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Effect of Randomly Distributed Glass Fiber Reinforcement on Strength Parameters of Concrete

[1]Dr. G.C.Behera, [2]Satabdi Swapna Behera

[1]Associate Professor, Civil Engineering Department,
Government College of Engineering, Kalahandi-766002
[2]M.Tech Student, IGIT Saranga, Dhenkanal, Odisha

Abstract:

Glass fibers provide better crack arresting properties both in micro and macro cracking stage due to their high tensile strength for which they are added in different volume fraction in concrete. The finely divided fibers can be easily dispersed in concrete matrix in large volume fraction. Here an attempt has been made to find out optimum dosage of fiber amount to for compressive strength of M25 grade of concrete. The present investigation is carried out with different volume fraction of fiber ranging from 0.1% to 0.5 % with interval of 0.1% added in M25 grade concrete. Compressive strength, split tensile strength and flexural strength with different fiber content concrete were found experimentally. Addition of fibers decreases the workability of the concrete. The strength was found to be increased with addition of fiber which proves the advantages addition of fiber to concrete. Maximum strength was noticed at 0.3 % fiber addition. The strength was found to be decreased after 0.3% and strength was found to be more than the strength of concrete with fiber on higher volume fraction of fiber content (i.e. 0.4% and 0.5%). The increase in the compressive strength, split tensile strength and flexural strength are around 22.85%, 13% and 20.62% respectively over normal concrete. Split tensile strength and flexural strength of fiber added concrete were estimated by different code values and from earlier researchers. The split tensile strength predicted by Huste and flexural strength predicted by CRRI are in well agreement with experimental results.

Keywords: Strength and testing of materials; fiber; Workability; Compressive strength; Flexural strength; Split tensile strength.

1.0 INTRODUCTION

Concrete is one of the most conventionally consumed construction material. It has several advantages such as; durability, formability and desired mechanical strength which gives it an edge over the other conventional building materials. But it has some disadvantages such as; low tensile strength and strain capacity. Concrete technology had undergone a major evolution in the last four decades and it is virtually possible to manufacture job application oriented concrete mixes with normal construction material. High strength concrete and ultra-high strength concrete are some examples of such tailored concrete which exhibit extremely higher strength at early ages but also exhibit unusual brittleness. Usually fibers are included in the cement matrix to improve the mechanical and fracture properties and several researchers have investigated the effects of fiber inclusion in cement matrix depended on the fiber content and type.

Insertion of fiber in matrix impacts significantly on the strength parameters as well as the workability of concrete. Several studies have displayed that the fibers can considerably increase the engineering properties of concrete such as the tensile strength, flexural strength, fatigue, deformation capability, toughness and load bearing capacity after cracking.

Conversely, the effect of fiber inclusion on the compressive strength of concrete is still under examination as some researchers observed an increase in the compressive strength with fiber inclusion where as some reported a decrease in the compressive strength. There are different types of fibers which have been used as reinforcing elements in cement matrix like asbestos, cellulose, steel, polypropylene, PVA, carbon, basalt, aramid, polyethylene, glass etc.

1.1 Glass Fiber

Glass fiber is a material comprising a lot of immensely fine fibers of glass. It has roughly comparable mechanical properties to other fibers such as polymers and carbon fiber. Although not as strong or rigid as carbon fiber, it is much cheaper and significantly less brittle when used in composites. Glass fiber reinforced concrete (GFRC) is a cementitious composite product reinforced with discrete glass fibers of varying lengths and sizes.

The glass fiber used is alkaline resistant as glass fibers are susceptible to alkali which decreases the durability of GFRC. Glass strands are utilized for the most part for outside claddings, veneer plates and different components where their reinforcing impacts are required during construction. GFRC is stiff in fresh state and has lower slump and hence less workable, therefore water reducing admixtures are used. Further the properties of GFRC depend on various parameters like method of producing the product.

Glass fiber is formed when thin strands of silica-based or other formulation glass are extruded into many fibers with small diameters suitable for textile processing. The technique of heating and drawing glass into fine fibers has been known for millennia; however, the use of these fibers for textile applications is more recent.

2.0 LITERATURE REVIEW

Glass fiber is a material consisting of numerous extremely fine fibers of glass. It is a light weight, extremely strong and robust material. Glass fibers are relatively less stiff and made from relatively less expensive material as compared to carbon fibers. It is less brittle and also has lower strength than carbon fibers.

Glass fiber has roughly comparable mechanical properties to other fibers such as polymers and carbon fiber. Although not as strong or as rigid as carbon fiber, it is much cheaper and significantly less brittle when used in composites. For that reason glass fibers are used as reinforcement for many polymer products to form a very strong and relatively lightweight fiber-reinforced polymer (FRP) composite material. This material contains a little or no air.

Patil and Shinde [1] conducted studies on GFRC and reported 20-25% increase in compressive strength and 15-20% increase in flexural and splitting tensile strength. The compressive toughness index, flexural toughness and shear toughness of ceramic concrete showed a considerable increase with an increase in the fiber content which was true regardless of the type of matrix or length of the fiber. Deshmokh and Bhusari [2] studied that concrete is a tension weak building material which is often crack ridden connected to plastic and hardened state, drying shrinkage and the like. Moreover concrete suffers from low tensile strength limited ductility and little resistance to cracking which can somehow be prevented by adding glass fiber to concrete mix. Rao and Seshadri [3] conducted durability studies on glass fiber reinforced concrete. The alkali resistant glass fibers were used to find out workability, resistance of concrete due to acids, sulphate and rapid chloride permeability test of M30, M40 and M50 grade of glass fiber reinforced concrete and ordinary concrete. The durability of concrete was increased by adding alkali resistant glass fibers in the concrete. The experimental study showed that addition of glass fibers in concrete gives a reduction in bleeding. The addition of glass fibers had shown improvement in the resistance of concrete to the acid attacks. Kene et al. [4] conducted experimental study on behavior of steel and glass Fiber Reinforced Concrete Composites. The study conducted on Fiber Reinforced concrete with alkali resistant glass fibers of 0% and 0.5% volume fraction and steel fibers containing 0% and 25% by weight of cement of 12 mm cut length and the results are compared. Selin et al. [5] studied that there has been a significant increase in the use of glass fibers in concrete for improving its properties such as; tensile strength and durability. The fiber concrete is also used in retrofitting existing concrete structure. Among many different types of fiber available today, glass fiber is a recent introduction in the field of concrete technology.

Jadav et al. [6] studied the performance of Glass Fiber Reinforced Concrete. The study revealed that the use of glass fiber in concrete not only improves the properties of concrete and a small cost cutting but also provide easy outlet to dispose the glass as environmental waste from the industry. From the study it could be revealed that the flexural strength of the beam with 1.5% glass fiber shows almost 30% increase in the strength. The reduction in slump observed with the increase in glass fiber content. Subramani and Mumtaj [7] reported the behavior of glass fiber in concrete. In this study sand has been replaced with glass fiber by 5%, 10% and 15% to produce concrete of high tensile strength as compared to traditional concrete. Kumari et al. [8] studied behavior of concrete beams reinforced with glass fiber reinforced polymer flats and observed that beams with silica coated Glass fiber reinforced polymer (GFRP) flats shear reinforcement have shown failure at higher loads. Further they observed that GFRP flats as shear reinforcement exhibit fairly good ductility. The strength of the composites, flats or bars depends upon the fiber orientation and fiber to matrix ratio while higher the fiber content higher the tensile strength. Alsayad et al. [9] studied the performance of glass fiber reinforced plastic bars as reinforcing material for concrete structures. The study revealed that the flexural capacity of concrete beams reinforced by GFRP bars can be accurately estimated using review on the Performance of Glass Fiber Reinforced Concrete the ultimate design theory. The study also revealed that as GFRP bars have low modulus of elasticity, deflection criteria may control the design of intermediate and long beams reinforced with FRP bars. Gornale and Quadri [10] studied the strength aspect of glass fiber reinforced concrete. The study had revealed that the increase in compressive strength, flexural strength, splitting tensile strength for M20, M30 and M40 grade of concrete at 3, 7 and 28 days were observed to be 20% to 30%, 25% to 30% and 25% to 30% respectively after the addition of glass fibers as compared to the plain concrete. Tassew and Lubell [11] also conducted a test to establish the influence of chopped glass fibers on the mechanical and rheological properties of ceramic concrete produced using a phosphate cement binder. They found that the flexural strength of ceramic concrete increased with increase in the glass fiber volume fraction irrespective of the mix composition or fiber length. Hanuma and Rao [12] However, the addition of higher volume of fibres leads to practical problems such as bundling, balling and reduction in workability, hence, researchers have observed reduction in strength and toughness.

2.1 Summary

An extensive study of literature suggests that glass fibres may enhance the toughness, flexural strength, tensile strength, impact strength, fatigue performance as well as the failure mode of the concrete when compared to plain concrete. The fire resistance of glass fibre reinforced concrete is also good.

3.0 SCOPE AND OBJECTIVE OF THE PRESENT STUDY

The main objectives of the present investigation are stated below.

- To study the effect of glass fiber reinforcement by adding varying percentage by volume of concrete on compressive strength, flexural strength and split tensile strength of concrete..
- To study the effect of glass fiber reinforcement on workability of concrete.
- To compare the results of Glass Fiber Reinforced Concrete (GFRC) with traditional concrete.

4.0 EXPERIMENTAL PROGRAM

To study the effect of glass fiber on strength properties of concrete an experimental program was taken up with addition of different percentages of fibers in concrete.

4.1 Materials:

Concrete is the most widely used construction material. The basic materials of concrete are cement, water, fine aggregates i.e. sand and coarse aggregates. The cement and water form a paste that hardens and bonds the aggregates together. Concrete in fresh state is plastic and can be easily moulded to any shape, as time passes it hardens and gains strength. The initial gain in strength is due to a chemical reaction between water and C2S and later gain in strength is due to reaction between C3S and water. Concrete is produced by either following nominal mix proportions in which the mix proportions are fixed as per grade of concrete required or mix design proportions, later produces more economical concrete. In the present study the materials used for the experimental program are described briefly in the following sections.

4.1.1 *Cement*

In the present work Portland pozzolana cement (PPC) 43 grade Ultra-tech cement was used. Standard consistency, initial setting time, final setting time, soundness test, fineness tests were carried out as per the Indian standard specifications and results are shown in Table-1.

Table 1: Physical Properties of cement

S.N	TEST PERTICULARS	RESULTSS
1	Specific Gravity	3.12
2	Standard Consistency	34%
3	Initial setting Time	45 minutes
4	Final setting Time	360 minutes
5	Soundness	1 mm expansion
6	Fineness	2.3%

4.1.2 *Fine Aggregate*

In the present work locally available (Brahmani river, Sarang ghat, Dhenkanal) sand is used and the physical properties were determined as per Indian Standard specification IS-383 [12]. The detailed sieve analysis results and physical properties are shown in Table-2 and Table-3 respectively.

Table- 2: Sieve Analysis of Fine Aggregate

IS Sieve Size (in mm)	Weight retained (in gram)	Percentage weight retained	Cumulative percentage retained	Cumulative percentage passing
10	0	0	0	100
4.75	24	2.4	2.4	97.6
2.36	113	11.3	13.7	86.3
1.18	157	15.7	29.4	70.6
0.6	231	23.1	52.5	47.5
0.3	289	28.9	81.4	18.9
0.15	168	16.8	98.2	2.1
Pan	18	1.8	100	0

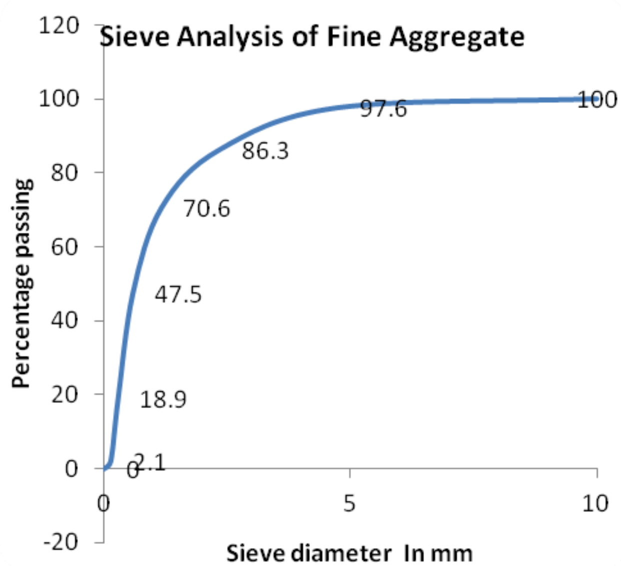

Figure-1: Sieve Analysis of Fine Aggregate

Table -3: Physical Properties of Fine Aggregate

S.N	Test Particulars	Results Obtained
1	Specific Gravity	2.63
2	Bulk Density	1808 Kg/m^3
3	Water Absorption	0,29%
4	Fineness Modulus	2.68
5	Sieve Analysis	Zone-III
6	Moisture Content	Nil

4.1.3 Coarse Aggregate

The coarse aggregates conforming to IS- 3883[13] were used in this investigation.

Table-4: Sieve Analysis of Coarse Aggregate

IS Sieve Size (mm)	Weight retained(Kg)	Percentage of weight retained	Cumulative Percentage of weight retained	Cumulative percentage of weight passing
40	-			100
20	3.996	39.96	39.96	60.04
10	5.643	56.43	96.39	3.61
4.75	0.361	3.61	100	0
Pan	-			

Table.5 Physical Properties of Coarse Aggregate

Sl. No	Test Particulars	Results Obtained
1	Shape	Angular
2	Specific gravity	2.78
3	Water Absorption	0.19 %
4	Moisture Content	Nil
5	Bulk density	1685 Kg/m^3
6	Size	10 to 20mm
7	Crushing value	24.94%
8	Impact Value	13.56 %

4.1.4 Water

Generally cement requires about three-tenth of its weight of water for hydration. Hence the minimum water-cement ratio required is 0.30. But the concrete containing water in this proportion is very harsh and difficult to place. Additional water is required to lubricate the mix, which makes the concrete workable. This additional water must be kept to minimum, since too much water reduces the strength of concrete. As per the recommendation of IS 456-2000 [14]. The pH of water shall not be less than 6. In the present work portable drinking water is used for the experimental study.

4.1.5 Admixture

In this investigation a water reducing admixture is used to obtain the desired workability as with increase in fiber content the mixture was becoming stiffer. A water reducing admixture named Sikament was used for the experimental program.

Table..6 Physical Properties of Sikament Admixture

Sl. No.	Test Particulars	Values
1	Specific Gravity	1 at 25^0C
2	Relative Density	1.21 Kg/l at 25^0c
3	pH- Value	≥ 6
4	Consumption Dosage	0.5 to 2% by wt. of cement

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4.1.6 Glass Fiber

Glass fibers are useful thermal insulators because of their high ratio of surface area to weight. The increased surface area makes them much more susceptible to chemical attack. By trapping air within them, blocks of glass fiber make good thermal insulation, with a thermal conductivity of the order of 0.05 W/(m·K). In this study AR-glass fibers are used and its physical properties are shown in Table 3.6.

Fig.2 Alkali Resistant Glass fiber

` **Table-7 Physical Properties of AR-Glass Fiber** .

S.N	PROPERTIES	VALUES
1	Specific Gravity	2.68
2	Elastic Modulus	72 GPa
3	Tensile Strength	1700 MPa
4	Diameter	14 Micron
5	Length	12 mm
6	No. of fibers	235 million /kg

4.2 Design Mix

In the first phase a conventional concrete of M-25 Grade with proportion 1:1.59:3.12 with w/c ratio 0.45 has been designed according to IS-10262-19882 [15] and its compressive strength, flexural strength and splitting tensile strength are determined at 7 days and 28 days curing period. In the 2nd phase glass fiber reinforcements of different proportion i.e. 0.1%, 0.2%, 0.3%,0.4 % and 0.5% were added by volume of concrete and its compressive strength, flexural strength and splitting tensile strength were determined at 7 days and 28 days. The results were compared with the conventional concrete

4.3 Preparation of Concrete Mould

The concrete mould is cleaned properly and the screws are tightened properly to make sure that no slurry will escape through the joint. After tightening the mould are oiled properly for easy striping of the specimen. The apparatus for testing for the fresh concrete is also oiled properly.

4.4 Mixing of Material

Materials were batched properly before casting and mixed thoroughly in the mixture machine. From the mixture machine, concrete was transferred to an iron trey and again mixed thoroughly manually.

4.5 Tests on Fresh Concrete

The workability test is conducted on fresh concrete just after completion of mixing process. The slump values are presented in Table-8.

4.6 Preparation of Samples

In this process concrete are placed in moulds such as; cube (150 mm X 150 mm X 150 mm), cylinders (150 mm X 300 mm) and prisms (500 mm X 100mm X 100mm) prepared for various tests. Proper care should be taken to remove the entrapped air by using vibrator. The concrete specimen with proper compaction attains maximum strength.

4.7 Curing

The fresh concrete is left to set for 24 hours. Then the concrete specimen is marked with permanent marker. Specimens are removed from the moulds. During the period of striping proper care should be taken to prevent the crushing of concrete on edges. Then the specimens were kept in the curing tank.

4.8 Tests on Hardened Concrete

To determine the properties of the hardened concrete; compressive test, split tensile test and flexural tests were conducted on the samples. The values are presented in Table-8.

Table-8 Experimental Results

SAMPLE	FIBER CONTENT (% of Total Volume)	SLUMP VALUE	COMPRESSIVE STRENGTH (N/mm^2)		SPLIT TENSILE STRENGTH (N/mm^2)		FLEXURAL STRENGTH (N/mm^2)	
			7 Days	28 Days	7 Days	28 ays	7 Days	28 Days
M-0	0.0	83	22.24	31.25	2.87	3.23	2.92	3.25
M-1	0.1	75	22.96	33.72	3.01	3.38	3.17	3.58
M-2	0.2	69	24.42	35.46	3.05	3.47	3.33	3.75
M-3	0.3	62	26.45	38.39	3.29	3.65	3.42	3.92
M-4	0.4	53	23.11	32.19	2.73	3.10	3.00	3.42
M-5	0.5	45	22.38	31.39	2.64	3.05	2.83	3.25

5.0 INTERPRETATION OF TEST RESULTS

The various strength parameters obtained from the experimental study were analyzed in this section and compared with theoretical calculations using different codes and formulas.

5.1 Slump

The slump values of different mixes were presented in the Table-8. It is observed that the workability of concrete decreases as the amount of glass fibers added to the concrete increases. From the Fig.3, it can be seen that the value of slump is 83 when no glass fiber is added to the concrete which means the workability is very good initially. When fiber content was increased, it is found the value decreases and with fiber content 0.5%, the value decreases to 0.45.This may be due to bonding of fibers with aggregates of concrete.

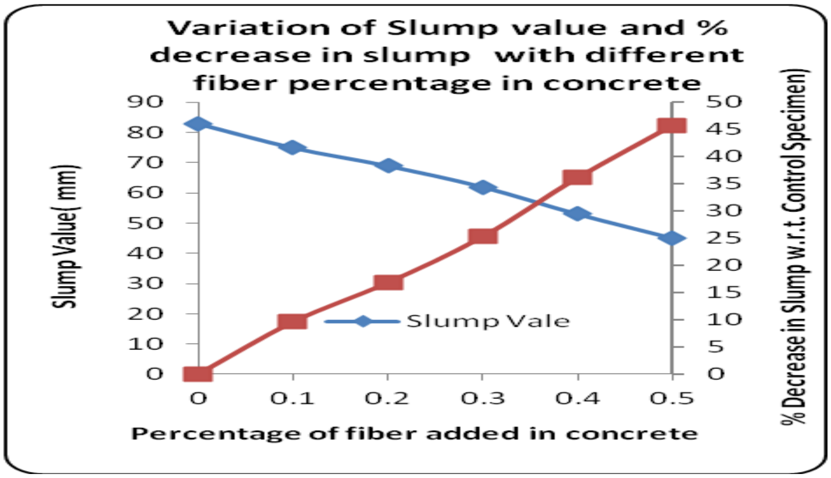

Fig.3 Variaton of Slump and decrease in slump w.r.t. Control specimen with different percentage of fiber content

5.2 Compressive Strength

Compressive strength of specimens at 7 days and 28 days with different fiber content were presented in Table. 8 and Fig.3.Compressive strength was found to be increasing with increase in fiber content up to 0.3% and then the strength is found to be decreasing. The 7 days compressive strength is increasing 3.24%, 9.8%, 18.93 %, 3.91% and 0.63 % with respect to the control specimens (MIX-0) for MIX-1, MIX-2, MIX-3, MIX-4 and MIX-5 respectively. The same is found to be increasing 7.9 %, 13.47 %, 22.85 %, 3.01% and 0.45 % with respect to the control specimen (MIX-0) for MIX-1, MIX-2, MIX-3, MIX-4 and MIX-5 respectively for 28 days compressive strength.

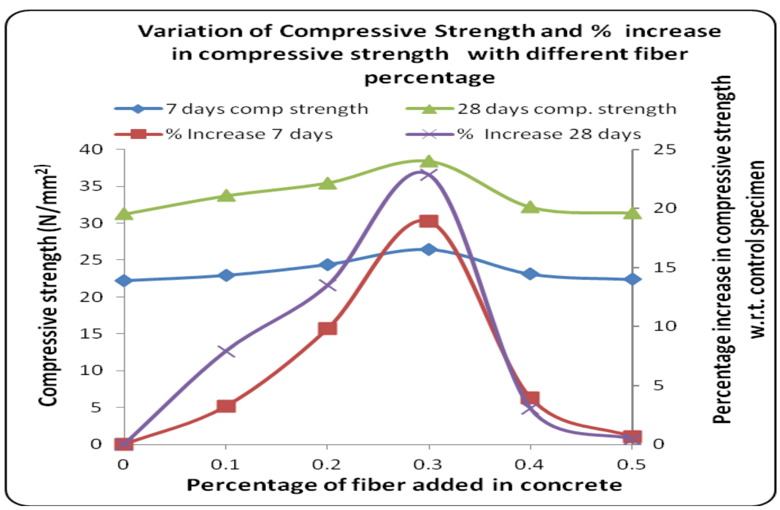

Fig.4 Variation of Slump and decrease in slump w.r.t. Control specimen with different percentage of fiber content

It is observed that that the strength is increasing with increase in fiber content as the fibers are capable of resisting the formation of crack at micro level and enhance the strength at pre-cracking stage. When volume fraction of fiber increases, there is reduction in strength.This may be due to higher the volume of fibres, higher will be the strength and toughness of the composite. However, the addition of higher volume of fibres leads to practical problems such as bundling, balling and reduction in workability, hence, researchers have observed reduction in strength and toughness.

5.3 Split tensile strength

The 7 days and 28 days split tensile strength of different specimens were presented in Table. 8. 7 days and 28 days split tensile strength along with predicted values by different researchers Rasid and Mansur [16], Mansur and Islam [17], Gambhir [18] are presented in Fig.5. Increase in compressive strength was plotted in Fig.6. There is maximum increase in 0.3% addition of fiber. For addition of 0.3 % fiber, the value is found to be increasing by 14.63% for 7 days strength w.r.t. control specimen. The same is found to be increasing by 13 % for 28 days strength. Beyond 0.3 % fiber, strength of concrete is found to be decreasing. The split tensile strength is found to be decreases by 8.01 % and 5.57 % w.r.t. control specimen for 7 days and 28 days respectively. This may be due to large volume of fibers assembled in one zone.

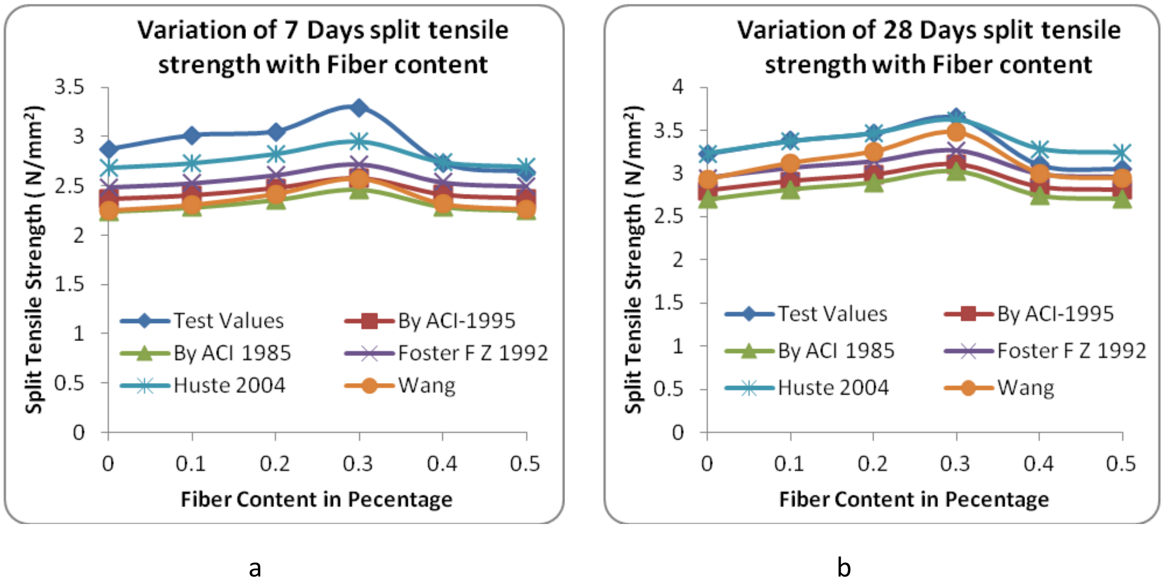

Fig. 5 Split tensile strength of different fiber contents at 7 days and 28 days along with values predicted by different formulas'

From the above figures and tables, it is clear that the split tensile strength of concrete increases with the increase in curing period. The percentage decrease in split tensile strength is plotted in Fig.7.It is observed from the figure that the split tensile strength is better predicted by Huste. The average decrease in predicted value by Huste is 5.33% for 7 days strength. The same is found to be increasing by 1,77% for 28 days strength.

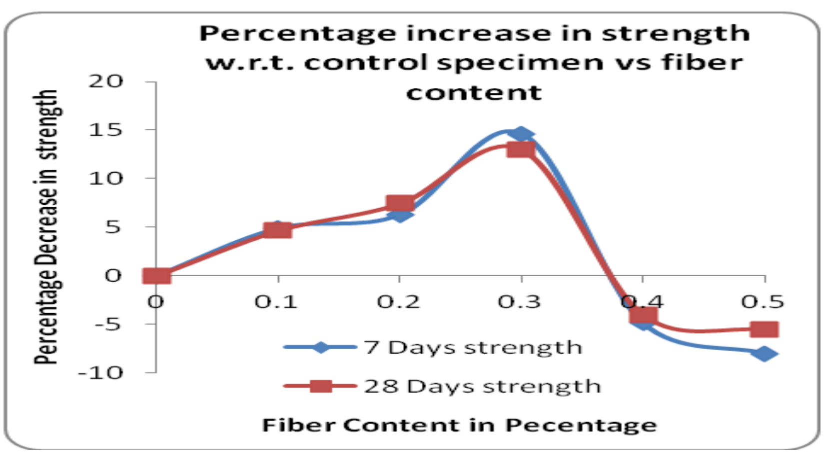

Fig.4 Variaton of Slump and decrease in slump w.r.t. Control specimen with different percentage of fiber content

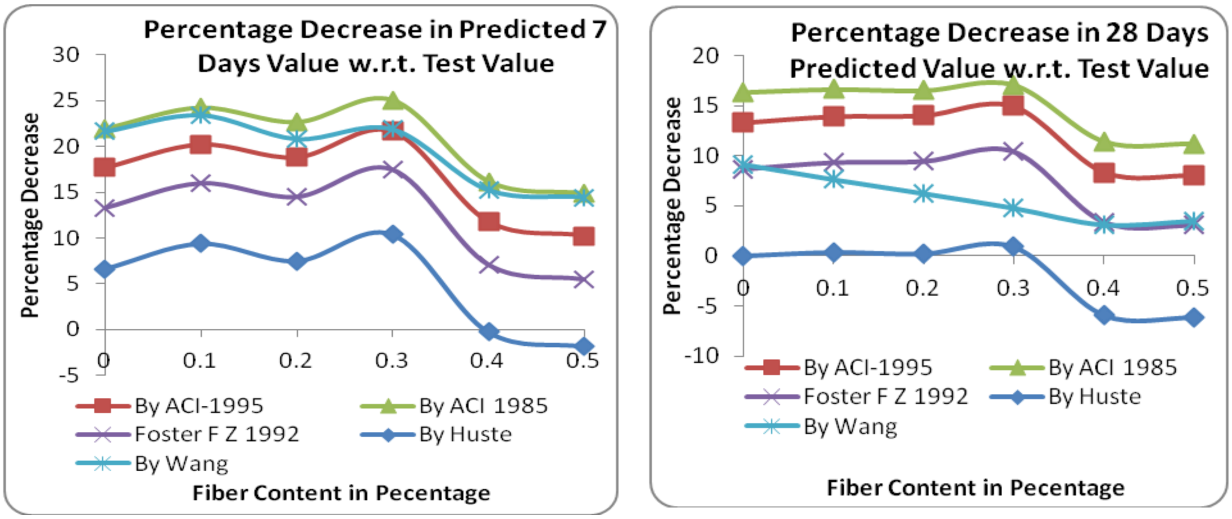

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Fig.7 Percentage of decrease in predicted split tensile strength w.r.t. test value for 7 days and 28 days with different percentage of fiber content

5.4 Flexural Strength

The 7 days and 28 days flexural strength is presented in Fig.8.The strength is found to be increasing with age of curing. The flexural strength is also increasing with addition of fibers up to 0.3% and then the strength is decreasing with respect to 0.3% for higher content of fiber. With addition of 0.5% addition of fiber the value is found to be decreasing than the specimen without fiber (control specimen) as plotted in Fig.9.

With addition of 0.3 % fiber, flexural strength is found to be increasing by 17.17% w.r.t. control specimen for 7 days strength and 20.62% for 28 days strength respectively.

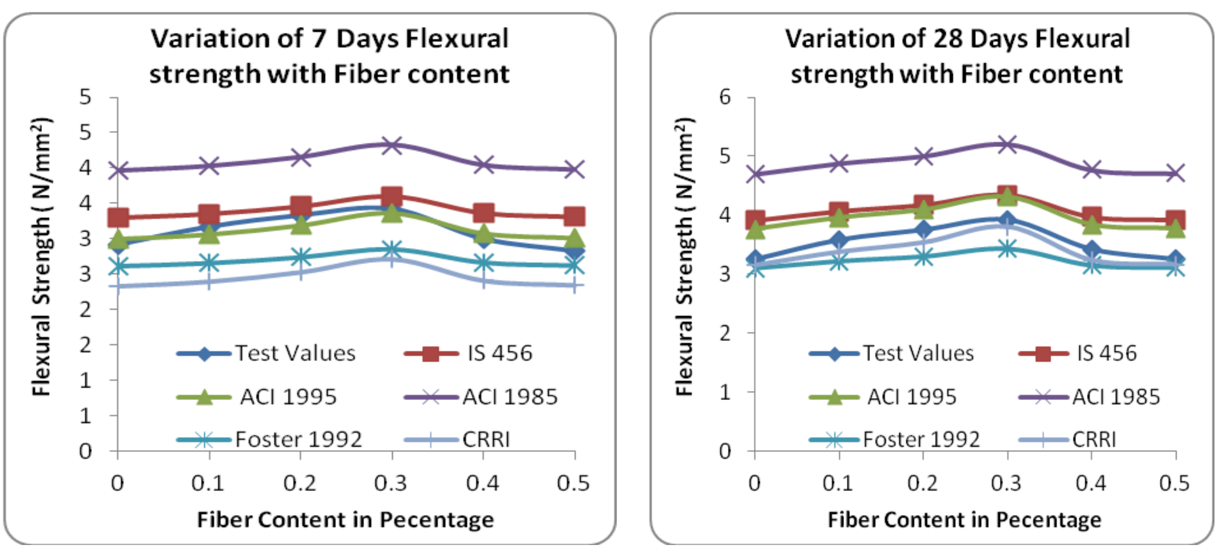

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Fig.8 Variation of flexural strength slump w.r.t. Control specimen with different percentage of fiber content in 7 days and 28 days

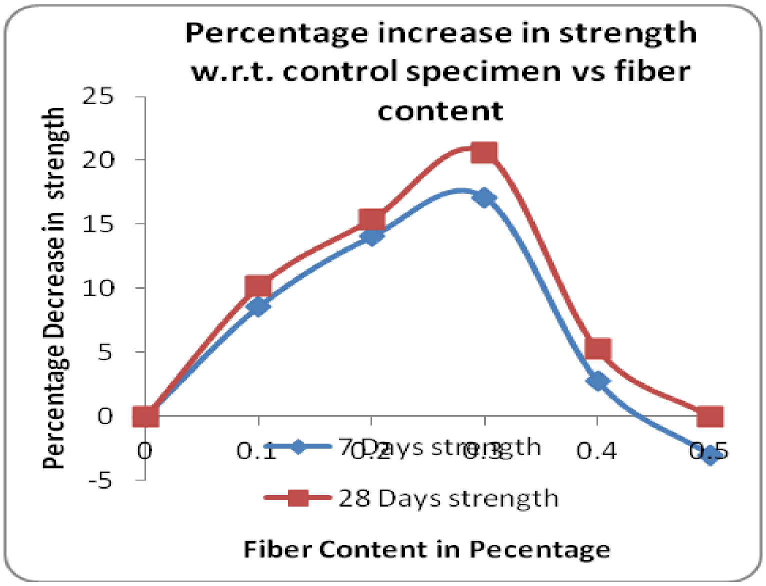

Fig.9 Percentage decrease in Flexural strength w.r.t. Control specimen with different percentage of fiber content in 7 days and 28 days

Percentage increases in predicted values of flexural strength by different researchers along with some codes are plotted in Fig.10. ACI-1995 best predicts the flexural strength for 7 days while CRRI well predicts the 28 days strength. ACI-1995 Behera and Behera [19] predicts maximum increase 6.42% w.r.t. test value for 7 days strength while for 28 days CRRI predicts maximum decrease 5.42% w.r.t. the test value.

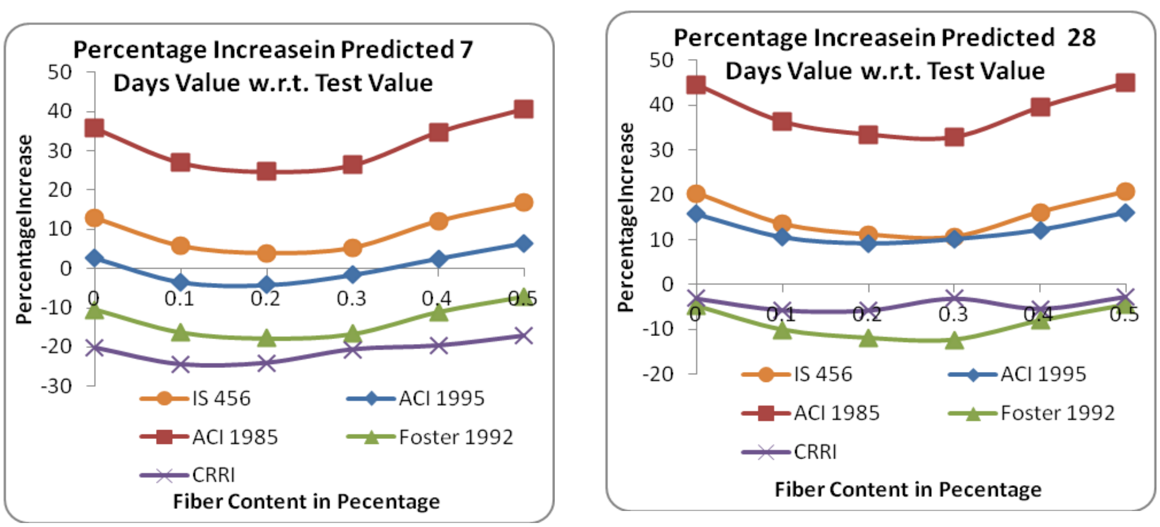

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Fig.10 Percentage of increase in predicted Flexural strength w.r.t. test value for 7 days and 28 days with different percentage of fiber content

6.0 CONCLUSION

From the experimental work and the predicted values of mechanical strength, following conclusions are derived.

- There is a significant change in the compressive strength, flexural strength and split tensile strength of concrete when glass fiber is introduced to it.
- The maximum values of compressive strength, split tensile strength and flexural strength are achieved at 0.3% addition of glass fibers by the volume of concrete.
- The increase in the compressive strength, split tensile strength and flexural strength are around 22.85%, 13% and 20.62% respectively over normal concrete due to the addition of glass fibers at 0.3%.
- The workability of concrete decreases with increase in the amount of glass fibers added to the concrete.
- Beyond 0.3% fiber, the split tensile strength is observed to be less than that of the conventional concrete by 4.02% and 5.27% for 7 days and 28 days strength concrete..

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