**Pakistan Journal of Engineering and Technology, PakJET**
Multidisciplinary | Peer Reviewed | Open Access

Volume: 1, Number: 1, Pages: 66- 70, Year: 2018

# Assessment of Bond Strength between Concrete and Repairing Cementitious Concrete in Tension and Shear

Imran Nazir[1], Khuram Rashid[2,*]

[1]Department of Architectural Engineering and Design, University of Engineering and Technology;
[2]Department of Architecture, University of Lahore
*Corresponding author: Khuram Rashid (email: khuram_ae@uet.edu.pk)

*Abstract*—**To evaluate the bond strength, an experimental work was performed in tension and shear between old concrete and new repairing concrete. Various adhesives, epoxies and fiber reinforced polymer sheet were used at interface on the roughened substrate surface to increase the bond strength. Steel wire brush was used for roughening of substrate surface. Bi-surface shear test and Split tensile test were performed on 150 mm cube to quantify the bond strength in shear and tension, respectively, of composite specimens. The solid specimen is referred to as bulk specimen compared with the composite specimen. Bulk specimen's tensile strength and shear strength were also assessed and it was observed that bond strengths is less than the bulk specimen strengths of both types, that is, tensile and shear. In composite specimens adhesive mode of failure was observed that verify the weakness of interfacial zone. Some improvement in bond strength was also observed with the application of different materials at interface.**

***Index Terms*—Bond strength, Concrete, Repair, Rehabilitation, Silica fume, Strengthening.**

## I. INTRODUCTION

Concrete is the cast-in-place, economic and readily available construction material. The regular concrete can be used a s repair material or various other materials may be added to enhance its properties as a repair material. Concrete may be used for a wide variety of structures that include highway bridges, high-rise buildings, tunnels, offshore structures, dams and parking structures. One of the major problems impacting the long-term performance of concrete repairs and bonded overlays is cracking or fracture and their debonding from the concrete substrate. It is a fact that most of the structures built during rapid urbanization of last six or seven decades have either passed their service life or their load rating does not match with the current needs. Rehabilitation and strengthening of this infrastructure is a need of the hour. Special techniques using well developed materials may be employed to not only repair and rehabilitate the structures but also to strengthen the existing structures for the present day loadings and other needs. This can prolong the useful service life of the structures and can increase their stiffness for reduced deflections and vibrations. A monolithic action between the substrate concrete and repairing concrete is essential for the repair to be successful. For this monolithic action, a suitably strong and durable bond between the existing concrete and the repair material is required. There are many materials and admixtures available in construction industry to improve the strength and durability of repairing concrete. Silica fume is one of them which is used as partial replacement of cement in the concrete.

Significant research literature is available regarding the mechanisms, limitations and improvements of bond between existing concrete and repair materials. However, the guidance available in the codes and specifications for keeping an eye on the bond behavior of the repair is limited. There are a large number of factors and practical issues related with the short term and long term performance of the bond strength of the repair materials. One of the major factors affecting this behavior is surface preparation of concrete substrate. A sufficiently clean, lightly rough and stable base material is required to improve the bond strength. It is to be noted that the debonding shear failure may only occur at the interface of the two materials but also just below the interface within the existing concrete surface. The selection of the bonding material itself for a particular application is also an important parameter.

## II. Literature Review

Concrete jacketing is most commonly used strengthening technique for structural elements. The concrete surface preparation is equally important for this type of repair. Sometimes, steel dowels are also introduced to strengthening the bond between the existing and the new concretes. Julio, Bronco and Silva and Bett [3], Klinger and Jirsa [4] experimentally studied the behavior of RC columns that were strengthened by jacketing. Surface cleaning and roughening were carried out by using sand blasting. Alcocer and Jirsa [5] worked on the behavior of deficient RC connections overlaid by jacketing. The concrete cover was removed to expose the outermost concrete aggregate by chisel and hammer. Subsequently, Alcocer [6] extended the experimental program by modifying the surface preparation technique. Surface was first prepared as in the original research but thick brush and vacuum cleaner were used in the second step to further clean the surface. Ramirez et al. [7] repaired partially damaged RC columns that were then tested to observe their behavior. The exposed concrete surface and reinforcing bars of all the columns to be repaired were thoroughly cleaned by brushing with a hard wire brush. The research work of Rodriguez and Park [8] consisted of experimentally studying the behavior of strengthened RC columns against simulated seismic loading. Concrete jacketing was used for the strengthening and chipping was employed to prepare the surface of the columns. Stoppenhagen et al. [9] also used jacketing technique to strengthen severely damaged concrete frames. These frames were then tested to evaluate their response against applied loading. An electric chipping hammer was used to roughen the concrete substrate. Influence of the roughness of the substrate surface for the concrete to concrete bond was studied by Julio et. al. [10]. They found that sand blasting is the best technique for roughening the substrate surface to get best bond strength in tension and shear.

All the above mentioned research points towards the importance of getting better bond strength between the original concrete and the concrete of the jacketing. However, the research on directly evaluating this bond strength is still limited. The bond at the interface between two concretes can be experimentally verified by performing either splitting tensile test or by direct shear test. Composite samples can be prepared by joining two pieces of concrete employing selected surface preparation method and bonding technique. Solid monolithic samples may be prepared for the required comparison. These samples are referred to as the “bulk” samples in this research work.

## III. Methodology

Split tensile and Bi-Surface shear tests were performed on three cubical specimens of size 150 mm for bulk and composite specimens to assess the bond strength in tension and shear between concrete and repairing cementitious concrete respectively. Number of specimens for each case is mentioned in Table-1.

### *Compressive strength*

Three cubical bulk specimens of 150 mm size for cement concrete and repairing cementitious concrete were tested to evaluate compressive strength of each material as shown in Fig.2. It was preferred that repairing concrete should have more compressive strength than substrate cement concrete.

### *Split tensile strength test*

As shown in Fig.1(a & b), bond strength in tension between old concrete and new repairing concrete composite specimens were evaluated by performing split tensile test according to ASTM C496 [1]. Bond strength in tension at the interface of two materials in the composite samples of was evaluated by using eq. (1). The same equation was also used for the bulk specimen. The average ultimate load was taken from the experimental data presented in Tables 2 and 3.

$$f_t = \frac{2P_{ut}}{\pi A_t} \tag{1}$$

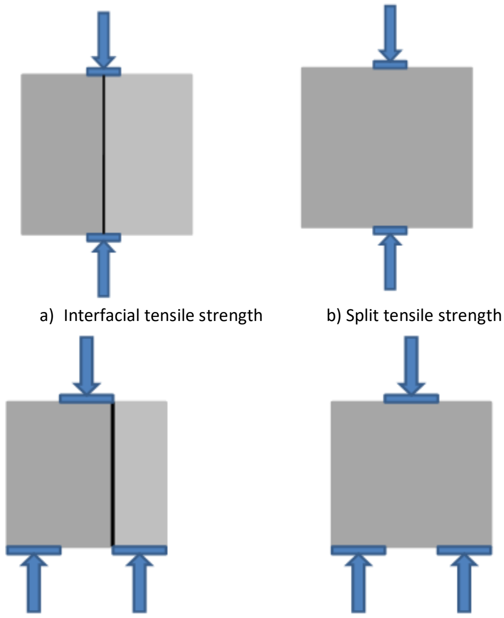
Where, $f_t$ = Bond strength in tension (MPa); $P_{ut}$ = Average ultimate load (N); $A_t$ = Area of interface ($mm^2$).

### *Bi-Surface shear strength test*

As shown in Fig.1(c & d), bond strength in shear between old concrete and new repairing concrete composite specimens were evaluated by performing bi-surface shear test. The test details as used by Momayez et. al. [2] were used for the present work. Bond strength in shear of bulk and composite specimens was evaluated by using eq. (2) from average ultimate load of three specimens (Table 2 and 3).

$$f_t = \frac{P_{uv}}{2A_v} \tag{2}$$

where, $\tau_v$ = Interfacial bond strength in shear (MPa); $P_{uv}$ = Average ultimate load (N); $A_v$ = Area of interface in shear ($mm^2$).



a) Interfacial tensile strength b) Split tensile strength

c) Interfacial shear strength d) Shear strength

Figure 1 Split and shear bond strength determination.

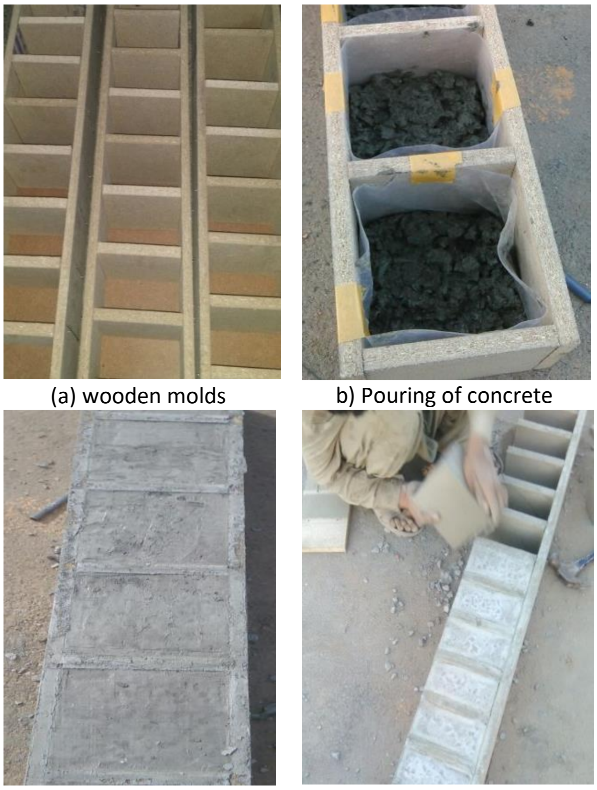
Various adhesives, epoxies and fiber reinforced polymer sheet were used at interface on the roughened substrate surface to increase the bond strength. Steel wire brush was used for roughening of substrate surface to get better bond offered by friction.

*Materials*

M-25 concrete (1:1:2) was prepared with water cement ratio (W/C) as 0.45 while repairing cementitious concrete was also prepared with the same mix and water cement ratio but 10% cement was replaced with silica fume. Four types of surface treatments; i) cement paste, ii) epoxy, iii) bonding adhesive and iv) fiber reinforced polymer sheet, were used to prepare the substrate surface and to test which type of chemical is most effective to improve the bond strength in tension and shear.

*Specimen preparation*

At 1st stage, 150 x 150 x 75 mm (6 x 6 x 3 in.) and 150 x 150 x 100 mm (6 x 6 x 4 in.) specimens were casted for composite specimens using cement concrete for split tensile strength and bi-surface shear strength test respectively. At the same time, bulk specimens of 150 x 150 x 150 mm (6 x 6 x 6 in.) size were also prepared using cement and silica fume in concrete. Wooden molds were prepared to cast these specimens. After 28 days of wet curing in water tank, specimens were taken out and were surface dried [Fig. 2]. Then, its surface having 150 x 150 = 22,500 sq.mm (36 sq.in.) area was roughened by using steel wire brush applied mechanically to get better roughened surface.



(a) wooden molds b) Pouring of concrete

(c) specimen before de-molding (d) De-molding of prepared specimens

Figure 2 Preparation of concrete specimens

Table 1 Number of specimens and types of tests performed to evaluate bond strength.

| Test | Strength | | |
|---|---|---|---|
| | Compressive | Tensile | Shear |
| Substrate concrete | 3 | 3 | 3 |
| Repairing concrete | 3 | 3 | 3 |
| [1]Comp-CP | --- | 3 | 3 |
| [2]Comp-C32 | --- | 3 | 3 |
| [3]Comp-SBR | --- | 3 | 3 |
| [4]Comp-FRP | --- | 3 | 3 |

[1]Composite specimens with cement paste at interface.
[2] Composite specimens with epoxy C32 at interface.
[3] Composite specimens with SBR at interface.
[4] Composite specimens with FRP at interface.

At 2nd stage, epoxy, adhesive, cement paste and fiber reinforced polymer sheet were applied, as per guidelines of vendor, on roughened substrate surface and remaining part of cubes were casted with cementitious concrete to form a complete 150 x 150 x 150 mm (6 x 6 x 6 in.) composite cube. After final setting time, specimens were de-molded and placed in water tank for 28 days curing.
After 28 days of curing, specimens were taken out. Cutting and grinding was performed on sides of the specimens whose surfaces were not proper, so that load can be transferred correctly.

(a) old treated substrate

(b) Pouring of repairing concrete

Figure 3 Preparation of composite specimens.

## IV. Results and Data Discussion

Replacement of cement with silica fume increases the density of concrete which ultimately results in more strength for repairing concrete (Table-II). Results also prove that shear strength of ordinary concrete or repairing concrete is more than tensile strength. 10% silica fume replacement gives better tensile and shearing strength than cement concrete without silica fume.

Table 2 Test results of bulk specimens.

| Test | Strength | | |
|---|---|---|---|
| | Compressive | Tensile | Shear |
| Substrate concrete | 30.31 | 3.69 | 6.03 |
| Repairing concrete | 43.42 | 4.85 | 7.87 |

Table 3 Test results of composite specimens.

| Specimen | Tensile (MPa) | Shear (MPa) |
|---|---|---|
| Cement paste at interface | 0.312 | 0.770 |
| Epoxy C32 at interface | 0.384 | 0.350 |
| SBR at interface | 0.462 | 0.530 |
| FRP at interface | 0.569 | 0.820 |

*Bond strength in tension*

Results dictate (Table-III) that fiber reinforced polymer is best surface treatment for bond strength in tension while at second, SBR latex gives better results. Epoxy stands at third number as its bond strength in tension is the lowest in chemicals. Cement paste as used locally in our country to bond old and new concrete is poor in tensile strength of bond. The results are graphically shown in Fig. 3.

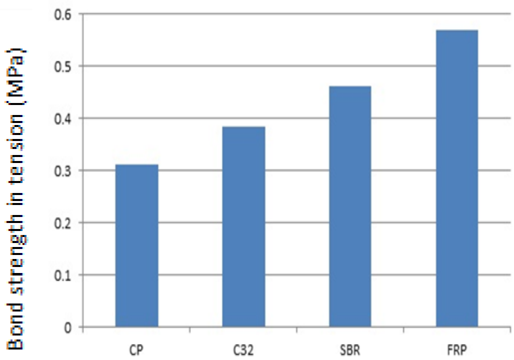



Figure 3 Bond strength in tension using different substrate surface treatments

*Bond strength in shear*

In case of shearing strength of bond between concrete and repairing concrete, FRP gives best results while cement paste is very close to FRP and was considered as best in shear too. Epoxy gives poor results. The results are graphically displayed in Fig. 4.

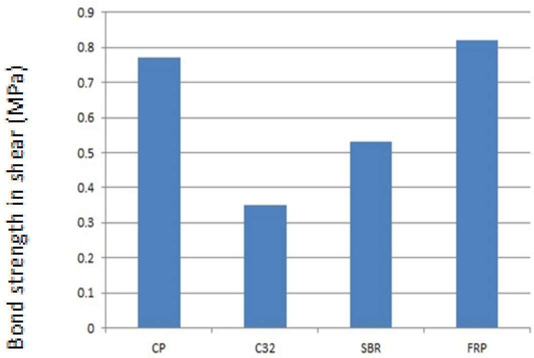



Figure 4 Bond strength in shear using different substrate surface treatments

## V. Acknowledgment

The author is grateful to Imporient Chemicals Pvt. Ltd. (ICPL) for providing epoxy, SBR latex and fiber reinforced polymer sheet. The author is very thankful to University of Engineering and Technology, Lahore and Techno Times Construction Company for assistance in casting and testing.

## References

[1] ASTM C 496-04, Standard test method for splitting Tensile strength of cylindrical concrete specimens, *ASTM International, USA*, 2004.

[2] A. Momayez, M. Ehsani, A. Ramezanianpour, H. Rajaie. Comparison of methods for evaluating bond strength between concrete substrate and repair materials, *Cem. Concr. Res. 35* (4) 748-757, 2005.

[3] ES. Julio, F. Branco, VD. Silva. Structural rehabilitation of columns using reinforced concrete jacketing. *Prog Struct Eng Mater* 5:29–37, 2003.

[4] BJ. Bett, RE. Klingner, JO. Jirsa. Lateral load response of strengthened and repaired reinforced concrete columns. *ACI Struct J;85*(5):499–508, 1988.

[5] S. Alocer, J. Jirsa. Assessment of the response of reinforced concrete frame connections redesigned by jacketing. In: Proceedings of the *Fourth US National Conference on Earthquake Engineering.* vol. 3. May; p. 295–304, 1990.

[6] JL. Ram_ırez, JM B_arcena, JI Urreta, e JA S_anchez. Repair of concrete columns with partial localized damages. *Report T 2.1 and 2.2 BREU–0186*–C, April 1991.

[7] SM. Alcocer. RC frame connections rehabilitated by jacketing. *J Struct Eng;119*(5): 1413–31, 1993.

[8] M. Rodriguez, R. Park. Seismic load tests on reinforced concrete columns strengthened by jacketing. *ACI Struct J* March–April:150–9, 1994.

[9] Dr. Stoppenhagen, JO. Jirsa, LA. Wyllie Jr. Seismic repair and strengthening of a severely damaged concrete frame. *ACI Struct J*; March–April:177–87, 1995.

[10]E.N.B.S. Julio, F. A.B. Branco, V. D. Silva. Concrete to concrete bond strength. Influence of the roughness of the substrate surface. *Cons. Buil. Mate.* 18 675-681, 2004.