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Effective Bond Length Evaluation of Fiber Implantation Methods in EBR Applications Using Particle Image Velocimetry

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ABSTRACT: The bond strength between fiber-reinforced polymer (FRP) laminates and concrete is the main factor affecting the behavior of concrete members strengthened by externally bonded reinforcement (EBR) method. The bond strength depends on several factors, such as surface preparation, concrete strength, FRP stiffness and thickness, and effective bond length. According to previous studies, using a bond length longer than the effective bond length, will not increase load-carrying capacity. Most existing theoretical models estimate bond strength based on the effective bond length. So, in order to achieve a satisfactory performance, it is important to determine the accurate value for the effective bond length of lap joints. In this study, in order to evaluate and compare the effective bond length of fiber implantation method and the conventional EBR method, 12 concrete specimens were prepared and examined. The effective bond length and the bond strength of specimens were determined using single-shear pull test and adopting particle image velocimetry (PIV) method and they were compared with the existing specifications such as ACI and fib. The results showed that using fiber implantation method instead of the conventional EBR method reduced the effective bond length by 20% and increased the bond strength between FRP and concrete substrate by 34%.

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1. INTRODUCTION

Determination of bond strength between FRP laminates and concrete is one of the important issues in the field of concrete members strengthening using FRP laminates [1, 2]. According to previous studies, the bond strength depends on several factors, such as surface preparation, concrete strength, FRP stiffness and thickness, and effective bond length [3, 4]. Increasing the bond length at first increases the load-carrying capacity, but beyond the effective bond length, cannot improve the capacity and prevent the FRP debonding from the concrete substrate. This has led many researchers to come up with methods for removing the phenomenon of FRP debonding and increasing the bond strength in the EBR method [5, 6].

2. METHODOLOGY

One method recently proposed by researchers to address the premature debonding of FRP laminate from the concrete substrate after exposure to elevated temperature is fiber implantation [7]. In order to prepared the specimens, first the holes with a diameter of 10 mm and a depth of 40 mm were drilled into the concrete, 50 mm apart and after cleaning inside the holes with the compressed air, carbon fiber strands with the length 80 mm are implanted inside the holes using epoxy resin so that half of their length buried inside the hole and other half stayed outside. Then, the free part of the strand was bent and adhered to the concrete surface in the direction of the applied tensile load. Finally, one layer of carbon fabric with 50 mm width was adhered to the concrete surface using epoxy resin with wet layup procedure on top of the implanted strands in order to develop a better bond.

In this research, four groups of specimens were prepared in order to evaluate the effect of fiber implantation method on reducing the effective bond length and improving the bonding behavior between concrete and FRP laminate. Two groups were prepared in conventional methods (sandblasting and wire brushing) and the other two ones were prepared with fiber implantation methods (with and without surface preparation). It should be noted that in this research, the effective bond length and bond strength of the specimens were obtained by using single-shear pull test and using particle image velocimetry (PIV) method.

3. RESULTS AND DISCUSSION

3.1. Bond strength and failure modes

According to the results, the average bond strength of wire-brushed and sandblasted specimens did not vary significantly and in agreement with the value obtained from the Chen and Tang model. Also, the failure mode of all specimens prepared by these two methods was FRP debonding from the concrete substrate. This is despite the fact that the specimens prepared by fiber implantation method, compared with the specimens prepared by conventional methods, had a 34% increment in

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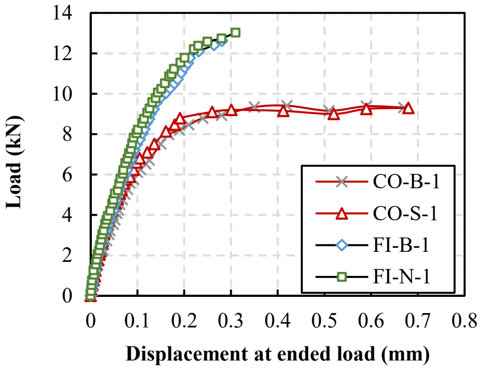

Fig. 1. Load-displacement curves of specimens

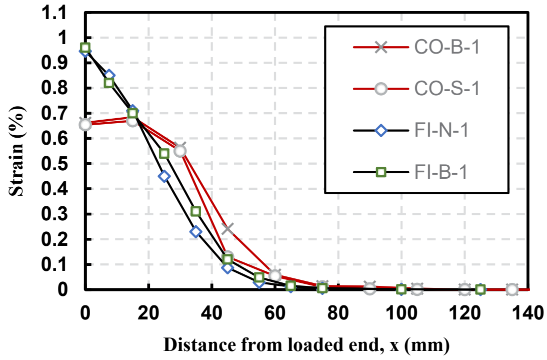

Fig. 2. Longitudinal strain profile of specimens

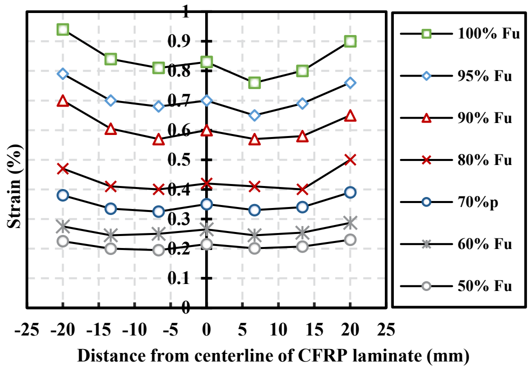

Fig. 3. Strain profiles along the width of FRP laminate corresponding to different load levels for fiber implanted specimen

bond strength, and the failure mode of all specimens was FRP rapture.

3.2. Load-displacement behavior

Load-displacement curves of wire-brushed and sandblasted specimens showed similar behavior. As shown in Figure 1, first by increasing the load, the displacement was increased proportionally and after reaching to about 95% of the ultimate load, the rate of the increase in displacement significantly increased.

The load-displacement curves of fiber implantation specimens showed different behavior. So that, the slope of the curves from the beginning until the moment of failure was almost constant and the value of this slope was greater than the initial slope of conventional specimens' load-displacement curves, which indicates the more stiffness of this method (see Figure 1).

3.3. Longitudinal strain profile

By examining the longitudinal strain profiles of conventional specimens, it can be observed that the applied force to CFRP laminate was transferred to the concrete block in the length of about 75 mm (close to the effective bond length obtained by Chen and Teng's equation: 73 mm).

Also, by examining the longitudinal strain profile of fiber implantation specimens, it can be observed that, the effective bond length for these specimens was about 60 mm (20% less than the specimens prepared by conventional methods), while the ultimate load in these specimens was 34% more than conventional specimens (see Figure 2).

3.4. Transverse strain profile

As shown in Figure 3, the strain distribution along the width of the FRP laminate was almost constant (especially in loads below 90% of the final load). This result shows a uniform transfer of load from a single-shear test device to FRP laminate (minor differences can be due to the difference in the thickness of the FRP laminates in wet layup systems). Also, the transverse strain profile of fiber implantation specimens showed that the strain on the two edges of the FRP laminate was relatively greater than the middle region, due to the lesser bond strength in these regions.

4. CONCLUSIONS

Based on the experimental and PIV analyses results of the current study, the following conclusions could be drawn:

- Average bond strength and effective bond length of a specimen prepared by wire brushing and sandblasting methods did not vary significantly and they were in the value obtained from the Chen and Tang model (ACI specification). The difference between the values obtained from the experimental and computational results was 4% and 3% for the bond strength and effective bond length, respectively. Therefore, the use of sandblasting and wire brushing methods have not significantly differed in the bond capacity.

- The failure mode of all specimens prepared by wire brushing and sandblasting methods was the premature debonding of FRP laminate from the concrete substrate. However, in fiber implantation method due to the transfer of stress to the concrete depth, the good bond strength between FRP laminate and concrete was achieved, and the failure mode of all specimens prepared by this method was FRP rupture. Therefore, the use of fiber implantation method instead of conventional methods can be a good method to remove the premature debonding of FRP laminate from concrete substrate.
- The effective bond length of specimens prepared by fiber implantation method was 20% less than the specimens prepared by conventional methods and the bond strength of specimens prepared by fiber implantation method was 34% more than the specimens prepared by conventional methods. Therefore, the fiber implantation method compared to conventional methods transmits more load in a less bond length from FRP laminate to concrete.
- The bond strength and effective bond length of specimens prepared by fibers implantation method in both series with and without surface preparation showed similar results. Therefore, in fiber implantation method, no surface preparation required and it was possible to remove the premature debonding of FRP laminate from the concrete substrate only by fiber implantation and surface preparation operations and achieve the maximum capacity of the FRP laminate.

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