Experimental Analysis on the Interface Bond Strength Between Old and New Concrete

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Abstract

The Reinforced Concrete (RC) jacketing technique is a widely adopted method for retrofitting, strengthening, and rehabilitating structural elements of RC structures. It involves applying a new layer of concrete over an existing layer previously composed of broken brick and natural stone aggregate with similar properties. Achieving monolithic action necessitates a comprehensive understanding of the bond behaviour at the interface between aged and newly cast concrete. This study also underscores the significance of considering the type of aggregate used in concrete. It evaluates the bonding between stone aggregate and brick aggregate, crucial for practical scenarios where both combinations are prevalent. The research focuses on investigating the influence of surface roughness and pre-wetting on bond behaviour at the interface of brick aggregate concrete. These factors are examined to elucidate their impact on monolithic performance at the joint between old and new concrete. Pre-wetting and surface roughness, due to their similar textures and potential for promoting monolithic bond formation, are found to enhance bond strength. Notably, chipping the surface after 24 hours of pre-wetting led to a significant increase in bond strength, with the direct shear test showing a 105% improvement and the slant shear test reporting a 32.5% increase compared to normal circumstances.

Keywords: Bond strength; Monolithic performance; pre-wetting; interfacial bond; surface roughness

1. Introduction

In many construction scenarios, such as rehabilitation, restoration, strengthening, and the construction of precast or cast-in-situ buildings, connections between concrete layers of varying ages are frequent. Due to the composite elements these connections produce, their interfaces must have a strong enough bond. Branco et al. [1] assert, however, that the transfer of shear loads between two concrete layers is a complicated phenomenon impacted by a number of factors. A few of these features include pre-wetting of surface, roughness of surface, bonding chemical or adhesive, existence of hair or micro cracks, shear connectors, density, curing, and the mechanical properties like compressive strength, tensile strength, etc. of the concrete. Santos [2] emphasizes the existence of a large number of design phrases that may be found in different papers, model codes, and norms as a result. The pre-wetting of the surface, roughness of the surface, bonding chemical or adhesive, presence of hair or microcracks, shear connectors, density, curing, and properties like compressive and tensile strength of the concrete have all been identified as influencing factors in previous researches [1-6]. Any repair or strengthening system throughout its service life must have an adequate bond strength between the substrate and overlay interface. Bond strength and the distribution of stresses can both be impacted by variations in material properties, including shrinkage, elastic modulus, and thermal mobility. The substrate, the overlay, and bond zone constitute the three components of the retrofitting or strengthening system, which can be thought of as a composite system with multiple phases [4], [5]. The area around the bond plane's interface, which is responsible for withstanding applied pressures, is incorporated in the bond zone. Pre-wetting conditions, bonding chemicals, surface roughness, steel connectors, and the presence of micro cracks on the substrate surface are just a few of the variables that might affect the bond strength and integrity. Although steel connectors are often recommended, their effectiveness is limited once slip occurs between the interfaces. Therefore,

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http://dx.doi.org/10.1016/j.cviu.2017.00.000.

the bond behavior between the interface surfaces is more crucial than the presence of steel connectors or keys. In the current study, the authors used both stone and brick aggregate concrete and performed the slant Shear and direct Shear tests on specimens with different interface circumstances (New casting with no treatment, surface roughening by chipping, surface roughening by wire brushing, pre-wetting of the treated surface for 0, 8, 16 and 24 hrs).

2. **Experimental program**

2.1. Materials

Using brick chips as the coarse aggregate with a mix ratio of 1:1.5:3, the average compressive strength of the slant specimens (substrate) was found to be 30 MPa, and the w/c ratio was 0.45. Contrarily, the overlay concrete, which was constructed using brick chips and a mix ratio of 1:1.25:2.5 and a w/c ratio of 0.40, had a compressive strength of 40 MPa. The compressive strength was determined to be 32 MPa in cases where stone aggregates were employed in the overlay, while maintaining the same mix ratio and w/c ratio. Following the similar mixing procedures, the samples were cast with half of their portion in 100 mm × 200 mm cylinders for the direct shear test. Twelve samples with dimensions of 200 mm × 200 mm × 400 mm and a surface inclination of 30° were made for each test substrate in the first phase. At the beginning of the study, 100 mm × 100 mm cubes and cylinders were cast collectively as shown in Fig. 2. The specimens were left outside for two months to imitate the conditions of a genuine substrate after a 28-days curing process. The desired surface treatment was then added to the remaining concrete cylinders and prisms as they were cast over the old aged or substrate concrete.

2.2 Methodology

Testing of Slant shear by using cylindrical specimen to assess the interface bond strength connected through adhesive was introduced by Kriegh [9]. But in this investigation, prismatic specimens were used to assess the interface bond behavior of concrete-to-concrete surfaces. The slant shear test can result in two different failure mechanisms: cohesive or collective failure, and bonding agent or joint failure.

The following were the aims of the experimental research: (a) to examine the failure mechanisms at the interfaces; and (b) to list the effects of surface pre-wetting on the strength of the bond of the interface while taking into account various methods to increase surface roughness. The approach shown in Fig. 1 for the slant shear test was used to determine the bond strength. In the present investigation, an efficient combination of surface roughness and pre-wetting conditions was used in place of an epoxy resin.

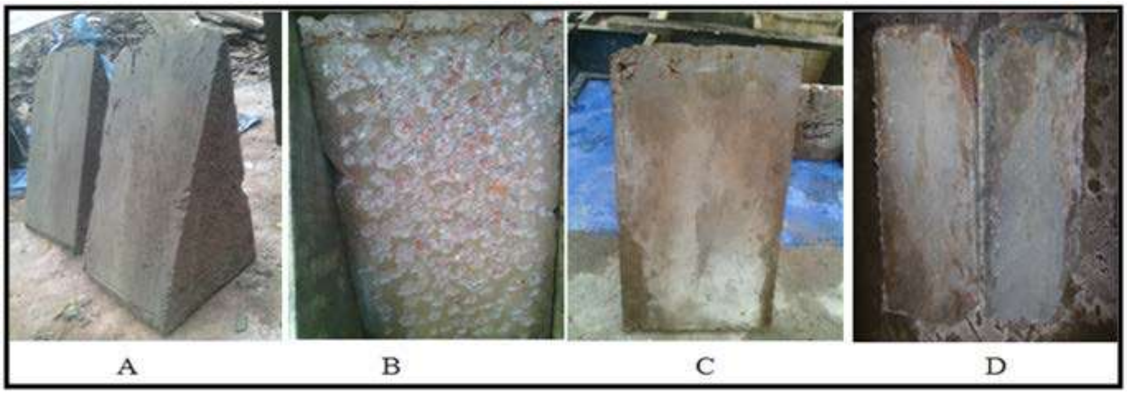

Fig. 1: A) Slanted Prism. B) Rough surface by chipping. C) Rough surface by wire brushing surface. D) Normal surface as found after casting

The samples were put through compression testing in accordance with the procedure for assessing the compressive strength of cubes or cylinders. The old aged prisms and semi cylinders were gently scrubbed and chipped using a chisel hammer and wire brush, respectively, to prepare the surfaces. The substrate samples were kept in an environment with a relative humidity of 50% for two months in order to produce an air-dry condition. The old aged concrete cylinders and prisms were submerged in water for varying times of 0, 8, 16, and 24 hours, respectively, to recreate pre-wetting circumstances. After removing the specimens from the water and ensuring surface dryness, new concrete was applied as shown in Fig. 3. To determine their slant shear and direct shear capacities, the cured specimens were subsequently compressed using a universal testing machine. Throughout the testing phase, the modes of failure and shear strengths of the planes were closely monitored.

Fig. 2: Cylindrical specimen of substrate concrete inside the forms

Fig. 3: Cylindrical specimen for overlay concrete

The shear bond tests were conducted using both cube and cylinder specimens, representing Phase I and Phase II, respectively, as depicted in Fig. 4. In this particular study, all tests were focused on Phase II, which involved the direct shear bond test using cylinder specimens.

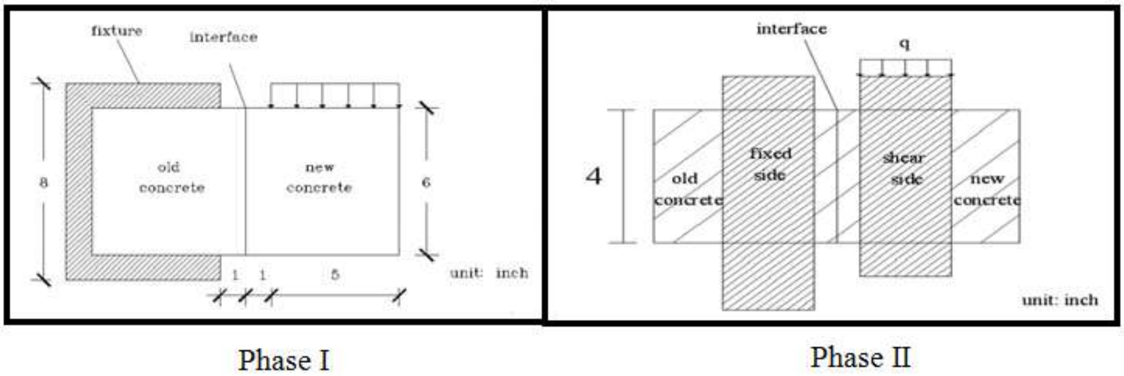

Fig. 4: Different phases of Shear flow

3. Results and Discussion

Table 1 displays the findings of the inquiry into the binding strength between the substrate and overlay at the interface for broken brick to broken brick aggregates and broken brick to stone aggregates. The samples are designated as Chipped, Wire Brush, and as Cast in Tables 1 and 2, respectively, using the letters C, W, and AC. The numbers that follow the hyphen indicate the length of the pre-wetting in hours. According to the findings, the chipped samples with a 24-hour pre-wetting time have the strongest bonds. Following that, the bond strength decreases in the order of 0, 8, 16, and 24 hours of pre-wetting. In comparison, the surface roughened samples using a wire brush during the same pre-wetting periods show lower bond strength values than the chipped samples. In contrast to the first two cases, the as-cast samples show worse bonding values. It should be noted that the samples' failure mode was determined to be unclear, which may have had an impact on the accompanying results.

It is significant to note that for various surface conditions and pre-wetting times, the results shown in Table 1 emphasize the changes in bond strength at the interface between the substrate and overlay. The chipped samples, which underwent a 24-hour pre-wetting period, demonstrated the highest bond strength, indicating the effectiveness of this surface treatment method. The bond strength gradually decreased as the pre-wetting duration decreased.

Table 1: Details of the test results and failure modes in slant shear test

Condition	First crack load (kN)	Failure load (kN)	Bond strength (MPa)	Failure mode
		Brick to Brick aggregate (BC to BC)		
C-0	120	435	5.18	Bond failure at interface
C-8	440	440	5.24	Bond failure at interface
C-16	467	494	7.07	Combined failure
C-24	500	604	7.20	Combined failure
W-24	440	520	6.19	Combined failure
AC-24	412	412	4.90	Bond failure at interface
		Brick to Stone aggregate (BC to SC)		
C-0	200	406	4.83	Bond failure at interface
C-8	222	406	4.83	Combined failure
C-16	422	422	5.03	Combined failure
C-24	480	502	5.98	Combined failure
W-24	147	456	5.43	Combined failure
AC-24	340	340	4.05	Bond failure at interface

Comparatively, the surface roughened samples achieved lower bond strength values than the chipped samples, regardless of the pre-wetting period. This suggests that while surface roughness can enhance bond strength, it is not as effective as chipping in promoting a strong interface between the substrate and overlay. In contrast, the As-cast samples exhibited the poorest bond strength results among the three surface conditions. This suggests that the binding strength at the contact is adversely affected by the lack of surface treatment. It is important to note that the samples' failure mode was determined to be unclear, which may have had an impact on the measured bond strength values. Further analysis and investigation are necessary to better understand the relationship between failure mode and bond strength in the different sample conditions. Overall, the findings highlight the importance of surface preparation and pre-wetting in concrete structures for generating a strong bond at the joint between overlay and substrate.

Table 2**:** Details of the test results and failure modes in direct shear test

Condition	Failure load (kN)	Bond strength (MPa)	Failure mode
Brick to Brick aggregate (BC to BC)			
C-0	18	2.29	Bond failure at interface
C-8	32	4.07	Bond failure at interface
C-16	34	4.33	Combined failure
C-24	38	4.84	Combined failure
W-24	24	3.06	Combined failure
AC-24	23	2.93	Bond failure at interface
Brick to Stone aggregate (BC to SC)			
C-0	12	1.53	Bond failure at interface
C-8	18	2.29	Bond failure at interface
C-16	20	2.55	Bond failure at interface
C-24	24	3.06	Bond failure at interface
W-24	22	2.80	Bond failure at interface
AC-24	18	2.29	Bond failure at interface

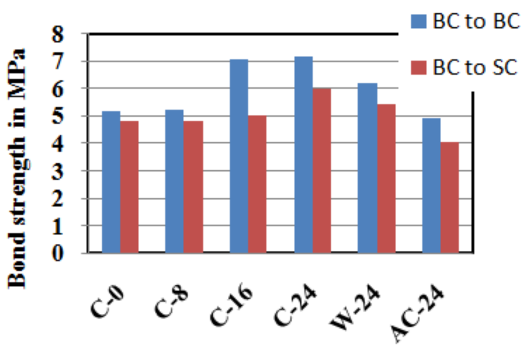

Fig. 6: Interfacial bond strength found in slant shear test

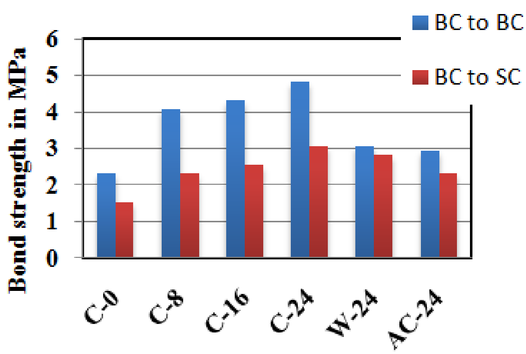

Fig. 7: Interfacial bond strength found in direct shear test

4. Conclusions

The study's findings can be summarized as follows:

- Bond strength observed between brick aggregates in comparison to stone aggregates was found to be higher in the current study. This can be endorsed to the similarity in textures between brick aggregates, which allows for a more monolithic behavior at the interface.
- The application of surface treatment through chipping and a 24-hour pre-wetting period yielded improved results in this study.
- The highest levels of bond strength in the current investigation was obtained in the Slant Shear testing, which showed more bond strength than the Direct Shear testing.
- After the surface was chipped and pre-wetted for 24 hours, the bond strength rose by 105% in the Direct Shear Test. Similar results were obtained in the Slant Shear Test, where the bond strength increased by 32.5% under the same circumstances.

Acknowledgements

The authors express their gratitude to the Department of Civil Engineering, DUET, Gazipur, for providing essential laboratory support.

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