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AN EXPERIMENTAL STUDY ON HARDENED PROPERTIES OF CONCRETE SPECIMENS AT INTERFACE OF OLD AND NEW CONCRETE

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Abstract— ***An experimental study was performed to evaluate the hardened properties of concrete specimens at interface of old and new concrete, using as cast substrate surface and a commercial epoxy resin based bonding agent under different laboratory tests. Laboratory tests, including splitting tensile strength (bond strength in tension), slant shear strength (bond strength in shear) and flexural strength (bond strength in flexure) tests were conducted. The influence of the strength of concrete on the hardened properties of old and new concrete interface, the substrate(old) concrete was kept unchanged with a compressive strength of 20 MPa. On the other hand, two different concrete mixes, with compressive strengths 25 MPa and 30 MPa were used for the new concrete. Splitting tensile half specimens were cast and surface left as cast. After the age of 28, 56 and 84 days, the new concrete was added thus make in it as full cylinder. Slant shear half specimens were cast and surface left as cast. After the age of 28, 56 and 84 days, the new concrete was added thus make in it as full prism. Splitting tensile half specimens were cast. After the age of 28, 56 and 84 days, the bonding agent was applied and the new concrete was added thus make in it as full cylinder. Slant shear half specimens were cast. After the age of 28, 56 and 84 days, the bonding agent was applied and the new concrete was added thus make in it as full prism. Flexural half specimens were cast. After the age of 28, 56 and 84 days, the bonding agent was applied and the new concrete was added thus make in it as full prism. Analysis of the results indicates that bond strength at interface of old and new concrete is almost same in compressive strength test. In split tensile strength test, bond strength at interface increased, when epoxy resin is used with comparison of as cast specimens. In slant shear strength test, bond strength at interface increased, when epoxy resin is used with comparison of as cast specimens. In flexural strength test, bond strength at interface increased, when epoxy resin is used. The application of an epoxy resin based bonding agent improve the bond strength.***

KEY WORDS— ***Substrate, Epoxy resin, Splitting tensile, Slant shear, Flexure.***

I.INTRODUCTION

The usage of concrete is unavoidable. So, the concrete should be eco-friendly and long lasting. It is used more than any man-made product in the world and the second most consumable product in the world, next to water. According to the 2009 Report Card of American Society of Civil Engineers (ASCE), The total investment of concrete repairs for five-years was estimated as 2.2 trillion dollars. To enhance the capacity and quality of infrastructure by overlaying or patching with rehabilitation materials, it is essential to understand the mechanical properties and behaviour at the interface between old and new concrete. The interface is the weakest link for composite behaviour and a source of premature failure. The bond strength at the interface between concrete layers cast at different ages is important to ensure the monolithic behavior of reinforced concrete composite members. Precast beams with cast-in-place slabs and strengthening of existing concrete members by adding a new concrete layer are typical examples of RC composite members. The properties of the interfacial bond mainly depend on the adhesion between the repair concrete and the concrete substrate at the interface, friction, aggregate interlock, and other time-dependent factors. Adhesion to the inter-face depends on different parameters such as, bonding agent , material compaction, cleanness and substrate moisture content of repair surface, specimen age, the existence of micro cracking at the substrate, and the shrinkage of the added concrete.

This paper assess the hardened properties of old and new concrete interface surface by applying bonding agent and as-cast using flexural test, slant shear test, splitting tensile test to quantify the bond strength in flexure, shear and indirect tension. Comparison and discussions of test methods, respectively.

II.PREVIOUS RESEARCH

There are some published works on adhesion of repairing materials to a concrete substrate where bonding agents used. Nevertheless, the results obtained by different researchers are not always in agreement. Furthermore, due to the variability of the parameters that influence the hardened properties of old and new concrete interface, it is not possible either to generalize or to extrapolate the conclusions drawn.

According to Magda(2015) concluded that cement paste bonding material showed reasonable results especially in the case of identical strength concrete for two halves of the composite and with roughened surface . That makes it more suitable and economical in the case of structure subjected to tensile stresses. In case of shear stress, the epoxy resin produced highest results in all cases whilst, cement paste gave the lowest values in shear. Bassam et al. (2013) says the bond strength between the UHPFC and substrate depends on the surface treatment increases the bond strength increases.

The slant shear test appeared to be suitable to predict both the bond strength and the failure mode of interface. The modified splitting test appears to be unsuitable for both purposes. The bond strength of the concrete to concrete interface increased with the increase of the difference of age between concrete layers. The increase of age between concrete layers, corresponding to a higher differential shrinkage, the failure load of the slant shear specimens also increases (Santos et al. 2011). The new concrete with low w/c ratio resulted in high compressive strength but low shear bond strength for saturated surface dry and air dry surface conditions compared to high w/c ratio(Shin et al. 2010).Concrete surface roughening by sandblasting provides a better method than applying the adapted bonding agent as the achieved bond strength of the interface was higher and the operation cost was lower (Julio et al.2005).

III.EXPERIMENTAL PROGRAMME

A. Old and New Concrete Properties

The mix design of old concrete used in this study ensures average characteristic compressive strengths 20 MPa at 28 days. The mix design of new concretes used in this study ensures average characteristic compressive strengths 25 MPa and 30 MPa at 28 days. The concrete contains Ordinary Portland Cement 43 grade, river sand with fineness modulus of 2.84confirming to Zone II, coarse aggregate with a maximum size of 20mm, a water-to-cement ratio of 0.52,0.48 and 0.43 for M20, M25 and M30 respectively. Mix proportions of the concrete are presented in Table 1. The cubes made with a old and new concretes have achieved an average 28 days cube compressive strength of 29.09MPa, 33.57MPa, 39.24MPa for M20, M25 & M30 respectively. The specimens used consists of (i)150mm diameter by 300 mm high cylinder for split tensile strength test (ii)150mm x150mm x 450mm prism for slant shear strength test and (iii)150mm x150mm x 700mm prism for flexural strength test. A commercial epoxy resin by name nitobond EP that is widely used in practice was chosen.

TABLE I
PROPERTIES OF MATERIALS

Item	**Mass density(kg/m^3)**			**Remark**
	M20	**M25**	**M30**	
OPC	320	350	380	OPC 43 grade
Fine Aggregate	731	694	677	F.M 2.84 (ZONE II)
Coarse Aggregate	1199	1196	1211	F.M 6.71
Water	166.4	168	163.4	
W/C Ratio	0.52	0.48	0.43	
Epoxy Resin	3.5 to 4.5 m^2/lt			Two component Colour : Transparent Specific gravity : 1.44 at 25 °C

B. Specimens Preparation

Each of the tested specimen comprised of two different mixes, being the M20 as a substrate and M25,M30 as a new concrete. The fresh M20 concrete was placed and left to set in its moulds for 24 hours after casting. After 24 hours the substrate specimens were demoulded and were cleaned and cured for another 28,56,84 days in a water curing tank. At the age of 28 days, before casting the new concrete, the surface of the substrate specimens were wiped dry with a damped cloth. Half of the substrate specimens surface was applied by epoxy resin. Substrate specimens were then placed into steel made moulds. The moulds were then filled with new concrete. The composite specimens were submerged in a water tank for 28 days before the experimental strength test. Repeat this process for after 56 and 84 days curing of substrate specimens.

C. Split Tensile Strength Test

Spilt cylinder indirect tensile strength test as per the specification of IS 5816:1999 was used to investigate the bond strength of old and new concrete. In this test, the specimens used have a diameter of 150mm and longitudinal length of 30 mm.

Fig. 1 Split tensile test specimens

The split tensile strength (T) was calculated by the following formulae:

$$T = 2P/\pi ld$$

Where T is the split tensile strength (in MPa); P is the maximum experimental force (KN); l is the longitudinal length (mm);and d is the diameter length (mm).

D. Slant Shear Strength Test

Slant shear test as per the specification of ASTM-C882:1999 was used to investigate the bond strength between old and new concrete. The new concrete was casted and bonded to the old concrete substrate specimens on a slant plane inclined angle of 30^{o} from the vertical axis to from a 150mm x 150mm x 450mm composite prisms specimens as shown in Figure Where the interface is subjected to the shear stress or the combination of shear stress and compression forces, the slant shear test is the most appropriate test for such bond assessments. This test method has become the most widely accepted method and has been adopted by a number of international codes. The bond strength for the slant shear strength was calculated by dividing the maximum load at by the bond area which can be expressed as:

$$S = P / A_L$$

Where S is the bond strength (MPa); P is the maximum force recorded (KN) and A_L is the area of the slant surface (mm2). In this case the slant surface area is taken as 150 x 150 /sin 30 = 45,000mm^2.

Fig. 2 Slant shear test specimens

E. Flexural Strength Test

Flexural strength test as per the specification of IS 516 :1959 was used to investigate the bond strength between old and new concrete. The new concrete was casted and bonded to the old concrete substrate specimens. In this test, the specimen have a size 150mm x 150mm x 700mm composite prisms specimens as shown in Figure

The flexural strength (f) was calculated by the following formulae:

$$f = Pl/bd^2$$

where f is the flexural strength(MPa); P is the maximum experimental force (KN); l is the longitudinal length (mm);b is the width (mm); and d is the depth (mm).

Fig. 3 Flexural strength test specimens

IV.DISCUSSION OF RESULTS

A. Split Tensile Strength Test

In this split tensile strength test , M20 grade was used as substrate concrete and M25 grade, M30 grade were used as added concrete. The added concrete at age of 28 days and substrate concrete at age of 56 days is indicated as L28, The added concrete at age of 28 days and substrate concrete at age of 84 days is indicated as L56, The added concrete at age of 28 days and substrate concrete at age of 112 days is indicated as L84.split tensile strength test results are shown in figures 5,6,7,8,9 and 10.

Fig.4 Failure specimen of split tensile test

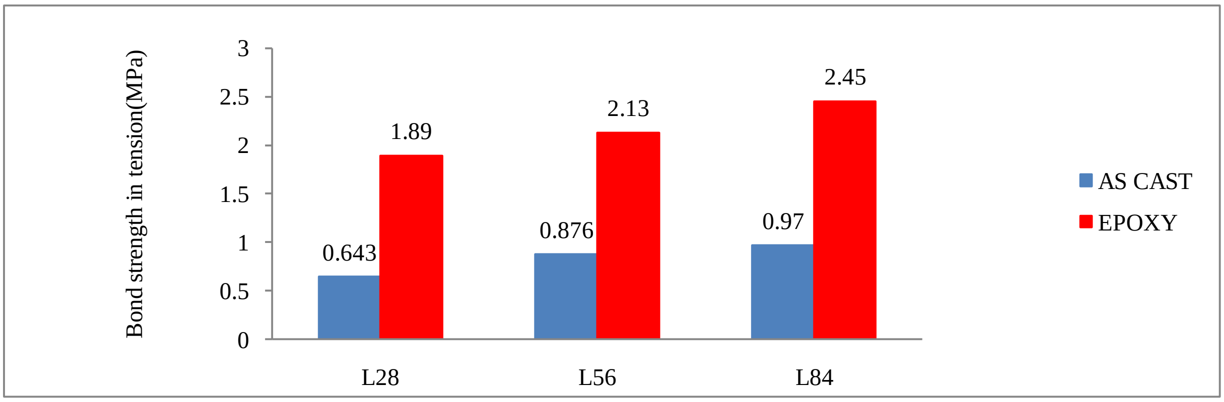

Fig. 5 Bond strength for different casting methods of split tensile test(M20:M25)

Bond strength for different casting methods of split tensile strength test results of M20:M25 and M20:M30 shown in figure 4. When compared bond strength of concrete for as cast and epoxy resin methods shows for L28,L56 and L84 are 2.94 times,2.43 times and 2.53 times increases in M20:M25.

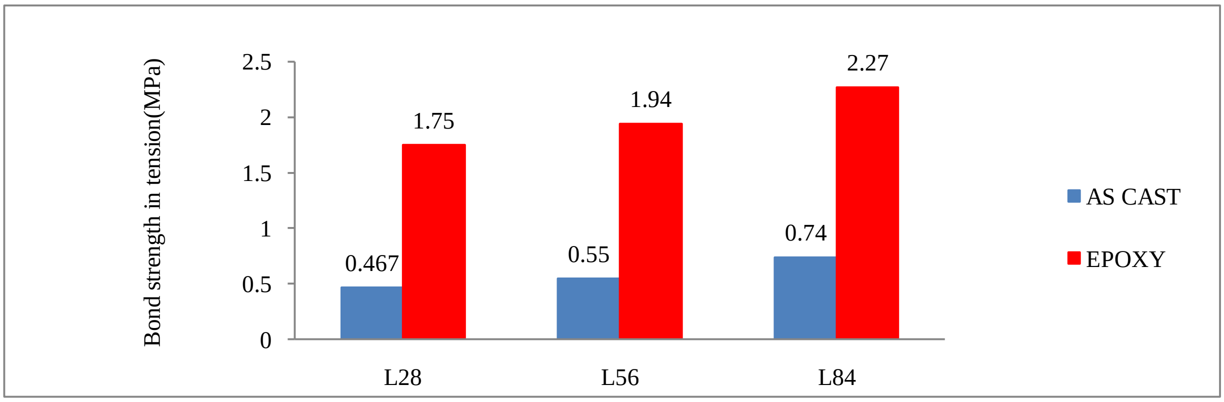

Fig. 6 Bond strength for different casting methods of split tensile test (M20:M30)

Bond strength for different casting methods of split tensile strength test results of M20:M25 and M20:M30 shown in figure 4. When compared bond strength of concrete for as cast and epoxy resin methods shows for L28,L56 and L84 are 3.74 times,3.52 times and 3.07 times increases in M20:M30.

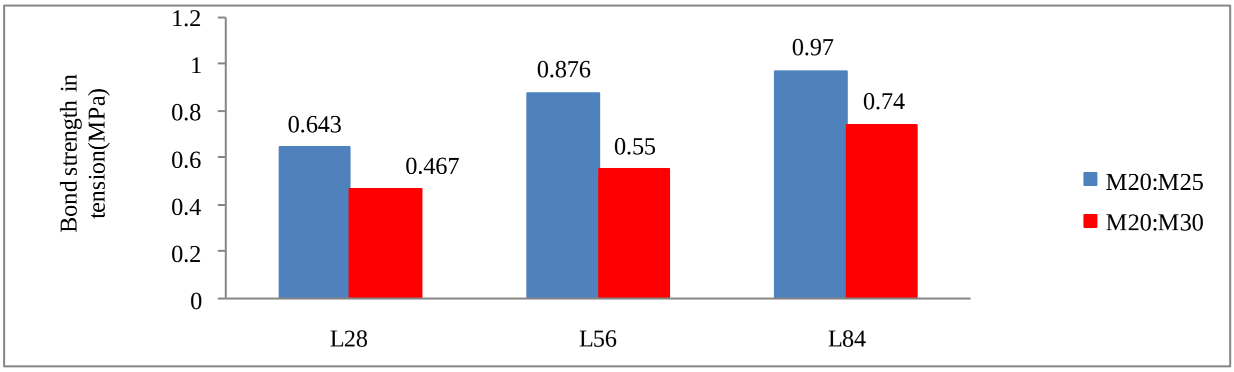

Fig. 7 Bond strength for different grades combination of split tensile test (as cast method)

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Bond strength for different grades combination of split tensile strength test results of as cast and epoxy resin methods results shown in figure 5. When compared bond strength of concrete for different grades combination of M20;M25 and M20:M30 for L28,L56 and L84 are 27.37%,37.21% and 23.71% decreases in as cast method.

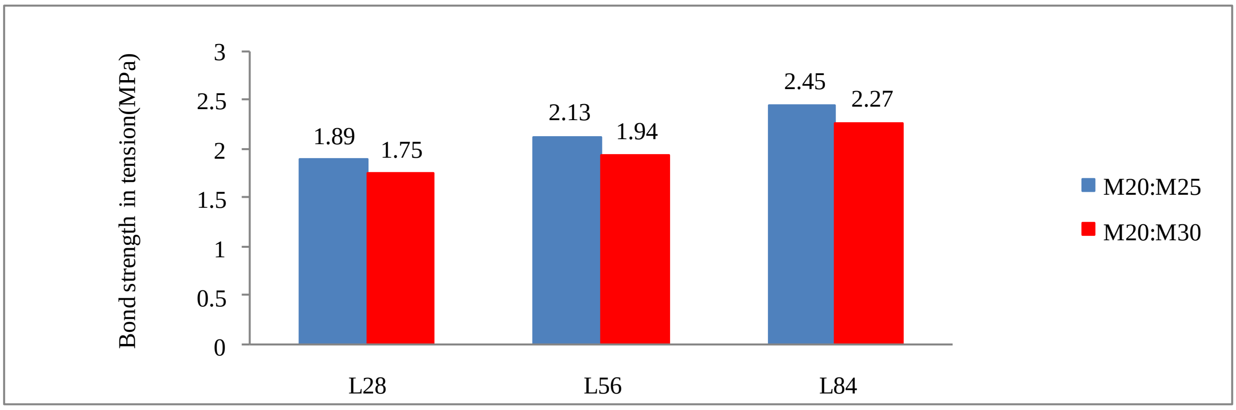

Fig. 8 Bond strength for different grades combination of split tensile test(epoxy resin method)

Bond strength for different grades combination of split tensile strength test results of as cast and epoxy resin methods results shown in figure 5. When compared bond strength of concrete for different grades combination of M20;M25 and M20:M30 for L28,L56 and L84 are 7.41%,8.92% and 7.34% decreases in epoxy resin method.

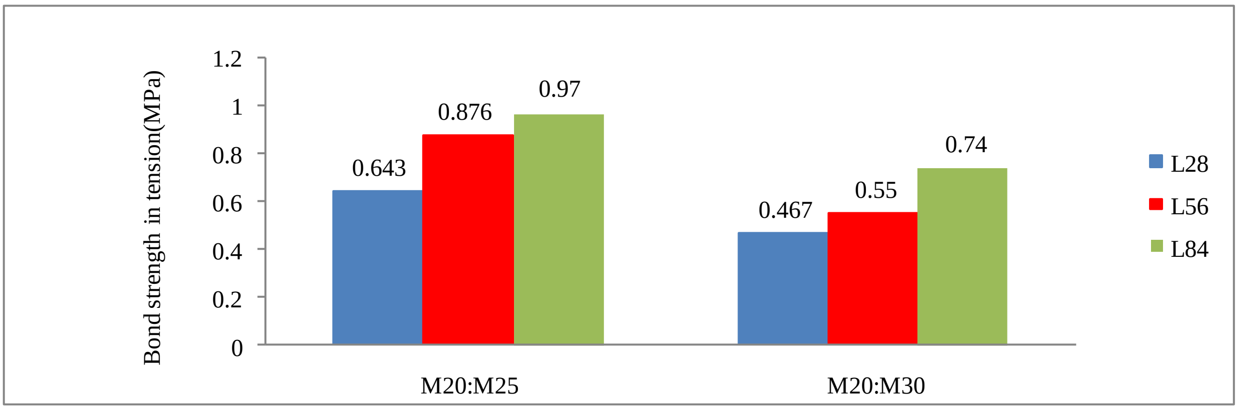

Fig.9 Bond strength for different age comparison of split tensile test (as cast method)

Bond strength for different Age comparison of split tensile strength test results of as cast and epoxy resin methods are shown in figure 6. When compared bond strength of concrete(as cast method) for age difference of L28 and L56 is 36.24% increases, L56 and L84 is 10.73% increases for M20:M25 , When compared bond strength of concrete(as cast method) for age difference of L28 and L56 is 17.77% increases, L56 and L84 is 34.54% increases for M20:M30 .

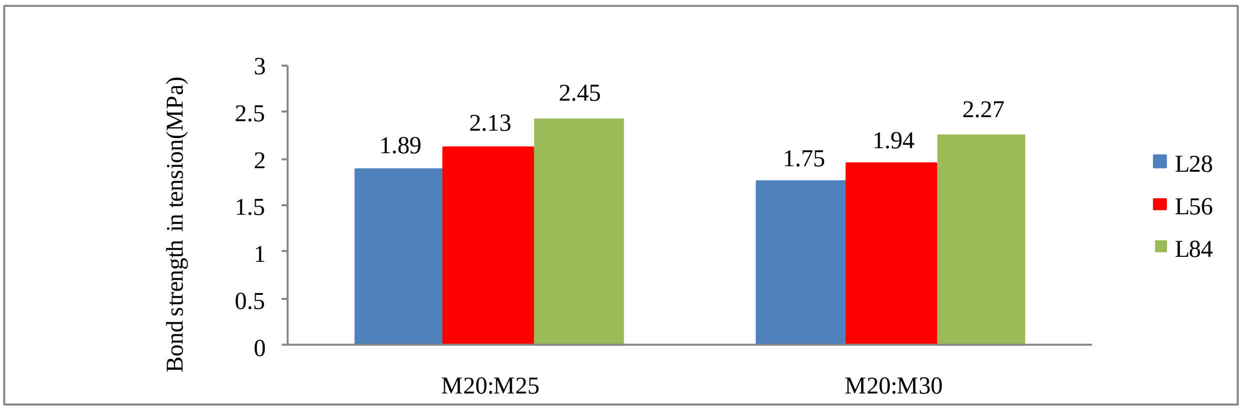

Fig.10 Bond strength for different age comparison of split tensile test (epoxy resin method)

Bond strength for different Age comparison of split tensile strength test results of as cast and epoxy resin methods are shown in figure 6. When compared bond strength of concrete(epoxy resin method) for age difference of L28 and L56 is 12.65% increases, L56 and L84 is 15.03% increases for M20:M25 , When compared bond strength of concrete(epoxy resin method) for age difference of L28 and L56 is 10.85% increases, L56 and L84 is 17.01% increases for M20:M30.

When compared to M20;M25 and M20:M30 bond strength in tension decreases due to adhesion between specimens. When compare to L84 of M20:M30 specimens by increasing workability with super plasticizer was shown in Table II.

Table II
Bond Strength of Specimens by Using Super Plasticizer

Grade	Slump height(mm)	Bond strength (MPa)
M20:M30	38	0.833
M20:M30	75	1.064

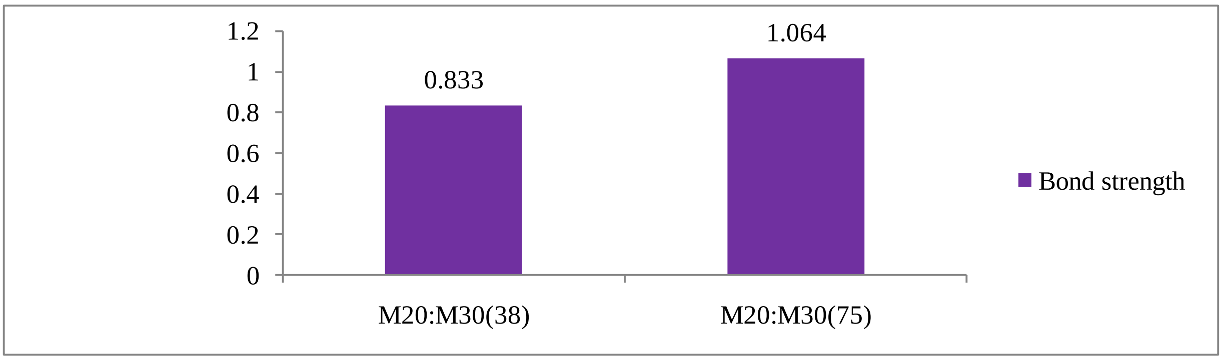

Fig.11 Bond strength for different workability of M20:M30

Bond strength in tension of M20:M30 by increasing the workability of new concrete (M30) is **27.73%** increased. When compared both specimens. when increased the workability adhesion between specimens was increased.

B. Slant Shear Strength Test

In this slant shear strength test, M20 grade was used as substrate concrete and M25 grade, M30 grade were used as added concrete. The added concrete at age of 28 days and substrate concrete at age of 56 days is indicated as L28, The added concrete at age of 28 days and substrate concrete at age of 84 days is indicated as L56, The added concrete at age of 28 days and substrate concrete at age of 112 days is indicated as L84.split tensile strength test results are shown in figures 13,14,15,16,17 and 18.

Fig. 12 Failure specimen of slant shear test

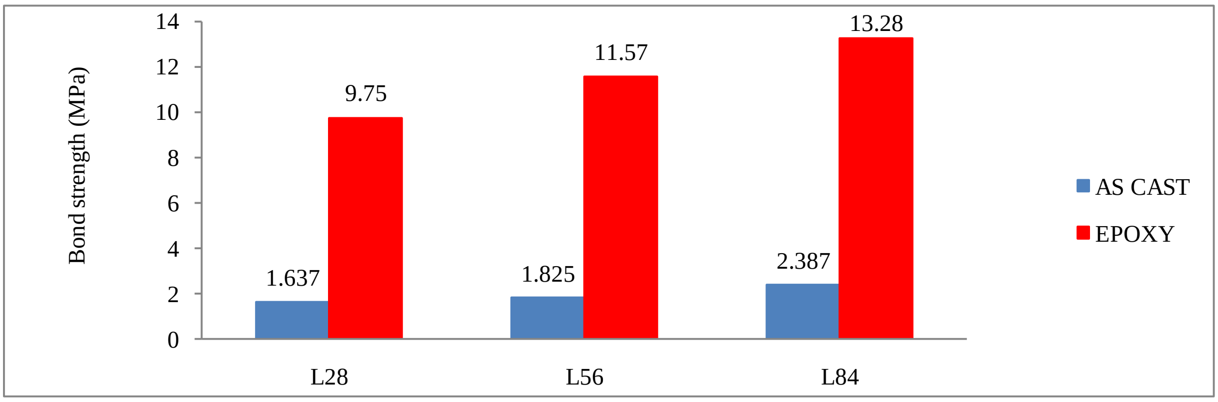

Fig.13 Bond strength for different casting methods of slant shear strength test (M20:M25)

Bond strength for different casting methods of slant shear strength test results of M20:M25 and M20:M30 shown in figure 7. When compared bond strength of concrete for as cast and epoxy resin methods shows for L28,L56, and L84 are 5.96 times,6.28 times and 5.56 times increases in M20:M25.

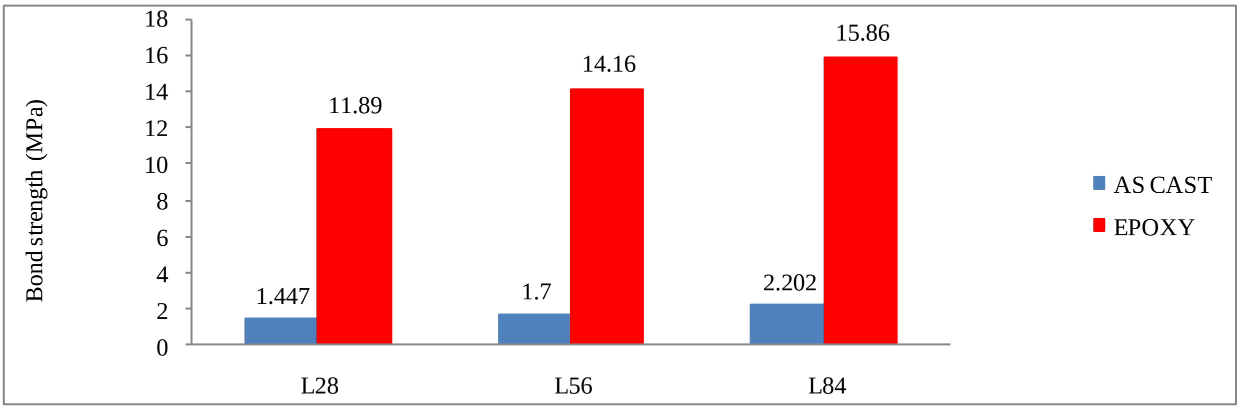

Fig.14 Bond strength for different casting methods of slant shear strength test (M20:M30)

Bond strength for different casting methods of slant shear strength test results of M20:M25 and M20:M30 shown in figure 7. When compared bond strength of concrete for as cast and epoxy resin methods shows for L28,L56 and L84 are 8.22 times,8.33 times and 7.21 times increases in M20:M30.

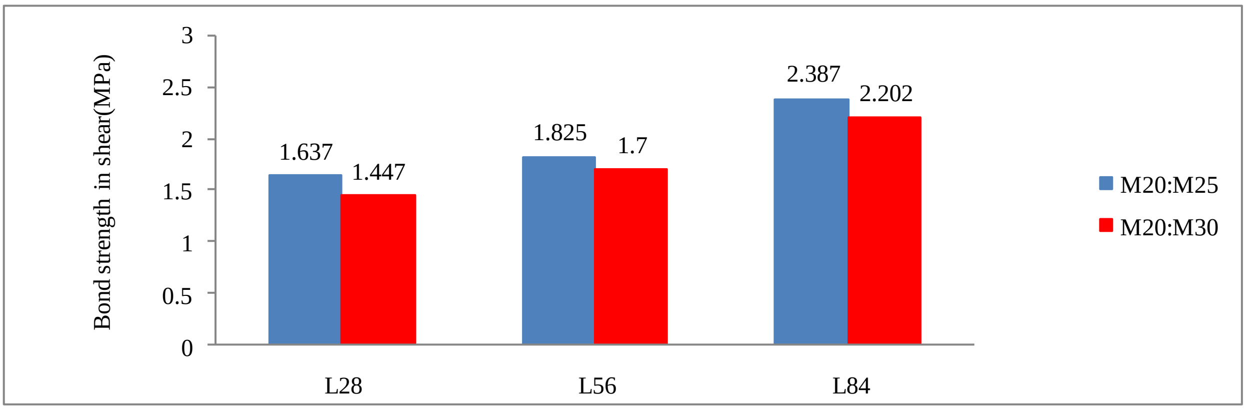

Fig.15 Bond strength for different grades combination of slant shear strength test (as cast method)

Bond strength for different grades combination of slant shear strength test results of as cast and epoxy resin methods results shown in figure 5. When compared bond strength of concrete for different grades combination of M20;M25 and M20:M30 for L28,L56 and L84 are 11.60%,6.84% and 7.75% decreases in as cast method.

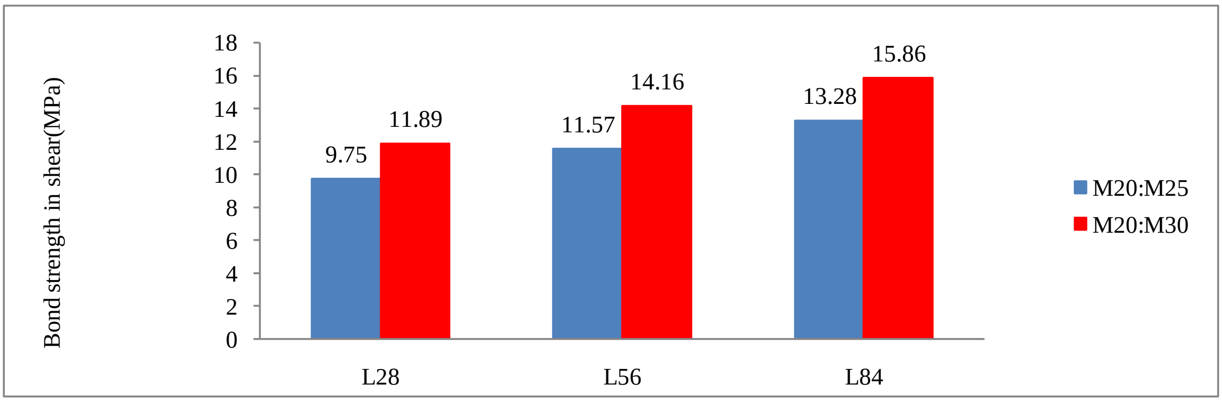

Fig.16 Bond strength for different grades combination of slant shear strength test (epoxy resin method)

Bond strength for different grades combination of slant shear strength test results of as cast and epoxy resin methods results shown in figure 5. When compared bond strength of concrete for different grades combination of M20;M25 and M20:M30 for L28,L56 and L84 are 21.94%,22.39% and 19.43% increases in epoxy resin method.

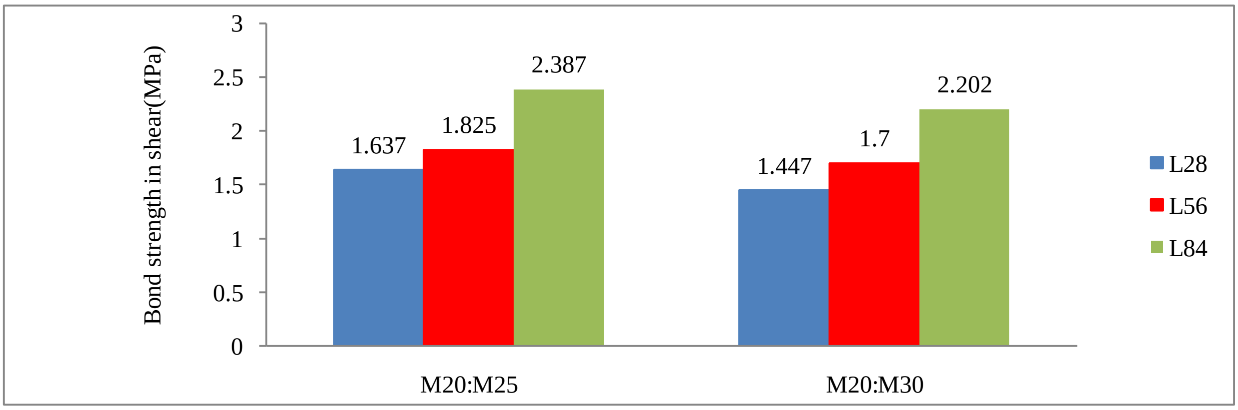

Fig.17 Bond strength for different age comparison of slant shear strength test (as cast method)

Bond strength for different Age comparison of slant shear strength test results of as cast and epoxy resin methods are shown in figure 6. When compared bond strength of concrete(as cast method) for age difference of L28 and L56 is 11.48% increases, L56 and L84 is 30.79% increases for M20:M25 , When compared bond strength of concrete(as cast method) for age difference of L28 and L56 is 17.48% increases, L56 and L84 is 29.53% increases for M20:M30 .

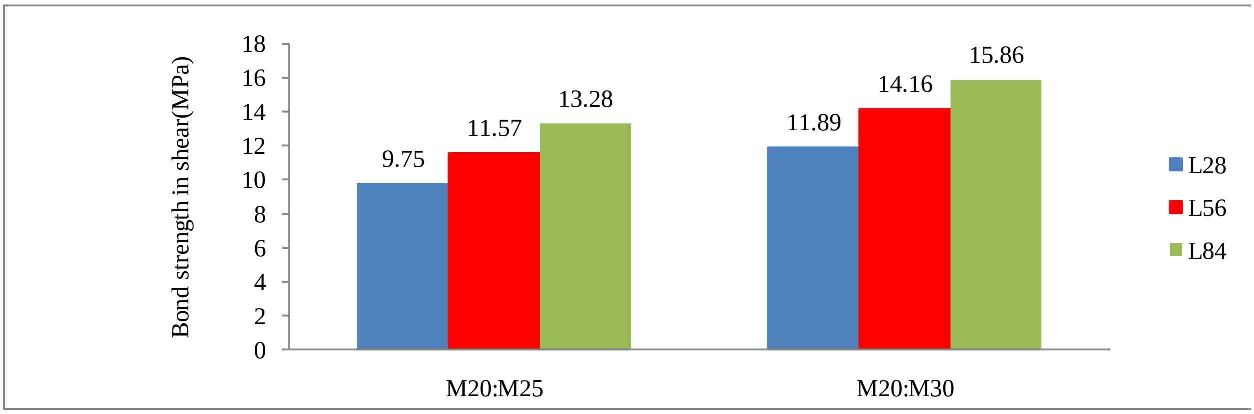

Fig.18 Bond strength for different age comparison of slant shear strength test(epoxy resin method)

Bond strength for different Age comparison of slant shear strength test results of as cast and epoxy resin methods are shown in figure 6. When compared bond strength of concrete(epoxy resin method) for age difference of L28 and L56 is 18.67% increases, L56 and L84 is 14.78% increases for M20:M25 , When compared bond strength of concrete(epoxy resin method) for age difference of L28 and L56 is 19.09% increases, L56 and L84 is 12% increases for M20:M30

C. Flexural Strength Test

In this flexural strength test , M20 grade was used as substrate concrete and M25 grade, M30 grade were used as added concrete. The added concrete at age of 28 days and substrate concrete at age of 56 days is indicated as L28, The added concrete at age of 28 days and substrate concrete at age of 84 days is indicated as L56, The added concrete at age of 28 days and substrate concrete at age of 112 days is indicated as L84. Only epoxy resin method used. There is no bonding between specimens in as cast method. Flexural test results are shown in figures 20 and 21.

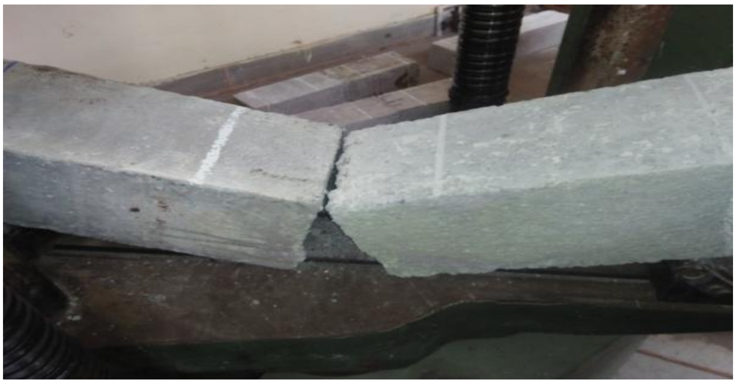

Fig.19 Failure specimen of flexural strength test

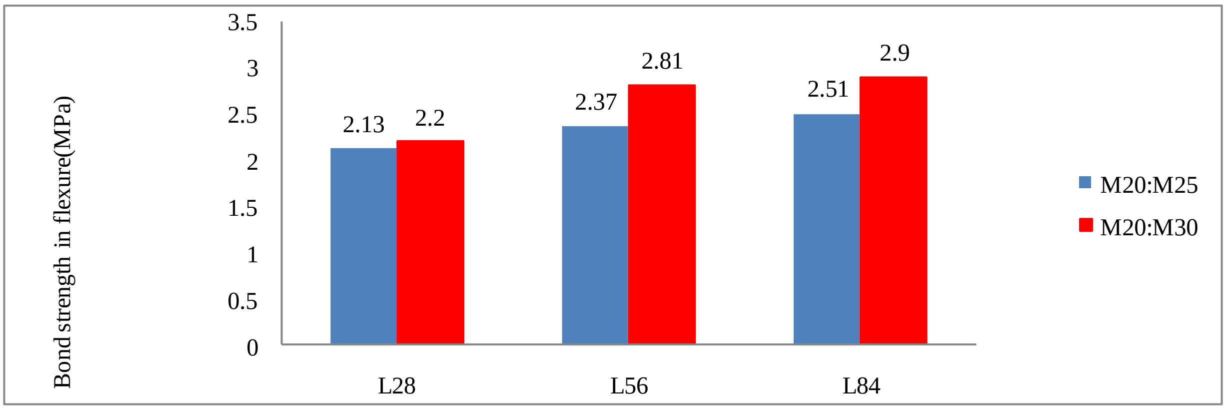

Fig. 20 Bond strength for different grades combination of flexural strength test

Bond strength for different grades combination of flexural strength test results are shown in figure 10.When compared bond strength of concrete for different grades combination of M20;M25 and M20:M30 for L28,L56 and L84 are 3.28%,18.56% and 15.42% increases in epoxy resin method.

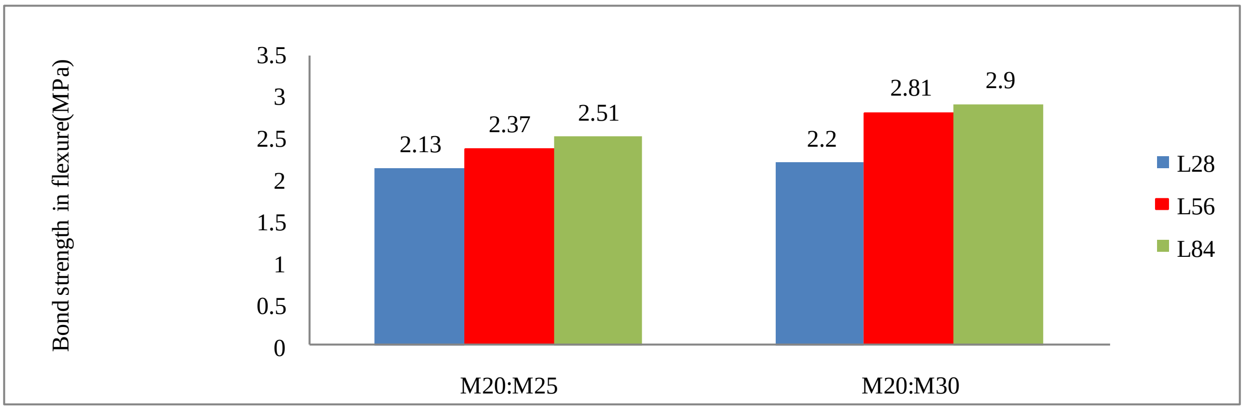

Fig.21 Bond strength for different age comparison of flexural strength test

Bond strength for different grades different age comparison of flexural strength test results are shown in figure 11.When compared bond strength of concrete(epoxy resin method) for age difference of L28 and L56 is 11.26% increases, L56 and L84 is 5.9% increases for M20:M25 , When compared bond strength of concrete(epoxy resin method) for age difference of L28 and L56 is 27.72% increases, L56 and L84 is 3.96% increases for M20:M30

V.SCOPE OF FUTURE WORK

Workability, age difference between specimens, surface roughness were important factors to influencing the bond strength of interface of concrete layers and further study can be required. Work can extended to evaluating bond strength between old and new concrete with different binder materials, partial replacements of coarse aggregate and fine aggregate. Evaluating bond strength of old and new concrete with different fibers and admixtures study can be required.
Evaluating bond strength of old and new concrete with applying different resins on interface. Evaluating bond strength of old and new concrete using of different surface roughness techniques. Evaluating bond strength of old and new concrete using different curing methods.

VI.CONCLUSION

Based on the results present here in, the following conclusions can be made
The bond strength of the concrete to concrete interface increased with the increase of the difference of age between concrete layers was observed. Split tensile strength observed that bond strength at interface of M20 and M25 increased 2.6 times, when epoxy resin is used with comparison of as cast specimens. Split tensile strength observed that bond strength at interface of M20 and M30 increased 3.44 times, when epoxy resin is used with comparison of as cast specimens. Bond strength of interface between M20 and M30 decreased when compared to M20 and M25 in split tensile strength. Slant shear strength observed that bond strength at interface of M20 and M25 increased 5.93 times, when epoxy resin is used with comparison of as cast specimens. Slant shear strength observed that bond strength at interface of M20 and M30 increased 7.92 times, when epoxy resin is used with comparison of as cast specimens. Bond strength of interface between M20 and M30 increased when compared to M20 and M25. Cohesive failure was observed when

epoxy resin used in slant shear strength test. Flexural strength observed that bond strength of interface between M20 and M30 increased when compared to M20 and M25.

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