Comparison of bond strength analysis on the interfacial layer of old and new concrete using latex, epoxy and glycoluril

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Abstract. Though other methods were updated for repairing a concrete structure, improving the bond strength of the interfacial layer with effective additives is still the remarkably outstanding technique since it highly improves the structure without any compromise with the quality and strength parameters. The primary reason for the investigation is to compare the market available materials like epoxy and latex with polymer based binding material named glycoluril by slant shear test in both compression and tension. In this comparative study, epoxy bonding depicts higher bond strength in compression than the latex bonding, whereas 3% of glycoluril bonding in the interfacial layer provided for 1cm thick in the interfacial layer were noted to improve the tensile bond strength between the old and new concrete layers which turns to be effective in the repair works of bottom of the slab/beam where tension is more.

1. Introduction

Being the highly used construction material, mortar and concrete obtained from Portland cement are lagging behind because of the lower chemical resistance, limited tensile strength and slower hardening process which induced the development of polymer modified concrete with polymer additives. The long-term durability and higher strength parameters [1] out do the other types of concrete when related to the polymer modified concrete [2]. Polymerization technique can be imparted for the rehabilitation of existing structures by adding up fresh concrete on the surface of the old concrete. Since the old concrete will not have adhesion property and natural bonding, it is overthrown by the usage of bonding adhesives[3,4] Though some techniques are adopted to evaluate the bond strength of the repaired concrete, slant shear method was noted to develop exact stress properties[5,6] and consistent results[7] than the others[8-10]. The slant shear specimens were casted as per ASTM C882[11] in which the specimen is cylindrical in shape with two equal halves casted with a 30° vertical diagonal surface. Even though few parameters are responsible for the bond strength between the overlay and the substrate, the surface parameter [12] plays the key role in the interfacial surface behavior.

2. Research significance
Rehabilitation of structures has become one of the challenging fields in concrete industry which promotes a sound structure without harming the previously layered concrete layers along with a perfect bonding between the old and new concrete. However, it is must to strengthen the substrate surface with an appropriate bonding agent which allows the adherence of old and new concrete which in turn extends the service life of the structures. The grooved acid etched specimens significantly performed well when compared with other types of surfaces in a study [13]. The bond strength is usually analyzed to define the bonding between the substrate surfaces and overlay concrete. Tensile strength, slant shear and rebar pull out test were conducted to evaluate the in between bonding of the repaired concrete. Few of them were also adopted to examine the adhesion properties of polymer modified mortar and concrete [14].

3. Experimental study

3.1. Materials

OPC with 43 grade fulfilling IS 8112 necessities was utilized in this investigation. Density of the cement is 3.32g/cm³ with specific area of 3400cm²/g. Zone II river sand with specific gravity of 2.56 and coarse aggregate having 20mm maximum size with specific gravity of 2.71 were used. Epoxy and latex were purchased in local market and glycoluril was synthesized according to the standard methodology expressed by Ji-Tai Li [16]. IS10262 used for designing the mix and proportion obtained 191.4 : 510 : 512 : 1157 (W:C:FA:CA) for both old and new concrete.

Three different monomers namely epoxy, latex and glycoluril were used for the polymerization process in the interface surface as show in table 1 for the concrete specimens. When compared with the other two monomers (latex and epoxy), there are very limited study with the glycoluril in polymer modified concrete/mortar for the repairing of the old concrete structures.

| Table 1. Concrete test matrix. |
|-------------------------------|
| Name of the Specimen | Glycoluril (gms) | Epoxy (gms) | Latex (gms) |
| CS | _ | _ | _ |
| CCG1% | 1.3 | _ | _ |
| CCG2% | 2.6 | _ | _ |
| CCG3% | 3.9 | _ | _ |
| CCG4% | 5.2 | _ | _ |
| CCE | _ | 100 | _ |
| CCL | _ | _ | 10 |

CS Control Specimen  
CCCP Cement Concrete with Cement Paste  
CCE Cement Concrete with Epoxy  
CCL Cement Concrete with Latex  
CCG 1% Cement Concrete with Glycoluril of 1%  
CCG 2% Cement Concrete with Glycoluril of 2%  
CCG 3% Cement Concrete with Glycoluril of 3%  
CCG 4% Cement Concrete with Glycoluril of 4%

3.2. Specimen preparation

In order to plot the bond strength of the interfacial layer in tension and in shear, the splitting tensile strength test and slant shear test were conducted respectively. Three sets of cylindrical specimens
(75mm diameter and 150mm height) were casted for each reading to obtain the level of bonding between the old and new concrete. The old concrete specimen was casted as half cylinders and water cured for 7, 14 and 28 days which is then completed with fresh concrete along with monomers (latex, epoxy and glycoluril of 1%, 2%, 3% and 4%) embedded in between. Epoxy and latex are applied on the surface of the old concrete using a brush (Fig. 1.) and then the new concrete is poured in continued by compaction on the surface. Whereas glycoluril is mixed along with cement paste and applied for 1cm thick on the surface of the old concrete followed by the completion of the cylindrical specimen with fresh concrete. Thus, formed specimens were dipped in the formaldehyde solution for a period of 24 hours which initiates polymerization of the monomer (glycoluril). Water curing is again carried out for the completed specimens for 7, 14 and 28 days. The geometry of the specimens was as such 30° slanting with the vertical shear plane as per the ASTM C882 standards. The grade of the concrete chosen for this study was M30

![Figure 1. Applying monomer on the half cylindrical specimen](image)

3.3. Bond strength analysis
The bond strength between the old and the new concrete were analyzed through the results obtained from the tensile strength and compressive strength analysis. An average value corresponding to three tests were considered. The compressive strength, tensile strength and bond strength were obtained from the test results of the prepared samples. Compressive strength and tensile strength were calculated from the respective compressive load and tensile load required for the failure of the composite specimen. Whereas the bond strength is calculated as (Maximum load)/(Area of slant surface) for further analysis[15]. The slant shears of the specimens were tested as shown in Fig. 2. The cylinder specimens were tested at 7, 14 and 28 days from the day of casting the complete specimen along with the polymerized monomer which is intended to improve the strength parameters of the concrete composite.
3.4. Types of failure

Three different types of failure modes were noted in the specimens after the tests were conducted namely the failure of the old concrete, failure of the new concrete and the failure of the interfacial layer as show in figure 3. The types of failure were analyzed both in tension and compression as shown in table 2 and 3.

![Figure 2. Testing of Slant Shear Bond Strength](image)

![Figure 3.](image)

**Table 2. Failure Modes in Compression**

| Type of mix | 7days     | 14 days   | 28days   |
|------------|-----------|-----------|-----------|
| CCCP       | Interfacial | Interfacial | Interfacial |
| CCE        | New Concrete | New Concrete | New Concrete |
| CCL        | Interfacial | Interfacial | Interfacial |
| CCG 1%     | Interfacial | Interfacial | Interfacial |
| CCG 2%     | Interfacial | Interfacial | Old Concrete |
| CCG 3%     | New Concrete | New Concrete | New Concrete |
| CCG 4%     | New Concrete | New Concrete | New Concrete |
Table 3. Failure Modes in Tension

| Type of mix | 7 days  | 14 days | 28 days |
|------------|--------|--------|--------|
| CCCP       | Interfacial | Interfacial | Interfacial |
| CCE        | Interfacial | Interfacial | Interfacial |
| CCL        | Interfacial | Interfacial | Interfacial |
| CCG 1%     | Interfacial | Interfacial | Interfacial |
| CCG 2%     | Interfacial | Interfacial | Interfacial |
| CCG 3%     | New Concrete | New Concrete | New Concrete |
| CCG 4%     | New Concrete | New Concrete | New Concrete |

The differential shrinkage of concrete in interfacial layer due to the different ages of old and new concrete resulting increase in stress. Due to the development of stress at interface most of the repaired concrete were shows decreased bond strength. Epoxy and glycoluril (3% & 4%) were noted to have failed with the new concrete which depicts their better resistance in compression whereas glycoluril (3% & 4%) specimens alone were noted to have failed with the new concrete showcasing a strong resistance towards the tensile failure.

4. Test results and discussion:

4.1. Bond strength

All the test specimens were tested after 7 days, 14 days and 28 days of casting the new concrete. Bond strength was calculated by dividing maximum load and interfacial area. The result shows that the bond strength was increasing by adding binding material in the interfacial surface. Bond strength were notably higher for the specimens developed with an interfacial layer of glycoluril (3% & 4%) and epoxy compared with the specimens developed with an interfacial layer of latex and glycoluril (1% & 2%) showing the effective bonding of the interfacial layer with epoxy and glycoluril (3% & 4%) monomers. The bond strength of the above specimens was also noted to increase with the age of the concrete as shown in the Fig. 4. There is no bond strength analysis for control specimen. Just to compare the reduction in compressive strength of CS with the bond strength of repaired concrete this was included in Fig. 4.
4.2. Compressive strength
The concrete specimens developed with an interfacial layer of the monomer epoxy as well as 3% of glycoluril developed higher compressive strength than the control specimen (M30 mix) at 28 days and 7 days which shows an rise in the compressive strength at early stage and later stage owing to the better hydrogen bonding thus reducing the porous nature of the respective samples (Fig.5.). Whereas modified specimens with latex in interfacial layer tend to develop lower compressive strength than the control specimen due to poor bonding in the interfacial layer. The latex in concrete affects degree of hydration of concrete. Due to this the strength development of the new concrete was reduced and its result in lower compressive strength. This also confirmed by Ma [17].

![Figure 5. Effect of different specimens on compressive strength (N/mm²)](image)

4.3. Tensile strength
The tensile strength of all the specimens developed with different monomers as interfacial layers were noted to show a rise along with the age of the concrete (Fig.6.). Notably glycoluril of 3% were noted to develop tensile strength slightly higher than the control specimen whereas specimens developed with epoxy and latex in the interfacial layers resulted in lower tensile strength than the control specimen which depicts the poor bonding of the interfacial layer in the tension zone. This test clearly shows that the glycoluril as binding material plays vital role in tension carrying capacity. Giving equal and slightly higher strength compared to the control specimen. So, this techniques with 3% glycoluril may be advisable for repairing concrete in tension zone like spalling of slab and beam.
5. Conclusion

Based on the results from the experimental program, the following conclusions were obtained:

- Though concrete and mortar are weak in tension, significant rise in tensile strength were noted in polymer modified concrete with 3% of glycoluril in the interfacial layer which in turn makes it feasible to be of used in the repair works of bottom of the slab/beam where tension is more.
- The development of stress due to the differential shrinkage at layer of the repaired concrete shows decreased bond strength and failure at the interface.
- Epoxy and latex developed very less resistance in tension owing to the brittle nature of the respective specimens.
- 3% of glycoluril also developed considerable rise in the compression strength along with a noticeable increase in bond strength since the particles are closely packed imparting an efficient hydrogen bonding.
- Repaired concrete with 3% and 4% glycoluril additives in tension strength test giving equal or slightly higher to the control specimen. So, this repair work is advisable in repairing spalling of concrete in slab or beam.

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