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Performance Of Concrete-To-Concrete Bond Strength in Wetland Area

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Abstract. One of the techniques of building rehabilitation methods is repairing. Repair is a rehabilitation process to restore the initial capacity of damaged structures on structural components. A fairly popular repair technique is concrete-to-concrete. The strength of this bonding depends on several factors. The mixture used to repair the material affects the bond strength, as does the surface treatment and curing conditions. The study analysedanalysed the influence of strong bonds on surface treatment and curing conditions. Surface preparations were performed with four methods: as cast, drill holes, grooving, and bonding agent. The curing cycle applied two conditions: normal and wet-dry, and the test objects were compressive strength tests, slant shear tests, tensile tests, and flexural tests. The study results showed that the influence of wet-dry environmental conditions was lower than normal environmental conditions, and the highest bond strength values were found in grooving treatments, drill holes, as cast and bonding agents.

1 INTRODUCTION

Structural collapse can be prevented by building rehabilitation methods, including strengthening and repairing. Strengthening is the process of raising the existing capacity of an undamaged structure (or structural component) to a certain level. On the other hand, repairing is a rehabilitation process to restore the original capacity of the damaged structural component [1]. A popular repair and reinforcement technique for degrading the quality of existing structural systems is reinforced concrete (RC) jackets. Several studies have shown that RC jackets increase load-bearing capacity and stiffness, improving overall structural performance. However, this method has disadvantages, such as heavy and thick material mass, time-consuming procedures, the large number of workers required, and increased stiffness. These reasons have led researchers to turn to new jacketing techniques with new alternative materials, such as fibre-reinforced polymer (FRP), cement-based materials, such as ferrocement, steel fibrous concrete or mortar, high-performance fibre-reinforced concrete, and self-compacting concrete (SCC) [2]. Over the past two decades, there has been an increasing interest in using FRPs by engineers in the repair and capacity enhancement of brittle RC elements. One way of using FRP to repair RC structures is by attaching it to the external surface. Previous studies have indicated that the effectiveness of using an external concrete attachment with FRP (Fiber-Reinforced Polymer) is contingent upon the quality of the attachment to the concrete surface [3]. The strength of the concrete-to-concrete bond (referring to the substrate that requires repair with an overlay on its surface) is influenced by

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several factors, including the preparation of the substrate's surface, the use of adhesives, the mechanical properties of the concrete, moisture content, the type of substrate, environmental conditions, surface tension conditions, and the presence of cracks in the substrate. The choice of mixture for the new concrete used in repair materials also affects the bond strength, although its impact is relatively smaller when compared to the mixture used in the substrate [4].

The addition of silica fume with an optimum dosage of 8% was able to increase the bond strength values by 184% and 244% at SSD and dry humidity in overlay [5]. Adding latex to the mix was also found to increase the bond strength. Lower bond strength is obtained with a higher water-to-cement ratio or smaller-sized fine aggregates due to higher shrinkage [6]. Aysha [7] conducted research on the surface preparation of shot blasting, wire brushing, partial surface peeling, and as cast. She found that bond strength value was highest with the shot blasting method, wire brush, partial surface peeling, and as cast. An analysis reviewed by Fathy et al. [4] reported that the increase in bond strength occurred in the range of 25%–32% with grooving and sandblasting surface preparation. In Al-Madani's research [8], it was discovered that the bond strength after sandblasting was significantly higher than that of drill holes and as cast. This research also aligns with that conducted by Valikhani [9]. An increase in bond strength of about 125% occurred in sandblasting, with an additional 17% increase in bond strength using mechanical connectors. From the above studies, it can be concluded that the surface preparation on the substrate affects the bond of the two concretes.

Based on the results of Zuo [10], severe degradation occurred on the surface of composite mortars during cool-heat rather than wet-dry environmental cycles. However, research conducted by Al-Madani [8] showed that, generally, environmental conditions did not significantly affect bond behaviour. Based on the above studies, there is a need for research on the effect of using an overlay with a higher compressive strength than the substrate, using surface preparation, such as grooving, as cast, bonding agent, and drill holes. Furthermore, the disparity in research results concerning environmental conditions necessitates further investigation into concrete repair. Therefore, this research aimed to evaluate the performance of concrete-to-concrete bonding under varying surface preparations and environmental conditions.

2 Experimental Program

This study aimed to investigate the variations of curing treatments (full wet/N and wet-dry/W) and surface preparation to the bond strength of concrete. The bond strength tests included a slant shear test, splitting tensile test and flexural test, as shown **Error! Reference source not found.**. There were four surface preparation methods, including As Cast (AC), Drill Holes (DH), Grooving (GV) and Bonding Agent (BA). A total of 104 specimens were tested, as outlined in **Table 2**.. The substrate (old concrete) was cast into different moulds, both cylindrical and beam-shaped. After 24 hours of casting, the specimens were removed from the moulds and left to cure for 28 days. Subsequently, the specimens were allowed to air dry for 2 days. Following this, the surface of the substrate was prepared before applying the overlay. Various surface preparation techniques are depicted in **Error! Reference source not found.**. The diamond head (DH) created grooves with a depth of 3-5 mm and a diameter of 2.25 cm, while grooving had a depth of 1 cm. The bonding agent used was a Bonding Adhesive Agent. After the surface preparation, the substrate specimens were transferred to moulds for overlay casting. After 24 hours of casting the overlay, the specimens were demoulded and subjected to two curing conditions: water/normal (N) and wet-dry (W), as shown in **Error! Reference source not found.**. In the case of wet-dry (W), for the cylindrical specimens, they were watered for 24 hours and then left to dry for 24 hours. For the beam-shaped specimens, they were watered for 7 days and subsequently dried for 7 days.

The mix proportions for both the substrate and overlay are provided in **Table 1**. The substrate employed coarse aggregate with a maximum aggregate size of 20 mm, a specific gravity of 2.613, and sand with a specific gravity of 2.783. The water-to-cement ratio for the substrate was 0.52. On the other hand, the overlay composition featured a water-to-cement ratio of 0.44, with coarse aggregate size and specific gravity matching those of the substrate. Additionally, this mixture incorporated a water-reducing agent, a high-range water reducer, and a retarding admixture (Sika Viscocrate 1050).

Table 1. Mix Proportions of substrate and overlay materials (kg/m^3)

Type	**Compressive strength (MPa)**	**Cement (kg)**	**Water (litre)**	**Fine Aggregate (kg)**	**Coarse Aggregate (kg)**	**Superplastizer (liter)**
Substrate	20	365.4	190	584.2	1300.4	-
Overlay	30	431.8	190	654.5	1163.6	3.0

(a) (b) (c)

Fig. 1. Specimens and test setups: (a) slant shear (b) splitting tensile (c) flexure

(a) (b)

Fig. 2. Curing conditions (a) Watering Normal-N (b) wet-dry-W

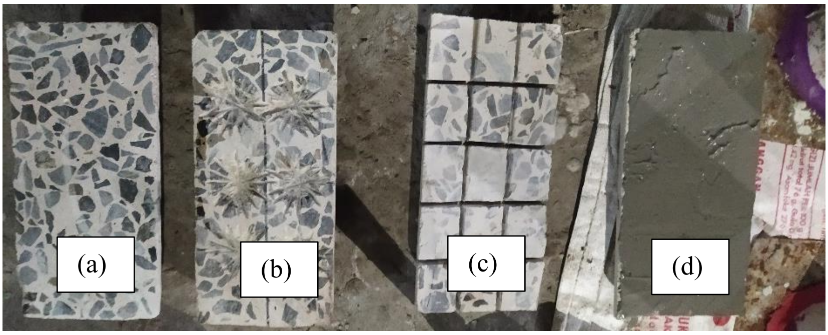


Fig. 3. Substrates surface prepared using (a) AC, (b) DH, (c) GV and (d) BA

Table 2. Details of specimens

Surface Prep	Slant Shear	Splitting Tensile	Flexure Test	Total Combinations
AC	3 tests × 3 specimens × 2 conditions	1 test × 3 specimens × 2 conditions	1 test × 1 specimens × 2 conditions	26
DH	3 tests × 3 specimens × 2 conditions	1 test × 3 specimens × 2 conditions	1 test × 1 specimens × 2 conditions	26
GV	3 tests × 3 specimens × 2 conditions	1 test × 3 specimens × 2 conditions	1 test × 1 specimens × 2 conditions	26
BA	3 tests × 3 specimens × 2 conditions	1 test × 3 specimens × 2 conditions	1 test × 1 specimens × 2 conditions	26

2.1 Bond Strength Tests

This study conducted three different bond strength tests to assess the performance of the bond between overlays and substrates, as shown in **Fig. 1**. The standard test procedures, specimen creation, and test setups are described as follows.

2.1.1 Slant Shear Test

According to ASTM C882 [11], the slant shear test is performed when the specimen is subjected to a combination of compression and shear. This process involves cutting the substrate at an angle of 30° from the vertical axis and re-casting it with overlay after surface preparation. The cylinders used in this study have a diameter of 11 cm and a height of 22 cm. The calculation of shear stress to determine the value of slant shear can be seen in Eq. 1.

$$\tau_n = \frac{P}{A_n} sin(\alpha)\cos(\alpha) \tag{1}$$

Where P is the failure load (kN), A_n is the area of the inclined plane (mm²) and α is the angle of the bonded inclined surface, i.e., 30°.

2.1.2 Splitting Tensile Test

Concrete's split tensile strength is a sign of its tensile strength. Cylinders were used as test specimens in this simple test procedure, carried out using typical compressive testing equipment. The reference for split tensile testing is ASTM C496 [12]. The used cylinder has a diameter of 11 cm and a height of 22 cm, such as in the slant shear test. Eq. 2 shows how to calculate the split tensile strength value.

$$f_{sp} = \frac{2P}{\pi A_{SP}} \quad (2)$$

Where P is the failure load (kN), A_{sp} is the area of the bond plane (mm²).

2.1.3 One-Point Flexural Test

The ability of concrete blocks placed on two supports to withstand forces in a direction perpendicular to the axis of the test object until the test specimen is broken, according to ASTM C293 [13]. The beam in this test is 15 by 15 by 55 centimetres. Using Eq. 3, one can get the flexural strength.

$$f_r = \frac{3P.L}{2b.h^2} \quad (3)$$

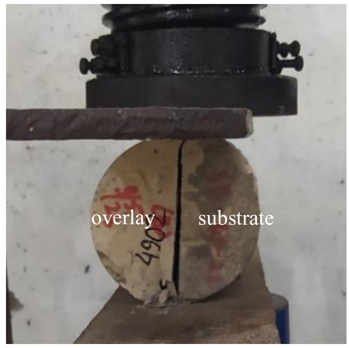
Where, P is the failure load (kN), L is the length of the supported span (mm) and b, d are the width and depth of specimen section (mm).

3 Experimental Results and Discussion

3.1 Slant Shear Test

The overall slant shear test results are presented in **Table 3**, **Fig. 4** and **Fig. 5**, including the average compressive strength of substrate and overlay and average bond strength. AC demonstrates the highest score, followed by DH, GV, and BA. This outcome is directly related to both the compressive strength of the substrate and the overlay. According to research by L. Courard [14], there are three factors, each with varying levels of influence on bond strength, as shown in **Fig. 6**. The properties of the overlay fall within the category of medium influence factors. The higher slant shear value of AC specimens can be attributed to the compressive strength of the overlay. This observation aligns with the approach presented in ACI 546.3R ACI 546.3R [15], where slant shear testing significantly impacts the compressive strength. Consequently, the AC specimens for slant shear tests exhibit notably higher values than the other three surface preparations. On the other hand, when comparing curing conditions, the slant shear testing results between N and W do not display substantial differences.

(a)



(b)

(c)

Fig. 4. Specimens after tested by setups (a) slant shear (b) splitting tensile (c) flexural test

Table 3. Slant shear test result

Surface Preparation	Compressive Strength (MPa)		Curing Conditions	Days	Slant Shear Strength τn (MPa)
	Substrate	Overlay			
AC	21.05	26.8	N	7	2,579
			N	14	3.224
			N	28	4.729
			W	7	2.543
			W	14	3.654
			W	28	4.836
DH	17.01	21.05	N	7	2.758
			N	14	3.081
			N	28	3.260
			W	7	2.687
			W	14	2.758
			W	28	2.866
GV	16.1	19.4	N	7	2.508
			N	14	2.830
			N	28	3.045
			W	7	2.328
			W	14	2.680
			W	28	2.866

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BA	21.04	23.67	N	7	1.719
			N	14	2.114
			N	28	2.651
			W	7	1.648
			W	14	2.042
			W	28	2.472

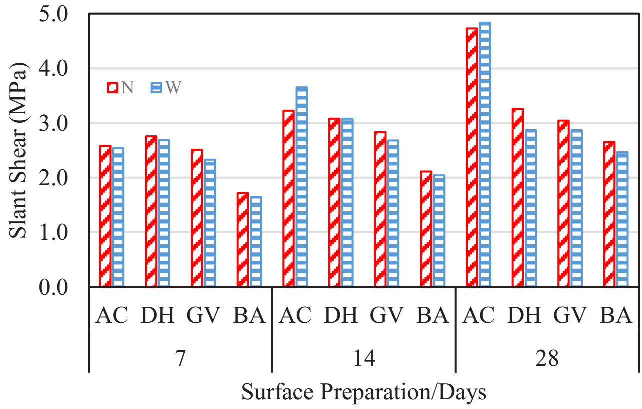

Fig. 5. Test result of slant shear

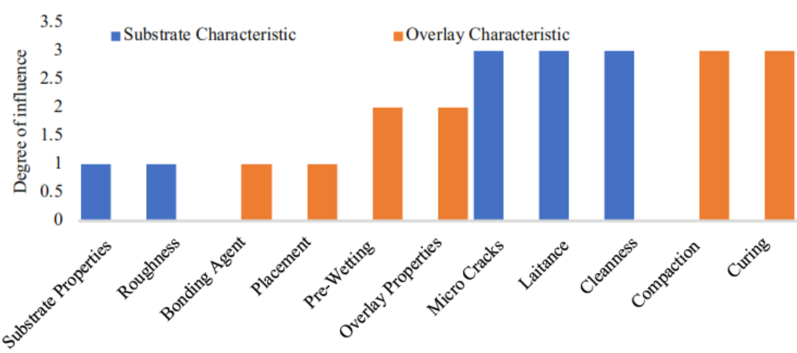

Fig. 6. Factors affecting bond strength [14]

3.2 Splitting Tensile

The value of GV was the highest among the other three surface preparation methods, as shown in **Fig. 7** and **Table 4**. The percentage increased in BA, DH, and GV in N conditions with AC by 33.51%, 50.6% and 151.35%, respectively. The percentages gained for DH, BA, and GV in the W conditions were 9.19%, 35.46%, and 97.29%, respectively. This indicates that GV has a greater impact than the other three surface preparations in the splitting tensile test. While the curing situation does impact GV and DH, it has a very minimal impact on AC and BA. The W condition was decreased by 33.93% in DH, whereas it was decreased by 28.47% in GV.

Table 4. Splitting tensile result

Surface Preparation	Compressive Strength (MPa)		Curing Conditions	f_{sp} (MPa)
	Substrate	Overlay		
AC	17.01	22.6	N	0.812
			W	0.740
DH	17.01	22.6	N	1.223
			W	0.808
GV	17.01	22.6	N	2.041
			W	1.460
BA	17.01	22.6	N	1.084
			W	1.002

3.3 Flexural Test

However, the BA could not be tested as the beams broke before the flexural test could be conducted. The curing condition also significantly influenced the specimens; in condition N, the flexural value was higher than in condition W. There was a decrease of 31.28% in the AC approach under W conditions, 24.87% for DH, and 30.97% for GV.

The GV value in this test exhibited a higher bond strength value than the other three surface preparations, as seen in

Table 5 and **Fig. 8**. Under N conditions, the DH and GV surface preparations showed percentage increases of 22.46 and 51.68 over AC, respectively. At the same time, BA experienced a 70% decrease. Under W conditions, DH and GV methods saw increases of 33.88% and 52.36%, respectively. However, the BA could not tested as the beams broke before the flexural test could be done. The curing condition also significantly influenced this specimen; in condition N, the flexure value was higher than in condition W. There was a decrease of 31.28% in the AC approach under W conditions, 24.87% for DH, and 30.97% for GV.

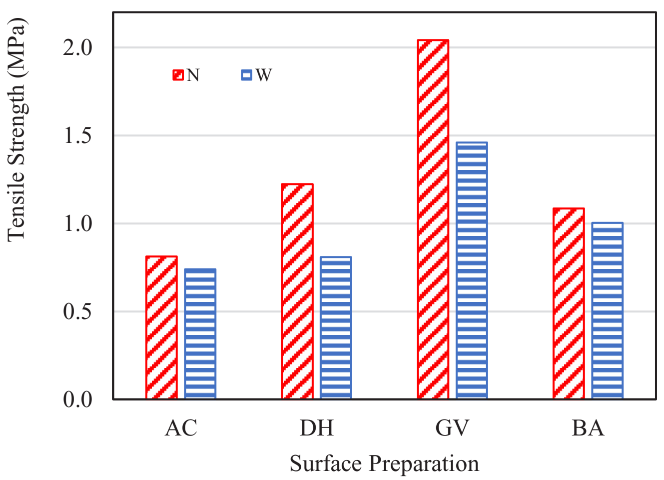

Fig. 7. Test results of splitting tensile

Table 5. Flexure test results

Surface Preparation	Compressive Strength (MPa)		Curing Conditions	f_r (MPa)
	Substrate	Overlay		
AC	18.85	26.8	N	2.97
			W	2.04
DH	18.85	21.05	N	3.63
			W	2.73
GV	16.66	19.4	N	4.5
			W	3.1
BA	16.66	26.8	N	0.89
			W	-

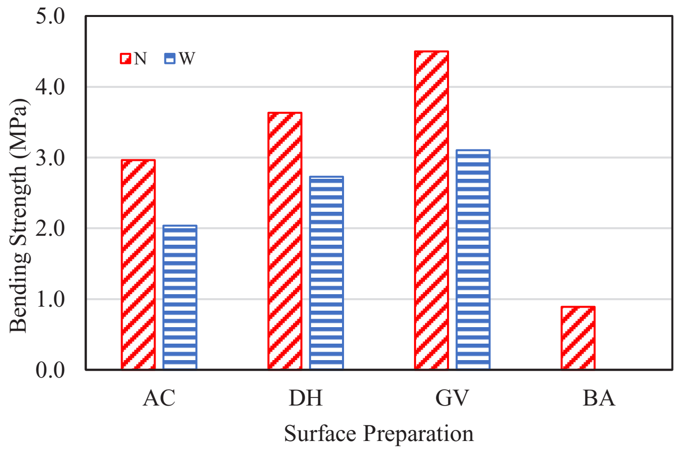

Fig. 8. Test result of flexure

The BA method consistently yielded the lowest test results among the three surface preparation methods. This finding aligns with various other research studies that have indicated that it can weaken surface joints by adding more fields to the surface layer. For instance, Al-Ostaz's research [16], showed that bonding agents can lower the value of slant shear by up to 40%. Furthermore, when considering the average flexural strength test results of connection beams, Novitasari's research [17] utilising the identical bonding agent product yielded the highest result of 0.77 MPa. In contrast, the monolith concrete beam registered 3.27 MPa, indicating a substantial decrease of 76.45 per cent.

4 Conclusion

The following inferences can be derived from this study.

1. Slant shear, split tensile strength, and flexural strength tests were used to assess the bond strength of concrete.
   - The slant shear test result showed that AC, followed by DH, GV, and BA, had the highest value. At 28 days, the slant shear test results under normal curing conditions were 4.73 MPa, 3.26 MPa, 3.04 MPa, and 2.65 MPa, respectively. This

is due to the overlay's compressive strength having a significant impact. Thus, compared to the other three surface preparations, the AC value was significantly larger.

- GV had the highest test value in the split tensile strength test, followed by DH, BA, and AC, with consecutive test values of 2.04 MPa, 1.22 MPa, 1.08 MPa, and 0.81 MPa under curing condition N.
- GV had the highest test value in the flexural strength test, followed by DH, AC, and BA at 4.49 MPa, 3.63 MPa, 2.97 MPa, and 0.89 MPa under curing condition N.

Based on the three tests mentioned above, it can be inferred that the GV surface preparation, followed by DH, has the most significant impact on bond strength. While using BA as a repair material remains debatable, this study determined that its use has no discernible impact on bond strength.

2. In both slant shear and splitting tensile tests, the curing condition has minimal impact on bond strength, but in flexural testing, it exerts a significant influence. When comparing the W condition to the N condition, there was a notable decrease of 31.28 per cent.

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