FRPRCS-14, Belfast - June 2019

Bond Performance of GFRP Rebars Embedded in High Volume Fly Ash Concrete

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Abstract

This study assess the bond strength of GFRP rebars in compared to that of mild steel. Two types of concrete were implemented, conventional concrete (CC) and high volume fly ash concrete (HVFAC). Cement replacement with ASTM type C fly ash at level of 70% (by weight) was used. Sixteen specimens were tested under the effect of pullout following the recommendation of RILEM. Two sizes of rebars were used; 13 mm (1/2 in.) and 19 mm (3/4 in.). Fresh and Hardened properties of the mixtures were observed. The test results showed that, in both conventional and high volume fly ash concrete, the bond strength of mild steel rebars were higher than those from GFRP rebars.

Keywords: Glass fiber (GFRP), Conventional Concrete, High volume fly ash concrete, bond strength

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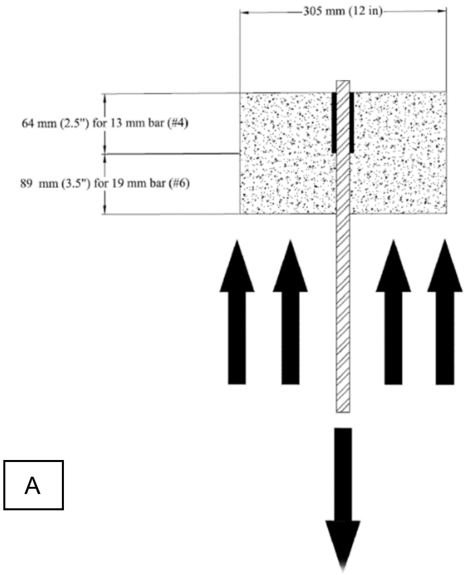
Introduction

One of the main issues of mild steel reinforcement is corrosion. Corrosion, if neglected, can lead to a structural deficiency of the corroded-reinforcement member. Therefore, repairs need to take place. In addition to the structural damage, corrosion repair is considered costly [1]. Glass fiber is considered one of the solutions due to its high resistivity to corrosion. On the other hand, cement is considered one of the main sources of CO_2 emission, therefore finding other alternatives to lessen the emission has been a must [2]. One of these alternatives is fly ash. Fly ash is a by-product of coal-burning of thermal power stations [3]. Per ASTM C618-08, primarily, there are three kinds of fly ash products: class C, F, and N. They differ between each other by the chemical compositions [4]. There has been a limited amount of research conducted on HVFAC concrete, most of the work was limited to 20% and 30% cement replacement with fly ash. Naik et al. [5] performed a pull-out test involving 10%, 20%, and 30% of cement replacement with fly ash and they concluded that the bond strength increased with increasing the fly ash percentage up to 20% maximum. On the other hand, conventional concrete and glass fiber bond performance has been evaluated by several researchers. Zenon et al. [6] performed a pull-out test on cube specimens. They involved several kinds of fiber reinforced polymers including glass fiber rebars and concluded that the bond strengths of the glass fiber was close to those resulted from mild steel rebars. In this study, 70% cement replacement with fly ash was evaluated using GFRP and mild steel rebars. Two rebar diameter were used, 13 mm (1/2 in.) and 19 mm (3/4 in.).

Experimental Work

Several methods can be implemented to study and evaluate the bond performance between concrete and reinforcement, including pull-out, beam-end specimen, and beam splice. In this study, pull-out test was selected to evaluate the bond performance of cylinder concrete specimens. ACI-408 does not recommend this test to determine development lengths. However, the test is valid when it comes to evaluating the relative performance between different types of concrete and reinforcing rebars [7, 8]. RILEM 7-11-128 [9] was implanted to design the pull-out specimens. The length of embedment of the reinforcement was ten times the rebar diameter. The debonded rebar length was half the embedment length. This length was implemented to ensure the dominant type of failure is pull-out and not splitting. Polyvinyl chloride pipe (PVC) was used to cover the needed debonded section of the rebar. RILEM's cover requirement was maintained with a total specimen diameter of 305 mm (12 in.). A sketch of specimen with applied forces is shown in Fig. 1A.



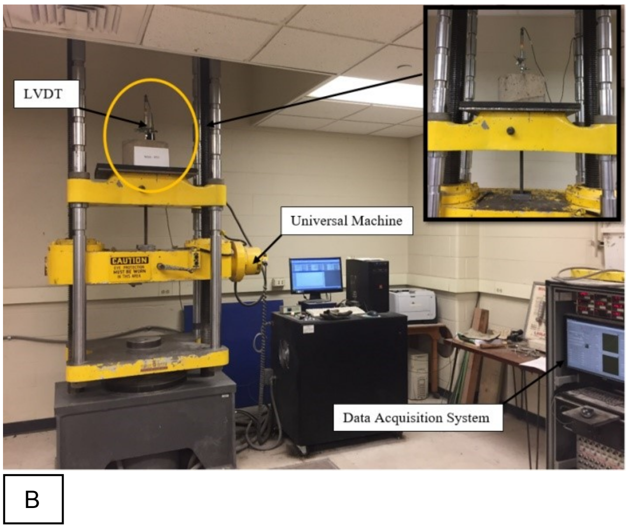


Fig.1: (A) Specimen's Forces and Dimensions, (B) Test setup

Material and Mixture Properties

ASTM class C fly ash and ASTM type I/II Portland cement were implemented in this study. The source of fine aggregate was natural sand and the coarse aggregate's source was crushed dolomite, 19 mm (0.75 in.) size. The steel rebars utilized were 13 mm (1/2 in.) and 19 mm (3/4 in.). They had a yield strength of 414 MPa (60 ksi). Their rib spacing, height, and relative area were in match with the ASTM A615-09 requirements [10]. On the other hand, the GFRP rebars were 100 Aslan from Owens Corning [11] and were made following the ASTM D7205 standards [12]. The same sizes used for the steel rebars were also used for the GFRP rebars. The targeted concrete compressive strength was 35 MPa (5 ksi). The concrete mixtures are shown in Table 1. Besides the cylinder pull-out specimens, quality control cylinders were taken at the time of the mixing and were then tested for compression at ages of 3,7,28, and 56 days. They were also tested for tension at ages of 28 and 56 days following the ASTM C39 and C496 recommendations [13][14]. The pull-out specimens were tested at an age of 56 days. For GFRP specimens, steel sleeve were provided at the grip location to avoid grip slippage and/or rebar crushing when the test is executed.

Table. 1: Concrete mixture proportions

Mix	Water kg/m^3 (lb/yd^3)	Cement kg/m^3 (lb/yd^3)	Fly Ash kg/m^3 (lb/yd^3)	Fine Aggregate kg/m^3 (lb/yd^3)	Coarse Aggregate kg/m^3 (lb/yd^3)	Air-Entraining Additive g/ml (lb/gal)
CC	176 (297)	449 (756)	0 (0)	657 (1107)	993 (1674)	161 (1344)
70% HVFAC	176 (297)	128 (216)	320 (540)	657 (1107)	993 (1674)	161 (1344)

Setup and Procedure of the Experiment

A-890 kN (200 kips) universal machine was utilized to perform the pull-out test. The specimens were flipped upside down (the rebar facing downward) and were then placed on top of a thin rectangular-shape rubber plate to make sure the specimens were situated evenly. One linear variable differential transformer (LVDT) was placed on top of the specimens where its measuring tip was positioned right on the middle of the rebar's unclamped end. A loading rate of 2.5 mm/min (0.01 in./min) was employed to ensure enough data points were stored and to exclude any dynamic effects. The specimens were loaded in tension to its maximum capacity. After that, the load was kept on going to gain enough data points to draw the load-slip curve. The test specimen and the setup are depicted in Fig. 1B.

Experiment Results

The same type of failure was experienced by all the specimens which it was rebar slippage. The results are shown in Table 2. The tested compressive strengths were normalized as they were different from the design ones. ACI 318-14 recommends that the bond strength normalization is done using the inverse square root of the designed and tested compressive strength of concrete. On the other hand, ACI 408R recommends the forth root instead of the second one. The bond strength was higher when the conventional concrete was used, because conventional concrete had higher compressive strengths than those of HVFAC. However, when 13 mm steel rebars were used, the bond strength was higher in the HVFAC. Possibly, in small diameter ribbed rebars, the mechanical bond has a better interlock with HVFAC.

Regardless the type of concrete, the bond strength resulted from using mild steel rebars were higher than those resulted from using GFRP rebars due to, possibly, the higher mechanical bond provided by the ribbed surface of the steel rebars. In addition, regardless of the rebar size, for steel as soon as the bond strength reached its peak capacity, a significant decrease occurred on the bond-slip curve which was then followed by a gradual and steady decrease in the load slip curve until total slippage occurred. For GFRP, the bond strength was steadily declining throughout the loading process with no sudden ups and downs. This steady mode of slippage could be due to the effect of GFRP rebar's sand coating, as even though they are much smaller than the ribs of steel rebars, referring to the size of interlock, they are way outnumbered than the steel ribs. As a result, having a sand-coated surface reduces the size of the fractured (cracked) area of concrete surrounding the rebar and thus drives the loss of bond strength to be steadier than that resulted from using ribbed rebars such as steel rebars.

Table. 2: Pull-out test results

<table>
<tr><th>Concrete Type</th><th>Rebar Size (mm)</th><th>Rebar Type</th><th>P (kN)</th><th>f'c test (MPa)</th><th>P/(f'c design/f'c test)^0.5 (MPa)</th><th>P avg. (kN)</th><th>COV . (%)</th><th>P/(f'c design/f'c test)^0.25 (MPa)</th><th>P avg. (kN)</th><th>COV. (%)</th></tr>
<tr><td rowspan="8">CC</td><td rowspan="4">#13</td><td rowspan="2">Steel</td><td>66</td><td rowspan="2">37</td><td>69</td><td rowspan="2">65</td><td rowspan="2">8</td><td>67</td><td rowspan="2">64</td><td rowspan="2">8</td></tr>
<tr><td>59</td><td>61</td><td>60</td></tr>
<tr><td rowspan="2">GFRP</td><td>54</td><td rowspan="2">37</td><td>56</td><td rowspan="2">50</td><td rowspan="2">14</td><td>55</td><td rowspan="2">50</td><td rowspan="2">14</td></tr>
<tr><td>44</td><td>45</td><td>45</td></tr>
<tr><td rowspan="4">#19</td><td rowspan="2">Steel</td><td>171</td><td rowspan="2">37</td><td>177</td><td rowspan="2">165</td><td rowspan="2">11</td><td>174</td><td rowspan="2">162</td><td rowspan="2">11</td></tr>
<tr><td>148</td><td>153</td><td>150</td></tr>
<tr><td rowspan="2">GFRP</td><td>119</td><td rowspan="2">37</td><td>123</td><td rowspan="2">118</td><td rowspan="2">6</td><td>121</td><td rowspan="2">116</td><td rowspan="2">6</td></tr>
<tr><td>103</td><td>103</td><td>103</td></tr>
<tr><td rowspan="3">70% HVFAC</td><td rowspan="3">#13</td><td rowspan="2">Steel</td><td>71</td><td rowspan="2">30</td><td>66</td><td rowspan="2">68</td><td rowspan="2">5</td><td>69</td><td rowspan="2">71</td><td rowspan="2">5</td></tr>
<tr><td>76</td><td>71</td><td>73</td></tr>
<tr><td>GFRP</td><td>34</td><td>30</td><td>31</td><td>33</td><td>8</td><td>33</td><td>35</td><td>8</td></tr>
</table>

			38		35			36		
	#19	Steel	158	30	146	146	0	152	152	0
			159		147			153		
		GFRP	79	30	73	78	8	76	81	8
			89		82			85		
Note: 1 mm = 0.04 in., 1 N = 0.22 lb., 1 MPa = 145 psi										

Conclusions

Corrosion is a serious issue in the civil engineering industry, therefore GFRP rebars have been on a continuous evaluation to see if they can successfully replace steel rebars as a main reinforcement in reinforced concrete structures. On the other hand, the cement-based concrete is not either issueless (it is not environment friendly), thus finding other alternatives have recently become a must. One of these alternatives is fly ash. In this study, a pullout test was conducted following the RILEM recommendation. Two types of concrete used, conventional concrete (CC) and high-volume fly ash concrete (HVFAC). A-70% cement replacement with fly ash was used in the HVFAC. Two sizes of reinforcement were employed. To compare the results, steel rebars were employed as control specimens. It was concluded that the bond strength of the mild steel rebar was higher than the GFRP's one. Also, rebar slippage was the failure mode of all the tested specimens. In addition, it was found, in both steel and GFRP rebars, that the higher the diameter of the rebar, the higher the bond strength.

Acknowledgements

The project was made possible with the financial support received from the ReCAST Tier 1 University Transportation Center at Missouri S&T (USA) and the material donations from Owens Corning. The authors would like to thank the Center for Infrastructure Engineering Studies and the Department of Civil, Architectural, and Environmental Engineering at Missouri S&T for additional support in executing the research study.

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