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A Modified Bond Wrench Test for Evaluating Bond Strength of Concrete Repairs

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Abstract

Bond wrench test is a widely used method to evaluate the quality of masonry work by determining the bond strength between masonry unit and bedding mortar. This paper presents the details of an experimental investigation using the modified bond wrench test apparatus to evaluate the quality of concrete repairs by determining old-to-new (substrate-to-repair) concrete bond strength. A modified bond wrench test set-up has been developed for this purpose. Performance of three bonding agents were evaluated by this test. Bond strength values of these specimens were determined also by splitting prism test and beam flexure test. A total of 83 specimens were subjected to various tests. Test results showed that good correlation exists between bond strength values obtained by beam flexure test, splitting prism test and modified bond wrench test described in this paper.

1. Introduction

In concrete repair applications, the bond between the old and new concrete usually provides a weak link in the repaired structure. The bond strength mainly depends on adhesion in interface, friction, aggregate interlock and time dependent factors. Each of these main factors in turn, depends on other variables. Adhesion to the interface depends on bonding agent, material compaction, cleanness and moisture content of repair surface, age of specimen and roughness of interface surface [1]. The most critical characteristics of the substrate surface are its roughness, cleanliness and moisture condition prior to application of repair material, and these are mainly dependent on workmanship. Workmanship plays an important role in good concrete repair and deserves an adequate attention. Also, inadequate substrate preparation is usually the main cause of bond failure in concrete repair [2]. Studies by Momayez showed that rough surface preparation leads to higher bond strength (9-25% increase) [1]. Sand blasting was the preparation method of the substrate surface that presented the highest values of bond strength is shear and tension [3].

In the case of testing of adhesion of repair materials to a concrete substrate, coated with different bonding aids, the results obtained by different researchers are not always in agreement. Tests by Climaco et al. showed that good bond can be achieved by casting the repair against mature concrete with no bonding aids, provided the base surface is dry and reasonably roughened to an extent that the aggregate is exposed and no damage is caused to the concrete near the joint[4]. Also, due to the variability of the parameters that influence the bond strength it is not possible to generalize or to extrapolate the conclusions drawn [5]. Following are some of the important observations reported by Julio from the available literature: Garbacz et al. state the increasing necessity of using a bond coat as the violence of the surface treatment increases [6]. Cleland and Long [7] concluded that the principal function of a bonding agent is to develop a bonding bridge between the repairing material and the concrete substrate. Talbot et al. [8] have stated that the use of bonding agent reduces the variability of bond strength results.

Tests indicated that increasing the compressive strength of the added concrete relative to the compressive strength of the substrate concrete improves the bond strength and changes the rupture mode from adhesive to monolithic [9]. The addition of short carbon fibers at 0.35 volume percentage resulted in mortars that bonded more strongly to old mortars. The increase in shear bond strength was up to 89%. This effect is attributed to the lowering of drying shrinkage by the fiber addition. The effect is largest when the fibers were used with latex, which was in the amount of 20% of the cement weight [10].

In addition to the above factors, the measured bond strength is highly dependent on the test method. Bond strengths of some tests were up to eight times larger than those obtained from others. Bond tests must be selected such that they represent the state of stress the repaired structure is subjected to in the field. The commonly used methods for evaluation of bond strength between old and newly added concrete/repair material are slant shear test, pull-off tests, splitting prism and bi-surface shear test [1]. Good correlation between the slant shear test and pull-off test results were observed by Eduardo, et al [3]. The slant shear test appears to be a generally satisfactory method in terms of being representative of realistic stress states at the joint and also in regard to simplicity, reproducibility and sensitivity. It has been adopted in many standards but test procedures are not agreed and there are significant differences in specimen dimensions, shape, joint angles and surface preparations [4]. An abstract of various tests evaluating bond strength between concrete substrate and repair materials is given in Table 1(provided at the end of this paper).

To compare and quantify the effects of various factors affecting bond in concrete repairs as described above, a simple bond test need to be devised. The concept of modifying the conventional bond wrench was drawn from the fact that the bond between masonry blocks and bedding mortar has been found to be well evaluated by bond wrench tests.

This paper presents the details of an experimental investigation to extend the use of Bond Wrench, to evaluate the quality of concrete repairs by determining the bond strength between concrete substrate and repair material under combined compressive stress and flexural tension. The performance of three bonding agents were evaluated by determining bond strength of repaired concrete specimens by modified bond wrench test, splitting tensile strength test and beam flexure test. A total of 83 specimens were subjected to various tests.

2. Experimental Programme

2.1. General

The experimental study consisted of the following:

(a) development of a bond wrench test set-up to determine substrate-to-repair bond strength
(b) evaluation of the bond strength performance of three bonding agents for repairing concrete specimens by bond wrench test, splitting tensile strength test and beam flexure test.
(c) studying the correlation between the bond strength values obtained from bond wrench test, splitting tensile strength and beam flexure test

2.2. Materials used

Cement used was Portland Pozzolana cement conforming to IS 1489 and the fine aggregate of zone II grading as per IS 383. Coarse aggregate used was graded crushed granite aggregate of maximum 12.50 mm size (IS 383-1970). Two bonding agents were selected based on the availability of products and reputation of the manufacturer. In addition, cement slurry, which is a conventional bonding agent, was also used. Thus, the bonding agents used for the study were:

a) Cement Slurry of flow able consistency
b) Styrene Butadiene Rubber (SBR) bonding agent (Solid content of 36%)
c) Epoxy bonding agent (base : hardener parts by weight 100 :87)

2.3. Bond wrench test for concrete repair testing

2.3.1. Fabrication of modified bond wrench

The modification aimed at fabricating a bond wrench test set-up for determining substrate-to-repair concrete bond strength by following the principle of ASTM C 1072 test procedure used for conducting bond tests on masonry. A bench vice fitted on a steel frame of sufficient height was used here to hold the repaired specimen in position. The expected failure loads also are higher compared to wrench test for masonry blocks. A stronger loading arm with longer lever arm was fabricated for the current setup. Safety chain and hooks were provided from an overhead frame, to hold the wrench arm during fixing of the specimens as well as after bond failure. The modified bond wrench set up is shown in fig. 1.

Fig. 1.modified bond wrench test set-up

2.3.2. Bond testing by Bond Wrench

The specimen used for testing consists of two parts as shown in figure 2. The lower part is concrete substrate prepared as a cube of size 100 mm. The upper part is the repair material which is to be placed after the application of bonding agent on the substrate face with a maximum thickness is it 3 mm. The size of the repair part is 100 mm X 100mm X 70 mm.

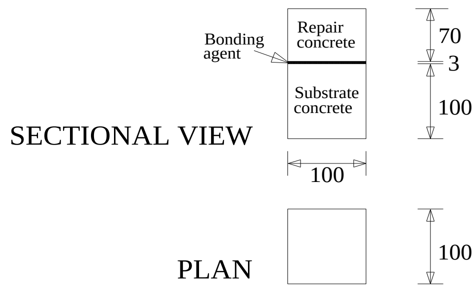

Fig..2 Dimensions of test specimen (mm)

The test specimen after curing was fixed to the bench vice and the wrench was tightened on the repair part as shown in fig 3(a). The load W_2 (lead shots or coarse aggregate of size 6 mm) was gradually and gently added to the loading pan of wrench till failure, as shown in fig 3(b). Photo of bench vice with specimen after testing is shown in fig 4. After failure of specimen the aggregate in the loading pan was taken out and weighed by an electronic balance. The flexural tensile bond strength was calculated as follows.

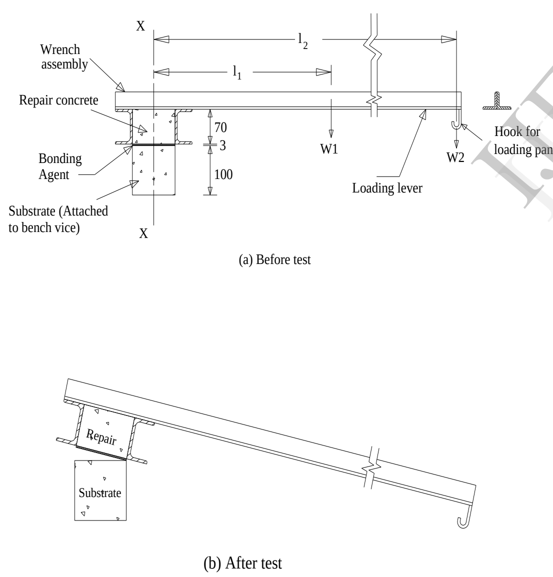

Fig. 3. Schematic of bond wrench

Calculation of bond strength (notations as shown in Figure 3)

Total vertical load acting at the bonded surface, $P = W_1 + W_2$

Moment about line XX (through centre of specimen), $M = W_1 l_1 + W_2 l_2$

W_1 is the self weight of wrench arm and l_1 is the distance from the centre of gravity of wrench to the line XX

W_2 is the applied load at which the specimen fails (applied at a distance of l_2)

Flexural tensile bond strength = $P/A – M/Z$

Where A is the area of bonded face and Z is the section modulus of the bonded face

Fig. 4. Specimen after bond failure

2.3.3. Preparation of Repaired concrete specimen

Repaired concrete specimens (Figure 1) were prepared as per the following procedure. (i) Casting of substrate cubes of 100 mm size and curing it for 28 days. The mix proportion for the substrate concrete was adopted to ensure a minimum compressive strength of 25 MPa. (ii) The surface of the substrate concrete cube prepared as per step 1 was cleaned with a metal wire brush and washed to remove any dust. (iii) On drying of the prepared surface, the bonding agent was applied. The thickness of the bonding agent was 2 to 3 mm in the case of cement slurry and SBR –cement mixture. In the case of epoxy bonding agent it was within 2 mm. (iv) Sufficient time was given to become the bonding layer semi-dry before placing the mould for casting the repair concrete. (v) Placing and finishing repair concrete in the mould to a thickness of 70 mm compacted well and finished. As the objective of the study was to determine the bond strength of specimens repaired using three types of bonding agents, the repair material used was concrete of grade M25, same as substrate. (vi) The specimen was demoulded after 24 hours, cured for 28 days and bond strength was determined using the Bond Wrench Apparatus. Details of specimens prepared are given in Table 2.

Table 2. Details of specimens prepared for various tests

Specimen code	OO	CO	SO	EO
Bonding agent used for repair	No bonding agent	Ce-ment slurry	SBR and Cement (Proportion 1:1 by weight	Two part epoxy

2.3.4. Testing

The test specimen was mounted on the vice as shown in Figure 1 and tightened. The wrench was placed on the repair part of the specimen, keeping it horizontal, and tightened after placing the packing plate. The loading bucket was hung from the hook and the safety chains placed in position. Loading was done by slowly and gently pouring 6mm aggregate into the bucket till the failure of the specimen. On failure, the wrench remained hanging by the two safety chains. The failure load was determined by weighing the aggregate in the bucket and the bond strength was calculated.

2.4. Splitting Tensile Strength Test (ASTM C496)

Cylinder specimens were fabricated with one half substrate (old concrete) and the other half repair concrete cast after the interface surface being thoroughly cleaned and applied with the bonding agent. Cylinder specimens (150 mm diameter, 300 mm high – 6 samples in each case) were cast using the different combinations of bonding agents. These cylinders were subjected to splitting test in a compression testing machine (Figure 5), after 28 days of curing.

Fig.5(a) Specimen for split test

Fig. 5 (b) specimen subjected to split test

2.5. Flexural Bond Strength Test (ASTM C78-02)

The specimen used in the test consisted of two halves of prisms, the first half being the concrete substrate and the second half the repair material, both of size 100x100x300 mm, cast keeping the bonding plane inclined at 45^0 to the axis of prism. The substrate part of the specimen was cast, cured for 28 days, the bonding surface was thoroughly cleaned, the bonding agent was applied by brushing as per the instruction given by the manufacturer, the repair concrete was cast to get the prism of size 100x100x500 mm and the curing continued for another 28 days. The repaired test specimens were tested under flexure by applying the third point loading (Fig 6) there by determining the flexural bond strength.

Figure 6 (a) Substrate and repaired beam

Fig.6(b) Flexure test on repaired beam

3. Results and Discussion

The results of the bond wrench test, beam flexure test and splitting cylinder test are presented in Table 3.(given at the end of the paper). The failure in the case of all specimens was at bonding plane (adhesive failure) which indicated that the strength measured represents the bond strength induced by the bonding agent. Fig. 7 shows the scatter and correlation between bond strength values determined by bond wrench test and the flexural bond strength by beam test, with a correlation coefficient of 0.995 as shown by the trend line in Fig 7(b). The scatter and correlation between bond strength values determined by bond wrench test and the splitting prism test are shown in Fig. 8, with a correlation coefficient of 0.90 and Coefficient of variation (COV) of all the test results within 20 %. These correlations points to the fact that Bond wrench test can be used as a method to evaluate concrete-to-concrete bond, especially in the case of old concrete-to-repair material bond.

In many concrete repair projects, large quantities of bonding agents and repair materials are being used. In order to assure the quality of repairs, testing of bonding characteristics of each batch of repair materials is essential before its adoption. This can be easily made possible with Bond Wrench Apparatus at the site. The consistency of quality of repair materials can be checked by testing the bond strength at 3, 7 and 28 days of curing in case of cementitious materials and even at a shorter periods in case of other materials like epoxy mortar. Thus testing by bond wrench apparatus can be considered as a comparatively simple and cost-effective method for Quality monitoring in repair projects.

4. Conclusions

Based on the results obtained from this experimental study, the following conclusions can be drawn.

1. A Modified bond wrench apparatus has been developed and experimentally proved that repaired concrete specimens to determine the substrate-to-repair bond strength can be successfully carried out using this apparatus.
2. Acceptable correlation between beam flexure test results and Modified bond wrench test results has been obtained, validating the use of bond wrench in evaluating concrete-to repair bond strength.
3. The results of splitting cylinder test and bond wrench test are also giving close correlation supporting the use of bond wrench in the evaluation of repair materials.
4. The suggested method of preparation of specimens for bond wrench test is simple and consumes lesser materials compared to the flexural bond testing by beam flexure test and split cylinder test. The testing requires only minimum and simple instrumentation which can even be operated by layman. The Apparatus can be fabricated locally and is a cost effective method of Quality monitoring in Repair projects.

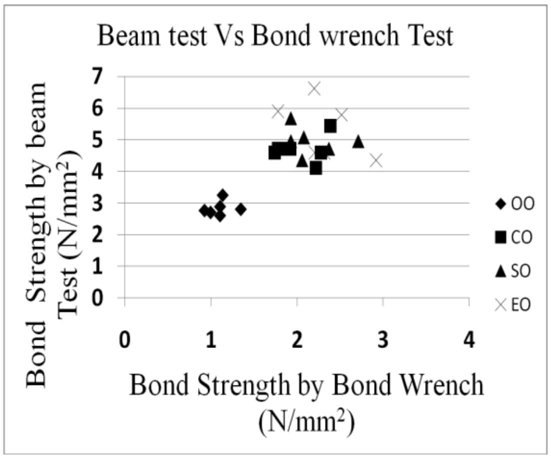

Fig.7(a) Scatter of beam and bond wrench results

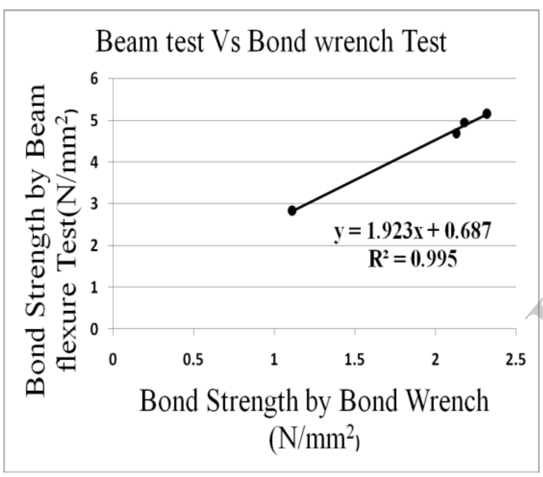

Fig.7(b) Correlation of bond strength values

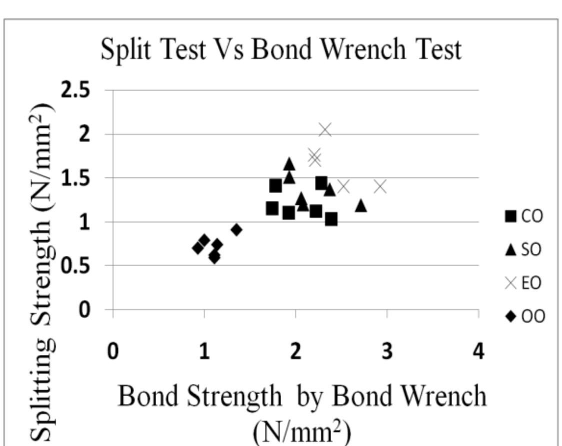

Fig.8 (a) scatter of split test and bond wrench results

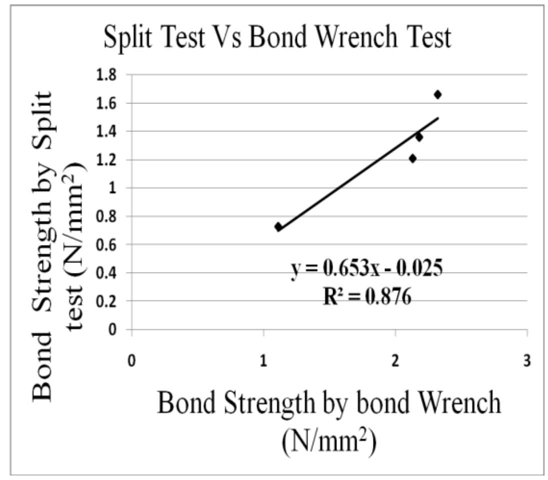

Fig.8(b) Correlation of bond strength values

5. The use of bonding agents showed considerable enhancement in bond strength values. The epoxy based bonding agent provided maximum adhesion. The results are in agreement with the earlier findings.

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Table 1. Summary of various test methods for determining bond strength

Category of test	***Result of test***	***Remarks***
Shear test[11],[12],[13]	*Shear bond strength*	*In mono surface shear test care required to avoid bending*
Tension test [12],[16],[19]	*Tensile bond strength*	*Misalignment may cause bending*
Pull off test (in situ) [15,18]	*Tensile bond strength*	*Popular in situ test. Misalignment may cause bending*
Slant shear test[8,14]	*Shear bond strength*	*Widely accepted test due to simplicity (compressive load only)*
KTH torsion test [11]	*Shear bond strength*	*Field testing of shear bond strength is possible. Not widely used*
Repaired beam flexure test [17]	*Flexural tensile bond strength*	*Used in research studies. Specimens are bigger.*
Proposed Bond wrench Test	*Flexural Tensile bond strength*	*Simple test method. Such stress state occur in many repaired elements*

Table 3: Results of Various Tests

Specimen Code	Bonding Agent Used	BOND WRENCH TEST			SPLITTING CYLINDER TEST			BEAM TEST		
		Average Flexural Tensile strength* (MPa)	Coefficient of Variation (%)	% Increase	Average Splitting Tensile strength* (MPa)	Coefficient of Variation (%)	% Increase	Average Flexural Tensile strength (BEAM) (MPa)	Coefficient of Variation (%)	% Increase
OO	No bonding agent	1.11 (6)	12.98	Control	0.73 (6)	15.85	control	2.83 (6)	7.80	control
CO	Cement Slurry	2.13 (12)	13.60	47	1.21 (6)	14.40	65	4.69 (6)	9.10	65
SO	SBR and Cement	2.18 (12)	12.20	96	1.36 (6)	13.58	86	4.95 (6)	8.80	75
EO	Epoxy	2.32 (6)	16.43	109	1.66 (6)	16.46	127	5.17 (6)	17.45	88

*Number of specimens tested is given in brackets