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Characterisation of Fibre Reinforced Resin Concrete

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Abstract: *Resin Concrete uses polymeric resin to replace cement concrete. Four types of polyester resins were identified with Methyl methacrylate as catalyst, calcium carbonate and fly ash as fillers along with river sand and coarse aggregate size of 10mm, 6mm were used to produce resin concrete. Seventy-two trial batches were carried out for preliminary investigation targeting compressive strength of more than 80 MPa (11.6 ksi) and four batches were shortlisted. These four batches along with the addition of glass fiber were taken for detailed investigation of stress strain behavior, young's modulus, Poisson ratio, various correlative equations among their mechanical properties and durability properties. Developed mix can be recommended for manufacturing various polymer products.*

Keywords: *resin concrete, unsaturated polyester resins, glass fibre, Young's modulus, Poisson ratio, correlative equations*

1.Introduction

Resin Concrete (RC) is a type of concrete which consists of resin, filler and aggregate mixture. Development of resin concrete dates back to early 1950s in which they replaced the cement and used resins as binder for some specific applications. Japan, United States, United Kingdom, European countries are widely using this type of concrete in manufacturing various products because of its superior mechanical and durability related property, rapid curing and excellent bond strength [1]. The main objective of this study is to develop the technology for manufacturing various polymer based products possessing higher mechanical and durability properties which are listed as follows.

-To develop the mix for resin concrete with higher mechanical and durability properties;
-To optimize the material for filler and resin types with the addition of glass fibers;
-To study the mechanical properties of resin concrete for sizing effect;
-To study the mechanical properties of resin concrete under different curing regime;
-To study the stress strain relationship of the developed mix;
-To derive the various correlative equations between flexural, direct tensile strength, UPV values with compressive strength.

Commonly used resins for RC are unsaturated polyester resin, methyl methacrylate (MMA), epoxy resins, furan resins, vinyl ester resins, polyurethane resins and urea formaldehyde resins. Furan resins are widely used in the European countries and MMA has limited applications because of its higher flammability property and disagreeable odour. However, MMA received few attentions because of its good workability and low temperature curability [2].

The choice of particular type of resin is based on the factors like cost, availability, good mechanical properties, and chemical resistance. For harsh environmental factors, epoxy resins are preferred over polyester resins for its better mechanical and durability properties. But the epoxy resins are less economical compared to the polyester resin types. Hence based on the factors like low cost, easy availability and good mechanical properties, unsaturated polyester resin types are selected for this study [3]. Earlier researches on polyester resin with 12% to 14% resin of concrete results showed the compressive strength of range 60 to 80 MPa and flexural strength of about 6 to 8 MPa. Hence this study targets the strength of more than 80MPa using industrial waste and minimum optimized resin percentage

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to obtain high performance concrete with higher mechanical and durability properties.

Other ingredients of RC consists of fillers and aggregate mixture. Two different fillers such as calcium carbonate and fly ash were used as fillers. Generally, 75 to 80% volume of the RC are occupied by aggregate and fillers. Aggregates are added in two different groups such as fine aggregate and coarse aggregate.

The properties of RCs are based on the conditions of preparation. Binder content, aggregate particle size, types and content of micro fillers and curing conditions have great impact on properties of RC. By taking all these factors, resin concrete is firstly optimized for the mix proportion for each ingredient to get the high compressive strength of more than 80MPa (11.6 ksi) and later detailed investigation on mechanical properties, durability properties, study of correlation among the mechanical properties are studied for the optimized mix and material.

1.1. Research significance

-Environmental aspects: Resin concrete completely avoids the usage of cement and water as binder thereby avoiding the CO_2 emissions from cement manufacturing industries.

-Scientific importance: The developed resin concrete can produce greater compressive strength, resistant against corrosion.

-Industrial importance: The low permeability, chemical resistance of resin concrete allows it to be used in Swimming pools, Sewer structure applications, Chemical storage tanks and pipes.

-Social importance: Resin concrete is of zero scrap value, low maintenance and repair cost.

2. Materials and methods

2.1. Materials

2.1.1. Resins

Resins can be available as monomer and pre-polymer. In this study, monomer is used. It is converted into polymer by the process called polymerization by addition of initiator such as catalyst and accelerator to the liquid resin. Unsaturated polyester resins such as isophthalic resin (I), orthophthalic resin (O), combination of isophthalic resin with 10% methyl methacrylate (IM) and combination of O with 10% IM were taken. Dicorboxylic acids and dihydroxy alcohols on polycondensation process forms polyesters. I and O resins are formed from phtalic acids of different diacids. Various binder properties of 4 different types of resins are shown in Table 1. Viscosity at 25°C, cps Brookfield Viscometer LV DV +Pro Spindle 63, rpm 60 for all the resin types varies from 300 - 400, Shelf life at 25°C for all the resin types are three months. Appearance of I type resin is straw yellowish clear liquid, O type resin is clear to pale yellowish liquid whereas IM and OM show pale yellowish clear liquid.

Table 1. Properties of different types of resin

TYPE	I	IM	O	OM
Specific gravity at 25°C gm/mL	1.1 to 1.12	1.10 to 1.12	1.11 to 1.12	1.11 to 1.12
Acid value, mg KOH/gm	15 to 20	15 to 19	23 to 27	20 to 24
Volatile content, %	36 to 40	36 to 40	35 to 39	36 to 38
Gel time at 25°C, min*	15 to 20	15 to 20	10 to 20	20 to 30
Peak exotherm °C**	175 to 185	170 to 180	170 to 180	160 to 170

2.1.2. Initiators

Initiators initiate the crosslinking between polyester and styrene molecules and convert the liquid resin into rigid solid. Catalyst and accelerator used as initiators in this study are Methyl Ethyl Ketone Peroxide (MEKP) and Cobalt Octoate (CO), respectively. About initiators of about 0.5% to 2% should be used by weight of resin, depending upon the required ambient temperature and setting time. In this study, accelerator of 1% and 1.5% catalyst by weight of resin is used. Thorough mixing of resin with initiators is suggested for optimum result and they should never be stored together or mixed as they would cause instant explosion. Hence, tightly closed containers preferably in atmosphere below 30°C in moisture free areas and kept away from direct sunlight, heat radiation and fire should be used.

2.1.3. Fillers

Two different fillers such as calcium carbonate and fly ash are used as fillers in this study. Fillers are generally added to fill the pores in between the fine and coarse aggregate and to avoid the voids. Filler percentage of 12 % to 15% by weight of concrete is used in most of the studies to get the optmised mix proportion. Hence filler percentage of 15% by weigh of concrete is used in this study [4]. Filler are usually less than 150 micron particles size. Calcium carbonate is widely used mineral fillers in the plastics industry and its use in rigid packaging has increased now a days. Another filler used is a coal combustion product that is composed of the fine particles of burned fuel that are driven out of coal-fired boilers together with the flue gases called fly ash. Bottom Ash that falls to the bottom of the firebox is used. The properties of calcium carbonate and fly ash as per the ASTM C 618 standards [5] are given in Table 2. These two types of fillers will greatly help in saving the energy and effectively using the industrial waste material so that it reduces the cost of resin concrete.

Table 2. Properties of fillers used

	Calcium carbonate	Fly ash type F
SiO_2, %	0.7	62.5
Al_2O_3, %	0.04	23.83
CaO, %	98	1.68
MgO, %	0.68	0.61
K_2O, %	-	1.80
MnO, %	-	0.055
P_2O_5, %	-	0.91
TiO_2, %	-	1.71
Na_2O, %	0.16	-
Fe_2O_3, %	0.04	6.28
SO_3, %	-	5

– = not measured items.

2.1.4. Aggregate mix

The fine aggregate passing through 2.36 mm sieve and coarse aggregate sizes of aggregates passing through 10mm and passing through 6.7mm sieve and retained on 300 mm are used for all the trial batches. These samples are kept in hot air oven at 100ºC ± 5ºC in order to remove any moist present in the aggregate. Moist sample will have huge impact in polymerization and it affects the strength of the concrete and hence maximum water content should be limited to 0.1% [6]. Hence these samples are oven dried for about four hours and cooled down to room temperature before use. These dried samples are taken and tried with various mix proportions of different sizes to calculate packing density of that material. After various trials batches showing dry packing density between 0.4 to 0.65 on aggregate mix, dry packing density of 0.55 are taken as optimized mix proportion for aggregates to reduce the maximum voids in the aggregate mix so that it leads to good compaction, increasing the strength of the concrete.

2.1.5. Fibers

There are different types of fibers such as glass, carbon, steel, polypropylene fibres etc are available in the market. Glass fibers are generally used to produce the fiber reinforced resin concrete to enhance the flexural properties of resin concrete. Albeit, glass fibre strength properties shown in Table 3 are somewhat lower than carbon fibre, it is less stiff, the material is typically far less brittle, and the raw materials are much less expensive. Its bulk strength and weight properties are also very favorable and it can be easily blended during mixing. 0 to 6% variations were carried out in different researches to obtain higher flexural properties [1]. In this study, 0.5% glass fibers of 25mm length of total volume of resin concrete are used.

Table 3. Properties of fiber used

Glass fiber	Fiber property
Length (mm)	25
Density	2.5
Young's modulus (GPa)	70
Tensile strength (MPa)	2000 -3500
Elongation at break (%)	2.5

2.2. Methodology
2.2.1. Sample preparation

Samples are prepared by casting 40mm x 40mm x 40mm cubes (1.57inch x 1.57inch x 1.57inch) for various trial batches and tested for preliminary compressive strength. As per the guidelines, more three times the maximum size of aggregate is sufficient for testing [7, 8]. Since the maximum size of aggregate used is 10mm, 40 mm cube sizes which is greater than 30mm are much satisfactory for initial investigation and later on it was checked with 70mm cube sizes for sizing effect since fiber of 25mm length was added to the optimised mix. For each trial, three identical cube samples of size 40mm (1.57 inch) were cast and tested for compressive strength. Thus for four types of resins, totally seventy two trial batches and two hundred and sixteen cubes were cast and tested.

This developed mix is then used for casting 70mm cubes (2.76 inch) to study the sizing effect compared with 40mm (1.57 inch) cubes, beam of size 40mm x 40mm x 160mm (1.57 inch x 1.57 inch x 6.3 inch), cylinders of size 100mm (3.94 inch) diameter and 200mm (7.87 inch) height for detailed investigation on mechanical properties of resin concrete. 40mm cubes (1.57 inch) were used in the study of durability properties of concrete.

2.2.2. Optimisation of mix

All the ingredients should be optimized to get the high- performance resin concrete. Resin percentage optimized in the literature was about 10 to 14% by weight of total material for various type of unsaturated polyester resin concrete. These were taken as reference for trial batches for all types of resin and cubes of size 40 mm x 40mm x 40mm (1.57inch x 1.57inch x 1.57inch) are cast. These trial batches were targeted for obtaining high compressive strength of more than 80 MPa (11.6 ksi). For each type of resin, trial batches such as 10%, 12%, 14% resin content as binder, calcium carbonate and fly ash as fillers of 15%, aggregate sizes of 6mm and 10mm were taken for initial study on mechanical properties to obtain the desired strength. The initiators percentage used are 1.5% MEKP as catalyst and 1% cobalt octoate as accelerator by weight of resin content under normal room temperature. 72 trial batches were cast with each batch consists of 3 samples and the samples were allowed for air curing for a period of about 7 days and tested for compressive strength since compressive strength remains constant after 7 days [3,6]. Preliminary test results for optimizing the mix shows that, 1) on varying the resin percentage for all the 4 types, 10% resin is insufficient and workability is less. For 14%, the resin content is high and it decreases the compressive strength in all the cases shown in Figure 1 Thus, 12 % of resin is optimized for all the resin types, 2) 10mm aggregate batches dominates the results compared to 6mm aggregates and aggregate size of 10mm, 3) Descending order of 4 different types of resins based on the preliminary compressive test are as follows. O→ I → OM→ IM shown in Figure 1 and optimized mix is shown in Figure 2.

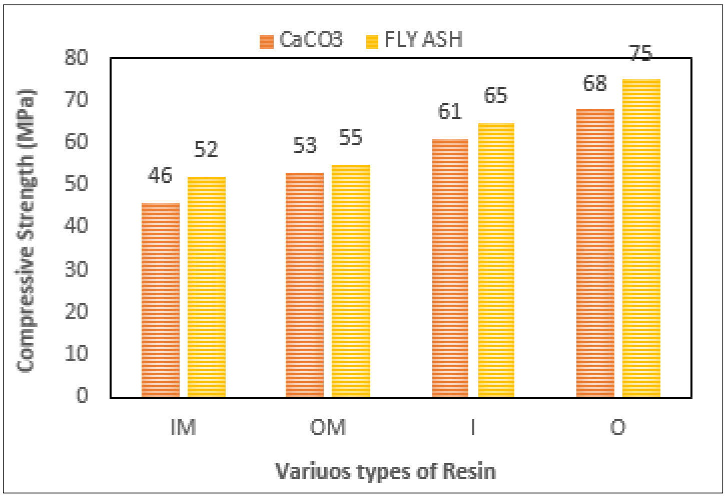

Figure 1. Compressive strength of various types of resins in 7 days (MPa)

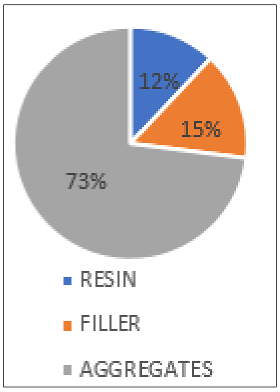

Figure 2. Optimized mix

2.2.3. Optimization of materials

From the preliminary study results, only two resin types I and O are chosen for further investigations. Out of these seventy two trial batches, only four batches were selected for detailed study of mechanical properties such as compressive strength, flexural strength and Split tensile strength to optimize the ingredient such as resin type and filler type. RC can also be reinforced with glass fibres of 25mm length to develop a FRRC (Fibre Reinforced Resin Concrete) to increase the mechanical properties, energy absorption capacity and impact resistance. With the addition of glass fiber, factors such as sizing effect, curing under different regime were also studied for these 8 batches. The sample nomenclature are as follows.

Sample Nomenclature:
I- Isophthalic resin
O- Orthophthalic resin
C- Calcium carbonate without fibres
F- Fly ash without fibres
CF- calcium carbonate with glass fibres
FF- Fly ash with glass fibres

3. Results and discussions

3.1. Mechanical properties of selected mix

3.1.1. Compressive Strength

Three identical specimens of type 40mm x 40mm x 40mm (1.57inch x 1.57inch x 1.57inch) cube were cast and tested to evaluate the preliminary compressive strength of each type of mixtures. To study the sizing effect on compressive strength, samples of 70mm cubes, were casted and tested (Figure 3,4). I and O type resins as binder are investigated with sizing effect such as action of 70mm cubes compared with 40mm (1.57inch) cubes under different curing regime such as the samples are cured at normal room temperature and at oven in 80°C for 8 h. These batches were again experimented with the addition of glass fibers to produce FRRC.

The experimental results of compressive strength for I and O type resins with and without fibers are shown in Figure 5 for calcium carbonate samples and Figure 6 shows the experimental results of compressive strength for I and O type resins with and without fibers for fly ash samples.

Figure 3.70mm Cubes with and without fibers for I and O type resins

Figure 4. Testing Sample in UTM

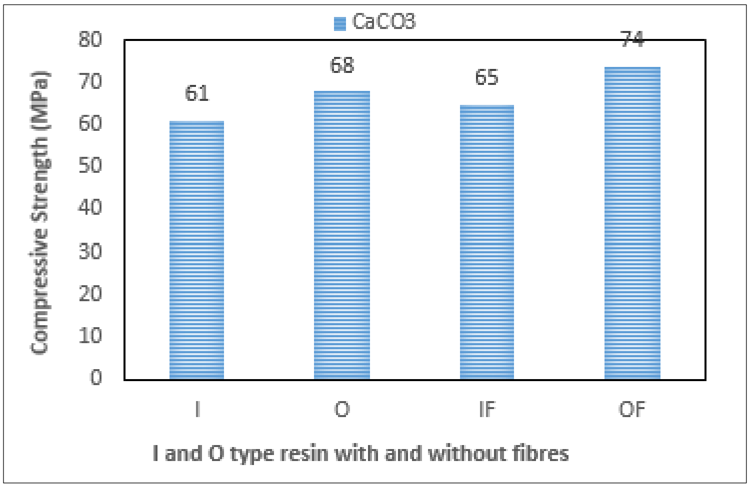

Figure 5. Compressive Strength of $CaCO_3$ samples at 7 days

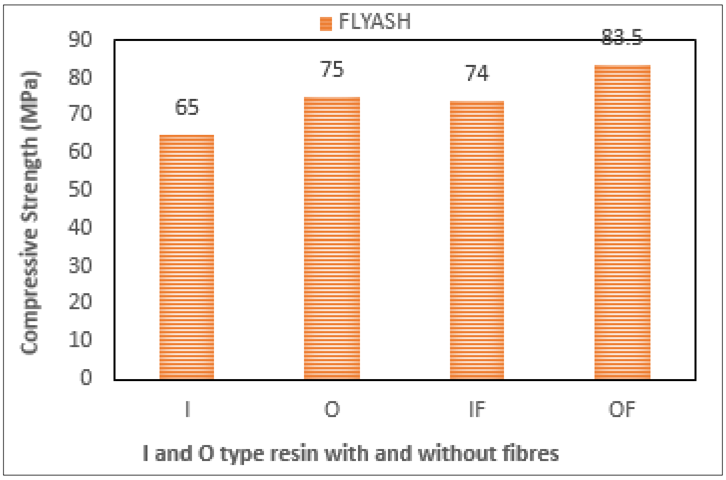

Figure 6. Compressive strength of fly ash samples at 7 days

3.1.2. Flexural strength

The beam specimen of size 40mm x 40mm x 160 mm (1.57inch x 1.57inch x 6.3inch) are tested under flexure using four-point loading method (Figure 7) using Universal testing machine for all the calcium carbonate and fly ash samples with and without fibers. Loads were applied 40mm (1.57 inch) from support on both sides at top of the specimen. Load (P) is gradually applied on the specimen until the specimen got failure and the flexural strength determined is shown in Figure 8. The test results showed increased strength with the addition of fibers than the beams without fibres. In both resin types, fly ash shows increased strength than calcium carbonate samples. Also, O type resin shows a high flexural strength than that of I type resin.

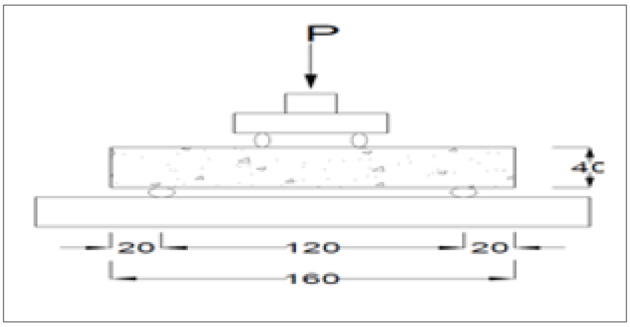

Figure 7. Test set up for flexure under 4 point static load (All dimensions are in mm) 1 mm = 0.039 inches

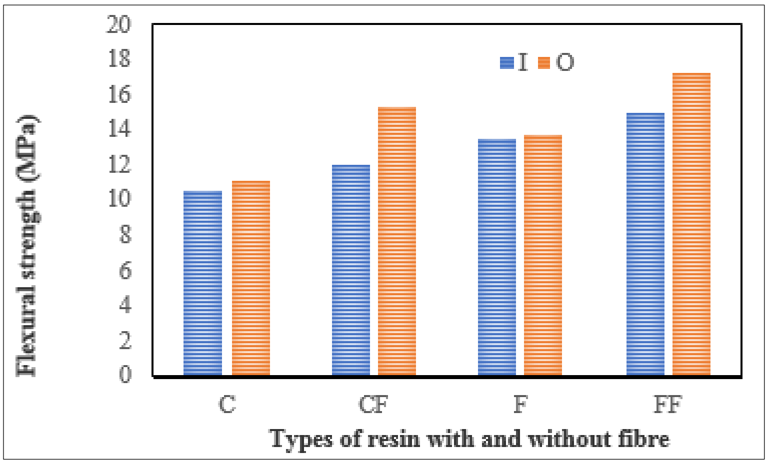

Figure 8. Average flexural strength of I and O type resins with and without fiber at 7 days ($CaCO_3$ and fly ash samples)

3.1.3. Spilt tensile strength

Cylindrical specimens of size 100mm (3.94 inch) diameter and 200mm (7.87 inch) height were cast with and without glass fibres for both type of resins and tested for tensile strength. The obtained results showed similar kind of tensile strength with the addition of glass fibers of fly ash samples for both type of resins. Test results are shown in Figure 9.

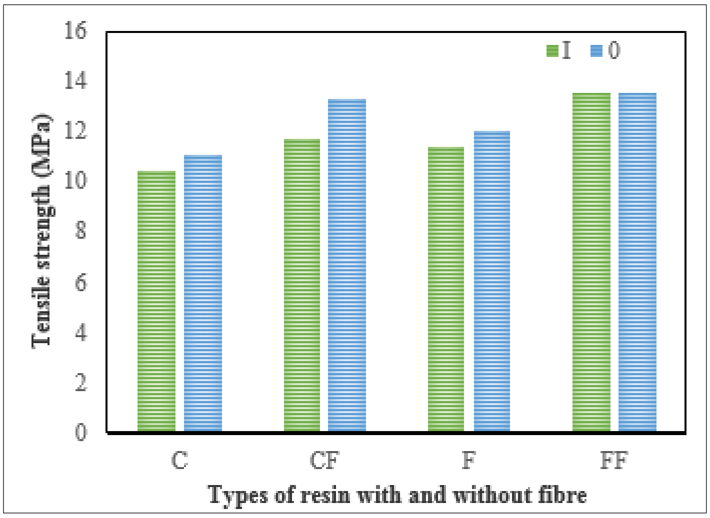

Figure 9. Average split tensile strength of I and O Type with and without fiber at 7 days ($CaCO_3$ and fly ash samples)

3.2. Durability properties

3.2.1. Water Absorption test

Water Absorption test is carried out to determine the durability or performance of resin concrete. Penetration of water due to capillary rise or due to the exterior surfaces exposed to aggressive environment will result in the reduction of strength and it highly affects the durability properties of concrete. The test is carried out as per ASTM D570 [9] in the hardened resin concrete as shown in Figure 10. Percentage of water absorption was calculated using this method and the results were found to be almost NIL which means that the concrete is impermeable and the resin works well as binder in RC.

Figure 10. 40mm cubes immersed in water

3.2.2. Acid tests

Samples are subjected to acids to determine the performance of concrete under aggressive environment. Experimental investigation of the resin concrete of samples size 40mm x 40mm x 40mm (1.57inch x 1.57inch x 1.57inch) were studied. Two different types of dilute nitric acid and sulphuric acid were taken for this experimental study and the samples are immersed in 5% dilute nitric acid (Figure 11) and 5% dilute sulphuric acids (Figure 12). As a result, the normal cement concrete is completely disintegrated with 2 to 5% dilute of nitric and sulphuric acids and the committee recommends the coating of polymer mortar on the top surface to prevent the disintegration of concrete under various aggressive acids [10].

Under this test, RC dry weight is noted and is immersed with these two types of acids and observations are made on weekly basis for the colour changes.

The samples are washed in water after removing from acids and allowed to dry. It is then tested for compressive strength. Weight of the sample and its corresponding compressive strength were recorded. The results showed that no colour change found, no loss in weight, 7 -7 % reduction in strength at 28 days for nitric acid samples and slight colour change found at 28 days, 1 to 2% loss in weight, 5 to 10% reduction in strength at 28 days for sulphuric acid samples. There is no deterioration of concrete is found in both the acid samples.

Figure 11. 40mm cubes immersed in 5% dil. Nitric acid

Figure 12. 40mm cubes immersed in 5% dil. Sulphuric acid

3.3. Analytical investigation
3.3.1. Stress strain behaviour
3.3.1.1. Static Young's Modulus for RC

The results showed that fiber reinforced fly ash based O type resin exhibited improved mechanical properties than other shortlisted batches. Hence this finalized batch were taken for the study of typical stress strain behaviour, young's modulus, dynamic modulus, Poisson ratio, various correlations among their mechanical properties and durability properties. Stress strain behaviour for that batch and is shown in Figure 13.

Static young's modulus (E_s) value from the stress strain curve is found to be 4.42 GPa (641.07 ksi). Also the decrease in young's modulus shows the material is more elastic in nature and showed more strain value than the traditional concrete.

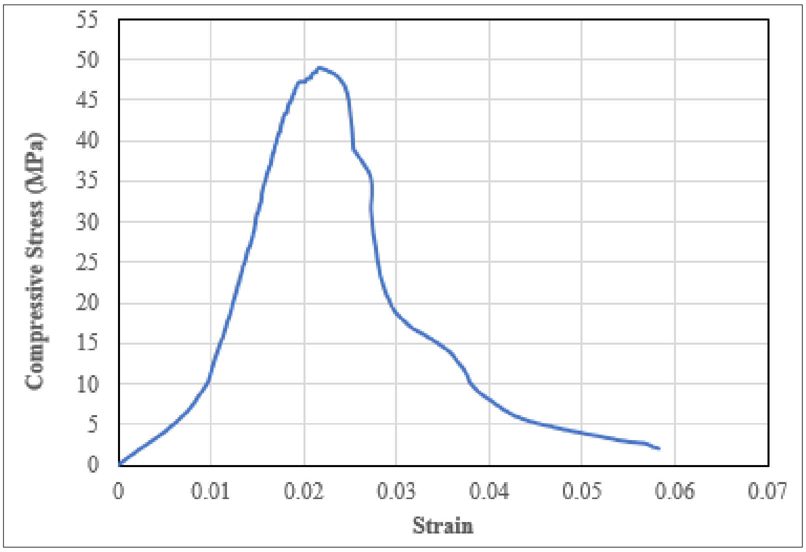

Figure 13. Typical stress strain behavior of O type fly ash based FRRC

3.3.1.2. Dynamic Young's Modulus for RC

The dynamic young's modulus is calculated using the Ultrasonic Pulse Velocity test as per IS 11311(1): 1992 [11]. UPV test is carried out to determine the homogeneity, presence of cracks, voids, quality of concrete. The main principle of accessing the concrete using this method is, larger velocities are obtained if the material is having good quality, homogeneity and uniform concrete. If there is a presence of crack or any voids, these pulses travel through the path and make the path longer by getting lower velocity values. The dynamic Young's modulus of elasticity (E_d) of the concrete may be determined from the pulse velocity (V) and the Poisson's ratio μ, using the following relationship given in eq. (1)

$$E_d = \frac{\rho(1+\mu)(1-2\mu)V^2}{(1-\mu)} \quad (1)$$

where:

E = dynamic young's modulus of elasticity in MPa,
Density (ρ) =2250 in Kg/m^3,
μ = 0.20 obtained from stress strain curve,
V = Pulse velocity in Km/s.

All the UPV values obtained are well within the range of 4000 to 4200 m/s and hence the concrete quality is good as per standards. Using the above equation the value of E_d is calculated as 35.7GPa (5177.85 ksi)

3.4. Correlative equations

3.4.1. Relationship between compressive strength and UPV

The relationship is obtained for the optimized resin type O between their compressive strength (f_{ck}) and ultra sonic pulse velocity, V (UPV) values. UPV test method is used to predict the strength of the concrete and the concrete quality. The test is carried out with the optimized developed mix and using their compressive strength values, analytical relationship between them is derived (Figure 14). The linear correlation coefficient (R^2) value is 0.948, which is close to 1. This indicates that the data is very close to the fitted regression line, and there is very little variability.

3.4.2. Relationship between compressive strength and flexural strength

Analytical equation of relationship between compressive and flexural strength is arrived for that finalised mix and the R^2 value is 0.946, which is almost forming a straight line and close to 1 showing less variability (Figure 15). Using these equations, the flexural strength of the samples can be calculated if the compressive strength is known. Theoretical relation and analytical relation between the flexural strength (f_r) and compressive strength (f_c) are given in equation (2) and equation (3) respectively.

Theoretical relation:

$$f_r = 1.72\, f_c^{0.5} \text{ MPa} \quad (2)$$

Analytical relation:

$$f_r = 9.4156\, f_c^{0.5} - 69.847 \text{ MPa} \quad (3)$$

$$R^2 = 0.946$$

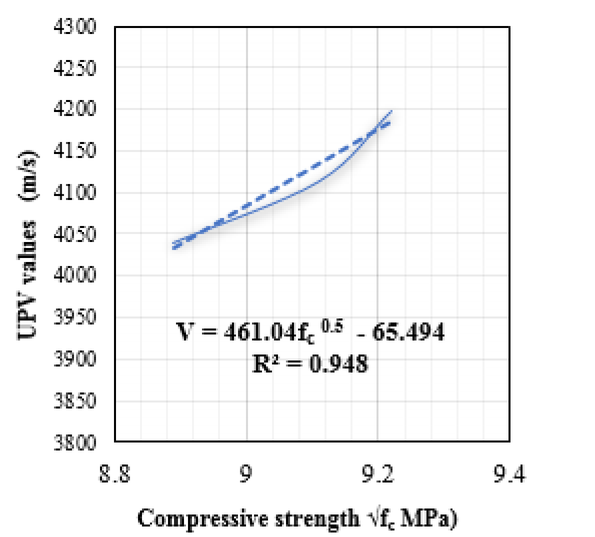

Figure 14. Correlation of compressive strength and UPV values

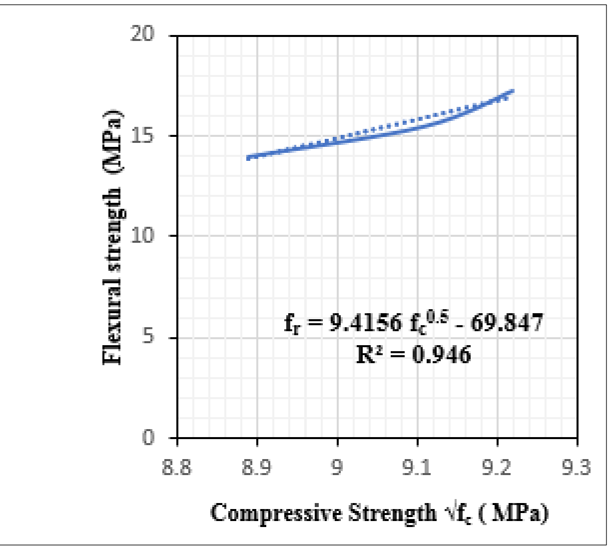

Figure 15. Correlation between compressive and flexural strength

3.4.3. Relationship between compressive strength and split tensile strength

Relationship between compressive strength and split tensile strength of the final optimised resin is derived by both means. Analytical equation is derived (Figure 16) from the graph values and mathematical expression for the same also been arrived. Using the below equations (4) and (5), value of tensile strength is known if the compressive strength is determined. Similar to other relationship equations, R^2 value is 0.9643 which is also equal to 1.

Theoretical relation:

$$f_t = 1.46\ f_c^{\,0.5}\quad \text{MPa} \qquad (4)$$

Analytical relation:

$$f_t = 10.227\ f_c^{\,0.5} - 81.045\ \text{MPa} \qquad (5)$$

$R^2 = 0.9643$

3.4.4. Relationship between flexural strength and tensile strength

Relationship between flexural strength and tensile strength of O type FRRC is shown in Figure 17. Theoretical expression for the same also been arrived shown in equation (6) states that the tensile strength is approximately 1.3 times higher than corresponding tensile strength sample. Similar to other relationship equations, R^2 value is 0.9292 which is also equal to 1 showing less variation.

Theoretical relation:

$$f_r = 1.28 f_t\ \text{MPa} \qquad (6)$$

Analytical relation:

$$f_r = 1.1311\ f_t - 6.0484\ \text{MPa} \qquad (7)$$

$$R^2 = 0.9292$$

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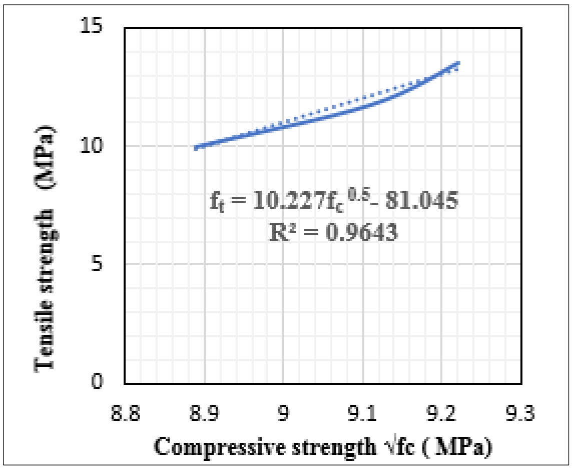

Figure 16. Correlation between split tensile and compressive strength

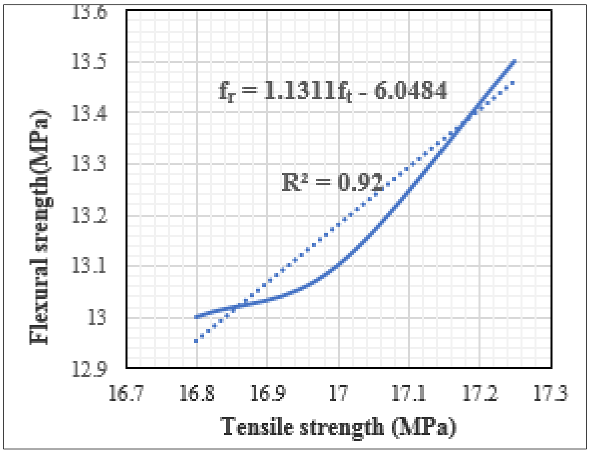

Figure 17. Correlation between split tensile and flexural strength

4. Conclusions

The study was conducted to investigate the various mechanical and durability properties of concrete under various environmental conditions and to derive the correlative equations to show the relationship between compressive strength and ultrasonic pulse velocity values, compressive strength and flexural strength, compressive strength and split tensile strength, flexural strength and split tensile strength. Based on the extensive study of Resin Concrete, the following conclusions can be underlined.

-Technology for fiber reinforced Resin concrete is developed with various properties like high strength > 80 MPa (11.6 ksi) and high durability properties;

-70mm (2.76 inch) VS 40mm (1.57 inch) cubes for the optimized mix and optimized materials showed slight increase in compressive strength of about 2 to 5 % for 70mm (2.76 inch) cubes compared to 40mm (1.57 inch) cubes in both resin types due to better compaction of cubes. Hence 40mm cubes are sufficient for study without fibers;

-Study of mechanical properties of optimised mix under different curing regime such as normal room temperature and samples cured at 80 degrees in oven for about 8 h shows increase in strength of about 4 to 7% of compressive strength for both types of resins;

-Albeit oven curing samples shows increase in strength, in order to cut down the cost of power supply which plays an additional cost during manufacturing process of various products using RC, normal room temperature is preferred than oven curing;

-Relation between analytical and theoretical equation relation between the flexural strength, direct tensile strength, UPV values with compressive strength for the final optimized mix and material was achieved.

-Study of durability properties on RC shows there is no water absorption and acid tests shows the permissible reduction of strength in both acids however there is no reduction in mass and no deterioration of concrete was found in both the acid types;

-Developed fiber reinforced resin concrete mix possess various mechanical properties such as high compressive strength of 80MPa (11.6 ksi), flexural strength of 17.25MPa (2.5 ksi) and Tensile strength of about 13.5MPa (1.96 ksi) and high durability properties;

-This developed mix can be recommended for manufacturing various products in different industries such as FRP pipes in chemical & petroleum plants, FRP covers, effluent storage tanks in Water treatment plants, power plant flooring tanks, swimming pools *etc*.

-Since the developed mix possess high mechanical properties and because of its nature of rapid curing of about within hours, this can be recommended for emergency mining jobs and repair works of bridges even without halting the traffic.

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