Islam and Young 2012). In this strengthening or retrofitting method, the performance of the CFRP-to-steel or concrete interface in providing an effective stress transfer is crucial. The enhance load carrying capacity and structural stability depend on the bonding performance of steel-adhesive-FRP interface. The characteristics of the bonding and debonding depend on adhesive, steel surface and CFRP materials. An investigation of bond behavior for CFRP strengthening steel structural sections has been conducted by Dilum (2010). Hu et al. (2020) have studied the bond behavior of hybrid FRP-to-steel joints. They investigated the experimental and numerical studies on the bond behavior of hybrid fiber-reinforced polymer (FRP)-to-steel single-lap joints. Test results showed that hybrid FRP-to-steel joints have similar failure modes with three-layered CFRP-to-steel joints. Kim and Smith (2010) studied a series of tests on the shear strength and behavior of FRP-to-metal joints. Shinde et al. (2018) has conducted a study on the dependence of repair strength on the size of FRP patch bonded to a cracked aluminum alloy panel. The failure was caused by the separation of the patch from the skin. For small-sized patches, the separation initiated at the crack edges, grew with the increasing applied load and caused the complete separation.

Fawzia et al. (2005) and Fawzia et al. (2010) conducted a series of experimental and numerical research on CFRP strengthened double strap steel joints under tension. They proposed bond-slip models strengthened steel by CFRP for three different types of adhesives. An accurate local bond-slip model is of the fundamental importance in the modelling of FRP-strengthened RC structures. The Bond-slip models for FRP sheets/plates bonded to concrete were proposed by Lu et al. (2005). Using pull out tests, local bond-slip models for FRP to-concrete interfaces have been developed. A detailed study on review and assesment of debonding strength models of FRP-strengthened RC beams have been conducted by Smith and Teng (2005). A new simple debonding strength model which was superior to existing models was also proposed. But they did not considered the comparison of performance of CFRP strengthening of steel, stainless steel and aluminum as well as concrete structures. Therefore, it is a novel researched to perform a comparative study between bond behavior and debonding characteristics of CFRP and steel, stainless steel and aluminum as well as concrete.

The objective of the research is to investigate the bond behavior and debonding characteristics for CFRP strengthening metal and concrete structural sections. A series of Butt joint coupon tests are conducted on steel, stainless steel and aluminum. A series of pull out tess are conducted between CFRP and concrete surface. A comparative study is conducted between bond behavior and debonding characteristics of CFRP and steel, stainless steel and aluminum as well as concrete. The effect of different parameters such as bond length, adhesive thickness, surface treatment and adhesive strain have been identified and investigated. Based on this observation, bilinear bond-slip models have been proposed for CFRP-to-steel, stainless steel, aluminum and concrete interfaces.

2. Matrial Properties

Six materials have been used to prepare the specimens. These are Aluminim, steel, stainless steel, CFRP, adhesive and concrete block as shown in Figure 1. In this experiment, carbon FRP fabrics Kor-CFW450 is used. Kor-CFW450 has fiber strength of 4900 MPa, fiber stiffness of 230 GPa, areal weight of 450 g/m^2, fabric thickness 0.255 mm. CFRP plate Kor-CLS0214 is used in this study has tensile strength of 3000 (MPa), E-Modulus of 165 GPa width 20 mm, and thickness 1.4 mm. Adhesive Kor-CPA 10 Base Resin and hardener used in this research have tensile strength of 49.8 MPa, shear strength of adhesive 29 MPa, Pot Life 70 min. Tensile yield stress is 245 MPa, 434 MPa, and 390 MPa, ultimate stress 268 MPa, 464 MPa, and 450 MPa, initial Young's modulus 68.3, 201.1, and 198.6 GPa for aluminum, stainless steel and mild steel tubular sections, respectively.

Figure 1. Aluminim, steel, stainless steel, CFRP, adhesive and concrete specimen

3. Experimental Program

A series of Butt joint coupon tests are conducted on FRP to steel, stainless steel, aluminum, and concrete interface. A total of 18 coupon specimens are tested considering 3 coupon specimens from each material. Out of 6 specimens, 3 specimens are tested with FRP plates and 3 specimens are tested with FRP fabrics. Six concrete blocks are tested for FRP plate and FRP fabrics interface. Aluminium, stainless steel, and mild steel coupon specimen thickness are 0.80 mm, 0.80 mm and 1.1 mm, respectively. Coupon specimen is prepared from web of the tubular sections according to American and Australian standard. Dimension of the coupon specimen is shown in Figure 2.

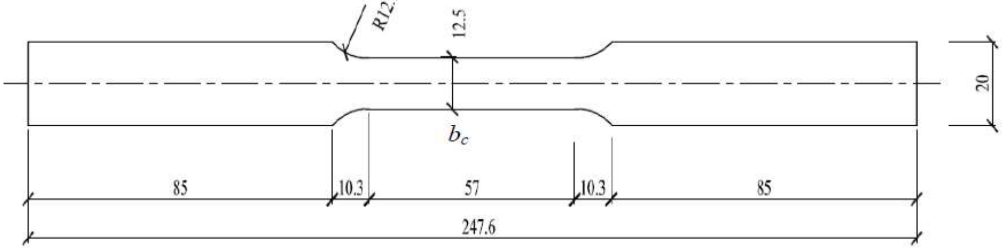

Figure 2. Dimension of coupon specimen

Coupon specimen is cut in middle for butt joint with FRP as shown in Figure 3. Intersected coupon specimen and CFRP attached coupon specimen are shown Figure 3. Surface is treated by grinder machine and then FRP is attached with coupon specimen as shown in Figure 3. Furthermore, concrete section 150 mm × 150 mm in is used with FRP plate and FRP fabrics for bonding and debonding testing.

Test setup for coupon specimens and concrete block specimens are shown in Figure 4. A dial gauge has been used to determine the elongation and the load were obtained from the universal testing machine (UTM). After the completion of setup arrangement, load was applied. From the test setup, it was ensured that the coupon specimen did not slip when load was applied. The total elongation was measured from dial gauge. The original FRP bonded lengths and cross sectional areas of the specimen were measured before the test started.

Figure 3. Intersected coupon specimen and CFRP attached coupon specimen

Figure 4. Test setup for coupon specimen and concrete block specimens

4. Results and Discussion

A series of test of Butt joint coupon tests are conducted on steel, stainless steel and aluminum. A series of pull out tests are conducted between CFRP and concrete surface. The metal specimens were prepared according to the standard specifications. A comparative study is conducted between the bond behavior and debonding characteristics of CFRP and steel, stainless steel and aluminum as well as concrete. Debonding and CFRP delimitations failure mode were observed for CFRP bonded steel-adhesive interface. The comparison of bonding stress between aluminum, stainless steel, steel and concrete are presented in Table 1. Bond stress was found 29.10 MPa, 21.11 MPa, 18.21 MPa and 7.63 MPa for CFRP to aluminum, mild steel, stainless steel and concrete surface, respectively. It is shown that aluminum surface takes higher load for debonding compared to others surfaces. Bonding stress of FRP-aluminum interface is higher than other mild steel, stainless steel and concrete surface. Aluminum surface properties, physical bonding, chemical bonding and mechanical interlocking bonding with CFRP is quite better and concrete. Bond-slip curve for FRP-aluminum, stainless stress, and mild steel and concrete surface is presented in Figure 5. Bonding of FRP fabric performance was quite better than FRP plate. Concrete surface was weakest performance of bonding FRP. Slip was varied 0.27mm to 0.42 mm. Based on the experimental observations and results, bilinear bond-slip models have been proposed for CFRP-to-steel, stainless steel, aluminum and concrete interfaces as shown in Fig. 5.

Table 1. Comparison of bonding stress between aluminum, stainless steel, steel and concrete

Material Descriptions	**Specimen Designation**	**Bond Stress (MPa)**	**Slip (mm)**	**Type of Failure**
Aluminum	AL$_1$FP$_1$	28.63	0.27	Deboning & CFRP
Aluminum	AL$_2$FW$_2$	29.10	0.35	Deboning & CFRP
Stainless Steel	SS$_3$FP$_3$	17.22	0.26	Deboning
Stainless Steel	SS$_4$FW$_4$	18.21	0.34	Deboning
Mild Steel	MS$_5$FP$_5$	20.89	0.31	Deboning & CFRP
Mild Steel	MS$_6$FW$_6$	21.11	0.36	Deboning & CFRP
Concrete	CC$_7$FP$_7$	6.90	0.34	Deboning
Concrete	CC$_8$FW$_8$	7.63	0.41	Deboning

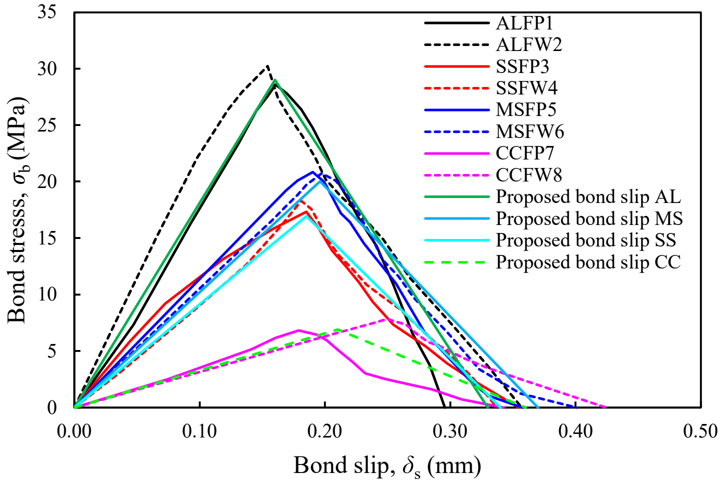

Figure 5. Bond-slip curve for FRP- aluminum, stainless stress, mild steel and concrete surface and proposed bilinear model

5. Conclusions

In this paper the test results from butt joint coupon specimens and pull out test under tension have been presented. A series of butt joint coupon tests have been conducted on CFRP to steel, stainless steel aluminum interface. A series of pull out tests are also conducted between CFRP and concrete surface. Debonding and CFRP delimitations between CFRP and subtrade interface failure mode were found in the coupon tests. The comparison of bonding stress between aluminum, stainless steel, steel and concrete is presented. It is shown that aluminium surface can carry higher load for debonding compared to mild steel and stainless steel and concrete surface. The bonding stress FRP-aluminum inface is higher than other mild steel, stainless steel and concrete surface. The bond-slip curve for FRP- aluminum, stainless steess, mild steel and concrete surface is presented. Based on the experimental observations and results, a bilinear bond-slip models have been proposed for CFRP-to-steel, stainless steel, aluminum and concrete interfaces.

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