PULL-OFF STRENGTH OF THE SPRAYED FRP ON SAND-WATER BLASTED AND WIRE BRUSHED CONCRETE SURFACES

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1 Introduction

For decades, fiber reinforced polymers (FRP) composite materials such as aramid, carbon and glass in sheets or plates form have been used as repair and strengthening materials due to their high strength to weight ratio with excellent corrosion resistance [1].

In recent, several researches on pull-off bond behavior and performance between FRP composites and concrete have been carried out [2, 3, 4]. Maerz et al. [2] has conducted experimental tests to evaluate the performance of the Dallas county bridge in Missouri, USA, by strengthening the bridge with the FRP composites prior to testing [2]. In order to evaluate the long term performance of the strengthened bridge with FRP composites, the pull-off tests were carried out for every 6 months up to date [2]. The results represented that all 10 samples obtained from the pull-off tests to date failed at the FRP sheet and coated epoxy interface [2]. In addition, the average failure loads for the 10 samples were around 43kN [2].

Winters et al. [3] investigated an enhancement in bond strength of FRP composite bonded to concrete structures with partially submerged pillars. Although this study focused on the method itself, they carried out 151 pull-out tests in accordance with ASTM D 4541 [8] by utilizing an Elcometer 106 adhesion tester [3]. A 0.1 × 0.1 m grid was drawn and 83 pulled-out tests were carried out above the waterline and the rest 68 pulled-out tests were conducted below the waterline to evaluate the failure strength of the specimens inside the water which always resulted in lower failure strength [3]. They reported that pressure bagging method had much higher improvement in the bond strength of the FRP-bonded concrete than vacuum bagging method [3]. It was concluded that different methods of securing the FRP on the concrete surface had significant impact on the bond behavior [3].

Al-Salloum et al. [4] carried out a series of experiments including concrete specimens wrapped by CFRP and GFRP systems exposed to high temperature for several hours. They evaluated the bond strength of the FRP-strengthened concrete subjected to elevated temperature environment for possible bond behavior deficiency in accordance with ASTM D 4541-09 standard [8][4]. The concrete specimens with compressive strength of 25 MPa at 28-days were prepared for the pull out test with single layer of CFRP and GFRP systems bonded to the specimens [4]. The results showed that significant loss in the bond strength was observed at a temperature of 200 °C in the case of the specimen strengthened with GFRP system compared to the specimen strengthened with CFRP system [4].

Up to date, no attempt has been made to investigate the pull-off bond strength between sprayed fiber-reinforced polymer (sprayed FRP) and concrete. The technique of sprayed FRP used in this study was firstly introduced from the University of British

Columbia [5, 6]. In this study, the pull-off bond behavior and performance of sprayed FRP on concrete will be evaluated under different concrete surface conditions, with the use of the primer coating on the concrete surface.

2 Experimental study

A series of experimental tests were carried out in accordance with ASTM D 4541-09 standard [8] with four different kinds of bonding conditions which influenced the behavior and performance of the bond strength between the sprayed FRP and concrete [7]. In this study, two different types of concrete surface conditions were prepared before the spraying of the FRP system [7]. The surface treatment of two specimens was achieved by sand-water blasting whereas that of the other two specimens was achieved by wire brushing [7]. In sand-water blasting, fine bits of material particles are sent on to the designated area at high-velocity to clean or etch a surface [7]. For this study, the purpose of the sand-water blasting method was to increase the roughness of the concrete specimen in order to achieve better bond strength between the sprayed FRP layer and the concrete surface [7].

In the case of the specimen with wire brushing surface treatment, the surface seems smoother compared to the sand-water blasted specimen surface [7]. Parts of aggregates cannot be found on the concrete surface with wire brushing and the overall surface roughness is less than sand-water blasted specimen surface [7].

Each of these specimens was applied with and without primer resin to evaluate the effect of primer on bond strength between sprayed FRP and concrete [7]. Details of experimental procedures such as surface treatment and application of primer resin can be found in Ha et al. [7]. Moreover, details of material properties, such as sprayed FRP, primer resin and concrete, and the spraying procedure can be also found in Ha et al. [7]. For this study, a portable adhesion tester was used in accordance with ASTM D 4541-09 standard [9].

Pull-off bond tests were conducted by attaching the loading fixture with an adhesive perpendicular to the surface of the specimen [7]. After the curing of sprayed FRP was achieved, a tension was applied normal to the test surface by gradually increasing the force until either a part of material was detached or a desired value was reached [7].

3 Test result and discussion

In the present study, pull-off bond strength, failure modes of the bonding layer are observed, which includes the influence of the surface conditions and the use of primer resin on the bond strength of the sprayed FRP [7]. Results of the pull-off bond strengths are summarized in Table 1. For the specimens with surface treatment condition of sand-water blasting, pull-off bond strength of sprayed FRP coating without the primer resin was higher than that of sprayed coating with primer resin [7]. With respect to specimens surface treated with wire brushing, the pull-off bond strength of the coating layer without primer resin was higher than that of sprayed FRP coating without the primer resin [7]. From the results, it was found that the pull-off bond strength of sprayed FRP coating without the primer on concrete surface treated by sand-water blasting was highest among the tested specimens [7].

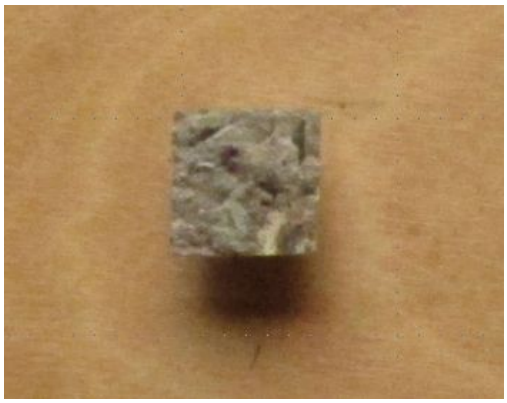
In accordance with ASTM D 7522-09 [10], typical failure modes for composite bonded to concrete substrate are classified as follows: concrete failure, interface failure between sprayed FRP and concrete substrate and mixed mode failure including concrete failure and interface failure [7]. In this study, concrete failure and mixed mode failure are observed as shown in Figure 1 [7]. Figure 1(a) shows a concrete failure which is the desired failure mode, showing a sound spayed FRP-adhesive system [7, 10]. One must note that poor surface preparation of the concrete specimen or initial

degradation can result in low pull-off strength of the mentioned concrete failure mode [10]. Figure 2(b) shows a mixed mode failure type which is known to be commonly observed in pull-off tests. It has been widely reported that in this failure mode, the failure propagates through one side of the fixture such as shown in the bottom left part of Figure 1(b) [10].

Four different kinds of test specimens were used for the testing [7]. Regards to the sand-water blasted surface treated concrete specimens, the one with primer coating resulted in a pull off strength of 3.7 MPa, where the other specimen without the primer coating resulted in 5.7 MPa [7]. In addition, with the wire brushing surface treated concrete specimen, 4.6 MPa pull off strength was observed with the primer coated specimen and 4.8 MPa pull off strength in absence of the primer coating [7].

In the present study, 5 pull-off tests are carried out for each specimen in the present study [7]. These are sand-water blasting and wire brushing surface treated concrete specimens with the application and absence of the primer coating [7]. From the results, 16 pull-off tests (out of 20 pull-off tests in total) resulted in concrete failure with and without the application of the primer coating onto the concrete surface before applying the sprayed FRP layer, while 4 pull-off tests resulted in mixed mode failure without primer coating on the concrete surface [7].

(a) Concrete failure



(b) Mixed mode failure

Figure 1 Failure modes for pull-off bond test [7]

An interesting observation is seen here where the sand-water blast treated specimen resulted in a lower pull-off strength (3.7 MPa) compared to the specimen with the wire brushing surface treated specimen (4.6 MPa) with the application of the primer coating [7]. However, in the absence of the primer coating, the results differ [7]. The sand-water blasting surface treated specimen showed higher pull-off strength of 5.7 MPa compared to the wire brushing surface treated specimen (4.8 MPa) [7]. This is a promising result since sand-water blasting a surface increases the roughness of the surface, thus increasing the contact area for the adhesive layer [7].

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