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Experimental Investigation of Mechanical Properties of Hybrid Sisal-Glass Fibre Reinforced Concrete

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Abstract**: The natural fibre (sisal) and artificial fibre (glass) compliments each other in many properties. Hence, using both the fibres in making reinforced concrete is a potential idea to get away with many hardships and disadvantages of traditional methods of making reinforced concrete. It was found that using glass fibre makes concrete susceptible to chemical attack and using sisal fibre reduces the workability of the concrete. In the present research study, the concrete was mixed with sisal fibre at various percentage of 0.5%, 1%, 1.5% and 2% by weight of concrete. The optimum value of sisal fibre to be used as reinforcement in concrete was concluded based on compressive strength at 7 days of curing. This sisal fibre reinforced concrete is then mixed with glass fibre at varying percentage of 0.3%, 0.6% and 0.9% to find the optimum value of glass fibre at which hybrid concrete behaves the best. Results from various tests are shown in this paper and the comparative study with normal concrete was done. It was observed that the optimum percentage for sisal fibre was 0.5% and that of glass fibre was 0.6%. Results with various percentages of sisal and glass are shown in this paper.

I. INTRODUCTION

The primary ingredients of concrete are aggregates mixed with cement. Aggregates may include stones, pebbles, gravels, sand and dust. But alone these ingredients are not sufficient to make the structures long lasting, strong, crack resistant, fire resistent, chemical resistant, tough and shock proof. Inspite of having high compressive strength the normal concrete is low on tensile strength. This is why concrete is reinforced with the material having high tension and chemical admixtures to vary its chemical and physical properties making it chemical, fire, crack and shock resistant. One of such material is fibres. The fibres can be natural and artificial. The artificial fibres like glass, steel, carbon and synthetic polymer can be used to improve textural properties and tensile properties of concrete. The study of steel fibres was initiated in 1963. Using glass fibres make concrete high in tensile strength, increases the thermal insulation, reduces crack formation and increase toughness. The glass has many advantages but it also makes concrete more prone to chemical attack as it increases its surface area to weight ratio. Moreover, glass is an artificial fibre and more and more exploitation of these resources would lead to their extinction for the future generation. The other option yet to be tried technically on a broad scale is the use of natural fibres like sisal, coconut, wood, bamboo and jute. These fibres are abundantly present in nature and hence cannot extinct. Moreover, mixing them with concrete also improves its properties like compressive strength, toughness, crack resistance, chemical resistance and tensile strength. Treating concrete with borax before adding sisal fibre also induces fire resistant property to sisal fibre reinforced concrete. Low cost, biodegradability and easy availability adds to the advantages of natural fibres. Both types of fibres have their advantages as well as disadvantages. It would be good to have reinforced concrete having advantages of both. The shortcomings of artifical fibres can be covered by natural fibre and vice-versa. Both the advantages of natural as well as artificial fibres in concrete could be achieved by mixing both types of fibre in fixed proportion. This paper deals with the study of mixing both fibres in concrete at various propotions.

Sanjay M. R et al.[1], studied the polymer concrete composite mixed with glass and natural fibres. They concluded that natural fibres have many advantages like low cost, low weight, eco-friendly nature, low specific strength, and biodegradability. If natural fibres are mixed with glass fibres in concrete, it may allow us to harness the fruitful advantages of both kinds of fibres. Chandramouli K et al.[2], studied the effect of adding glass fibres of length 12mm and thickness of 14 microns to different grades of concrete as M20, M30. M40 and M50. Adding glass fibres made concrete crack resistant. The compressive strength of concrete increased varying from 20% to 25% and split tensile strength increased by 15% to 20% after 28 days of mixing. Abdul Ruhman et al.[3], studied the effect of adding 4cm long and brushed sisal fibres to M20 and M25 grade of concrete. 0.5%, 1% and 1.5% of fibres by weight of cement were added in M20 and M25 grade of concrete and it was noted that tensile and compressive strength increased by 3.416% and 50.53% respectively with 1.5% addition of fibre in M20 grade mixture. Tensile and compressive strength increased by 3.904% and 52.51% respectively with 1.5% addition of fibre in M25 grade. C.Selin Ravikumar et al.[4], conducted an experiment where they added 45mm long glass fibres to M25 grade of concrete at varying percentage of 0.5% and 1% to check improvement in concrete properties. They concluded that adding 1% of fibre gave better results increasing the concrete properties like flexural, split tensile and compressive strength by 75%, 37% and 35% respectively. Athiappan et al.[5], studied the mechanical properties of concrete after adding the sisal fibre varying from 0.1% to 0.5% by weight of cement. The study was followed by the conclusion that 0.3% of sisal fibre addition gave best results resulting in increase of flexural strength, ductility, stiffness and energy ductility whereas workability and modulus of rupture decreased with increase in percentage of sisal fibre.

II. SCOPE AND OBJECTIVES OF THE STUDY

The objectives of the present study are as follows:

A. To develop fibre reinforced concrete mix using sisal fibre at different percentages and to develop Hybrid fibre reinforced concrete mix incorporating both sisal and glass fibre at constant optimum sisal fibre and glass fibre at different percentages.

B. To check the effect on workability and determine the compressive and tensile strength for both sisal fibre and hybrid fibre reinforced concrete mix at different percentages. To suggest the optimum dosage of sisal and hybrid fibre in concrete mix.

III. EXPERIMENTAL PROGRAMME

A. Constituent Materials

1) Cement : Ordinary Portland Cement (OPC) of grade 43 has been used throughout the experimental investigation. Various tests such as consistency test, and initial and final setting time test were conducted on cement sample to match the BIS code requirement. Various physical properties of cement have been shown in Table 3.1.

Sr. No	Properties	OPC 43 Grade	Requirement as per IS code
1.	Standard Consistency (using Vicat's apparatus)	29	-
2.	Initial Setting Time (min.)	125	>30 min.
3.	Final Setting Time (min.)	355	<600 min.
4.	Specific Gravity	3.15	3- 3.15
5.	Specific Surface Area	2761	>2250
6.	Soundness test (Le-Chatelier apparatus)	0.8	10 (max.)

Table 3.1. Physical Properties of OPC 43 Grade Cement

2) Fine Aggregates : Natural coarse river sand was used as fine aggregate procured from Khuda Ali Sher, Chandigarh from the local contractors. Sieve analysis was done to determine the zone of sand as per IS: 383-1970. Physical properties of sand like specific gravity, silt content and fineness modulus were determined. Various physical properties of fine aggregates are given in Table 3.2

Table 3.2. Physical Properties of Fine Aggregates

Properties	Test Results
Specific Gravity	2.63
Fineness modulus	2.50
Silt content	4.6 %
Grading Zone	Zone III

3) Coarse Aggregates

Crushed aggregates, angular in shape have been used in experimental work. Grading of coarse aggregate was done according to IS: 383-1970 and nominal size was determined. Two different coarse aggregates of nominal size 20 mm single size and 10 mm graded were combined in ratio of 2.5:1 to obtain graded aggregates. Specific gravity and water absorption of coarse aggregates were determined as per IS 2386 (part III) – 1963; Table 3.3 shows the physical properties of coarse aggregates.

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Table 3.3 Physical Properties of Coarse Aggregates

Properties	Test Results
Specific Gravity	2.77
Water absorption of 20 mm Aggregate	0.96 %
Water absorption of 10 mm Aggregate	0.89 %
Grading ratio of 20 mm to 10 mm	2.5:1

4) Sisal Fibre: Sisal fibre used in this study has been extracted from the leaves of the plant i.e. Agave Sisalana. It was procured locally from Gogreen Products limited, Chennai. Sisal fibre is a low cost, environment-friendly, biodegradable, and renewable fibre which could be a good substitute to synthetic fibres. It is easily available in the market and can be handled safely with bare hands. Sisal fibre was added to the concrete mix at a replacement level of 0.5, 1, 1.5 and 2% by weight of cement. Sisal fibre was in lengths of 40-50 cm when procured from Gogreen products. Manually we had to cut it in the size of 30mm which was used for our experimental work. Physical properties of sisal fibre are given below in Table 3.4.

Table 3.4 Physical properties of Sisal Fibre

Properties	Test Results
Tensile Strength (Mpa)	385-728
Elongation at Break (%)	2.75
Diameter (mm)	0.8 -1.2
Density (g/cm3)	1.58
Young’s Modulus (Gpa)	9-22
Moisture	6.55

5) Glass Fibre

The glass fibre used in this study is E- glass fibre, it was procured from Gogreen Products Limited, Chennai. Glass fibre is an artificial fibre and will get depleted within time. Many precautions have to be taken care off while using glass fibre as it cannot be used with bare hands. E-Glass fibre was added to the concrete mix @ of 0.3, 0.6 and 0.9% by weight of cement. E-glass fibre of size 25mm was used for experimental work. Physical properties of E-glass fibre is given below in **Table 3.5.**

Table 3.5 Physical properties of Glass Fibre

Properties	Units	Test Results
Density	Mg/m^3	2.59
Fibre Diameter	inch	0.0053
Tensile Strength	MPa	2010
Young’s Modulus	GPa	81
Strain	%	More than 1.5

* measured by researchers

6) Water : The potable tap water at room temperature conforming to the requirements of water for mixing and curing as per guidelines given in IS: 456-2000 was used.

7) Super Plasticizer: The name of super plasticiser used in the present study is “CONPLAST SP 430G8”

B. Mixture Proportion

Firstly, Reference concrete mix (C) of M 35 grade was designed as per IS 10262: 2009. After this, proportioning for sisal fibre reinforced concrete mixes at 0.5%, 1%, 1.5% and 2% replacement of cement (by weight) with sisal fibre was carried out. Then compressive and split tensile strength test was conducted on this developed sisal fibre reinforced concrete for obtaining optimum percentage of sisal fibre for hybrid concrete. After this, hybrid fibre reinforced concrete (both sisal and glass fibre) were developed by taking fixed sisal fibre percentage (optimum) and glass fibre at 0.3%, 0.6% and 0.9% respectively in each group of HFRC. The

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fine aggregate content and water cement ratio was kept at 605.32 kg/m^3 and 0.38 in all the mix group of sisal and hybrid fibre reinforced concrete. Coarse aggregate content was also same (1259.90 kg/m^3) in all the concrete mix groups.

Table 3.2.1 Mix proportioning for sisal fibre reinforced concrete

Mix Group (Sisal fibre reinforced concrete)	Cement Content (Kg/m^3)	w/c	Water Content (Kg/m^3)	Sisal fibre Replacement (%)	Fine Aggregate (Kg/m^3)	Coarse Aggregate (Kg/m^3)		Super Plasticizer @ 1.2% by weight of cement (Kg/m^3)
				Sisal fibre	River Sand	20 Mm	10 mm	
C	435	0.38	172	0	605.32	899.93	359.7	5.22
$SC_{0.5}$	432.825	0.38	172	0.5	605.32	899.93	359.7	5.22
SC_1	430.65	0.38	172	1	605.32	899.93	359.7	5.22
$SC_{1.5}$	428.475	0.38	172	1.5	605.32	899.93	359.7	5.22
SC_2	426.3	0.38	172	2	605.32	899.93	359.7	5.22

Mix Group	Cement Content (Kg/m^3)	w/c	Water Content (Kg/m^3)	Hybrid fibre Replacement (%)		Fine Aggregate (Kg/m^3)	Coarse Aggregate (Kg/m^3)		Super Plasticizer @ 1.2% by weight of cement (Kg/m^3)
				Sisal fibre	Glass fibre	River Sand	20 mm	10 mm	
C	435	0.38	172	0	0	605.32	899.93	359.7	5.22
$HC_{0.3}$	431.52	0.38	172	2.175	1.305	605.32	899.93	359.7	5.22
$HC_{0.6}$	430.215	0.38	172	2.175	2.61	605.32	899.93	359.7	5.22
$HC_{0.9}$	428.91	0.38	172	2.175	3.195	605.32	899.93	359.7	5.22

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Table 3.2.2 Mix proportioning for hybrid fibre reinforced concrete

Super plasticizer was added at the rate of 1.2 % by weight of cement. The control concrete is denoted by "C", sisal fibre reinforced concrete mix by "SC_X" and hybrid fibre reinforced concrete mix by "HC_X". Where "x" denotes the percentage replacement of cement with sisal in case of "SC_x" and with glass in case of "HC_x".

C. Testing

Consistency of sisal fibre reinforced concrete mix groups having replacement percentage 0.5%, 1%, 1.5% and 2% and hybrid fibre reinforced concrete mix groups having fixed sisal fibre percentage (optimum) and glass fibre at 0.3%, 0.6% and 0.9% were determined in accordance to IS: 1199-1959. Testing for compressive strength of sisal and hybrid fibre reinforced concrete was carried out as per IS: 516-1959. For each mix group of sisal and hybrid fibre reinforced concrete, a set of three cubes of 150×150×150 mm was prepared for testing at 7 and 28 days of curing respectively; this way a total of 42 cubes were cast. The specimens were tested in Compression Testing Machine (CTM) of capacity 3000 KN.

For split tensile strength test a total of 24 cylinders were cast for testing at 7 and 28 days curing. At least 3 cylindrical specimens of each mix group of sisal and hybrid fibre reinforced concrete were cast for testing at each stage of curing. The test was carried out as per IS: 5816-1999. The load was applied gradually and increased continuously at a rate of approximately 140/cm^2/min.

IV. RESULTS AND DISCUSSION

A. Effect on Workability

The consistency of sisal fibre and hybrid fibre reinforced concrete for each mixed group has been determined using the slump test in accordance with IS: 1199-1959. The test results for the workability of sisal fibre and hybrid fibre reinforced concrete mix at varying replacement percentages are shown in Table 1 and Table 2.

Table 1 Slump Values for sisal fibre reinforced Concrete

Mix Group	Replacement percentage (%)	Slump (mm)
C	0.0	75
$SC_{0.5}$	0.5	67
SC_1	1	63
$SC_{1.5}$	1.5	59
SC_2	2	54

Table 2 Slump value for hybrid fibre reinforced concrete

Mix Group	Replacement Percentage (%)			Slump (mm)
	Sisal	Glass	Total	
C	0	0	0	75
$HC_{0.3}$	0.5	0.3	0.8	64
HC_1	0.5	0.6	1.1	61
$HC_{1.5}$	0.5	0.9	1.4	57

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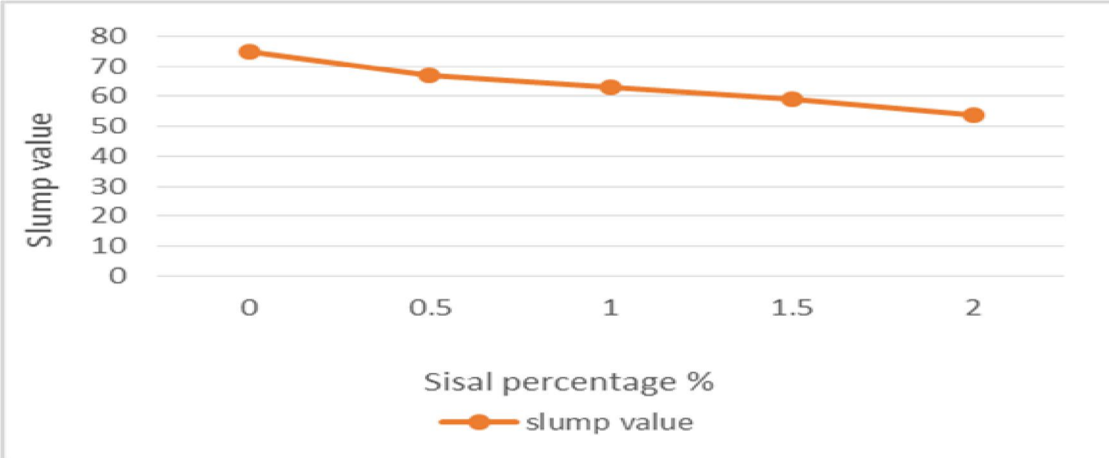

Fig 1 Effect on the workability of sisal fibre reinforced concrete

From Figure 1, the increment in the content of sisal fibre in concrete mix caused the decrease in the concrete slump. Observation during mixing and casting showed that despite decrease in the slump, the workable mix was produced at all replacement percentage level. However, some difficulty in finishing was experienced in case of casting of sisal fibre reinforced concrete mix $SC_{1.5}$ and SC_2 as concrete mix became harsh. For concrete mix having hybrid fibre, the slump was also decreasing with the addition of glass fibre as shown in Fig 2. The reduction in the workability of sisal fibre and hybrid fibre concrete mix might be attributed to the combined effect of following two factors: 1), the sisal fibre and glass fibre had high surface area as compared to the cement which leads to the more friction between cement matrix and other aggregates and 2) coagulation and lumps are formed in the mix which makes the concrete difficult for workability

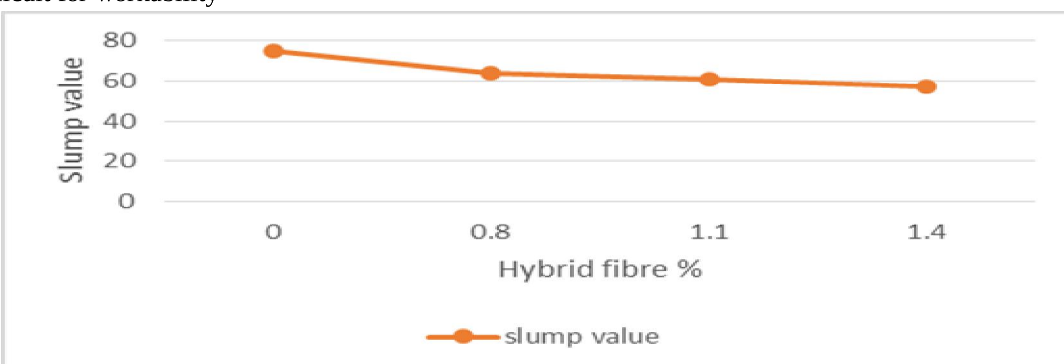

Fig 2 Effect on the workability of hybrid fibre reinforced concrete

B. *Effect on Compressive Strength*

For obtaining the optimised percentage of sisal fibre compressive strength test was conducted on each mix group of sisal fibre reinforced concrete. The test results of optimisation are shown in Table 3.

Table 3 Compressive strength results for optimization of sisal fibre

Mix group	Compressive Strength (N/mm^2) at 7 days
C	31.22
$SC_{0.5}$	38.66
SC_1	36.38
$SC_{1.5}$	34.22
SC_2	29.2

From the table , we can see that the compressive strength is maximum at 0.5%, therefore, the optimised value of sisal fibre was taken 0.5% for developing hybrid fibre reinforced concrete. For developing hybrid reinforced concrete mix the sisal fibre content was kept constant at 0.5% in all the mix proportions of HFRC and glass fibre percentage was varied at 0.3%, 0.6% and 0.9%. The compressive strength testing was carried out for different mix group of hybrids fibre reinforced concrete at 7 and 28 days as per IS: 516-1959. The test results of compressive strength are shown in Table 4. From the test results, it has been found that on replacing cement with the sisal and glass fibre, there is significant increase in compressive strength of concrete with respect to control concrete.

Table 4 Compressive strength of sisal and glass fibre reinforced concrete

Mix Group	Replacement percentage (%)		Compressive strength (N/mm^2)	
	Sisal	Glass	7 days	28 days
C	0	0	31.22	44.25
$SC_{0.5}$	0.5	0	38.66	51.15
$HC_{0.3}$	0.5	0.3	40.23	57.47
$HC_{0.6}$	0.5	0.6	43.64	60.34
$HC_{0.9}$	0.5	0.9	39.79	56.84

The increase of compressive strength might be attributed to the combined effect of 1) high tensile strength of glass fibre and sisal fibre 2) increased toughness and 3) crack formation is very small. Figure 3; shows the variation in the compressive strength of hybrid fibre reinforced concrete with the increase in glass fibre percentage and constant sisal fibre percentage in all hybrid mix at 7 and 28 days. The compressive strength increased with the increase in the percentage of hybrid fibres in the concrete mix, as shown in Figure 3. Also, it illustrates that the compressive strength of hybrid fibre reinforced concrete increases with the increase in curing time.

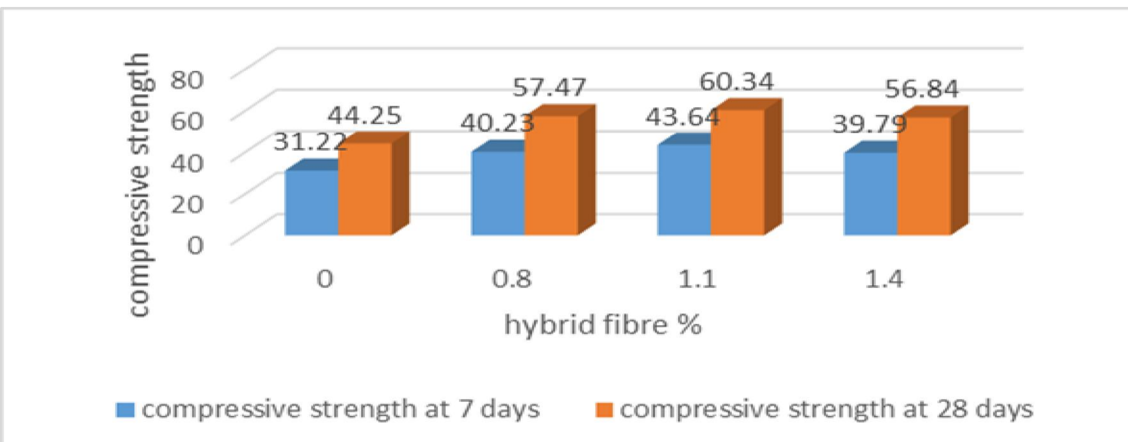

Fig 3 Variation of compressive strength of hybrid fibre reinforced concrete with constant sisal fibre % and varying glass fibre %

C. Effect on Split Tensile Strength

The split tensile strength test was carried out for different mix group of hybrids fibre reinforced concrete (both sisal fibre reinforced concrete and hybrid fibre reinforced concrete at 7 and 28 days as per IS: 5816-1999. Table 5 shows the results obtained from split tensile strength test for all the mix group of hybrids fibre reinforced concrete. The effect of using hybrid fibre (sisal + glass) fibre as a replacement for cement on the split tensile strength of concrete has been illustrated graphically in Figure 4. From the figure it can be conferred that there is an increasing relationship between tensile strength and hybrid fibre content for hybrid fibre reinforced concrete. However, the increase in split tensile strength was more in hybrid fibre reinforced concrete as compared to conventional concrete or sisal fibre reinforced concrete for all replacement percentages at 7 and 28 days. Maximum tensile strength for hybrid fibre reinforced concrete at 28 days was 4.5 N/mm^2 at 1.1 % hybrid fibre content, Moreover, minimum split tensile strength at 28 days for hybrid fibre reinforced concrete was 4.40 N/mm^2, at 1.4 % hybrid fibre content.

Table 5 Split tensile strength of sisal and glass fibre reinforced concrete

Mix Group	Replacement Percentage (%)		Split Tensile Strength (N/mm^2)	
	Sisal	Glass	7 days	28 days
C	0	0	3.02	4.33
$SC_{0.5}$	0.5	0	3.08	4.39
$HC_{0.3}$	0.5	0.3	3.12	4.44
$HC_{0.6}$	0.5	0.6	3.15	4.5
$HC_{0.9}$	0.5	0.9	3.10	4.40

The increase of split tensile strength might be attributed to the combined effect of 1) high tensile strength of glass fibre and sisal fibre 2) increased toughness and 3) bridging of crack formation due to the addition of sisal and glass fibre. Figure 4; Shows the variation in the split tensile strength of hybrid fibre reinforced concrete with increase in glass fibre percentage and constant sisal fibre percentage in all hybrid mix at 7 days and 28 days. The split tensile strength increased with the increase in the percentage of hybrid fibres in the concrete mix, as shown in Figure 4. Also, it illustrates that the split tensile strength of hybrid fibre reinforced concrete increases with increase in curing time.

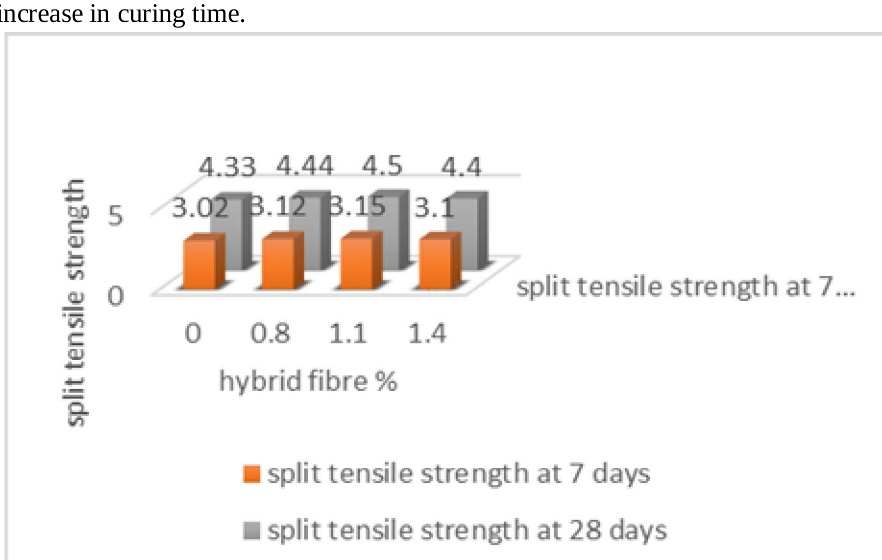

Fig 4. Variation of Split Tensile Strength of hybrid fibre reinforced concrete with constant sisal fibre % and varying glass fibre %

From fig. 4 it could be seen that with an increase in the percentage of hybrid fibre (sisal + glass) split tensile strength increases at both 7 and 28 days. All the concrete mix having hybrid fibres have more split tensile strength at 7 and 28 days with respect to reference concrete. The maximum split tensile strength of 3.15 N/mm^2 and 4.5 N/mm^2 at 7 and 28 days was obtained at 1.1% fibre percentage. There is a linear increment of split tensile strength up to 1.1% and then a decrease in compressive strength could be seen at 1.4% addition of hybrid fibre.

IV. CONCLUSION

The following conclusions have been derived based on the extensive and rigorous experimental study carried out by the researcher:

A. With the increase in hybrid fibre content in the concrete mix, workability decreases. However, the workable mix was achieved at 0.8 and 1.1 replacement; but above this percentage, concrete mix became little harsh at 1.4 % replacement level.

B. The strength parameters such as compressive and split tensile strength showed an increase in their value when hybrid fibres were added. The increment in strength increased with increase in the percentage replacement of cement with hybrid fibres.

C. For optimised percent of sisal fibre to be used in hybrid fibre reinforced concrete was 0.5%.

D. However, the strength increment at 0.8%, 1.1% and 1.4% was more in hybrid fibre reinforced concrete as compared to conventional concrete or sisal fibre reinforced concrete. The compressive strength of hybrid fibre reinforced concrete for 0.8%, 1.1% and 1.4% replacement level has been increased by 29.87, 36.36 and 28.45 % at 28 days on using hybrid fibres. Whereas, the split tensile strength of hybrid fibre reinforced concrete for 0.8%, 1.1% and 1.4% replacement level has been increased by 2.54, 3.92 and 1.61 % at 28 days on using hybrid fibres. This show that hybrid fibres have improved the compressive and split tensile strength of conventional concrete. The reason for the improvement in strength might be attributed to the improved and greater bonding between cement matrix, fibres and other aggregates which lead to the better interfacial interaction and bridging of cracks and better strength provided by fibres in tension.

E. Observations made during compression test showed that the failure behaviour pattern in control concrete was brittle, major cracks appeared and concrete portion separated out from the main specimen. Whereas in hybrid fibre reinforced concrete the failure behaviour pattern was gradual and not brittle, micro size cracks appeared and no concrete portion was separated out; the whole specimen remained intact. Thus possibility of enhancing the capability of bearing loads under flexural and tensile conditions.

F. Hybrid fibre reinforced concrete can find its application in areas where high tensile and compressive strength is required.

V. LIMITATIONS OF THE STUDY

Most of the factors in the present study have been considered and taken care of in order to address various aspects and problems related to hybrid fibre reinforced concrete, however, there are some limitations related to present study which the researcher had not been taken in to account. These limitations were as follows:

A. The alkali resistant glass fibre was not considered in the present study.

B. Pre-treatment of fibres with chemicals may behave in a different manner with concrete mix and may have a same or different impact on the strength parameters.

C. The decrease in length of fibres could have resulted in better results on mechanical properties of hybrid fibre reinforced concrete.

D. Use of another type of cement for preparing the concrete mixes.

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