STUDY ON STRENGTH AND DURABILITY OF FLY ASH AND GGBFS BASED GEOPOLYMER CONCRETE

Neethu Susan Mathew[1], S. Usha[2]

[1](*M.Tech Student, Sree Narayana Gurukulam College of Engineering, Ernakulam, Kerala, India*)

[2](*Professor, Civil Department, Sree Narayana Gurukulam College of Engineering, Ernakulam, Kerala, India*)

Abstract: ***The use of supplementary cementitious materials as partial replacements for the cement in concrete will play a significant role with respect to the environmental control of greenhouse effects and global temperature reduction. The development of geopolymer concrete (GPC), in which all of the Portland cement is replaced with fly ash and ground granulated blast furnace slag (GGBFS) in combination with sodium hydroxide and sodium silicate solutions, offers a promising alternative to ordinary portland cement concrete. This paper compares the strength, durability and bond strength characteristics of fly ash and GGBFS based geopolymer concrete with M30 grade OPC concrete. The results indicated that geopolymer concrete showed an improvement of 20%, 10.2% and 4.7% in the 28th day compressive strength, splitting tensile strength and flexural strength respectively in comparison with the control mix. The bond strength were also comparable to the control mix. The durability studies showed that geopolymer concrete are less porous and more compact.***

Key Words: *Geopolymer, Flyash, GGBFS…*

1. Introduction

In 1978, Davidovits proposed that a binder could be produced by a polymerisation process involving a reaction between alkaline liquids and compounds containing alumina and silica. [1] .The binders created were termed "geopolymers". Unlike ordinary Portland/pozzolanic cements, geopolymers do not form calcium-silicate-hydrates (CSHs) for matrix formation and strength, but the aluminosilicate gel formed by geopolymerization binds the aggregates and provides the strength to geopolymer concrete. Source materials and alkaline liquids are the two main constituents of geopolymers, the strengths of which depend on the nature of the materials and the types of liquids [2].

Materials containing silicon (Si) and aluminium (Al) in amorphous form, which come from natural minerals or by-product materials, could be used as source materials for geopolymers. Kaolinite, clays, etc., are included in the natural minerals group whereas fly ash, silica fume, slag, rice-husk ash, red mud, etc., are by-product materials. For the manufacture of geopolymers, the choice of source materials depends mainly on their availability and cost, the type of application and the specific demand of the users [3]. Metallurgical slag was also used as a raw material to make geopolymer and it was found that the addition of slag enhanced the properties of the geopolymer.

Among the available raw materials, fly ash has attracted more attention due to its ability in improving geopolymer physical properties and its availability in large quantities [4]. However high compressive strength geopolymer composite was obtained at elevated temperatures curing which restricts its application to precast elements. Therefore an attempt has been made to prepare geopolymer concrete with fly ash and GGBFS, cured at room temperature and comparison has been made for strength and durability characteristics with M 30 grade OPC.

2. EXPERIMENTAL PROGRAM

2.1. Materials

43 grade OPC cement having specific gravity of 3.15 was used for cement concrete. For geopolymer concrete siliceous pulverized fly ash obtained from Hi-Tech private limited, Tuiticorin, India, having a specific gravity of 2.2 and low calcium, ground granulated blast furnace slag of specific gravity 2.9 obtained from the, JSW Steel Limited, Salem, India, were used as the source material. Table 1 gives the oxide composition. 97% purity sodium hydroxide (NaOH) pellets and sodium silicate (Na_2SiO_3) with 28.13% Na_2O, 28.13% SiO_2, and 40.74% H_2O were used. For the NaOH solution, NaOH pellets were mixed with distilled water and stirred until all the pellets were completely dissolved. The solution was then left for 24h before use. Coarse aggregate used were locally available crushed angular granite metal of 20 mm size having the specific gravity of 2.74 and for fine aggregate manufactured sand having the specific gravity of 2.6 were used.

Table 1: Oxide Composition

Oxide%	GGBFS	Fly Ash
SiO_2	33.05	48.67
Al_2O_3	16.36	14.31
Fe_2O_3	0.53	3.51
CaO	45	1.03
MgO	6.41	0.39
SO_3	1.21	0.14
Na_2O	0.13	0.21
K_2O	0.42	0.79
TiO_2	-	1.13
MnO	-	0.02
L.O.I	3.05	6.2

3. MIX PROPORTIONS

3.1. Design mix

Mix design for M30 cement concrete as per IS 10262:2009 was prepared as control mix with ratio of 1:1.5:2.5 and 0.4 w/c ratio. The control specimens were water cured for 28 days.

3.2. Geopolymer mix

For comparing geopolymer concrete with control mix, geopolymer concrete with mix proportion (1:1.5:2.5) was adopted. The combination ratio of fly ash and GGBFS as binder was selected by conducting mortar cube test with varying ratios as shown in Table 2. Flyash to GGBFS ratio as 50:50 was selected for geopolymer concrete mix design.

Table 2: Compressive Strength Results

Si.no	Mix proportion	7thday compressive strength
1	90% fly ash + 10% GGBS	-
2	80% fly ash + 20% GGBS	-
3	70% fly ash + 30% GGBS	18.85N/mm^2
4	60% fly ash + 40% GGBS	29.8N/mm^2
5	50% fly ash + 50% GGBS	33.9N/mm^2
6	40% fly ash + 60% GGBS	24.4N/mm^2
7	100 % GGBS	28.7N/mm^2

Table 3 provide the proportions of the control mix (M30) and geopolymer mix (GPC) mixtures per cubic meter of concrete. For the alkaline activators, the parameters chosen for the mixture constituents include a ratio of sodium silicate solution-to-sodium hydroxide solution, by mass, as 2.5, sodium hydroxide solution molarity as 8 M, and a ratio of activator solution-to-binder, by mass, as 0.35.

Table 3: Proportion of the mixes per m³

Ingredients	M30 (kg/m³)	GPC(kg/m³)
OPC	450	-
Fly ash	-	225
GGBFS	-	225
Fine aggregate	670	670
Coarse aggregate	1152	1152
Sodium silicate solution	-	45
Sodium hydroxide solution	-	112.25
Water	180	119.154

3.3. Mixing

NaOH pellets were dissolved in distilled water and thoroughly mixed with Na_2SiO_3 one day prior to the casting. Fly ash, GGBFS and aggregates were mixed homogeneously and then the prepared alkaline solutions were added to it. The mixing of total mass was continued until the mixture become homogeneous and uniform in colour.

3.4. Curing Conditions

The specimens were casted and allowed to set for 24 hours. The specimens were then removed from the moulds and kept wrapped in polythene sheets till testing at ambient temperature.

4. TESTS AND RESULTS

4.1. Compressive strength

The compressive strength of geopolymer concrete cubes at 7th day and 28th day, according to IS 516-1959 are shown in Table 4 and Chart-1. 20% increase in the compressive strength was observed for geopolymer concrete compared to M30 OPC concrete with same mix proportion. Results show that geopolymer concrete attains the target strength at 7th day itself.

Table 4: Compressive Strength Results

Mix ID	Binder Composition	Compressive Strength N/mm²		Percentage Increase
		7th day	28th day	
M 30	OPC	21.9	33.77	-
GPC	50% Flyash+ 50% GGBFS	29.95	40.44	20%

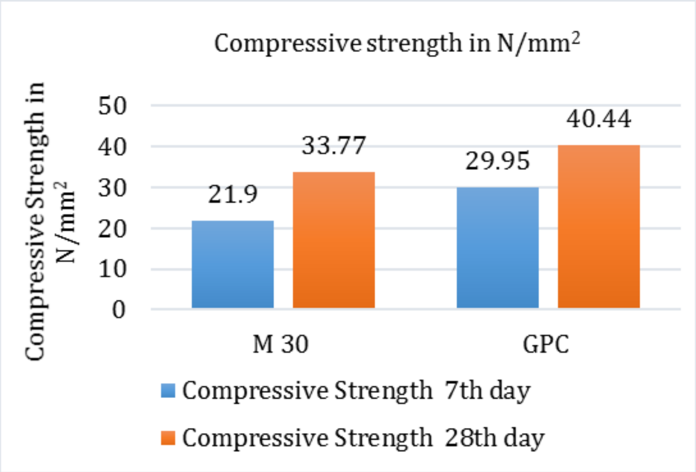

Chart -1: Compressive Strength Results

4.2. Splitting tensile strength

A direct measurement of ensuring tensile strength of concrete is difficult. One of the indirect tension test methods is split tension test. The split tensile strength test was carried out on the compression testing machine. The casting and testing of the specimens were done as per IS 5816: 1999. The results show that there is an increase of 10.2% in the tensile strength for GPC in comparison with M30 control mix.

Table 5: Tensile strength results

Mix ID	Binder Composition	28th day Tensile strength N/mm²	Percentage Increase
M 30	OPC	2.757	-
GPC	50%Flyash+ 50% GGBFS	3.0401	10.2%

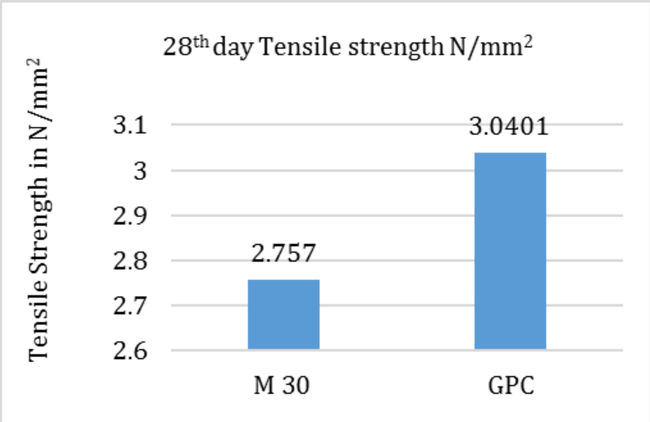

Chart -2: Splitting Tensile Strength Results

4.3. Flexural strength

The beam specimens of size 100 × 100 × 500 mm were prepared & tested for flexural strength on OPC and geopolymer concrete as per IS 516-1959. Chart-3 shows the results for the average of three specimens. The results shows an increase of 4.7% in the flexural strength of GPC in comparison with M30.

Table 6: Flexural strength results

Mix ID	Binder Composition	28th Day Flexural Strength N/mm²	Percentage increase
M 30	OPC	5.25	---
GPC	50% Flyash + 50% GGBFS	5.5	4.7%

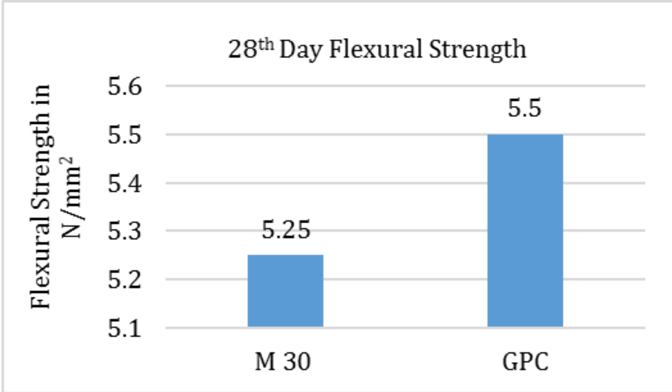

Chart -3: Flexural Strength Results

4.4. Modulus of elasticity

The modulus of elasticity is essentially the measurement of the stiffness of a material. Modulus of elasticity of concrete is a key factor for estimating the deformation of buildings and members, as well as a fundamental factor for determining modular ratio, m, which is used for the design of section of members subjected to flexure. Knowledge of the modulus of elasticity of high strength concrete is very important in avoiding excessive deformation, providing satisfactory serviceability, and for cost-effective designs. Chart-5 shows the average value of modulus of elasticity determined by means of an extensometer as per IS 516 -1959.

Table 7: Modulus of elasticity of mixes

Mix ID	Binder Composition	Modulus Of Elasticity (N/mm²)
M 30	OPC	18195.36
GPC	50% Fly ash +50%GGBFS	20526.17

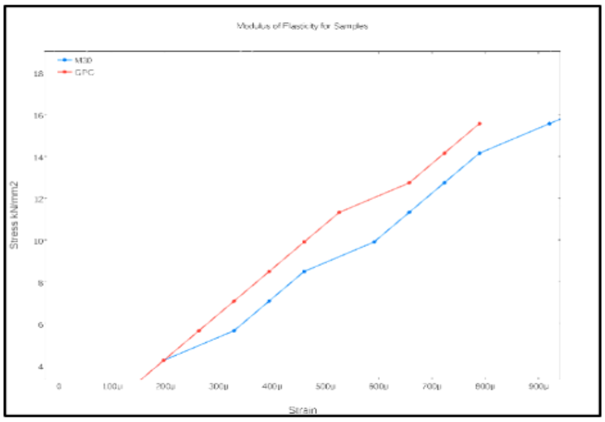

Chart -4: Stress Vs Strain graph

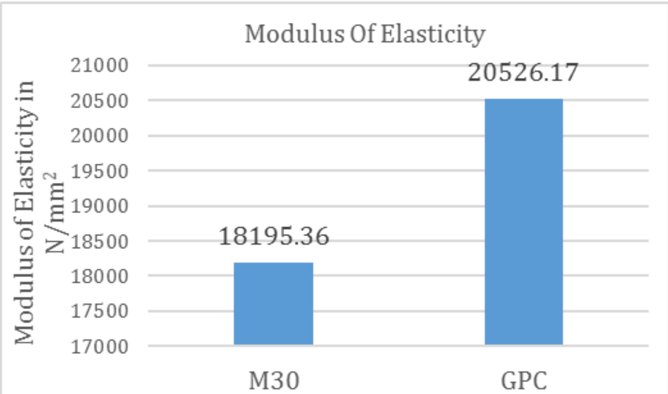

Chart -5: Modulus of Elasticity

4.5. Pull out test for the determination of bond strength

The pull out test was done as per IS 2770-1967- Part-1 for 100 mm cube specimens containing 12 mm dia reinforcement. The test setup is as shown in Fig-1. The failure was marked by splitting of the cover and slipping of the reinforcement. The nominal bond strength was calculated as follows:

$$nominal\ bond\ strength = \frac{P}{\pi \O L}$$

Where, P= pull at failure, Ø= bar diameter and L= length of embedment. Table 8 gives the load at failure and bond strength for the specimens. The load Vs slip is as shown in Chart- 6.The results shows that the bond strength of the two specimens are comparable even though GPC failed at an earlier stage.

Fig -1: Pull Out Test Setup

Table 8: bond strength results

Mix ID	Binder Composition	Load at failure KN	Bond Strength N/mm²
M 30	OPC	39.6	10.50
GPC	50% Fly ash + 50% GGBFS	38.3	10.159

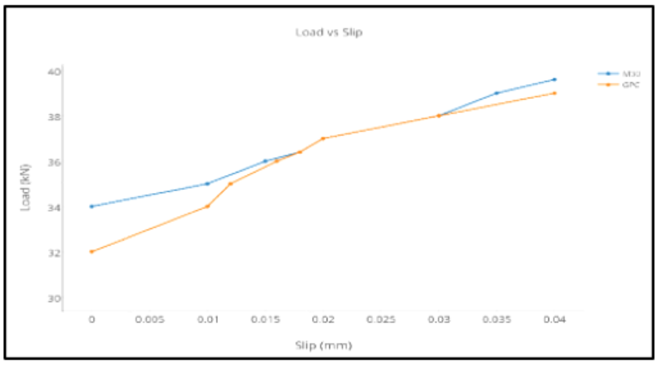

Chart -6: Load Vs Slip

4.6. Water absorption percentage

Water absorption is measured by measuring the increase in mass as a percentage of dry mass. Saturated water absorption test was conducted at the age of 28 days on 100 mm cubes in accordance with IS. 2185- 1979.

$$Water\ Absorption = \frac{Ws - Wd}{Wd} \times 100$$

Where Ws = weight of specimen at fully saturated condition and Wd = weight of oven dry specimen. The water absorption percentage of OPC was compared with geopolymer concrete as shown in Chart-7. For good concrete the increase in masses should be less than 10 % by initial masses. The results show that GPC helps in reducing the water absorption capacity by 58% which proves that GPC is denser and compact.

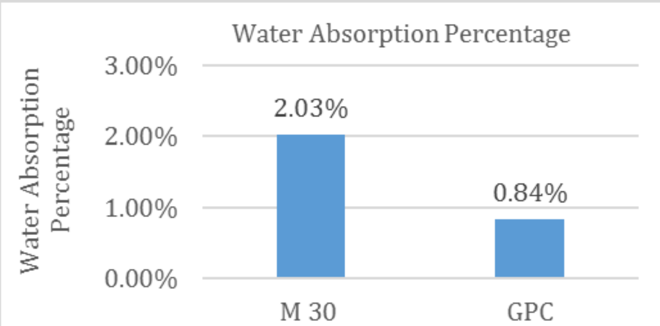

Chart -7: Water Absorption Percentage Results

4.7. Sorptivity test

This test method is used to determine the rate of absorption (sorptivity) of water by measuring the increase in the mass of a specimen resulting from absorption of water as a function of time when only one surface of the specimen is exposed to water. The exposed surface of the specimen is immersed in water and water ingress of unsaturated concrete dominated by capillary suction during initial contact with water is recorded. Fig -2 shows the test setup. This test method is based on that developed by Hall who called the phenomenon "water sorptivity." The sorptivity test was done for M30 grade OPC mix, geopolymer concrete. The initial sorptivity, defined in accordance with ASTM C1585-04, includes data measured from 1 minute up to 6 hours as shown in the Table 9.

$$I = \frac{M_t}{A_\rho} \quad \text{and} \quad I = S_i\sqrt{t}$$

where I is the cumulative absorbed volume after time t per unit area of inflow surface (mm^3/mm^2), M_t the change in specimens mass at the time t, ρ the density of fluid and A the cross-sectional area in contact with fluid.

Fig -2: Sorptivity test set up

Table 9: Sorptivity results

Time min	Avg. wt. of M30 (gm)	Avg. wt. of GPC (gm)	S_i of M30 $mm/\sqrt{min}$	S_i of GPC $mm/\sqrt{min}$
0	1.057	1.027	--	--
30	1.073	1.042	2.373	2.227
60	1.079	1.049	0.616	0.684
120	1.082	1.053	0.193	0.290
180	1.084	1.057	0.168	0.257
240	1.087	1.060	0.128	0.145
300	1.089	1.062	0.114	0.084
360	1.091	1.062	0.048	0.013

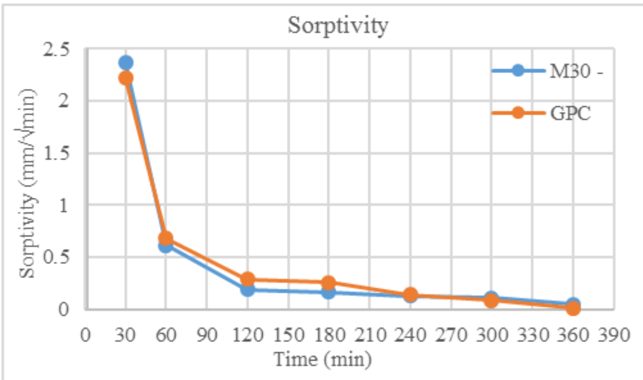

Chart -8: Sorptivity Result

4.8. Density

The density of concrete is the measurement of concrete's solidity or the measure of its unit weight. The mixing process of concrete can be modified to obtain a higher or lower density concrete. Understanding concrete density is an important part of knowing the possibilities and limitations of what concrete can be used for.

Table 10: Density Results

Mix ID	Binder Composition	Density kN/m^3	Variation in density
M 30	OPC	24.43	-
GPC	50% fly ash + 50% GGBFS	23.482	-3.8%

From the results as shown in Table 10 it can be seen that the density of geopolymer concrete is less than 3.8% compared to that of cement concrete. Due to the reduction in density the self-weight of structures can be reduced which is highly advantageous.

4.9 ECONOMIC FEASIBILITY

Geopolymer concrete (GPC) manufactured using industrial waste like fly ash, GGBS is considered as an eco-friendly alternative to Ordinary Portland Cement (OPC) based concrete. The reduction in the carbon dioxide emission from cement production can contribute significantly to the turning down of the global thermostat. Furthermore, very little drying shrinkage, low creep, excellent resistance to sulphate attack and good acid resistance offered by the fly ash and GGBFS based geopolymer concrete might yield additional economic benefits when utilized in infrastructure applications. However the feasibility of production of geopolymer concrete with Ordinary Portland Cement (OPC) based concrete in terms of the cost for production must be evaluated for its practicability

The cost for the production of the different mixes taken for study are evaluated in the **Table 11.** The cost includes the transportation charges also.

Table 11: Calculation of cost per m^3

Material	Rate	M30	GPC
Cement	Rs 7.5/ kg	3375	0
Fly ash	Rs 2.75/ kg	0	618.75
GGBFS	Rs 5/ kg	0	1125
Fine aggregate	Rs 450/ m^3	198.35	198.35
Copper slag	Rs 750/ m^3	0	0
Coarse aggregate	Rs 200/ m^3	135.529	135.529
NaOH pellets	Rs 50/ kg	0	558.25
Na_2SiO_3 solution	Rs 15/ kg	0	1683.7
Total cost per m^3		Rs 3708.87	Rs 4319.579
Variation		--	16.46 %

Even though the materials used for the production of geopolymer concrete are industrial by-products, the cost for the production of geopolymer concrete is higher than control mix because of the transportation cost and cost of the alkaline activator solution. When the strength and cost for the different mixes are compared it can be concluded that geopolymer concrete is more favourable than OPC based concrete. Chart-9 shows the parametric comparison (CS= Compressive Strength, FS= Flexural Strength, TS = Tensile Strength, BS= Bond Strength, WA = Water Absorption Percentage, S= Sorptivity) between M30 mix and GPC. By keeping the values of M30 as unity the ratio difference in the parameters for GPC are plotted. The variation shows that even though GPC is more costly, it offers more strength than the control mix.

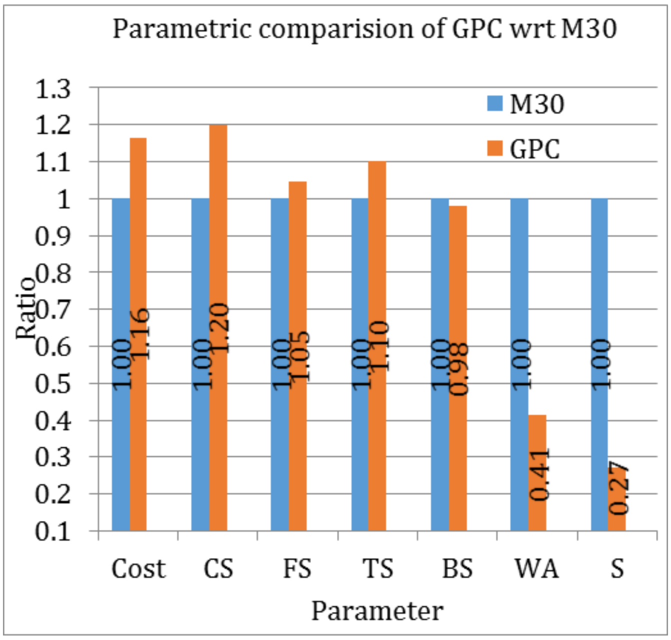

Chart -9: Parametric Comparison Results

5. CONCLUSIONS

1. The slag to fly ash ratio required for geopolymer concrete which can be cured at ambient temperature is found to be 50: 50
2. Ambient cured fly ash–ground granulated blast furnace slag (GGBS) based geopolymer concrete attains the target compressive strength at 7^{th} day itself and hence can be used for structural application where early strength is required.
3. The average split tensile strength of geopolymer concrete is higher than the control mix by 10.26%.
4. The flexural strength values for geopolymer concrete mixture is higher than OPC control mix by 4.7%.
5. The modulus of elasticity of geopolymer concrete is more than the control mix by 12.8%.
6. The bond strength values of geopolymer concrete are comparable with OPC based concrete.
7. The water absorption capacity of geopolymer concrete is much lesser than OPC based concrete which shows that geopolymer concrete is more durable.
8. Geopolymer concrete can reduce the sorptivity by almost 72.9%, thereby improving the durability of concrete.
9. The density of geopolymer concrete is less than 3.8% than the control OPC concrete mix.
10. The cost for production of geopolymer concrete is higher than the control mix due to high transportation cost of the by-products and cost of alkaline activators.

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- IS 10262:2009; Mix design of concrete.
- IS 456:2000; Plain and Reinforced concrete code of Practice.
- IS 383:1970; Specification for coarse and fine aggregates from natural sources for concrete
- IS 516: 1959; Methods of tests for Strength of concrete
- IS 2770-1967- Part-1; Methods of testing bond in reinforced concrete
- IS 5816: 1999. ; Splitting tensile strength of concrete - method of test
- IS. 2185- 1979 ; Specification for concrete masonry units

- ASTM C1585-04; Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes

BIOGRAPHIES

Neethu Susan Mathew is a PG scholar in the field of Computer Aided Structural Engineering at Sree Narayana Gurukulam College of Engineering, Mahatma Gandhi University. She received her Bachelor of Engineering degree in Civil Engineering from the Sree Narayana Gurukulam College of Engineering in 2012. Her field of interest includes mix design proportioning and development of eco-friendly concrete.

S Usha is working as Professor in the Civil Engg Dept. of SNGCE, Kerala. She has 13 years of Industrial experience. She obtained M Tech in Structural Engg. She has guided students for their M Tech and B Tech projects in the field of Geopolymer composites and concrete, Analysis of laminated plates and structures. She has several publications in National and International Journals.