Experimental Study on Bond Characteristics of Adhering Sand and Ribbed Surface FRP Bars with Concrete

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ABSTRACT

The mechanical performance of fiber reinforced polymer (FRP) reinforced concrete structure is directly affected by the bond behavior between concrete and FRP bars, which is obviously different from steel bars. The bond characteristics of adhering sand and ribbed surface FRP bars (ASRSFBs) and plain FRP bars were investigated in pullout tests and compared to that of ribbed steel bars and plain steel bars, respectively. Results of the tests indicated that ASRSFBs showed good bond capacity with concrete and the bond strength and slip values of the profiled FRP bars were a little lower than that of ribbed steel bars, while the plain FRP bars were proved to be unable to serve as reinforcement owing to far lower bond strength than that of plain steel bars. Moreover, the specimens reinforced with ASRSFBs exhibited a pull-out failure mode, and the adhering sand on the surface of FRP bars were ground into powder-like. Shear slip was found between ribbed protrusion and core fiber of FRP bars, causing longitudinal shear-bond failure. It was concluded that the bond strength was controlled by the type of resin.

INTRODUCTION

The bond characteristics of FRP bars and concrete directly influence carrying capability, crack width and spacing of FRP reinforced concrete member, which are of great importance to determine concrete cover depth and anchorage length [1]. According to previous researches, the main factors that affect bond performance of FRP bars are as followed: concrete strength, bond length, diameter and surface form of bars, etc [2-5]. Different type of fiber, fabrication process and surface treatment

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lead to diverse bond behaviors. The author developed new type adhering sand and ribbed surface carbon FRP bars (ASRSCFBs) and adhering sand and ribbed surface glass FRP bars (ASRSGFBs) cooperating with enterprise and studied their mechanical properties by pullout tests.

**EXPERIMENTAL PROGRAM**

The new ASRSFBs were fabricated by technology of pultrusion processing, and the continuous carbon fibers or glass fibers were bonded with epoxy resin by a certain proportion. A bundle fiber twined around the FRP bar to shape dent thread on the surface, after which adhering sand process was carried out. Plain FRP bars were also studied as a comparison. The fiber volume fraction of ASRSFBs and plain FRP bars was 68% and 45%, respectively. The material properties of diverse FRP bars were listed in Table I.

A total of 20 concrete specimens were tested by symmetrical pullout experiment. Each specimen included a 100 mm concrete cube with a single FRP bar embedded vertically along the central axis. There were 7 specimens embedded ASRSCFB (No. from CF-1 to CF-7), 7 concrete cubes reinforced with ASRSGFB (No. from GF-1 to GF-7), the rest of 6 concrete cubes were equally reinforced with plain FRP bar (No. PF-1 and PF-2), ribbed steel bar (No. RS-1 and RS-2) and plain steel bar (No. PS-1 and PS-2). A 50mm long plastic pipe was embedded at the loaded end to separate the FRP bar and the surrounding concrete in order to eliminate the influence of local compressive stress on the bond performance. What’s more, the free end of FRP bar was anchored with a steel sleeve considering its anisotropy characteristic. Electro-hydraulic servo universal testing machine was used to apply uniform loading.

**TEST RESULTS AND DISCUSSION**

In this section, test results are presented and analyzed in detail with regard to the pullout capacity of diverse specimens. Slippage values at the free end were measured with dial indicator, and the load-slip curve of some specimens were illustrated in Figure1 and Figure2.

**Bond Failure Modes**

As can be seen from Figure1, the specimens embedded ASRSFBs did not appear relative slip at the initial stage of loading, indicating that the applied load was transferred to concrete mainly by the chemical bond action between the FRP bar and the surrounding concrete. By increasing load, a slip appeared and increased linearly, with the chemical bond decreasing gradually. At this stage, both friction against the surrounding concrete and mechanical interlocking contributed to the bond force between FRP bar and concrete. For the new ASRSFBs, it is friction force that plays
TABLE I. MECHANICAL PROPERTIES OF FRP BARS.

| Type of FRP bars | Diameter (mm) | Tensile strength (MPa) | Elongationrate (%) | Elasticity modulus(GPa) |
|------------------|---------------|------------------------|--------------------|------------------------|
| ASRSCFBs         | 9.5           | 1779                   | 1.65               | 136                    |
| ASRSGFBs         | 9.5           | 993                    | 2.31               | 72                     |
| Plain GFRP bars  | 9.5           | 40                     | 2.15               | 40                     |

a relatively major role. By further increasing the applied load up to ultimate load, the load-slip curve showed a significant turning point, and interfacial debonding of surface thread and core fiber emerged with audible crack sound. The slippage displacement developed until FRP bar was pulled out. Eventually, the ASRSFBs exhibited a longitudinal shear-bond failure mode accompanied by exfoliation of surface thread and core fiber.

For plain FRP bars, as presented in Figure2, no slip displacement was observed at the beginning of loading, which was the same with ASRSFBs, demonstrating that bond force was provided by chemical bond before slipping whether plain FRP bars or ASRAFBs. However, the chemical bond force was so small that slip emerged at a low level of load. With the increase of loading, interface slip developed fast due to little mechanical interlocking and friction force. In later period, slip increased more slowly than before as a result of the process of roughening the outside surface of the fiber to increase friction force. Finally, the FRP bar was pulled out.

Comparison with Steel Bars

According to test results, the bond capacity of ASRSFBs was a little lower than that of ribbed steel bars, and the bond behavior of ASRSGFBs was a little less than that of ASRSCFBs. While the bond strength rebound phenomenon of ASRSFBs that results from the adhering sand treatment is superior to steel bars. Researches have proved that strength of concrete has a little contribution to bond strength when FRP bars are pulled out of concrete member [6]. Thus, conclusions can be made that type of resin plays a control role to bond strength, the strength of concrete and type of fiber have a little influence. Therefore, the bond strength of ASRSGFBs and ASRSCFBs is very close to each other although the elastic modulus of CFRP bar is about 2 times as much as GFRP bar.

The bond capability of plain FRP bars was less than that of plain steel bars, which was approximately 40 percent of that of ASRSGFBs. The slip values at peak point were 2.7 times as much as ASRSGFBs. Consequently, the plain FRP bars have no ability to serve as reinforcement.
CONCLUSIONS

A total of 20 pullout test specimens were tested in order to investigate the bond characteristics of ASRSFBs in comparison with the ordinary ribbed steel bars. The main findings obtained from the experimental tests led to the following conclusions:

1. The new profiled ASRSFBs showed good bond performance with concrete. The adhering sand treatment can be an efficient method to enhance the bond capability of the FRP bars in the concrete member. The bond capacity of ASRSFBs is just a little less than that of ribbed steel bars, and slip values at peak point of load-slip curve are a little lower than that of ribbed steel bars.

2. The bond failure of specimens embedded ASRSFBs is caused by interfacial shear slip of surface ribbed protrusion and core fiber of FRP bars with the adhering sand on the surface grounded into powder-like. It is type of resin that dominates the bond capability.

3. The bond property of plain FRP bars is too poor to act as reinforcement bars.

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