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An Experimental Investigation of Mechanical Properties of Bonded Concrete

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***Abstract* — This paper presents an experimental study to measure mechanical properties of bonded concrete specimens. The bond between freshly mixed and hardened concrete has been a concern in repair and retrofit projects as well as staged construction of concrete members. This concern has roots in the time-dependent behavior of concrete, beginning with early-age concrete and continuing with long-term performance and durability of concrete. Moreover, environmental conditions generally complicate the behavior of concrete and resulted deformations such as shrinkage and creep. Application of chemical adhesives and epoxies is a common technique to enhance the bond at the interface of old and new concrete elements. The presented methodology includes preparation of bonded specimens with application of grout and adhesive agents. Mechanical strengths of specimens have been reported based on compressive, tensile, flexural, and shear testing. Results indicate that bonding agents are more effective in tensile and shear behavior of bonded samples.**

***Index Terms* — adhesives, bonding, grouting.**

I. Introduction

Bonding between freshly mixed and hardened concrete is a major concern in repair, retrofit, and strengthening projects, as well as new projects with staged construction. These projects are often necessary due to poor design, problems in construction, or inadequate maintenance of structures. The time-dependent behavior of concrete is a bonding concern when delays are present in the process of concrete placement, disregarding the intentional or incidental nature of the delay. Moreover, changes in occupancy, environmental and loading conditions, and extended use of structures may also warrant repair or retrofit which requires bonding new and old concrete elements [1]-[3].

The general objective of concrete repair is to re-instate the properties of damaged element in respect to service, strength, and durability. Similarly, strengthening aims to enhance the properties of existing members with the aid of new materials. In these areas, the load transfers between new and old concrete through their interface, where bonded properly, as well as reinforcing dowels, where embedded adequately. Thus, bonding, either between freshly mixed and hardened concrete or between concrete and reinforcing bars is an essential factor in securing the load transfer. In plain concrete, the interfacial bonding is practically the only resisting force against cracking, as frictional resistances are generally accompanied with relative sliding movements. In addition, placement of dowels and anchored reinforcing bars is cost-prohibitive for plain concrete applications, and non-constructible in case of incidental delays in concrete placement. Thus, developing interfacial bond might be the preferred option for most applications. It should be noted that repair and retrofit projects, when executed properly, are cost effective solutions in comparison to a demolish-and-rebuild alternative for concrete structures [4]-[5].

Performance measures of repairing materials generally include:

a. Adhesion
b. Thermal deformations
c. Permeability
d. Protecting embedded steel components
e. Mechanical strengths
f. Ease of application
g. Thaw and freeze cycling strength
h. Chemical resistance.

Environmental and loading conditions further influence the criteria for selecting materials and methods of the repair. The method of repair, such as injection, cast-in-place, and shotcrete, impose additional requirements for the selection of materials [6]. Furthermore, application of fiber-reinforcement [7]-[11], recycled materials [12]-[16], and manufactured lightweight aggregates [17]-[19] interact with decision making procedures to determine the appropriate materials in respect to sustainability performance measures such as cost, energy, and emissions throughout the service life of the infrastructure [20]-[22].

Conventional concrete is the most basic repair material, particularly for large-volume applications. Mortars and pastes can similarly cover thin applications. However, the shrinkage of the fresh cementitious mix requires special treatment to avoid immediate cracks at the interface between new and old concrete elements. There are numerous additives, polymers, and resins to treat this problem by shrinkage compensating expansion of the concrete. However, focused treatment of the interface by epoxies and adhesives is often an economic solution for large volume applications [23], [24].

This paper focuses on mechanical strengths of bonded specimens with application of selected adhesives and epoxies. The objective of this paper is to present a methodology to measure the mechanical performance of bonded specimens for any general bonding agent. Results provide insights on expected performance of these bonding agents.

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II. Methodology

A. Materials

The selected mix design for concrete samples included 350 kg of cement per cubic meter of concrete, with the water-cement-ratio of 0.5. The result of slump test was 45 mm. The selected adhesive was a commercial silicone-based adhesive added to the mixing water of concrete at 1-1 volumetric ratio. The selected grout was a commercial non-shrink grout (Fig. 1).

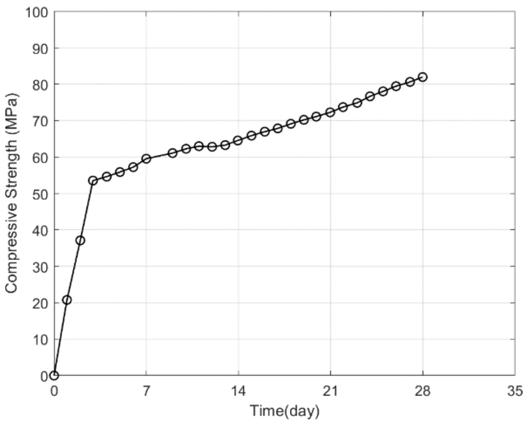

Fig. 1. Compressive Strength of the Grout.

B. Preparation of Specimens

Experimental investigations included three groups of specimens:

a. Witness specimens (group A): These samples were cast with plain concrete in one piece for comparison purposes.

b. Bonded specimens with plain concrete (group B): These samples were bonded with plain concrete without any adhesive or grout.

c. Bonded specimens with bonding agents (group C): These samples were bonded with selected adhesive or grout.

Two methods of repair were studied in these experimentations:

a. Interface method (method 1): Plain concrete (group A) was placed in half of the concrete mold and cured properly. Then, the second half was filled with new concrete and curing was repeated for the second half. This method resulted in an interface with zero thickness between old and new concrete (Fig. 2).

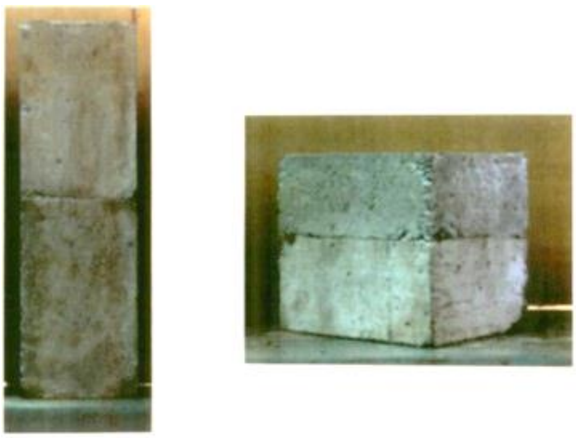
Fig. 2. Bonding Interface between New and Old Concrete.

b. Joint method (method 2): The entire mold was filled with plain concrete (group A), except for a 10-mm gap at the middle of the mold. After initial curing, the gap was filled with repair materials (Fig. 3).


Fig. 3. Repaired Longitudinal Gap between New and Old Concrete.

Table 1 lists specimen groups, repair methods, and their descriptions. All specimens were steam cured. In addition, selected witness samples (group A) were cured with water for comparison purposes. This comparison indicated that steam-cured specimens gained 95% of the 7-day strength of water-cured specimens. Regardless, the evaluation of results is based on comparison between relative strength of specimens to the strength of the witness sample. Thus, conclusions are independent of common preparation and curing techniques.

TABLE I: Compressive Strength Results

Specimen Group	Description of Repair Method
A	Witness
B-1	Jointed Concrete
B-2	Grouted Jointed Concrete
C-2	Grouted Jointed Concrete with Adhesive

C. Testing

Specimens were tested for following measures:

a. Compressive strength [25]: Standard cube (150 mm) samples of each specimen group were tested for compressive strength. The load was applied perpendicular to bonding interface and joint (Fig. 4).

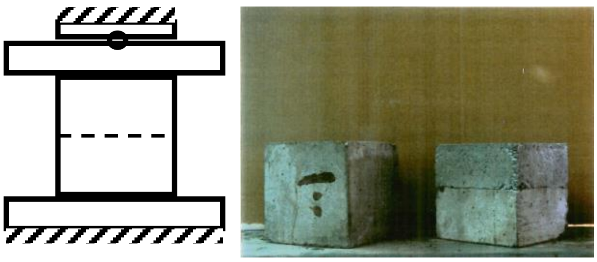
Fig. 4. Location of Bonding Interface/Joint (dashed line) in the Compression Test Setup.

b. Flexural strength [26]: Four-point-loading standard samples (150 x 150 x 500 mm) were tested on 450 mm span loaded at 150 mm spacing for flexural strength. Bonding interface and joint were placed at the middle segment of the beam, parallel to the loading system (Fig. 5).

c. Tensile strength [27]: standard cylindrical (150 x 300 mm) samples of each specimen group were tested for splitting tensile strength. Bonding interface and joint were oriented parallel to both loading system and longitudinal direction of specimens (Fig. 6).

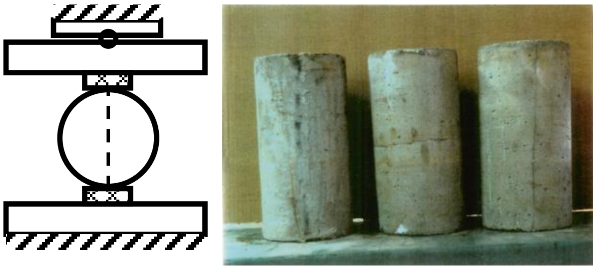

Fig. 5. Location of Bonding Interface/Joint (dashed line) in the Splitting Tensile Test Setup.

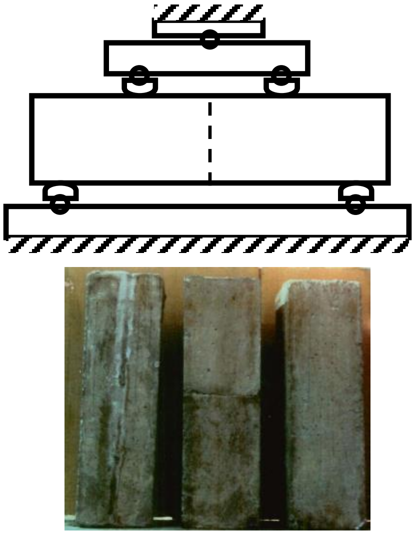

Fig. 6. Location of Bonding Interface/Joint (dashed line) in the Flexural Test Setup.

d. Shear strength: Cube (150 mm) samples of each specimen group were loaded at different angles to measure the shear strength (Fig. 7).

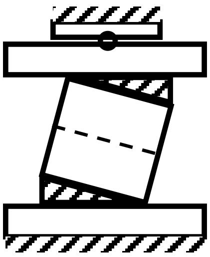

Fig. 7. Location of Bonding Interface/Joint (dashed line) in the Shear Test Setup.

III. Results

A. Compressive Strength

Table 2 shows the average result of compression tests on selected specimens. Observations indicate that all repaired samples showed a reduction in strength in comparison with the uniformly casted witness sample. However, application of adhesive and grout together partially compensated this reduction.

TABLE 2: Compressive Strength Results

Specimen Group	Compressive Strength (MPa)	Relative strength to witness sample (%)
A	26.6	100
B-1	15.3	57.4
B-2	15.8	59.4
C-2	20.7	77.9

B. Flexural Strength

Table 3 shows the average result of flexural tests on selected specimens. While the strength of jointed specimen was negligible, the grouted specimen showed the same strength as of the witness sample.

TABLE 3: Flexural Strength Results

Specimen Group	Flexural Strength (MPa)	Relative strength to witness sample (%)
A	1.3	100
B-1	Negligible	Negligible
B-2	1.3	100

C. Tensile Strength

Table 4 shows the average result of split-tensile tests on selected specimens. The advantage of using grout in repairing cracks is well presented in these results, where the strength of grouted specimen has exceeded the strength of the witness sample.

TABLE 4: Tensile Strength Results

Specimen Group	Tensile Strength (MPa)	Relative strength to witness sample (%)
A	1.04	100
B-1	0.69	66.6
B-2	1.46	140
C-2	1.60	153

D. Shear Strength

Table 5 shows the average result of shear tests on selected specimens. Reported strength values combine compression and shear loads at given angles, i.e. 10%, 20%, and 30%. The resulted shear strength for grouted specimens have exceeded the strength of witness sample for all angles. Presence of compressive stresses in these tests allows inclusion of friction forces to be considered in the overall shear strength values. Observations indicate that grouted specimens gained 20% to 30% extra strength in shear.

TABLE 5: Shear Strength Results

Specimen Group	Compressive Strength (MPa)			Shear Strength (MPa)		
Angle	10%	20%	30%	10%	20%	30%
A	1.66	1.44	1.32	0.17	0.29	0.39
B-1	1.46	1.35	1.22	0.15	0.27	0.37
B-2	2.15	1.92	1.88	0.21	0.39	0.56
C-2	2.05	1.73	1.50	0.20	0.35	0.45

IV. Conclusion

Fig. 8 provides a comparison between mechanical properties of various specimen groups and repair methods. This figure indicates that presence of joints has reduced the strength of all specimens. Application of grout has had a positive influence on the strength of repaired specimen for all tests. Application of adhesives in addition to grout has not necessarily enhanced the strength further. Repair methods have been highly influential in tensile and shear tests.

Concluding results indicate the effectiveness of the proposed methodology in assessing repair methods and materials. However, the number of specimens is not large enough to allow reliable conclusions on the appropriateness of applied methods and materials. Practitioners should consider proper testing programs before specifying any method or material of concrete repair.

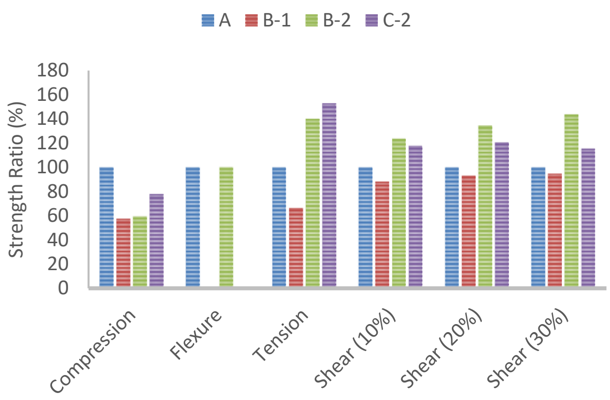

Fig. 8. Strength Ratio for Various Specimens and Repair Methods

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