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The Effect of Addition of Carbon Fibers on Mechanical Properties of High Strength Concrete

S. M. Kinayekar[1], Dr. V. D. Gundakalle[2], Kishor Kulkarni[3]

P.G. Student, Department of Civil Engineering, KLES Dr. MSSCET, Belgaum, Karnataka, India[1]

Professor, Department of Civil Engineering, KLES Dr. MSSCET, Belgaum, Karnataka, India[2]

Assistant Professor, Department of Civil Engineering, KLES Dr. MSSCET, Belgaum, Karnataka, India[3]

Abstract:High Strength Concrete (HSC)is dense, homogeneous and has the improved engineering properties and durability as conventional concrete. In recent years, HSC has gained wide application in the construction industry. High strength Concrete is a concrete having similar ingredients as conventional concrete, such as cement, fine aggregate, coarse aggregate and water. The paste of HSC requires high volume of cement content and less water to binder ratio. The stability and flowability of HSC is achieved by increasing the cement content or employment of mineral admixtures. However, increasing the cement content causes high cost, higher heat of hydration and higher drying shrinkage. This can be reduced by employing mineral admixture such as fly ash and ground granulated blast furnace slag etc. In the present investigation, cement content for HSC mix is replaced with fixed percentages of fly ash (10%) and carbon fiber are added in volume fraction (0 to 0.60%), also the Carbon Fiber Reinforced Polymer (CFRP) strip are placed in different layer (single, double and triple layer) with varying width of CFRP strip (0 to 80 mm). The hardened concrete properties of HSC were studied and the regression analysis was carried out on the experimental investigation. The study concludes that carbon fibers can be effectively used as a reinforcing material in HSC.

Keywords:High strength concrete, Fly ash, Carbon fiber, CFRP strip, Regression analysis.

I. INTRODUCTION

High Strength Concrete (HSC) is a special type of concrete that has a specified compressive strength of 60 N/mm^2 or greater. High strength concrete is a most economic concrete, realized when it is used in the columns of High-Rise Buildings, Parking garages, Bridge decks, and other installations requiring improved compressive strength and density. For HSC usually selected pozzolanic and chemical admixtures are employed, and attainment of a low water to cementitious material ratio is considered essential. Many trial mixtures are often required to generate the data necessary to identify optimum mixture proportions Reported by ACI Committee 211.4R-93 [1].

High strength concrete is considered as a relatively brittle material as the concrete is strong under compression and weak under tension or flexure. Carbon fibers are inert, medically safe, chemically stable, low in density, and their strength-to-density ratio is one of the highest among all fiber types. Carbon fiber has a very high tensile strength (2110 to 2815 N/mm^2)and young's modulus. Patodi,and Rarhod, have concluded that, cement composites made with carbon fiber, as reinforcement will have very high modulus of elasticity and flexural strength[2]. Aziz and Tahahave found improved structural propertieswhen flexure behavior of high strength concrete beams reinforced with carbon fiber polymer rebars with and without chopped carbon fiber, [3]. Addition of discontinuous fibers to concrete makes it a homogeneous and isotropic materials and converts brittleness into a ductile behaviour.

Aziz and Tahacarried out experimental work on mechanical properties of carbon fiber reinforced High Strength Concrete. The study reports that, when concrete cracks, the randomly oriented fibers start arresting both the randomly oriented micro-cracking and its propagation and thus improving strength and ductility[4]. These carbon fibers are manufactured by carbonizing polyacrylonitrile yarn at high temperatures and then aligning the resultant graphite crystallites by a process called hot stretching. Polyacrylonitrile based carbon fiber were not commonly used in FRC because of their high cost.In the early 1980s, the less expensive short pitch based carbon fiber was developed, and used

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as fiber reinforcing material in precast concrete applications[5]. The technique of dispersing short pitch based carbon fibers randomly in the concrete mix is carried out by two methods in the carbon fiber reinforced concrete technology. One is to mix the fibers with cement and aggregate in dry state known as "Dry Mix" method. Second is to first disperse the fibers in water with hydroxyl Ethyl cellulose (0.06% by weight of cement) and then pour the dispersion into the slurry with cement and aggregate known as "Wet Mix" method. The second method is much more practical for dispersion of short pitch based carbon fibers in the carbon fiber reinforced concrete technology, specially chosen so as to have appropriate strength. Wet Mix is an effective method of dispersion of carbon fibers only if dispersant chemicals are used with water[6].

In this study, cement content in the HSC mix is replaced with fixed percentages of fly ash (10%) and carbon fiber are added in volume fraction (0 to 0.60%), also the carbon fiber reinforced polymer (CFRP) strip are placed in different layer (single, double and triple layer) with varying width of CFRP strip (0 to 80 mm). The hardened properties of HSC were studied and the experimental results were validated by regression analysis.

II. MATERIALS AND EXPERIMENTATION

A. Materials

- *Cement*: Ordinary Portland cement (OPC) (53 grade) with specific gravity of 3.15 and fineness of 292 m^2/kg confirming to IS 8112:1989 is being used.
- *Fine aggregate*: The sand used for the experimental program was locally procured and was confirming to zone-III. The specific gravity of fine aggregate was 2.58 and bulk density 1600 kg/m^3.
- *Coarse aggregate*: Locally available crushed angular coarse aggregate having maximum size of 12.5 mm were used in the present work. The specific gravity of coarse aggregate was 2.90 and bulk density 1553kg/m^3.
- *Fly ash (FA)*: Fly ash from Raichur thermal power station, Karnataka has been used as cement replacement material with a specific gravity of 2.2 and blains fineness of 229 m^2/kg.
- *Carbon fiber*: The carbon fiber used is obtained fromengineering India, Pune. The density of carbon fiber is about 1800 kg/m^3 and tensile strength of fiber is 4137 N/mm^2.
- *Water*: Potable tap water was used for the preparation of specimens and for the curing of specimens.
- *Superplasticizer*: The super plasticizer used is Conplast SP430, which is obtained from FOSROC chemicals, Bangalore.
- *Hydroxy Ethyl Cellulose (HEC)*: The Hydroxy Ethyl Cellulose used as in this experiment was obtained from FOSROC chemicals, Bangalore. The viscosity of HEC is 4.75 % in water at 20^{o}C
- *Epoxy*: Epoxy is the resin based bonding agent, which is obtained from FOSROC chemicals, Bangalore.

B. Mixture Proportions

In the present investigation10% cement is replaced by fly ash, this is optimised by trial workability test which is kept constant. ACI Method (ACI 211.4R-93) of mix design is adopted for designing M60 grade of concrete [1]. Mix proportion for cubic meter of concrete is presented in Table1.

Table 1: Mix Proportion for cubic meter of concrete

Particulars	**Quantity (kg/m^3)**
Cementitious material (90% Cement + 10 % FA)	546
Fine aggregate	694
Water	169
Coarse aggregate	1050
Superplasticizer	8.19

Necessary care is taken in proportioning the ingredients. The cement, fly ash and fine aggregates were mixed in dry condition until the mixture was thoroughly blended. The coarse aggregate was then added and mixed till to distribute it

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uniformly. Initially 70% of water was added to the dry mixture to attain homogeneity and then the remaining 30% suspension of superplasticizer prepared in water was added and mixing was continued to obtain homogeneous mix.
The carbon fiber is used in varying length 10 mm, 20 mm, and 30 mm with 0%, 0.10%, 0.20%, 0.30%, 0.40%, 0.50% and 0.60% in volume fraction. Cube specimens of size 150 mm were cast to determine compressive strength and cylindrical specimens of diameter 150 mm and height 300 mm were cast to determine splitting tensile strength and modulus of elasticity of concrete. Flexural strength of concrete was calculated by preparing beam specimens of size 500×100×100 mm. Mix designations for various percentage of addition of carbon fiber are shown in Table 2.
To determine flexural and load deflection response of CFRP beams, CFRP layer strip is used in single, double and triple layers with varying width 20mm, 40mm, 60mm and 80mm. Table 3 shows mix designations for CFRP beams.

C. Testing

Hardened properties were determined by conducting compressive strength on cubes, splitting tensile strength and modulus of elasticity on cylinders, flexural strength and load deflection response on beams. The compressive strength test on cube specimens is conducted as per IS 516-1959. Split tensile test is carried out on compression testing machine as per IS 5816-1999. Modulus of elasticity test is carried out on universal testing machine as per IS 5816-1999. To determine flexural properties of concrete beams two point loading system is adopted and testing is carried out by as per IS 516-1959.

Table 2: Mix Designation for fiber content in volume fraction.

Fiber Volume fraction (%)	**Length of carbon fiber (mm)**		
	10	**20**	**30**
0	NC	NC	NC
0.10	A1	B1	C1
0.20	A2	B2	C2
0.30	A3	B3	C3
0.40	A4	B4	C4
0.50	A5	B5	C5
0.60	A6	B6	C6

Table 3: Mix Designation for fiber content in CFRP beam.

Fiber content in layers	**Width of CFRP strip (mm)**			
	20	**40**	**60**	**80**
0	NC	NC	NC	NC
1	D1A	D2A	D3A	D4A
2	D1B	D2B	D3B	D4B
3	D1C	D2C	D3C	D4C

III. RESULTS AND DISCUSSION

A. Hardened properties

a) Compressive strength

Figure 1 presents the variation of compressive strength vs carbon fiber content. From the fig. 1 it is observed that, compressive strength increases with fiber length and fiber content. The increase in strength is more predominant for 30 mm length fibers. For the given fiber content, 30 mm length fibers show highercompressive strength compare to 10 mm and 20 mm length fibers. At 0.60% fiber content 30 mm length fiber shows 4.59% increase incompressive strength whereas the increase is by 2.11% and 2.81% for 10 mm and 20 mm length of fibers respectively, compared with the strength of high strength concrete with 0% fiber.

b) Split tensile strength

The test results on split tensile strength of HSC with carbon fibers is shown in Table 4 and plotted in Fig 2. It is observed from the Fig. 2, that the split tensile strength shows increase in strength with fiber content and length. As observed in compressive strength, 30 mm length fibers exhibit higher increase in split tensile strength compare to 10 mm and 20 mm length fibers, but the increase insplit tensile strength is more compared to the increase in compressive strength. Addition of 30 mm length fibers show higher strength by 12.80% at 0.60% fiber content compared to high strength concrete with 0% fibers.

c) Flexural strength

Flexural strength test results are given in Table 4 and plotted in Fig 3, show significant improvement in flexural strength with the addition of carbon fibers. The increase in strength is more sensitive with fiber length and content compared to compressive and split tensile strength, for a given fiber length and content. Maximum increase of 20.49% in flexural strength is observed at 0.60% content for 30 mm length fiber compared to a flexural strength of high strength concrete with 0% fibers.

d) Modulus of elasticity

Test results forModulus of elasticity indicate that the addition of carbon fibers show marginal increase in the elasticity. Similar to strength properties the modulus of elasticity also shows increased values at higher fiber length and fiber content.

e) Flexural strength(for CFRP beam)

Flexural behaviour of high strength concrete with carbon fiber reinforced polymer (CFRP) exhibit gradual enhancement in flexural strength with fiber width and number of layers. 20 mm width strips show less effective at single and double layer whereas 80 mm width strips at double and triple layer exhibitsignificant increase in flexural strength of high strength concrete.

f) Load deflection response under flexural loading

Load deflection response under flexural loading with the addition of carbon fibers, the beams show higher deflections before failure, thus increasing the toughness of high strength concrete. The increase in deflection is gradual with fiber length and content. With addition of 30 mm length fibers the increase in deflection is more significant compared with the addition of 10 mm and 20 mm length fibers. For 0.60% addition with 30 mm length fibers the increase in deflection is 3.12 mm which is 50.32% higher compared with reference mix.

g) Load deflection response of CFRP beam under flexural loading

Load deflection behaviour under the variation of loading shown in Fig 7 indicates gradual increase in deflection with increase in fiber width and number of layers. Addition of higher width and higher number of layers exhibited higher deflections. Addition of CFRP shows higher increase in deflection than addition of carbon fibers in volume fraction. Thus improves the toughness of high strength with CFRP. For 20 mm width strips with three layers, the increase in deflection is 39.68% and for 80 mm width fibers it is higher by 62.10% compared with the deflection of beams of high strength concrete without CFRP strips.

B. Regression analysis

a) Compressive strength

From the regression analysis of the test results the best-fit polynomial equation for compressive strength is

f_{ck}= 60.8+3.08×F+0.0433×FL and the percentage of error lies between +1.1 to -0.7.

b) Split tensile strength

From the regression analysis of the test results the best-fit polynomial equation for split tensile strength is

f_{st} = 6.99+1.39×F+0.00911×FL and percentage of error lies between +1.2 to -5.3.

c) Flexural strength

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From the regression analysis of the test results the best-fit polynomial equation for flexural strength is f_{fs} = 4.97+1.71×F+0.0111×FL and ppercentage of error lies between +2.9 to -1.4.

d) Modulus of elasticity

From the regression analysis of the test resultsthe best-fit polynomial equation for split tensile strengthis E = 36907+3146×F+51.3×FL and the percentage of error lies between +2.1 to -1.0.

e) Flexural strength (for CFRP beam)

From the regression analysis of the test results the best-fit polynomial equationfor flexural strength is f_{fs} = 4.27+0.703×Fly+0.0259×Fw and the Percentage of error lies between +16.6 to -7.7.

Notations

f_{ck} =Compressive strength in N/mm^2
f_{st} =Split tensile strength in N/mm^2
f_{fs} =Flexural strength in N/mm^2
E =Modulus of Elasticity in N/mm^2
f_{fs} =Flexural strength (for CFRP beam) in N/mm^2
FL =Fiber length in mm
F =Fiber volume fraction in %
Fly =CFRP strip in layers
Fw =Width of CFRP strip in mm

Table 4: Hardened properties of HSC using carbon fiber.

Length of Carbon Fiber (mm)	% of CF	Compressive Strength (N/mm^2)	Split Tensile Strength (N/mm^2)	Flexural strength (N/mm^2)	Modulus of elasticity (N/mm^2)
10	0	61.49	7.08	5.12	37722
	0.10	61.64	7.22	5.24	37903
	0.20	61.79	7.32	5.40	38098
	0.30	62.08	7.50	5.56	38256
	0.40	62.23	7.60	5.70	38510
	0.50	62.68	7.79	5.87	38617
	0.60	62.82	7.88	6.06	38905
20	0	61.49	7.08	5.12	37722
	0.10	61.79	7.27	5.34	38120
	0.20	61.93	7.41	5.52	38311
	0.30	62.23	7.60	5.71	38709
	0.40	62.53	7.74	5.85	38952
	0.50	63.12	7.88	6.04	39400
	0.60	63.27	8.03	6.24	39932
30	0	61.49	7.08	5.12	37722
	0.10	61.93	7.36	5.40	38406
	0.20	62.68	7.55	5.62	38792
	0.30	63.12	7.74	5.82	39433
	0.40	63.56	7.88	5.96	39800
	0.50	64.15	7.93	6.23	40413
	0.60	64.45	8.12	6.44	41230

Table 5: Flexural strength test results (for CFRP beam)

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Fiber content in layers	Flexural strength (N/mm²)			
	Width of CFRP strip (mm)			
	20	40	60	80
0	5.12	5.12	5.12	5.12
1	5.54	5.79	6.06	6.54
2	5.94	6.63	7.07	8.06
3	6.42	7.34	8.07	9.42

Table 6: Load deflection response test results

% of CF	Deflection (mm)		
	Length of CF (mm)		
	10	20	30
0	1.55	1.55	1.55
0.10	1.67	1.70	1.77
0.20	1.80	1.92	2.09
0.30	1.95	2.10	2.32
0.40	2.10	2.29	2.60
0.50	2.19	2.44	2.89
0.60	2.37	2.64	3.12

Table 7: Load deflection response test results (for CFRP beam)

Fiber content in layers	Deflection (mm)			
	Width of CFRP strip (mm)			
	20	40	60	80
0	1.55	1.55	1.55	1.55
1	1.84	2.14	2.34	2.45
2	2.19	2.65	3.05	3.22
3	2.57	3.17	3.94	4.09

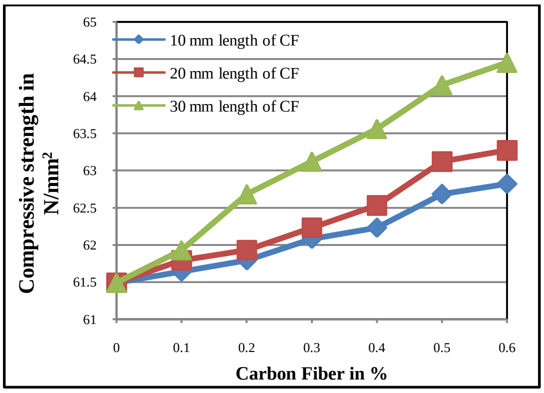

Fig:1. Compressive Strength V/s carbon fiber

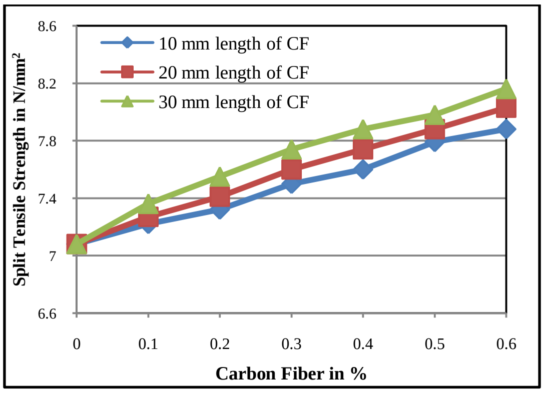

Fig:2. Split Tensile Strength V/s carbon fiber

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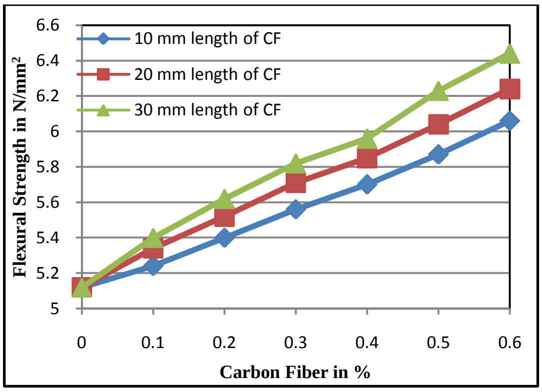

Fig:3. Flexural Strength V/s carbon fiber

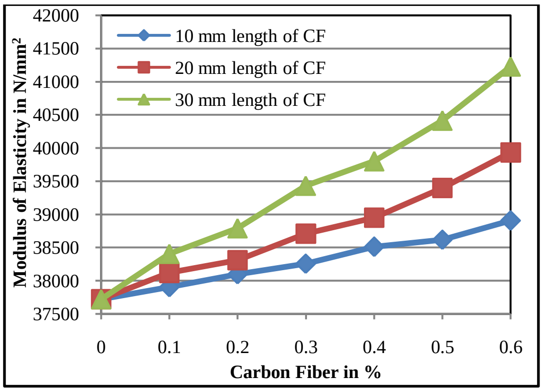

Fig:4. Modulus of ElasticityV/s carbon fiber

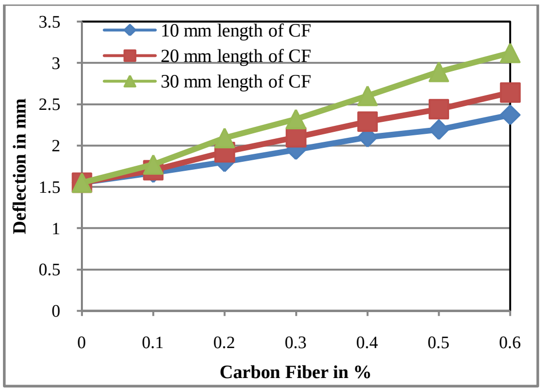

Fig:5. Loaddeflection response

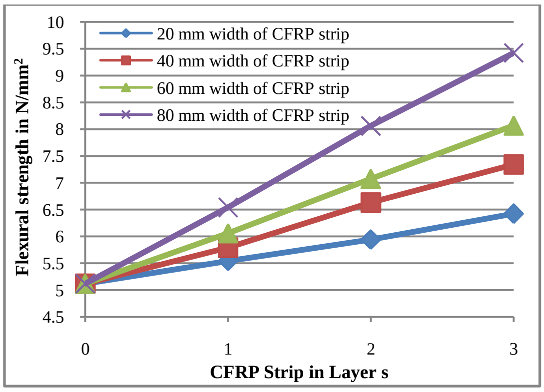

Fig. 6Flexural Strength (for CFRP beam).

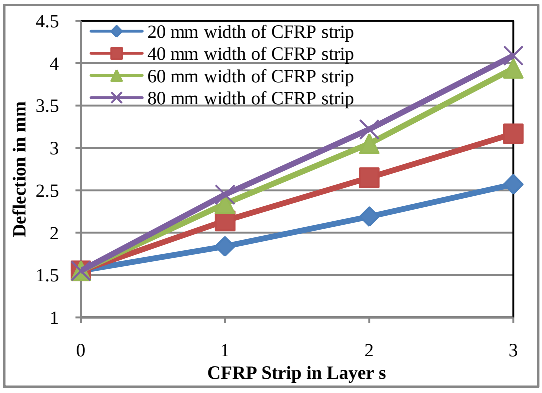

Fig:7. Load deflection response (for CFRP beam).

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IV. CONCLUSION

The addition of carbon fiber as fiber reinforcing material in HSC with 10 percent fly ash show improved mechanical strength properties.High strength concrete with the addition of 80 mm width of CFRP strip exhibited higher increase in flexural strength and deflection than the addition of volume fraction carbon fiber.Regression analysis of mechanical properties indicated that the relationship between predicted strength of concrete is higher than experimental strength of concrete and these proposed equations may be preferred for its simplicity and suitability to analysis.

REFERENCES

[1] Reported by ACI Committee 211, "Guide for Selecting Proportions for High-Strength Concrete with Portland Cement and Fly Ash", ACI 211.4R-93, pp. 1-13, 1998.
[2] Patodi, S. C., and Rarhod, J. D., "Advancement in Fiber Reinforced Cementitious Composites an Overview", Masterbuilder, pp.122-136, 2010.
[3] Omar, Q. A., and Bahman, O. T., "Flexure Behavior of High Strength Concrete Beams Reinforced With Carbon Fiber Reinforced Polymer Rebars With and Without Chopped Carbon Fiber", International Journal of Scientific Research in Knowledge, pp. 123-139, 2013.
[4] Omar, Q. A., and Bahman, O. T., "Mechanical Properties of High Strength Concrete with and without Chopped Carbon Fiber", International Journal of Civil Engineering, Vol. 2, Issue 1, pp. 1-12, 2013.
[5] Banthia N., Bindiganavile V., Jones J., and Novak J., "Fiber Reinforced concrete in Precast Concrete Applications", PCI Journal, pp. 33-46, 2012.
[6] Deborah and Chung, D. L., "Carbon Fiber Reinforced Concrete", Strategic Highway Research Program, National Research CouncilWashington, pp. 1-17, 1992.
[7] Spiegel, M. R., Schiller J., and Srinivasn, R. A.,"Probability and Statistics" McGraw – Hill, Second Edition, 2000.
[8] Zheng and Chung, "Carbon Fiber Reinforced Cement Composites Improved By Using Chemical Agents", Cement and Concrete Research, Vol. 19, pp. 25-41, 1988.
[9] Chen and Chung, "Concrete Reinforced With up to 0.2 Vol% of Short Carbon Fibers", Journal of Composites, vol. 24, No. 1, pp. 33-52, 1992.
[10] Chung,D. D. L., "Cement Reinforced With Short Carbon Fibers: a Multifunctional Material", Journal of Composites, Part B 31, pp. 511-526. 1999.
[11] Victor, C. Li., "Large Volume, "High Performance Applications of Fibers in Civil Engineering", Journal of Applied Polymer Science, Vol. 83, pp. 660–686, 2002.
[12] Ramana, V.P.V., Kant, Morton, S.E., Dutta, P.K., Mukherjee and Desai,Y.M., "Behavior of CFRPC strengthened reinforced concrete beams with varying degrees of strengthening", pp. 461-470, 2000.
[13] Newhook, Ghali, ASCE,F., Tadros, and ASCE,M., "Cracking and Deformability of Concrete Flexural Sections with Fiber Reinforced Polymer", Journal of Structural Engineering, pp. 1195-1201, 2002.
[14] Hacha, R. E., andRizkalla, S. H., "Near-Surface-Mounted Fiber-Reinforced Polymer Reinforcements for Flexural Strengthening of Concrete Structures", ACI Structural Journal, pp. 717-726, 2004.
[15] Chung,D. D. L., "Dispersion of Short Fibers in Cement",Journal of Materials in Civil Engineering, pp. 379-383, 2005.
[16] Ohu, R. B., Jaafar,M. S.,Aznieta, F. N., and Alwathaf,A. H., "Performance of Concrete Beams Reinforced with Embedded CFRP Plates", the Indian Concrete Journal, pp. 7-13, 2012.
[17] IS 516:1959, Methods of tests for strength of concrete, BIS, New Delhi.
[18] IS 5816:1999, Splitting tensile strength of concrete- method of Test, BIS, New Delhi.