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Experimental Study on Mechanical, Flexural and Shear Behaviour of Nylon- Glass Hybrid Fibre Reinforced Concrete Beam

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***Abstract* - Concrete made with Ordinary Portland cement has certain characteristics: it is relatively strong in compression but weak in tension and tends to be breakable. The deficiency in tension can be defeated by the use of conventional rod reinforcement and to some extent by the inclusion of a sufficient volume of certain fibres. Change in the performance of the fibre-matrix composite after it has cracked, is due to the addition of fibres, thereby improving its toughness. There has been an increasing interest in finding new applications for nylon-fibre-reinforced composites that are traditionally used for making ropes, mats, carpets, fish net and others. The purpose of this research is based on the investigation of the use of nylon fibres and glass fibres in structural concrete to enhance the mechanical characteristics of concrete. In this work, the mechanical properties , flexural and shear properties of RC beams were studied by incorporating glass and nylon fibre in various percentage by weight of concrete.**

Keywords: Glass Fibre, Nylon Fibre, Workability, Flexural Strength , Shear Strength.

I. INTRODUCTION

Concrete is a relatively brittle material. To improve its engineering properties, adding fibre materials is the ideal solution. Nowadays, many types of fibres are available, such as steel fibres, carbon fibres, polypropylene fibres, nylon and glass fibres, etc. Adding a single type of fibre into concrete has limited functions, thus many current researches are oriented to the development of hybrid fibre in concrete to obtain better material properties. Fine and highly flexible fibres can control the dry shrinkage and micro-cracks, while the thick and highly stiff fibres are able to sustain the macro-cracks resulting from high stress. Further, these two types of fibres can complement each other and further improve the engineering properties of concrete.

The strength and durability of concrete can be changed by making appropriate changes in its ingredients like cementitious material, aggregate and water and by adding some special ingredients. Hence concrete is very well suited for a wide range of applications. However concrete has some deficiencies as low tensile strength, low post cracking capacity, brittleness and low ductility, limited fatigue life, not capable of accommodating large deformations, low impact strength. The presence of micro cracks at the mortar-aggregate interface is responsible for the inherent weakness of plain concrete. The weakness can be removed by inclusion of fibres in the mix. Different types of fibres, such as those used in traditional composite materials have been introduced into the concrete mixture to increase its toughness, or ability to resist crack growth. The fibres help to transfer loads at the internal micro cracks. Such a concrete is called fibre-reinforced concrete (FRC). Thus fibre-reinforced concrete is a composite material essentially consisting of conventional concrete or mortar reinforced by fine fibres.

A hybrid fibre reinforced concrete is formed from a combination of different types of fibres, which differ in material properties remain bonded together when added in concrete and retain their identities and properties. the hybridisation of fibres provide improved specific and synergistic characteristics not obtained by any of the original fibres acting alone.

The fibres can be imagined as an aggregate with an extreme deviation in shape from the rounded smooth aggregate. The fibres interlock and entangle around aggregate particles and considerably reduce the workability, while the mix becomes more cohesive and less prone to segregation. The fibres are dispersed and distributed randomly in the concrete during mixing and thus improve concrete properties in all directions. Fibres help to improve the post peak ductility performance, pre-crack tensile strength, fatigue strength, impact strength and eliminate temperature and shrinkage cracks. Essentially, fibres act as crack arrester restricting the development of cracks and thus transforming an inherently brittle matrix, i.e. cement concrete with its low tensile and impact resistances, into a strong composite with superior crack resistance, improved ductility and distinctive post-cracking behaviour prior to failure.

The objectives of the present study are:

- To study the workability.
- To study the compressive strength.
- To study the splitting tensile strength.
- To study the flexural strength.
- To study the shear and flexural properties of RC beam.

II. EXPERIMENTAL INVESTIGATION

The aim of the project is to The experimental plan has been designed to generate the ultimate strength and behaviour of hybrid fibre reinforced RC beams under two point loading. so the experimental programme is divided into two groups. first programme is to find the mechanical properties of concrete and second is to find flexural and shear behaviour of RC beams.

A. Materials

Cement: Ordinary Portland cement of 53 grade confirming to IS: 12269-2013 was used. It was tested for its physical properties such as standard consistency test, initial setting time test, final setting time test, specific gravity test as per IS 4031 - 1999.

Aggregate: The size, shape and gradation of the aggregate play an important role in achieving a proper concrete. The flaky and elongated particles will lead to blocking problems in confined zones. The sizes of aggregates will depend upon the size of rebar spacing. The coarse aggregate chosen for concrete was typically angular in shape, well graded, and smaller than maximum size suited for conventional concrete; typical conventional concrete should have a maximum aggregate size of 20mm. Gradation is an important factor in choosing a coarse aggregate. Gap-graded coarse aggregate promotes segregation to a greater degree than the well graded coarse aggregate.

Fine Aggregate: M sand was used as fine aggregate in the present investigation. The sand was free from clayey matter, salt and organic impurities. The sand was tested for various properties like specific gravity, bulk density etc., and in accordance with IS 2386-1963.

Coarse Aggregate: Machine crushed angular metal of 20mm nominal size from the local source was used as coarse aggregate. It was free from impurities such as dust, clay particles and organic matter etc. The physical properties of coarse aggregate were investigated in accordance with IS 2386 -1963.

Glass fibre: Glass fibre is much cheaper and significantly less brittle when used in composites and is therefore used as a reinforcing agent. they also improves toughness, flexural strength etc. fibres were added into the mix 0.2% by weight of concrete.

Fig 1. Glass fibre

Nylon fibre: Nylon fibres increases the resistance to plastic shrinkage during curing and has good impact resistance. Waste nylon fibre from fish net was used for the study.

Fig 2. Nylon fibre

Reinforcing bars: Two numbers of 10mm diameter HYSD bars at the bottom and two numbers of 8mm diameter HYSD bars at top were used as longitudinal reinforcement. two legged stirrups of 6mm diameter bars are provided as shear reinforcement.

Super Plasticizer: Super plasticizer conforming to IS-9103-1979 by trade name Conplast SP 420 was used as a water reducing agent to achieve the required workability.

Water: Generally, water that is suitable for drinking is satisfactory for use in concrete. Water from lakes and streams that contain marine life also usually is suitable. Hence water available in the college water supply system was used for casting as well as curing of the test specimens.

B. Mix Design

The experiment was carried out to investigate strength properties of concrete mixes of grade M30 and the mix proportion were obtained as 1:1.742:2.596. Water cement ratio was 0.45. five mixes were made namely GNFRC, GNFRC1, GNFRC2,GNFRC3 and GNFRC4 to determine the mechanical properties and properties of fresh concrete. GNFRC with 0% fibre is considered as control mix and other four mixes GNFRC1, GNFRC2, GNFRC3, GNFRC4 consists of 0.25%, 0.50%, 0.75% and 1% by weight of concrete respectively. Glass fibre were added at a constant percentage of 0.2% by weight of concrete for all these mix.

TABLE I. QUANTITIES OF INGREDIENTS USED FOR MIX PROPORTIONS

Particulars	Quantity (kg/m3)
Cement	318
Fine aggregate	554
Coarse aggregate	825
Water	197

C. Specimen details

Details of number of specimens are given in Table.

TABLE 2. SPECIMEN DETAILS

Sl. No	Specimen	Property	Size	Numbers
1	Cube	Compressive strength	150x150x150mm	30
2	Cylinder	splitting tensile strength	300mm height and 150mm diameter	15
3	Beam	Flexural strength	500x100x100mm	15
4	Large beam	Flexural and shear behaviour	1200x100x 150	20
Total number of specimens				80

D. Preparation and casting of specimens

For each mix six concrete cubes for compressive strength test, three cylinders for splitting tensile strength test , three beams for flexural strength test were casted . To study the flexural behaviour ten reinforced concrete beams of 1200 x 100 x 150 mm were casted. To study the shear behaviour ten reinforced concrete beams also casted. for each type, two reinforced concrete beams of size 1200 x 100 x 150mm long were casted. the reinforcement details of the beams for flexural and shear are shown in fig. 4 and fig. 5 respectively. concrete was mixed in concrete mixer in the laboratory. all specimens were vibrated with a mechanical vibrator and were stored at temperature of about 23^0C in the casting room. they were demoulded after 24 hours in a water curing tank. after 28 days, large beams were white washed for easy detection of cracks.

TABLE 3. BEAM DETAILS

Sl. No	Glass fibre weight(%)	Nylon Fibre Weight (%)	Flexural behaviour	Shear behaviour
1	0.2	0	GNFB0	GNSB0
2	0.2	0.25	GNFB1	GNSB1
3	0.2	0.50	GNFB2	GNSB2
4	0.2	0.75	GNFB3	GNSB3
5	0.2	1.0	GNFB4	GNSB4

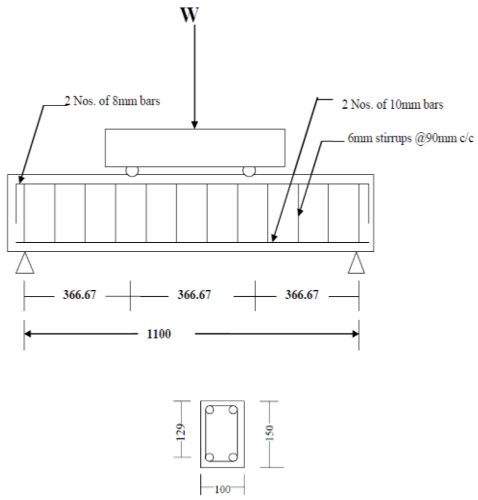

Fig 3. Beam reinforcement details (flexural)

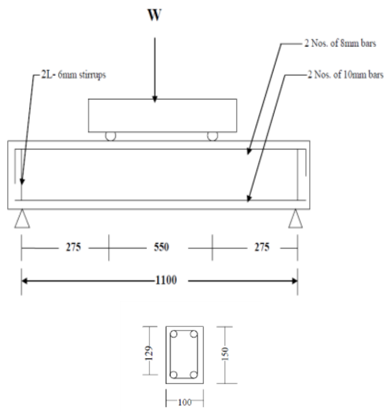

Fig 4. Beam reinforcement details (shear)

E. Testing on specimens

Testing of concrete specimens plays an important role in controlling and confirming the quality of concrete. Thus the experimental investigation carried out was divided into three main headings. They are as follows:

1. Study on workability
- Slump test
- Compacting factor test

2. Study on strength
- Cube compressive strength
- Splitting tensile strength of cylinders
- Flexural strength of beams

3. Study on flexural and shear behaviour of RC beams.

F. Test setup for studying flexural and shear behaviour

A two point flexural bending system was adopted for the tests. Specimens were tested in a loading frame of 2000 kN (200 t) capacity with an effective span of 1100 mm. Load cell of 200 kN capacity with a least count of 1 kN was used to measure the applied load.. The load was increased in stages till the failure of the specimen in the case of monotonic loading and at each stage of loading deflection at mid span was found out using a dial gauge.

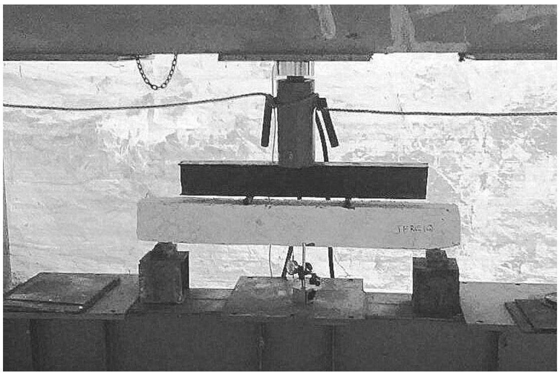

Fig 5. Test set up for RC beams

IV. RESULTS AND DISCUSSIONS

A. Properties of fresh concrete

Studies conducted on fresh properties were given in Table 4. From the results obtained it can be concluded that the slump and compacting factor decreases with the percentage increase in fibres.

TABLE 4. PROPERTIES OF FRESH CONCRETE

Sl. No	Mixes	Workability	
		Slump (mm)	Compacting factor
1	GNFRC	32	0.80
2	GNFRC1	30	0.78
3	GNFRC2	28	0.77
4	GNFRC3	27	0.76
5	GNFRC4	25	0.75

B. Properties of hardened concrete

1. Cube compressive strength: Compressive strength of all concrete mix were determined at 7 and 28 days of curing. From test results it can be concluded that there is an increase in strength with the increase in fibre upto 0.5% by volume of concrete. GNFRC2 was obtained as the optimum mix. Percentage increase in 7th day compressive strength for GNFRC2 is 18% and 28th day compressive strength 15%.

2. Splitting tensile strength of cylinders : Splitting tensile strength is determined at 28 days of curing. From these results , it can be seen that the splitting tensile strength of cylinder of GNFRC2 was higher than GNFRC. Percentage increase in strength of GNFRC2 is 22%.

3. Flexural strength of beams: Flexural strength was determined at 28 days of curing. From these results, it can be seen that the flexural strength of GNFRC2 is higher than GNFRC. Percentage increase in strength of GNFRC is 26%.

C. Flexural behaviour of RC beams

All test beams were designed as under reinforced beams; therefore the tensile steel must have reached its yield strength before failure. For an under reinforced beam failure is characterised by crushing of concrete in compression after yielding of tensile reinforcement.

All the beams were tested under two point loading. As expected flexure cracks initiated in the pure bending zone. As load increases , existing cracks propagated and new cracks developed along the span. The width and spacing of cracks varied along the span. In all, the crack patterns observed were similar to those reported in the literatures.

The cracks at the mid span opened widely near failure. Near peak load, the beam deflected significantly, thus indicating that the tensile steel must have yielded at failure. The final failure of beams occurred when concrete in the compression zone crushed, accompanied by buckling of the compressive steel bars. The failure mode was typical of that of an under reinforced beam. The crack patterns are shown in fig 6.

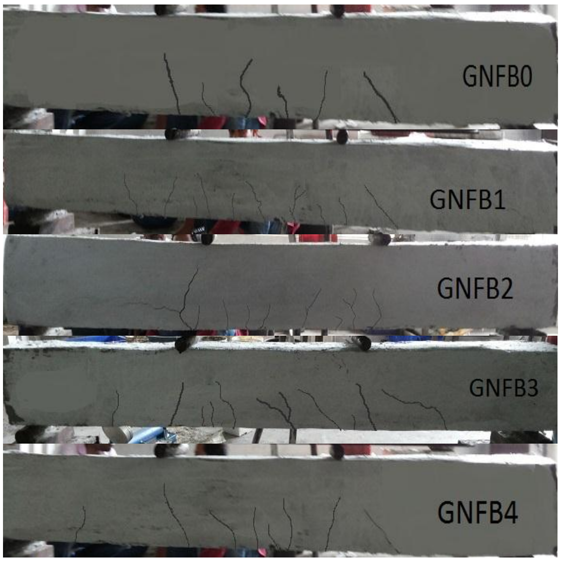

Fig 6. Crack patterns showing flexural failure

1. First crack load and ultimate load: Average values of test results of two specimens for each percentage addition are given in table 5. First crack load was determined from the load deflection plot corresponding to that point on the curve at which the curve deviated from linearity. From the table it can be observed that the first crack load and ultimate load increase with addition of fibres.

TABLE 5.TEST RESULTS FOR FLEXURAL BEAM SPECIMENS

Sl. No	Beam Designation	First Crack Load (kN)	Ultimate Load (kN)	Deflection at Ultimate Load (mm)
1	GNFB0	16	36	6.8
2	GNFB1	18	38	6.9
3	GNFB2	20	42	7.1
4	GNFB3	22	44	7.35
5	GNFB4	24	46	7.54

2. Energy absorption capacity: the amount of energy the material can absorb before failure is called energy absorption capacity. The area under the load deflection curve as shown in fig 8 gives the energy absorption capacity. For flexural members structural ductility is defined as the ratio of ultimate deflection and yield deflection of the tensile reinforcement. Toughness gives the energy absorption capacity of concrete.

TABLE 6. ENERGY ABSORPTION CAPACITY

Sl. No	Beam Designation	Energy absorption (kNm)
1	GNFB0	0.150
2	GNFB1	0.168
3	GNFB2	0.179
4	GNFB3	0.185
5	GNFB4	0.190

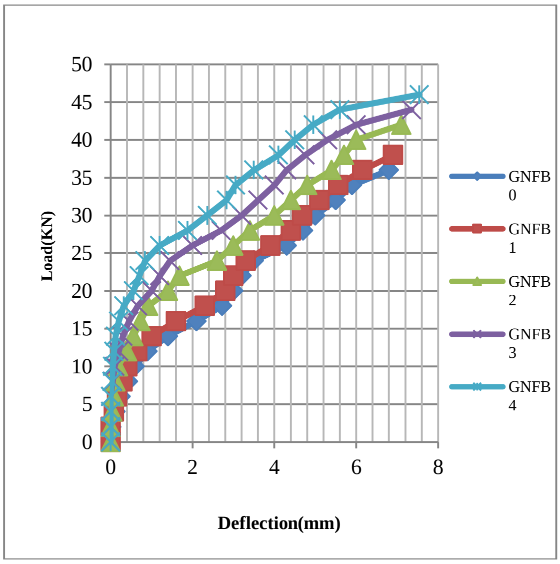

Fig. 8 Comparison of load versus deflection curve for flexural beams

D. Shear behaviour of RC beam

1.load deflection behaviour: all the plots show linear behaviour till the formation of first crack. This is termed as pre cracking stage. After that the slope of the curve decreases. This indicates the formation of multiple cracks and hence reduction in flexural rigidity of beam specimens. In this stage, deflection increases nonlinearly with the load. Beyond this stage plots become more or less flat and the specimen with fibres showed a sudden drop in the load beyond peak load. On the other hand GNSB exhibits more or less flat descending portion, which indicates improvement in ductility due to the fibres and enhancement of stiffening effect of concrete in between cracks in the tension zone. Referring to fig 9, it may be noted that ductility increases significantly for GNSB4 specimen.

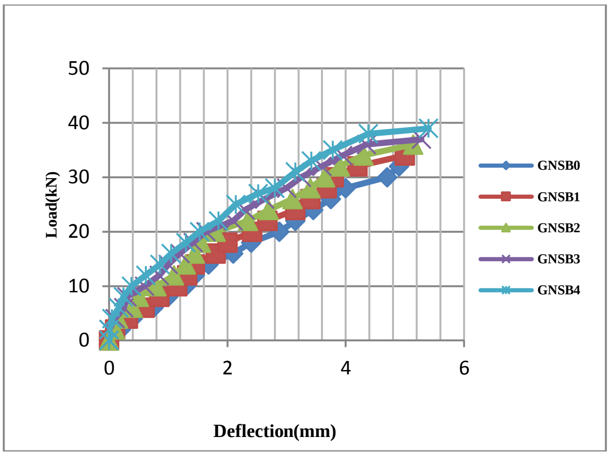

Fig.9 Comparison of load versus deflection for shear beams

2. First crack load and ultimate load: Average values of test results of two specimens for each percentage addition are given in table 7. First crack load was determined from the load deflection plot corresponding to that point on the curve at which the curve deviated from linearity. Referring to table 7, addition of hybrid fibre to beams showed an increase in the first crack load than ordinary beams. This is due to the increase in the tensile strain carrying capacity of concrete in the neighbourhood of fibres. Maximum first crack load was obtained for GNSB4. Ultimate load also increases with the addition of hybrid fibre to the beams when compared to control specimen GNSB0. When fibres added to concrete, they intercept the cracks and this causes deviation of cracks from its initial propagation. This results in the demand of more energy absorption, which in turn increases the load carrying capacity. Maximum ultimate load was obtained in GNSB4 and the percentage increase in ultimate load was 22%.

TABLE 7. TEST RESULTS FOR SHEAR SPECIMENS

Sl. No	Beam Designation	First Crack Load (kN)	Ultimate Load (kN)	Deflection at Ultimate Load (mm)
1	GNSB0	10	32	4.9
2	GNSB1	12	34	5.0
3	GNSB2	13	36	5.14
4	GNSB3	14	37	5.28
5	GNSB4	15	39	5.4

3. *Energy absorption capacity:* The energy absorption capacity could be obtained from the area under the load deflection plot. Due to sudden shear failure, full long deflection plot could not be obtained. Therefore area upto peak load was taken to compare the energy absorption capacities as shown in table 8. The energy absorption capacity is maximum for GNRC4.

TABLE 8. ENERGY ABSORPTION CAPACITY FOR SHEAR SPECIMENS

Sl. No	Beam Designation	Energy absorption (kNm)
1	GNSB0	0.85
2	GNSB1	1.00
3	GNSB2	1.15
4	GNSB3	1.30
5	GNSB4	1.44

4. *Crack patterns and failure mode:* During loading, cracks appeared after the first crack load, in the flexural span. As the load increased further, along with additional flexural cracks, diagonal cracks also developed in the shear span. Further increase of load led to widening of cracks already formed and the diagonal cracks propagated at a faster rate leading to the failure of the specimen. At the ultimate stage most of the cracks traversed up the beam and sudden failure occurred at the shear span and one of the wide diagonal cracks was found to have reached the top face of the beam. The crack patterns are shown in Fig.10.

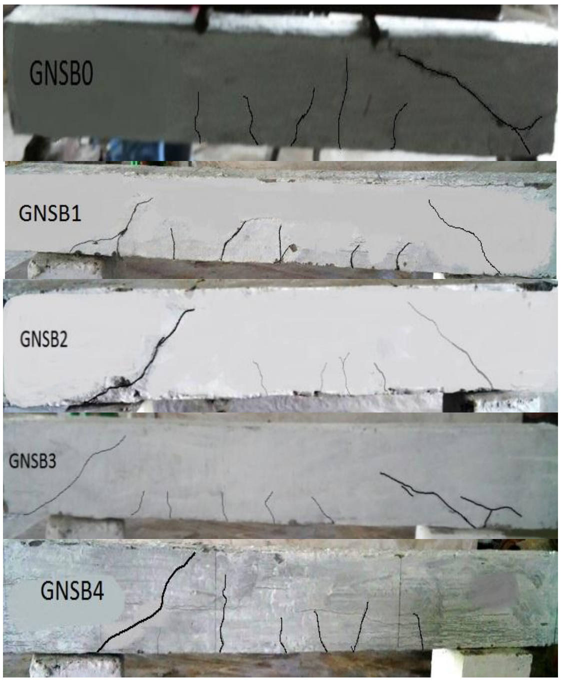

Fig 10. Crack patterns showing shear failure

IV. CONCLUSION

The major conclusion drawn from the study are presented below:

- The workability of hybrid fibre reinforced concrete decreased with the increase in percentage of fibre addition.
- The compressive strength of fibre reinforced concrete with 0.2% glass fibre and 0.5% nylon fibre had high strength than other proportions. Percentage increase in 7th day compressive strength is 18% and 28th day compressive strength is 15%.
- The splitting tensile strength and flexural strength of hybrid fibre reinforced concrete increase upto 0.5% addition of nylon fibre and then decreased.
- The load deflection characteristics of the hybrid fibre reinforced beam specimens were better than control mix. GNFRC specimens with 0.2% glass fibre and 1% nylon fibre showed better performance compared to other mix. Similar behaviour was observed for shear specimen also.
- While the addition of fibres improved the first crack load significantly, the improvement was marginal for ultimate load in case of flexural failure. The first crack load was found to have increased by about 50% at 1.0% weight fraction of nylon fibre when compared to the specimens without fibres. However the increase in ultimate load was found to be only 22%.
- The toughness of reinforced concrete beams, increased as the weight fraction of hybrid fibres increased. Test results showed that the energy absorption capacity increased significantly for beams with addition of nylon fibre 1% by weight of concrete.
- The addition of fibre also improved ultimate load, first crack load in case of shear failure of specimen.
- Crack width and number of cracks were less in case of hybrid fibre reinforced beam.

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