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An Overview of Interface Behaviour between Concrete to Concrete

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Abstract: This paper describes the investigations of concrete composite units consisting of two concrete parts. Flexural strengthening of concrete elements by adding new concrete layers is a common strengthening technique. A specific feature of concrete composite structures is the existence of an interface between the component parts which may be the weakest zone in view of the occurring discontinuity of the construction material. It is found that interface preparation and the type of strengthening (tensile or compressive) considerably influence effectiveness. Through a comparison between strengthened and respective monolithic and initial specimens, the efficiency of the strengthening technique is evaluated.
This review was aimed at studying the repair materials, repair techniques and test methods for evaluation of bond strength between concrete substrate and repair material.

Keywords: *Bond strength, Composite concrete beams, Interface, Surface preparation, Substrate*

I. Introduction:

Concrete-to-concrete interfaces are present both in new and existing structures. Two distinctive situations can be identified (1) placing hardened concrete against hardened concrete parts, such as the case of precast members for viaducts and bridge decks; and (2) placing fresh concrete against hardened concrete parts, such as the rehabilitation and strengthening of existing structures by concrete jacketing or concrete overlay.

The bond strength of the concrete-to-concrete interface is influenced by several parameters but mainly by (1) the surface preparation (2) the use of bonding agents; (3) the compressive strength of the weakest concrete (4) the moisture content of the substrate (5) the curing conditions (6) the stress state at the interface (7) the presence of cracking and (8) the amount of steel reinforcement crossing the interface among others.

Compatibility of the repair material with the existing substrate is an important consideration if the repair is to withstand all the stresses induced by influences such as volume changes and chemical and electrochemical effects. This paper briefly reviews some of the major requirements for design and construction of durable repairs.

II. Repair Materials:

Much of the concrete repair work undertaken in the first half of the century was relatively simple from a materials engineering perspective, as it primarily involved replacement of damaged or deteriorated concrete with conventional Portland cement based concretes, mortars, grouts or gunites (sprayed mortars). Since about 1960's, however a plethora of new enhanced concrete repair materials and systems have been introduced and found increasing utilization. These have ranged from polymer modifiers for Portland cement based products (primarily styrene butadiene, acrylic and some vinyl copolymers) to pure polymers such as epoxy resins, polyesters and some polyurethane based systems. Other non-Portland cement based materials, such as high alumina cements and magnesium phosphate based repair products have also found application.

In order to provide with a durable repair the design engineer must first answer some important questions.

- What are the important properties for the repair material/system?
- What is the sensitivity (to installation) and durability of the proposed repair material/system?

A. *Properties*

Major differences exist in the mechanical properties of resin mortars (polymer concretes) compared to plain cementitious mortar. The mechanical properties of polymer modified cementitious mortars tend to be intermediate between resin mortars and plain cementitious mortars. The plain cementitious mortar will probably have mechanical properties closest to most substrate concretes. Some would argue that it is thus the most appropriate repair material to use to attain compatibility between the repair and surrounding concrete. This view, while appropriate for certain types of repairs, may not provide the best remedial solution for others.

B. *Interfacial Stresses*

Stresses on the bond interface of repairs in the field can be affected by factors such as those listed below,

- Plastic and drying shrinkage strains in the repair material
- Heat generation from early heat of hydration or polymer reaction thermal stresses (including thermal shock when hot repair material is exposed to cold ambient temperatures)
- Time dependent volume changes, such as drying shrinkage (or expansion in shrinkage compensated

cements), autogenous shrinkage, carbonation shrinkage and creep
- Dead loads and changing live loads and dynamic loads
- Thermal stresses from diurnal or seasonal temperature changes, or external heat sources
- Frost build-up or salt crystallization pressures
- Other factors such as impact loads or changes in moisture gradient in the repaired system.

C. Polymer Concrete

Property mismatch can prevail between polymer concrete repair materials and substrate concretes, but they are used for their exceptional physical and chemical properties such as:
- Low permeability to ingress of chlorides and other aggressive chemicals
- Ability to rapidly set and harden (even in below freezing temperatures for certain polymers) and for the structure to be quickly returned to service
- Excellent chemical resistance to attack from many aggressive chemicals
- Ability to be applied in much thinner layers/sections than Portland cement repairs.

They are able to work as repair materials in certain applications because of the generally superior tensile, adhesive and shear bond strength compared to most cementitious materials, low values of total shrinkage(for at least most epoxy and acrylic based formulations) and the ability to redistribute stresses at the bond interface over time through creep relaxation.

III. Repair techniques:

Some techniques for repairing and/or strengthening structures involve adding new concrete to an existing concrete substrate. To improve the bond strength, it is common to increase the roughness of the substrate surface. The surface roughness, the use of a bonding agent and the moisture content of the substrate can have a significant influence in the bond strength of the interface and failure mode of composite concrete members with layers cast at different ages.

Since composite concrete members are cast at different ages, different concretes are frequently adopted. Even with the same mixture design, differences are obtained in the compressive strength and therefore in the Young's modulus. In this case, the weakest concrete layer controls the failure of composite members. Furthermore differential stiffness due to different Young's modulus at each layer also affects the behaviour of the composite members since additional stresses are induced at the interface.

A. Surface Roughness

Preparation techniques such as wire-brushing, sand-blasting, shot-blasting, chipping and hydro-demolition are frequently used to remove the superficial layer. Additionally to the roughness increasing procedure, a bonding agent can be used to improve the bond strength. In this case, epoxy-based resins are the most commonly adopted in bond fresh/hardened to hardened concrete parts but the resulting benefits are not widely accepted by researchers. Some suggest that an adequate bond can be only achieved by combining the use of bonding agents with a proper technique to increase the substrate roughness mainly when the substrate presents a smooth surface.

The specimens with the substrate surface treated with sand-blasting showed the highest values of bond strength in shear (14.13 MPa) and the lowest values of variation coefficient (8.56%).

B. Bonding Agents

When the substrate is saturated or presents high moisture content, even with its surface dry the influence of the surface preparation is less significant. In these conditions the use of a bonding agent is advantageous but also less significant in comparison to the same conditions but with a dry substrate.

Many state that bonding agents are not necessary provided that substrate concrete is dry and properly roughened to expose the aggregates. Moreover, the influence of the surface roughness appears to be more significant when cement mortars or polymer modified cement mortars are used, since when epoxy resins are adopted failures do not frequently occur at the interface. Besides roughness and bonding agents the influence of parameters such as temperature, and in particular the effect of cyclic variations should be evaluated for each specific situation since they can control the behaviour of the interface.

C. Pre-wetting

In relation to pre-wetting the substrate surface, opinions diverge about the most appropriate situation. Saucier and Pigeon make reference to the AASHTO-AGC-ARTBA Joint Committee that recommends a dry surface of concrete, except in dry and hot summer days, and the Canadian Standards Association Standard A23.1 that recommends wetting the surface for at least 24 h before casting the new concrete. Emmons mentions that the moisture level of the substrate may be critical in achieving bond. He states that an excessively dry substrate may absorb too much water from the repair material while excessive moisture in the substrate may clog the pores and prevent absorption of the repair material. Therefore, a saturated substrate with a dry surface is considered to be the best. The influence of pre-wetting the substrate surface on the bond strength indicates that this variable does not have a significant influence.

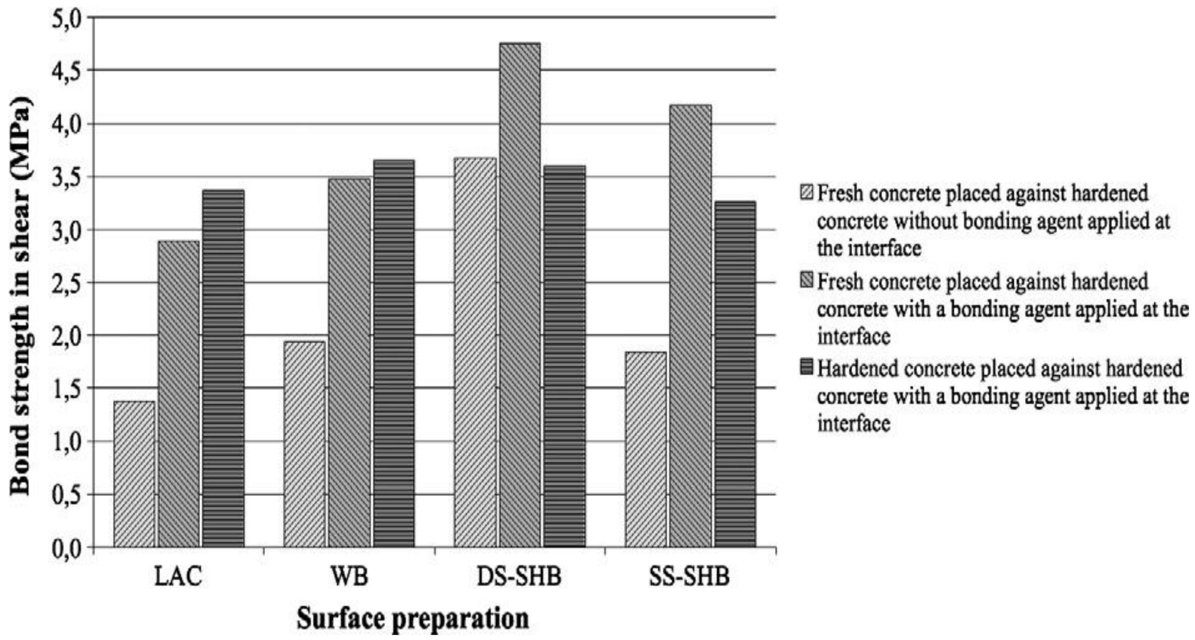

Fig.1 Surface preparation

LAC – Left As Cast; **WB** – Wire brushing;
DS-SHB – Dry Substrate-Shot Blasting; **SS-SHB** – Saturated Substrate- Shot Blasting

Current practice also recommends pre-wetting the substrate concrete in the 24 h that precede the cast of the new concrete layer to achieve a saturated substrate with a dry surface. Under hot and dry weather conditions, pre-wetting is fundamental to achieve a good bond. Nevertheless, in the case of high moisture or free water at the substrate surface bond strength decreases.

D. Curing

Current design codes for concrete structures do not explicitly present provisions for the curing procedure of composite members cast at different ages and therefore the influence of differential shrinkage is often neglected. This is a key parameter since different concretes with different curing conditions indeed exist in composite members. It is usual recommended to start curing immediately after the cast of the added concrete extending it for at least 3–7 days to improve the bond strength. Parameters such as relative humidity and temperature, as well as the exposure to wind, rain and solar radiation must be considered.

The bond strength between concrete layers can also be improved by increasing the compressive strength of concrete and therefore the contribution of cohesion for the shear strength. A proper curing process ensures that the maximum stresses between the substrate concrete and the added concrete do not lead to debonding and micro-cracking at the interface. It should be highlighted that the stress state at the concrete-to concrete interface is very complex since it comprises a combination of shear and normal stresses. When acting on the material properties, namely the compressive strength of each concrete layer, it is possible to design the failure mode of composite members by specifying the differential stiffness between layers. For the same level of shear stresses, normal stresses increase at the interface when the differential stiffness between concrete layers increases. This means that it is possible to define the failure mode to be adhesive, due to debonding at the interface or cohesive by concrete crushing at the bulk. Nevertheless, the increase of the differential stiffness increases stress concentrations is other zones of the interface.

IV. Test methods:

Several tests are available to measure the bond strength, but only little information is available on comparison of these various tests methods and the resulting bond strength values. There is a need to compare different tests for measuring bond strength and to establish a relationship among the values obtained from each test.

A. Bond Strength

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 interface depends on bonding agent, material compaction, cleanness and moisture content of repair surface, specimen age, and roughness of interface surface. Friction and aggregate interlock on interface depend on parameters such as aggregate size, aggregate shape, and surface preparation. In addition to the above factors, the measured bond strength is highly dependent on the test method used. Size and geometry of specimen and the state of stress on the contact surface are quite dependent on the chosen test method. It is noted that certain standard tests have been developed for specific applications and state of stress.

There are two problems that need to be addressed. First, what types of tests are appropriate for evaluating the bond strength for the state of stress that is commonly found in buildings, i.e., shear stress caused by loading and time dependent factors. Second, what relationship exists between the results of different test methods?

B. Existing methods

The existing tests to determine the bond between concrete substrate and repair material can be divided into several categories.

The **first category** of tests measures the bond under tension stress. Pull-off, direct tension and splitting are the main tests under this category.

1) Pull-Off test

The pull-off test is a tension test and has been chosen for two reasons (1) to evaluate the bond strength in tension of the interface and (2) it can be carried out in situ. The adopted geometry for the pull-off specimens was a 0.20 m cube with the interface line at the middle. A core of 75 mm diameter was drilled into the added concrete and extending 15 mm beyond the interface into the substrate. A circular steel disc was bonded, with an epoxy resin, to the surface of the core. A tension force was applied to the disc, with a commercial device at a steady rate of 0.05 MPa/s, until failure occurred.

2) Direct Tension test

In the direct tension test, the tensile force is transmitted to the concrete specimen either by glued metal or by special grips. A very careful alignment of the specimen in the axis of loading is essential. Even a very small amount of misalignment may introduce eccentricities that will cause large scatter in test results. Performing a good tension test is difficult and time consuming. However, a recently proposed variation of the direct tension test, referred to as pull-off test, is easier to carry out and can produce good results.

3) Splitting Test

Indirect tension tests include the flexural test and the splitting test. The flexural test offers low efficiency (the area of the bonded surface subjected to loading is small compared to the specimen volume). For such tests, only a very small part of the bonded plane is subjected to the maximum stresses. Splitting test is more efficient in that regard.

In the splitting test, a prism with circular or square cross-section is placed under longitudinal compressive loading. Tension stresses cause failure in a plane passing through upper and lower axes of loading and split the specimen into two halves. The splitting tensile strength of concrete is regarded as an indication of its tensile strength. The test method is simple to perform and uses the same cylindrical specimen and test machine as a standard compression test. The splitting tensile test as per ASTM C496, as an indirect tensile test, was conducted to evaluate the bond strength between the NC substrate and concrete.

Fig. 2 Cylindrical splitting specimen at failure

The **second category** of tests measures the bond under shear stresses and is called direct shear methods. Several tests fall under this category, including L-shaped, monosurface shear, etc.

1. Direct Shear Test

In most cases, the bond surface for a direct shear test is actually subjected to shear stress and a small bending stress. When a steel plate is used to transmit the shear force along the bond line, some stress concentration at the edge of the bonding plane is induced. Smaller stress concentration leads to smaller scatter in test results.

The **third category** measures the bond strength under a state of stress that combines shear and compression. All slant shear tests mentioned previously fall under this category.

2. Slant Shear Test:

The slant shear test uses a square prism or a cylindrical sample made of two identical halves bonded at 30ºor 45º and tested under axial compression and during loading, the interface surface is under compression. The slant shear test as per ASTM C882 has become the most widely accepted test and has been adopted by a number of international codes as a test for evaluating the bond strength of resinous repair materials to concrete substrates. However, there is no general agreement among researchers as to the appropriateness of this test for non-resinous materials.

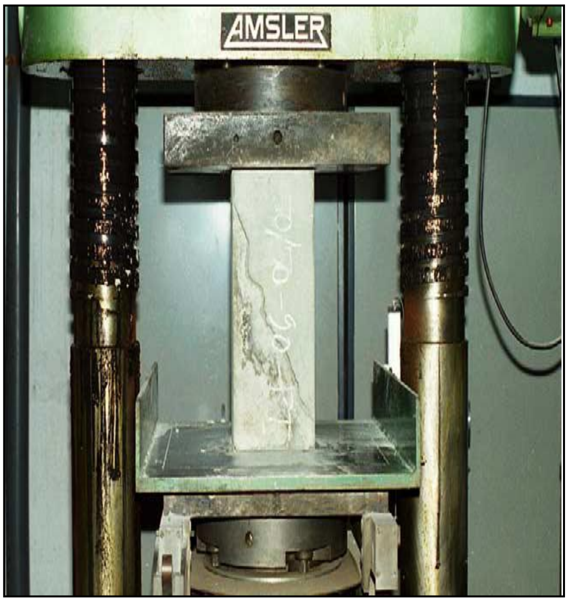

Fig. 3 Slant Shear Test

V. Summary and Conclusions:

The conclusion and summary were based on previous experiments and results:

1. The surface roughness, the use of a bonding agent and the moisture content of the substrate can have a significant influence in the bond strength of the interface and failure mode of composite concrete members with layers cast at different ages.

2. The best technique from highest to lowest decreases in the following order: Sand blasting, Wire brushing, partially chipped & As cast. In relation to the influence of pre-wetting the substrate surface, results seemed to indicate that its effect is not significant.

3. The measured bond strength decreases with the test method in the following order: slant shear, Bi-Surface shear, splitting, and pull-off.

4. A good correlation between the slant shear test results and the pull-off test results has been observed, validating the use of the latter test to evaluate in situ the bond strength between different concrete layers, which ranged from 9% for pull-off to 25% for slant shear tests.

Further studies are necessary to evaluate the bond strength of the interface of composite concrete members with layers cast at different ages, when different strengths and densities are adopted namely (1) a normal concrete (NC) (2) a high strength concrete (HSC) (3) a lightweight aggregate concrete (LWAC) (4) a ultra-high performance fibre reinforced concrete (UHPFRC) (5) Self-Compacting concrete (SSC) and (6) ultra-high performance concrete (UHPC).

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