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EFFECT OF U-SHAPED GFRP SHEAR KEYS ON THE BOND BETWEEN GFRP PLATE AND CONCRETE

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Abstract- The role of the bond between fiber-reinforced polymer (FRP) interface and concrete carries a key role for an interface-concrete composite structure. Various researches are conducted to study the effectiveness of different techniques for improving the bond between the FRP strips and concrete. The current study evaluates the effectiveness of the new type of U-shaped GFRP shear key on the bond between the GFRP plate and concrete. Specifically, double-lap shear tests are conducted on specimens with GFRP shear key bonded GFRP plates to evaluate the rupture modes, the extreme load, the stiffness of interface (interfacial), and curves with load on the y-axis and slip on the x-axis for static loading. The tests are conducted on the double-lap shear specimens sized 514 mm x 100 mm x 100 mm. The bond length (222.5 mm) of the GFRP plates is kept higher than that of the effective bond-length bonded with Type A epoxy resin. C60 concrete having 184 kg, 392 kg, 660 kg, 1214 kg, and 2.94 kg of water, cement, sand, aggregates, and water reducer, respectively per $1m^3$ of the mix is used. The influence of the shear key and its position variation i.e. 80 mm and 160 mm from the loading end is evaluated in comparison to the GFRP-concrete double-lap shear specimen without a shear key. The use of shear keys along with the interface imparts significant enhancement in the bond between the concrete and GFRP plate. Shear key located at 80 mm from loaded end performed well as compared to that at 160 mm in increasing bond strength between concrete and GFRP plate. It can be concluded that the gap between the shear key and loading end also has a considerable effect in increasing the bond between concrete and GFRP plate.

Index Terms- GFRP Shear key, interfacial bond, GFRP plate, concrete

I. INTRODUCTION

Fibre Reinforced Polymer (FRP) has noticeable benefits such as high resistance to corrosion, fatigue, lightweight resistance, and huge strength. Being a structural material, it can be the best choice as an alternative to steel. One of the effective ways to get rid of issues due to corrosion of steel in a severe environment is to use FRP [1]. Advantages of the FRP-concrete composite structure encompass a higher level of industrialization, lightweights, elevated strength, design versatility, and zero corrosion as compared with structures of the traditional materials [2-4]. Therefore, the application and development of FRP materials with ultra-high durability and reinforced concrete composite structures are getting more attention.

Interface bonding between concrete and the FRP plate has the role of a medium for load transmission from concrete to FRP plate. Therefore, interface bonding has a key role in increasing the strength of concrete by the FRP plate. Studies showed that the interface was prone to interfacial peeling and slippage during the application of load, which affected the shear resistance of the interface of the composite structure, resulting in premature separation of FRP materials and concrete and not able to fully exercise their full mechanical strengths [5-7].

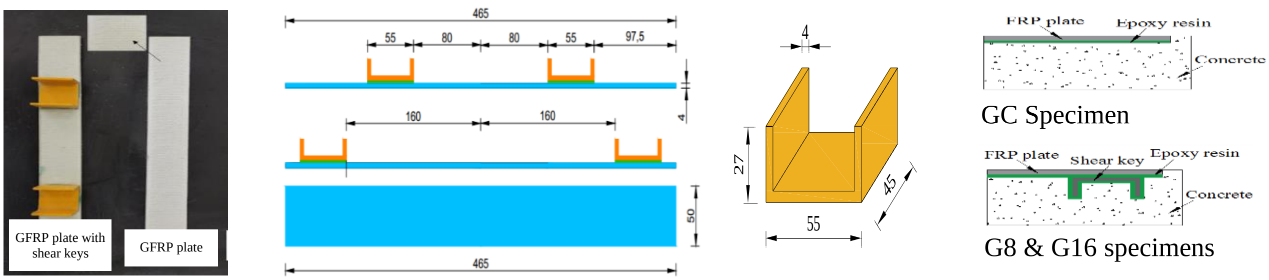
Numerous researches are conducted so far related to the mechanical characteristics of the FRP-concrete composite interface. The shear mechanical and shear properties of the FRP-concrete interface were investigated for the three types (i. bolted, ii. Hybrid, and glued) of connections [8]. The best shear resistance was noticed for the hybrid connection along with an increase in extreme load capacity with an increase in the number of bolts. The use of a shear key (SK) with an interface of FRP and concrete was also noticed to be an adequate interface type of combination for improving the bond strength between concrete and FRP plate [9]. But the reported studies are limited to the dry bond interface only.

Consequently, in the current study, double-lap shear tests are performed on specimens with GFRP shear key bonded GFRP plates. The outcomes are reported in the modes of failure, the ultimate capacity of load, the interfacial stiffness, and the curves of load vs slip for the static loading.

II. EXPERIMENTAL PROGRAM

A. Materials

P.O.42.5, an Ordinary Portland cement [10] is used. The maximum size of gravel and river sand is 20 mm and 0.5 mm, respectively. Glass fiber reinforced polymer (GFRP) plates having unidirectional fibers with transverse surface mats are used. The nominal thickness and width of the GFRP plate are 4 mm and 50 mm, correspondingly. The tensile strength, Young's modulus, and Limit elongation of GFRP plates measured as per the appropriate standards of China [11] are 516 MPa, 33 GPa, 1.60 %, respectively. The U-shaped GFRP shear keys are used having a size of 55 mm × 45 mm× 27 mm × 4 mm. Fig. 1 presents GFRP plates, locations of shear keys on the plates of GFRP, size of the shear key, and schematic view of an interface for each type of specimen. For increasing the force of anchoring, the area of contact between the plates of GFRP and shear keys is roughened and then epoxy resin is used for pasting the shear key on the exact locations of the GFRP plate. The adhesive bond between GFRP shear keys and GFRP plates is increased by keeping a steel block on the top of GFRP shear keys for 7 days. The Tensile strength, Modulus of elasticity, and Limit elongation of epoxy resin named as Type A measured as per the appropriate standards of China [12] are 34.7 MPa, 2.42 GPa, and 2.71%, correspondingly.



(a) (b) (c) (d)

Fig.1 (a) GFRP plates, (b) locations of the shear keys on the GFRP plates, (c) Shear key size, and (d) schematic view of the interface

B. Casting and testing procedure

A typical preparation procedure is shown in Fig. 2. The specimens are cured in the standard room of curing by following the concerned standard of China [13]. Curing is carried out for 28 days. The average compressive strength of C60 concrete measured as per the relevant standard of China [14] is 72.0 MPa.

(a) Preparation of WB interface specimens (b) Preparation of SK interface specimens (c) Concrete casting (d) Concrete curing

Fig. 2 Preparation procedure of test specimens

C. Nomenclature of specimens and loading scheme

Three samples are tested for each type of specimen. An average of three results is taken as a corresponding property for each type of specimen. The control specimen without a shear key is named GC while the specimen with the shear key at 80 mm from the loading end is named as G-8 while that of other with 160 mm distance from the loading end is named as G-16. Total 9 number of samples. Universal testing machine with 100 kN capacity is used for Double lap shear tests, as revealed in Fig. 3.

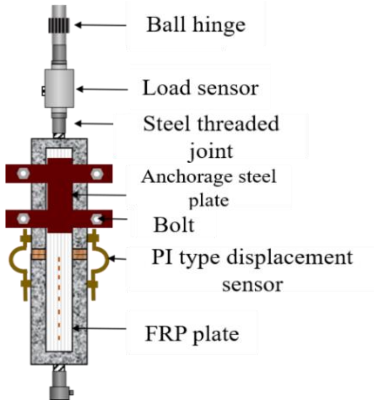


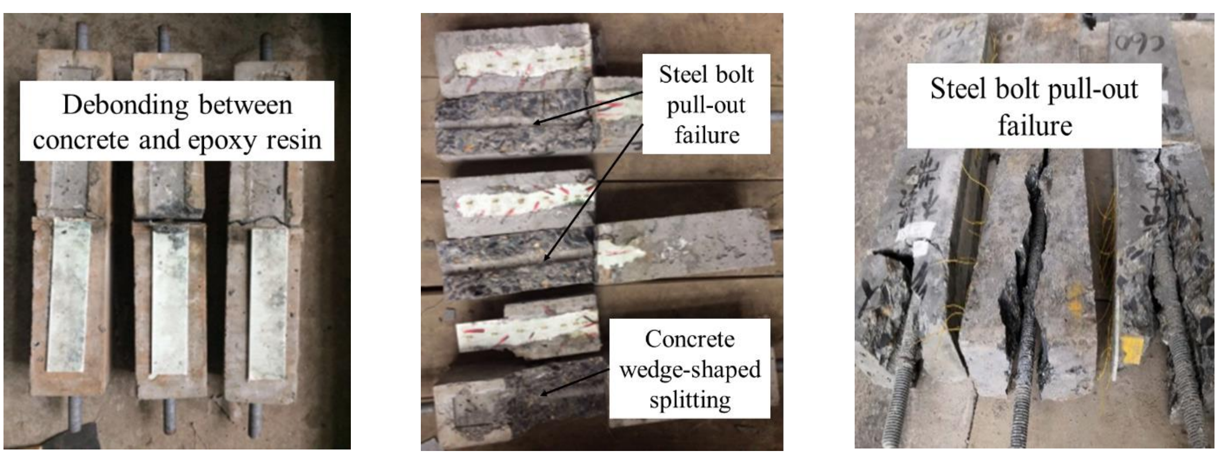
Fig.3 Graphic illustration of the loading device

III. TEST RESULTS AND ANALYSIS

A. Modes of failure

Three different modes of rupture are observed for the specimens:(1) Detach between the layer of the epoxy resin and the coating of concrete as a result of the deficient union of the interface of epoxy resin and concrete, (2) Pull-out of steel bolt happened for the reason that the force of fastening between concrete and the steel bolt was less in comparison to that of the bearing strength of the interfacial, and (3) Failure due to wedge-split of concrete between the wooden partition and shear key, the possible reason may be smaller concrete's tensile strength as compared to the interfacial bearing strength attributable to the high concentration of the stress between wooden partition at the loading end and GFRP shear key. The same observations were reported in other research studies [7,15].

Figure 4a displays the rupture mode noticed for the CG specimen, which was categorized by interfacial peeling amid the FRP plate and epoxy resin. It shows that full transfer of the load between the concrete and GFRP plate is not achieved due to pre-mature peeling of the GFRP plate. Shear key fail failure for one sample and steel bolt pull-out failure for two samples accompanied by the wedge-split of the concrete are observed for G8 specimens (with the shear key at 80 mm from the loaded end) as shown in Figure 4b. This supports the role of the shear key in utilizing the greater strength of the GFRP plate in supporting the applied loads and moments in addition to concrete without debonding. The rupture mode of the specimen (G16) having shear key distance at 160 mm is the failure of due to pull-out of steel bolt without any damage to the shear key as shown in Figure 4c. Pull-out of steel bolt is noticed, which could be described that the force of fastening between concrete and steel bolt was feebler as compared to the interfacial bearing capacity. And the wedge-split breaking of the concrete between the wooden partition and the shear key happened.



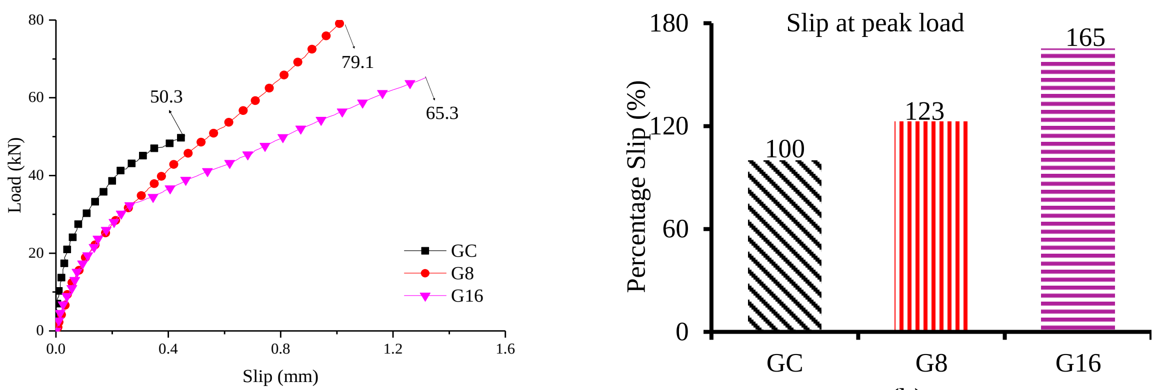
(a) CG (b) G8 (c) G16

Fig. 4 Interface failure modes of four interface of GFRP plate specimens

B. Load-slip curves

The load vs slip curves of each test specimen are given in Figure 5(a). The interface anti-slip stiffness can be judged and compared by the slope of the initial elastic phase of the load-slip curve. The lowest slip of 0.8 mm is noticed for the epoxy resin GC specimen having GFRP plates without any shear key. While the slip for the G8 and G16 specimens having GFRP plates containing resin of epoxy on the bonded interface with the shear key is 0.98 mm and 1.32 mm, respectively. By equating the load carrying capacities, G8 outperformed the companions in increasing the load carrying capability of the specimen. The peak load of the G8 is 28.8 kN and 13.8 kN more than that of the GC and G16, respectively, as shown in Figure 5(a). The percentage comparison of the slip at peak load are shown in Figure 5(b). The slip at peak load of G8 and G16 is 23% and 65%, respectively greater than that of the GC.

GC specimens provided a satisfactory level of composite action. For G8 and G16, the bond of the FRP plate and shear key can be more fragile as compared to that exists between concrete and the FRP plate, which leads to a decline in the interfacial stiffness. Conclusively, the rate of slip increased for the shear key specimen with a low gradient of the primary elastic phase of the load-slip curve in comparison to that of the GC specimen. A variation in the positions of the shear key has tiny influence over the interfacial stiffness of the elastic phase. But the larger effect in the post-elastic region of the curve. It can be explicated that a smaller distance from the loading end was expected to produce a huge concentration of stress between the loaded end and shear key, and at a larger distance from the loading end do not effectively limit the interfacial detachment.

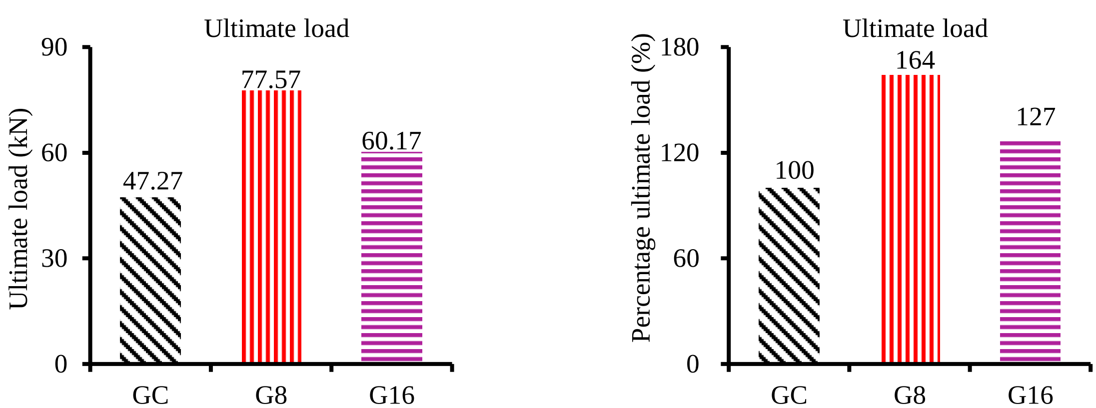


(a) (b)

Fig. 5 (a) Load-slip curves, (b) Percentage comparison of slip at peak load

C. Extreme load capacity

Figure 6(a) displays the extreme load capacity of the specimens. The extreme load of 47.27 kN, 77.57 kN, and 60.17 kN are observed for GC, G8, and G16, respectively. The extreme load of the G8 is 30.3 kN and 17.4 kN larger than that of the GC and G16, respectively. It is observed that the shear key enhanced the extreme load capacity significantly as compared to that of the specimen without a shear key.



(a) (b)

Fig. 6 Ultimate loads (a) extreme load capacity (b) Percentage comparison of extreme load capacity

Most importantly the shear key gap from the loading end also affected the load carrying capacity. It can be observed that the extreme load capacity of the GC and G16 is considerably lesser as compared to that of the specimen (G8) with a shear key located at 80 mm from the end of loading. The percentage comparison between the extreme load of the specimens is demonstrated in Figure 6(b). The extreme load-carrying capacity of the G8 and G16 is 64% and 27% greater than that of the GC. Variation in the shear key location showed a significant impact on the extreme load capacity of the specimen. An increase in the gap of the shear key from the loading end negatively affected the extreme load capacity of the specimen, indicating a decrease in the bond strength. This confirms that the distance of the shear key from the loaded end also needs to be considered to ensure better bonding between the interface and GFRP plates for attaining the required increase in strength. As per the considered case, the gap of the shear key from the loading end is inversely proportional to the bond strength between concrete and the GFRP plate.

IV. CONCLUSIONS

Subsequent conclusions are made from the present experimental results:

- Interfacial peeling (premature detachment) between the GFRP plate and epoxy resin is noticed for the specimen without GFRP shear key while the introduction of shear key helped in utilizing the full strength of the GFRP plates without any interfacial peeling and interface failure.
- At the peak loads, the slip of 0.8 mm, 0.98 mm and 1.32 mm are noticed for the GC (GFRP plates reinforced specimen without shear key), G8 (GFRP plates reinforced specimen with the shear key at 80 mm from the loaded end), and G16 (GFRP plates reinforced specimen with the shear key at 160 mm from the loading end), respectively.
- The extreme load-capacity of G8 and G16 is 64% and 27% greater than that of the GC

The experimental outcomes showed significant improvement due to the use of GFRP shear keys along with the interface of GFRP plates in the extreme load capacity and capacity of the peak load of the double-lap shear specimen. Besides, pre-mature debonding of GFRP plates is also prevented by GFRP shear keys. Conclusively, the shear keys improved the bond between concrete and the GFRP plate. Further investigations are required to evaluate the optimized location and size of the GFRP shear keys for attaining the maximum possible strength enhancement.

V. ACKNOWLEDGMENT

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