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Epoxy as Admixture in Concrete

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ABSTRACT.

This study looked at how epoxy resin concrete behaved under varied curing circumstances, temperatures, and epoxy content levels. Under actual working conditions, mechanical attributes like compressive strength and lateral strain are assessed. Findings from specimens of various shapes that simulated concrete specimens with compressive strengths ranging from (10 MPa to 30.5 MPa) and lateral strains ranging from (0.025 to 0.21%) are reported. The findings demonstrated that using epoxy resin increased compressive strength, and that adding more epoxy to the concrete mixture appeared to enhance strength. The best strength could be obtained at a temperature of (75 C°).

Keywords: epoxy resin, job Curing, Wire Mesh Bucket, Pycnometer, admixure, tension surface.

Introduction

Because of its strong compressive and tensile characteristics as well as superior adhesive qualities, epoxy resin has established a place in the building industry. The majority of uses in recent years have involved cementing together damaged or deteriorated construction. As a result, research and uses have focused on its adhesive qualities. Of course, engineers are aware of its great strength, but there hasn't been much investigation in this area. Despite having high compressive and tensile strengths, epoxy concrete—which uses epoxy resin compound instead of cement paste—hasn't been employed frequently in concrete building. The use of epoxy concrete is certainly constrained by the price of epoxy resin because the cost of epoxy. Since epoxy concrete costs around Rs 20,000 per cubic meter, the expensive cost of epoxy resin unquestionably restricts its use. Due to its quick setting characteristics, only the restoration of bridges with high traffic volumes can support its use; the repaired bridges can be opened to traffic in just a few hours. The partial replacement of the cement paste with epoxy was thought to be worth investigating in order to see if some of the properties of the pure epoxy concrete would be preserved, even though higher strength concrete can be made in other ways.

In this article, the tests were planned to determine the effect of epoxy content upon the compressive strength and modulus of rupture under job Curing conditions.

Materials used

a. Cement

53 grade Ordinary Portland cement OPC (UltraTech OPC Cement) was used in this study. The chemical composition of the cement is given in Table 1. The paste, composed of Ordinary Portland cement and water, was prepared according to IS 10262-2009 ANNEX A Specification with a water/cement weight ratio of 0.45. The conditions of cement paste preparation were kept constant in all composites in order to evaluate the actual effect of epoxy resin.

Table 1. Chemical composition of 53 grade ordinary Portland Cement (OPC) used

S. No	Chemical Compound	Weight in percentage	Limits
1.	Al_2O_3	4.49	3-8%
2.	SiO_2	18.87	17-25%

3.	CaO	66.65	60-67%
4.	Fe_2O_3	4.94	0.5-6%
5.	K_2O	0.43	0.4-1.3%
6.	MgO	0.87	6% (max)
7.	Na_2O	0.12	0.4-1.3%
8.	SO_3	2.58	1.3-3.5%
9.	Loss of ignition	1.05	4% (max)

Table 2. Physical Properties of Ordinary Portland Cement according to IS 12269 (1987)

Physical properties		Test Results	Limits acc to IS standards	Tests performed
Color		Grey	Grey	Visual
Specific gravity		3.15	3.15	Le-Chatelier Flask
Bulk Density		3150 kg/m^3	3150 kg/m^3	Le-Chatelier Flask
Average Particle size		1.5 µm	1-50 µm	Sieve Test
fineness		225 m^2/kg	225 m^2/kg (min)	Blain Air Permeability Test
consistency		31.5%	25-45%	Vicat apparatus
Specific Surface area		225 m^2/kg	225 m^2/kg (min)	Blain Air Permeability Test
Initial setting time		40 mins	30 minutes	Vicat apparatus
Final setting time		6 hours	600 minutes	Vicat apparatus
Compressive strength	3 days (72 hours)	26.5 MPa	27 MPa	Universal Testing machine
	7 days (168 hours)	35 MPa	37MPa	Universal Testing machine
	28 days (672 hours)	53 MPa	53 MPa	Universal Testing machine
Autoclave expansion		4.5 mm	5mm	Le Chatelier Test

b. Fine aggregate

River Sand of grading zone II is used in this study. which is graded as per IS 383, Table 4 (clause 4.3) and constitutes 25.52% of the total weight of concrete used.

Table 4. Percentage Passing for zones II fine aggregate as per IS Standards

IS Sieve Designation	Percentage passing for grading zone II
10 mm	100
4.75 mm	90 - 100
2.36 mm	75 - 100
1.18 mm	55 - 90

600 microns	35 - 59
300 microns	8 - 30
150 microns	0 - 10

Table 5. chemical and physical properties of sand used

Property	Specifications	Result	Limit as per IS Standards
Specific gravity	IS 2386 Part-3 (1963)	2.46 kg/m^3	2.5 to 3.0
Absorption %	BS 8007	0.78%	not greater than 3%.
Dry unit weight	IS 2386-3 (1963)	1590 kg/m^3	1540-1600
Sulphate content	IS 2386-2 (1963)	0.23%	0.4%
Silt content	IS 2386	0.7%	3 %
Material finer than 75U IS Sieve smaller than	IS 383(1970)	1.4%	3%

c. Coarse Aggregate

Aggregates are the important constituents of the concrete which give body to the concrete and also reduce shrinkage. Generally, aggregates occupy 70 to 80 % of total volume of concrete.

And here it is 73 86 % of the total weight of the concrete. Where coarse aggregate is 65.44% of the total aggregate used. Grading of aggregate is done as per IS 383(1970) Table 2 (clause 4.2) and the specific gravity of the aggregate used is determined by Wire Mesh Bucket test (For Aggregate Coarser Than 6.3mm) and Pycnometer (For Aggregate Finer Than 6.3mm) and it is come out to be 2.73 kg/m^3.

Table 3. Percentage Passing for 20mm aggregate as per IS Standards

IS Sieve Designation	Percentage passing for single sized aggregates of nominal size(mm)			
	63 mm	40 mm	20 mm	16 mm
20 mm	0 – 5	0 – 20	85 – 100	100

d. Water

The water used in the mixes was ordinary water obtained from the Medi-caps University Indore.

e. Admixture

The epoxy resin used as an admixture was Ciba Araldite 6010 {Di glycidyl ether of bisphenol A). It was produced by the Ciba Products Company, Fair Lawn, New Jersey. It is a water insoluble, transparent, thermosetting material in liquid form having an epoxy equivalent of 195, and a viscosity of 160 poises at 25 degrees C. The curing agent used was Ciba Hardener 951 (triethylene tetramine) • The formulation of the epoxy resin system used in the tests was 100 parts of resin and 20 parts of curing agent by weight.

Table 6. Physical Properties of Epoxy used

Physical Property	Results
Visual Appearance	Clear, No contamination

Color	Transparent
Epoxy Value	5.2 - 5.5 eq./kg
Epoxy Equivalent	182 - 192 g/eq
Viscosity @ 25°C (77°F)	11,000 - 13,000 MPa
Density @ 25°C (77°F), g/cm3	1.15 - 1.18 g/cm3
Flash Point (closed cup)	254 °C (490 °F)
Specific gravity	1.0

TESTS PERFORMED

1. Compressive Strength

Twenty-seven cubes were cast from three batches of concrete with different percentages of epoxy resin compound. Each batch consisted of nine cubes of size 150mm x 150mm x 150 mm. these cubes were cast in ISI approved Concrete Cube Mold made of cast iron and of size 150 x 150 x 150mm with base plate see in figure 1. They were placed in the curing room which was maintained at 75°F and 100 per cent relative humidity. After three days, all of the cubes were removed from the curing room and were kept outside the curing room until the proper age for testing. This was done to simulate job curing conditions. And the rest kept for total submerged curing.

Figure 1. ISI approved CI Concrete Cube Mold of size 150 x 150 x 150mm with base plate.

The tests were performed in accordance with the " IS 516 (1959): Method of Tests for Strength of Concrete”. Cubes were tested at ages of 7, 14 and 28 days. All cylinders were loaded to failure and the ultimate loads were recorded. The compressive strength of the specimen was calculated by dividing the ultimate load by the cross-sectional area of the specimen

Where,

P f = A

f = unit stress in pounds per square inch

P = ultimate load in pounds

A = cross-sectional area of the cylinder in square inches

Table 7. Compressive strength of different samples

Property	Beam with epoxy percentage of		
	0%	4%	8%
Date of test	28.02.2023	01.03.2023	01.03.2023
Age of specimen	28 days	28 days	28 days
Curing conditions	Steam curing under atmospheric conditions	Steam curing under atmospheric conditions	Steam curing under atmospheric conditions
Size of specimen	150 x 150 x 150 mm	150 x 150 x 150 mm	150 x 150 x 150 mm
Cross sectional area	22,500 mm^2	22,500 mm^2	22,500 mm^2
Weight of specimen	24.24 kg	25.02 kg	25.59 kg

Maximum load	627 KN	685 KN	845 KN
Compressive strength	27.86 N/mm2	30.44 N/mm2	37.55 N/mm2

Figure 2. Comp. Strerngth of samples containing 0% of epoxy as admixture

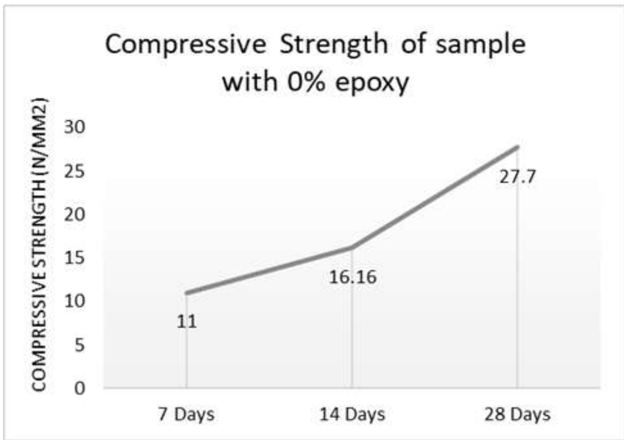

Figure 3. Comp. Strerngth of samples containing 4% of epoxy as admixture

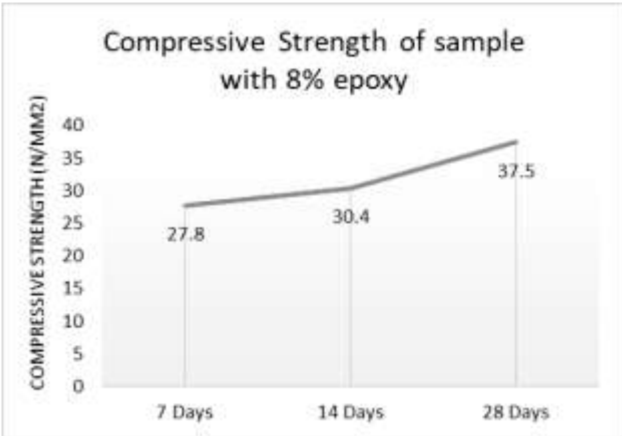

Figure 4. Comp. Strerngth of samples containing 8% of epoxy as admixure

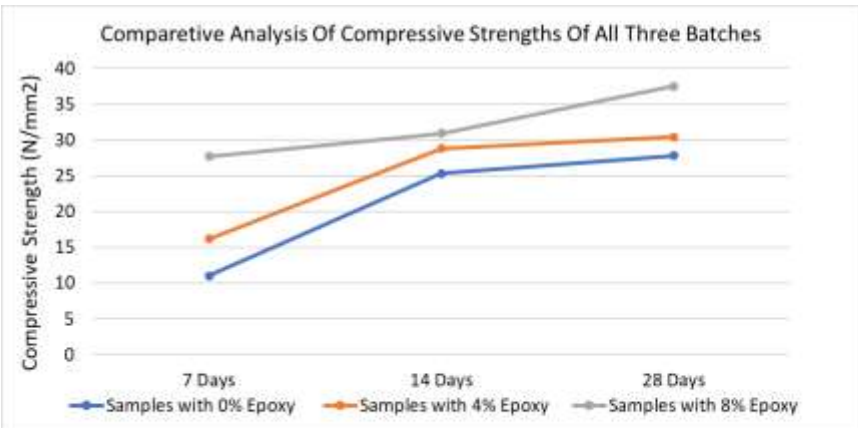

Figure 5. Comparative comp. Strerngth of all samples

Flexural Test

Flexural test evaluates the tensile strength of concrete indirectly. It tests the ability of unreinforced concrete beam or slab to withstand failure in bending. The results of flexural test on concrete expressed as a modulus of rupture which denotes as (MR) in MPa or psi. here the flexural test on concrete beam is conducted using three-point load test (IS 516 (1959) Clause 8: Test For Flexural Strength Of Moulded Flexure Test Specimens).

Equipment & Apparatus

Beam mold of size 100 x 100 x 500 mm (when size of aggregate is less than 19 mm)

Tamping bar (400 mm long, weighing 2 kg and tamping section having size of 25 mm x 25 mm)

Flexural test machine– The bed of the testing machine shall be provided with two steel rollers, 38 mm in diameter, on which the specimen is to be supported, and these rollers shall be so mounted that the distance from center to center is 400 mm for 100 mm specimens. The load shall be applied through two similar rollers mounted at the third points of the supporting span that is, spaced at 133 mm center to center. The load shall be divided equally between the two loading rollers, and all rollers shall be mounted in such a manner that the load is applied axially and without subjecting the specimen to any torsional stresses or restraints. suitable arrangement which complies with these requirements is indicated in Fig. 6

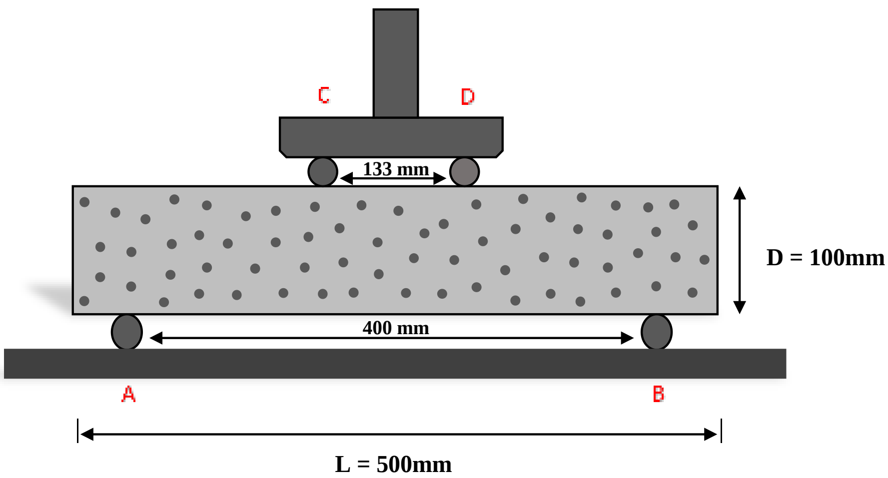

Figure 6. Arrangement of beam in Flexural testing machine

Procedure

Prepare the test specimen by filling the concrete into the mold in 3 layers of approximately equal thickness. Tamp each layer 35 times using the tamping bar as specified above. Tamping should be distributed uniformly over the entire cross section of the beam mold and throughout the depth of each layer. Clean the bearing surfaces of the supporting and loading rollers, and remove any loose sand or other material from the surfaces of the specimen where they are to make contact with the rollers. Circular rollers manufactured out of steel having cross section with diameter 38 mm will be used for providing support and loading points to the specimens. The length of the rollers shall be at least 10 mm more than the width of the test specimen. A total of four rollers shall be used, three out of which shall be capable of rotating along their own axes. The distance between the outer rollers (i.e. span) shall be 3d and the distance between the inner rollers shall be d. The inner rollers shall be equally spaced between the outer rollers, such that the entire system is systematic. The specimen stored in water shall be tested immediately on removal from water; whilst they are still wet. The test specimen shall be placed in the machine correctly centered with the longitudinal axis of the specimen at right angles to the rollers. For molded specimens, the mold filling direction shall be normal to the direction of loading.

The load shall be applied at a rate of 180 kg/min for the 100 mm specimens.

The Flexural Strength or modulus of rupture (f_b) is given by

$$f_b = \frac{Pl}{bd^2}, \qquad \text{---- (1)}$$

when a > 20.0cm for 15.0cm specimen or > 13.0cm for 10cm specimen or

$$f_b = \frac{3\,Pa}{bd^2}, \qquad \text{---- (2)}$$

when a < 20.0cm but > 17.0 for 15.0cm specimen or < 13.3 cm but > 11.0cm for 10.0cm specimen.

Where,

a = the distance between the line of fracture and the nearer support, measured on the center line of the tensile side of the specimen

p = max. Load (N)

l = supported length (mm)

b = width of specimen (mm)

d = failure point depth (mm)

Hence, by formula (1),

$f_b = \frac{Pl}{bd^2}$,

$f_{b\,I} = \frac{5650\ X\ 400}{100\ X\ (87)^2} = 2.98$

$f_{b\,II} = \frac{5700\ X\ 400}{100\ X\ (78)^2} = 3.74$

$f_{b\,III} = \frac{5850\ X\ 400}{100\ X\ (72)^2} = 4.51$

The fracture is said to be 'Unsatisfactory failure' is when the fracture initiates in the tension surface outside of the middle third of the span length by approximately more than 5 percent of the span length. When 'a' is less than 110 mm for a 100 mm specimen, the results of the test shall be discarded.

Table 8. Modulus of rupture of different samples

Property	Beam with epoxy percentage of		
	0%	4%	8%
Identification Mark	I	II	III
Date of test	08.03.2023	08.03.2023	08.03.2023
Age of specimen	28 days	28 days	28 days
Curing conditions	Steam curing under atmospheric conditions	Steam curing under atmospheric conditions	Steam curing under atmospheric conditions
Size of specimen	100 x 100 x 500 mm	100 x 100 x 500 mm	100 x 100 x 500 mm
Span length	500 mm	500 mm	500 mm
Maximum load (P)	5650 N	5700 N	5850 N
Supported length (l)	400 mm	400 mm	400 mm
Failure point depth (d)	87 mm	78 mm	72 mm
Modulus of rupture (f_b)	2.29	3.74	4.51

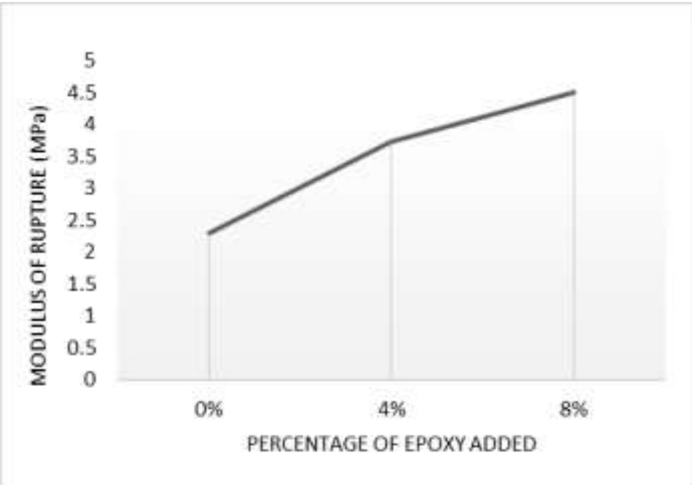

Figure 7. Modulus of Rupture of different samples at the age of 28 days

Results and Discussions

The results of the compressive tests are shown in Figures 2 to 5. Figure 5 shows the relation between percentage of admixture used and compressive strength at the ages of 7, 14 and 28 days under job curing conditions. In Figures 2, 3 and 4, compressive strength was plotted against age for Mix A, B and C for clear analysis. Under job curing conditions, the average compressive stress at 7 days of Mix B and C specimens is 43.48% and 39.57% of Mix A respectively. The compressive stress at 14 days of Mix B and C Specimens is 56.11% and 53.16% of Mix A. At the age of 28 days, the strength of Mix B and C is 89.64% and 73.87% of Mix A. The increase in compressive strength due to the increased amount of admixture under job curing conditions is nearly linear at the ages of 14 and 28 days.

The results of the tests on flexural strength of beams are shown in Figure 7. This Figure shows the relation between modulus of rupture at the age of 28 days and percentage of admixture used. The average strength of specimens of Mix B and C is 61.23% and 50.78% of Mix A respectively.

Because all beams were also cured in job curing conditions and increase in percentage of admixture is also same for hence the curve plotted for modulus of rupture vs. percentage of admixture follows the same pattern of that for compressive strength under job curing conditions.

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