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Mechanical Properties of Concrete and Hollow Concrete Blocks Containing Steel and Nylon Fibres

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Abstract: *An attempt has been made in this paper to study the effect on the mechanical properties of the concrete and hollow concrete block when different types of fibres were added to the mix. The two different types of fibres added include Steel fibres with hooked end and of length 60mm at five different fibre ratios of 2.5%, 2.75%, 3.0%, 3.25% and 3.5% and Nylon fibres having a length of 18mm at the content of 0.5%, 0.75%, 1.0%, 1.25% and 1.50%. The concept of fibre hybridization was also analyzed and the effect was studied by preparing concrete mix with various percentage combinations of steel and nylon fibres at a total fibre ratio of 3% by weight of cement. The investigation focused on finding the optimum values of fibres to be added and also carried out the compressive strength and tensile strength of concrete with and without fibres. The compressive strength of hollow concrete blocks made with and without fibres was also analyzed. The samples of concrete and hollow concrete blocks were cast and immersed in water for a curing period of 28 days. The results on strength of fibre added concrete and hollow concrete block obtained was compared with the control mix result and the study concludes that the steel fibre and nylon fibre added concrete and hollow concrete block showed an improvement in the mechanical properties for each fibre ratio considered. Out of the various combinations of steel and nylon fibre tried, the best compressive strength improvement was exhibited by the concrete mix with 3% of the steel fibre without any addition of nylon fibres while the best tensile strength improvement was shown by the concrete mix with 2.25% of steel fibre and 0.75% of nylon fibre.*

Keywords: Compressive strength, Flexural Strength, Hooked end steel fibres, Nylon fibres, Split tensile strength.

I. INTRODUCTION

By increasing the resistance to cracking in concrete, the tensile strength and strain capacity of concrete can be improved. Many researchers have taken efforts to increase the resistance to cracking by adding different types of fibres in concrete. The concrete thus obtained is known as Fibre Reinforced Concrete (FRC) [1]. However, the fibres which are used in FRC must have good mechanical properties, should be durable when embedded into the cementitious matrix [2]. The behaviour of FRC is influenced by the dimensions such as length and diameter of the fibre used. It is also affected by the shape of the fibre and also the type of material [3][4]. The distribution of fibres in concrete also depends on the above-mentioned parameters [5]. Many types of fibres made of Polypropylene, Glass, Nylon, Steel, Natural Cellulose has been used in FRC and they are widely used in commercial applications [6][7][8][9][10]. Some researchers are of the opinion that adding fibres in concrete not only improves the tensile strength but also shows signs of improvement in ductility, toughness and durability properties of hardened concrete [11]. Many researchers used FRC with combinations of fibres made of different materials or geometry known as hybrid FRC (HyFRC). Such HyFRC's enhances the structural members' post-cracking response [12]. In a well-designed HyFRC, the interaction between the fibres results in better performance than that of FRC with a single fibre [13][14]. Based on the suggestions of some authors, the main objective of the use of fibres of different types in combination in concrete is aimed at controlling emergence of cracks on the cementitious materials, at respective areas namely: (i) at different zones, (ii) at different size levels and (iii) during different loading stages [15].

By adding steel fibres in concrete, both the tensile strength and the compressive strength are improved. A lot of researches have been carried out in the past to prove that the Steel Fibre Reinforced Concrete (SFRC) enhanced the resistance in the areas of cracking and impact. The addition of steel fibres in concrete impaired the workability because of two reasons. The first reason is due to the elongated shape of the fibre and the second reason is the large surface area offered by the fibre. Therefore, the amount of fibre that can be added is limited and the maximum amount needs to be determined. In order to make the best use of the steel fibres added, they need to be distributed homogeneously in the mix. Or in other words, the fibres should not form clusters in the mix while mixing. The commonly used areas where SFRC includes industrial pavements where good control over the shrinkage cracking is essential, for the lining of tunnels and also for precast roof elements. Some studies claim that the steel fibre added concrete shows notable improvement in compressive strength [16] while other authors suggest that this argument is not sustainable [17].

The incorporation of Nylon fibres in concrete showed improved mechanical properties and the concrete also exhibited satisfactory resistance in the micro-cracking developed in the initial period. Because of the above property nylon fibre reinforced concrete (NFRC) is used for casting the deck slabs.

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Only a few studies have been carried out using nylon fibre as reinforcement. Some authors [18] claim that the nylon fibre added concrete decreases the strength due to compression even though there is a remarkable increase in the tensile strength.

In this study, an effort has been made to analyze the impact of the inclusion of steel fibres, nylon fibres and hybridization of both the fibres on the strength of concrete and hollow concrete blocks. Steel fibres with hooked end with a length of 60mm were used at five different fibre ratios of 2.5%, 2.75%, 3.0%, 3.25% and 3.5%. Nylon fibres at the content of 0.5%, 0.75%, 1.0%, 1.25% and 1.50% were used in the work. The length of the nylon fibre used was 18mm. The effect of fibre hybridization was also analyzed by preparing three mixtures which were obtained by combining steel and nylon fibres at a total fibre ratio of 3% by weight of cement. The three mixtures used in the study include FRC with 100% steel, 75% steel & 25% nylon and 50% steel & 50% nylon fibres. The characteristics of the steel and nylon fibre used in the work are listed in Table I.

II. OBJECTIVES, SCOPE AND METHODOLOGY

A. Objectives

The foremost intention of this investigation was to determine the properties of Steel fibre and Nylon fibre reinforced concrete specimens made with different fibre dosages. The various properties were studied on the fresh concrete as well as on the hardened concrete. The mechanical properties of the fibre included concrete were also compared with the properties of the concrete without fibre.

B. Scope

The steel fiber dosages chosen for the study were 0%, 2.50%, 2.75%, 3.0%, 3.25% and 3.5% by weight of cement. The dosages selected for Nylon fibres include 0.5%, 0.75%, 1.0%, 1.25% and 1.5% by weight of cement. The steel and nylon fibre combination includes three different mixes i.e., 100% steel, 75% steel & 25% nylon and 50% steel & 50% nylon fibres.

added concrete and the compressive strength of fibre added hollow concrete blocks. The results obtained from the fibre added specimens were compared with the control specimens. Optimum fibre content was also obtained by analyzing the various strength properties such as compressive, split tensile and flexural. The methodology adopted in this paper is shown in figure 1

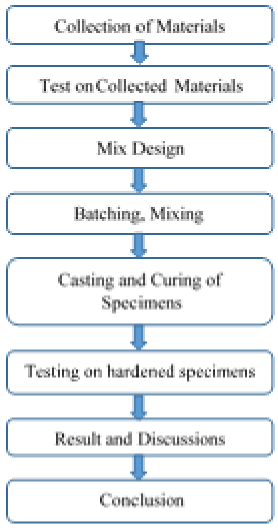

Fig. 1. Experimental Methodology

III. EXPERIMENTAL INVESTIGATION

A. Materials

The properties of each material in a concrete mix were studied. As specified by relevant IS codes, different tests were conducted for each material. For making the various concrete mixes, Ordinary Portland cement, coarse aggregate, M Sand, Steel fibres, Nylon fibres and water were used.

- Cement: - OPC53 cement of 3.15 specific gravity was utilized. The standard consistency obtained was 32%. It recorded an initial setting time of 30 minutes and a final setting time of 420 minutes. Standard mortar cubes were immersed in water for a period of 28 days. After the curing period of 28 days, the compressive strength test was conducted and the value was measured as 54 MPa. All properties of cement were in accordance with IS269:1976.
- Fine Aggregate: - M sand passing through 4.75mm IS sieve as per IS: 383-1987 was used as the fine aggregate. The various tests were performed for the physical properties and the corresponding values obtained are shown in Table II.

Table- I: Characteristics of Steel and Nylon fibres used

Type of fibre	Shape of fibre	Specific Gravity (gram/cubic cm)	Length of the fibre (mm)	Diameter of the fibre (mm)	Aspect Ratio (l/d)	Tensile Strength (MPa)
Steel	Hooked End	7.86	60	0.75	80	620
Nylon	Straight	1.14	20	0.03	666.67	440

C. Methodology

Materials required for the experiments were procured and their properties were found. The mix design of M15 grade concrete was done as per IS 10262-2009. The fresh properties of concrete for different fibre dosages were found using slump value. Specimens for determining mechanical properties of concrete and hollow concrete blocks with and without steel fibres and nylon fibres were cast and immersed in water for a curing period of 28 days. After the curing period, the specimens were taken out of the water and they are wiped clean and dried in open air. The specimens were subjected to various strength test such as compressive strength, flexural strength and split tensile strength of fibre

- Coarse Aggregate: - Crushed stone aggregates of nominal maximum 10mm size was used as the coarse aggregate. It is ensured that they are free from deleterious materials like silt content, clay and contamination of chloride. The various test for specific gravity, aggregate impact value, fineness modulus and water absorption was carried out and the values obtained are as given in Table III.

Table- II: Physical Properties of M Sand used

Sl. No	Properties	Values
1	Grading	Zone 2
2	Specific Gravity	2.57
3	Bulk Density	1560kg/m^3
4	Fineness Modulus	2.83
5	Water Absorption	1.2%

Table III: Properties of Coarse Aggregate

Sl. No	Properties	Values
1	Specific Gravity	2.65
2	Aggregate Impact Value	33.8%
3	Size	Max. Size 10mm
4	Fineness Modulus	6.02
5	Water Absorption	0.15%

- Superplasticizer: - A commercially available superplasticizer (Glenium) having the properties shown in Table IV was used. The superplasticizer added was 0.85 % by weight of cement to all mixes conforming to IS 9103:1999.

Table IV: Properties of Superplasticizer

Sl. No	Description	Values
1	Colour	Amber
2	Structure	Poly Carboxylic Ether Based
3	Density	1.082 -1.142 kg/ltrs
4	Chlorine content	< 0.1
5	Alkaline Content	< 3

- Fibres: - Hooked end steel fibres and Nylon 6 fibres were used in various proportions. The experiment includes concrete with steel fibres, concrete with nylon fibres and concrete with various combination of steel and nylon fibres. In the investigation five different percentages of 2.5%, 2.75%. 3%, 3.25% and 3.5% steel fibres by weight of cement and 0.5%, 0.75%, 1.0%, 1.25% and 1.5% nylon fibres by weight of cement were incorporated to concrete.
- Water: - Clean potable water tested in the laboratory and which satisfies the drinking standards was used for the preparation of specimens and also for curing of the specimens.

B. Design of Concrete Mix

This process involves the selection of ingredients like cement, aggregates and water in the required proportions. The main intention of doing a mix design is to obtain a concrete having desired strength and also an economical one. The concrete thus prepared must be durable and also should be workable. This process has been carried out and the final mix proportion (cohesive) mentioned in Table V below is the basis for the present investigation.

Table- V: Materials used in the Mix

Sl. No	Ingredients	Quantity (kg/m^3)
1	Water	150
2	Cement	319.8
3	Fine Aggregate	767.4
4	Coarse Aggregate	1151.4
5	Water Cement Ratio	0.50

Concrete cubes samples of size 150mm x 150mm x 150mm, Concrete cylinder specimens of size 150mm diameter and 300mm height, Concrete beam samples of size 500mm x 100mm x 100mm and hollow concrete blocks with dimensions 400 x 200 x 200mm were cast for conducting various strength tests such as compressive, flexural and split tensile test in the laboratory.

C. Test Program, Procedures and Testing Methods

Water cement ratio of 0.5 was used for preparing the concrete samples. Different strength tests were carried out on concrete added with steel fibres, concrete added with nylon fibres and concrete added with different percentage combinations of steel and nylon fibres. The various percentage of fibres added to the concrete was taken by the weight of the cement used. Five different percentages of 2.5%, 2.75%. 3%, 3.25% and 3.5% steel fibres by weight of cement were added to concrete. The nylon fibers were also placed in concrete randomly (0.5%, 0.75%, 1.0%, 1.25% and 1.5%) by weight of cement. An effort has also been taken in the present investigation to study the strength of steel-nylon hybrid fibre added to concrete for three different steel-nylon fibres percentages. The percentages adopted includes 100% steel and without nylon fibres, 75% steel and 25% nylon fibres and 50% steel and 50% nylon fibres added to concrete. The concrete cube samples were cast in 150mm cubic mould in order to obtain the compressive strength. Hollow blocks of size 400 x 200 x 200mm were also prepared to obtain the compressive strength. Cylindrical steel moulds with diameter 150mm and height 300mm are used for cylindrical concrete specimens for obtaining the split tensile strength. Concrete beams of size 500mm x 100mm x 100mm were cast for performing the flexural strength test. All the specimens were immersed in water for a period of 28 days before testing.

After the curing period, all the specimens were taken out of the water and they are wiped clean and dried in the open air. Compression tests were carried out on 150mm cube specimens using a compression testing machine as per IS 516-1959. Hollow concrete block specimens were also subjected to compression test using universal testing machine.

Split tensile strength was executed on cylindrical specimens using compression testing machine as per IS 5816:1999 and beam specimens were exposed to two-point loading as per IS 516:1959 to study the flexural strength. All the test was carried out on the concrete specimens made using fibre added concrete and also on the concrete specimens made without the addition of any type of fibre which is specified as the control specimens.

IV. EXPERIMENTAL INVESTIGATION

A. Compressive Strength

The compressive strength obtained on concrete cubes made without the addition of fibres was 19.2N/mm^2 and hollow concrete block compressive strength was 3.8 N/mm^2. The variation of cube compressive strength of different fibre added concrete obtained after the curing period of 28 days is shown in figure 2 and are presented in Table VI. The values obtained after the test shows that the incorporation of steel fibres, Nylon fibres and various combinations of steel and

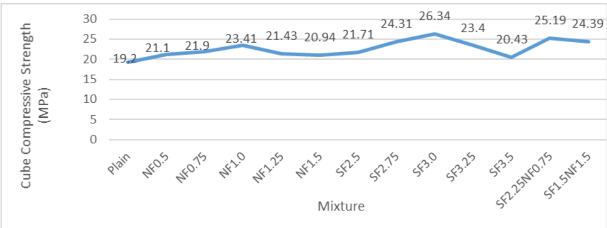

Fig. 2. Cube Compressive Strength of Steel, Nylon and Steel-Nylon hybrid fibre added concrete

nylon fibres improve the compressive strength. Also, the cube compressive strength of nylon fibre added concrete increases up to 1% fibre content and thereafter the strength is decreased. The maximum cube compressive strength obtained was 23.41N/mm^2 and the percentage increase of strength after the curing period was obtained as 21.9% when compared with the concrete without adding any fibre. When different percentages of steel fibres were added to concrete, the optimum was obtained as 3% and beyond that, the strength was seen to be decreasing. The maximum strength was obtained as 26.34N/mm^2 with a percentage increase of 37.1%.

Three combinations of steel and nylon fibres in concrete was tried by keeping the fibre content to 3%. In the first case, 100% of steel fibre was used. The second case includes specimens with 75% steel fibres and 25% nylon fibres in concrete. The third case consists of specimens with 50% steel fibres and 50% nylon fibres. Out of the above three cases mentioned, the specimens with 100% steel fibres showed maximum compressive strength.

The variation of compressive strength on different fibre added hollow concrete block after a period of 28 days of curing period is shown in figure 3 and are presented in Table VI. As expected, the hollow block compressive strength was obtained similar to the cube compressive strength with only a slight difference in percentage increase in the strength. The optimum fibre content was obtained as 1% in the case of nylon fibre added hollow block concrete and it is 3% when steel fibre was included in the concrete used for making hollow blocks. The maximum compressive strength was obtained as 4.6N/mm^2 which gives an increase of 21.1% and 5.21N/mm^2 with a percentage increase of 37.2% with nylon and steel added hollow block respectively. In the case of steel-nylon hybrid hollow concrete block, a result similar to the cube compressive strength was obtained. The maximum hollow block compressive strength was obtained when 100% of steel fibres was added to concrete. The addition of nylon fibres along with steel fibres reduces the compressive strength.

The values obtained from the compressive test show that the fibre included concrete perform better than the concrete without fibres due to the ability of fibres to resist the crack extension. The presence of fibres reduces the concentration of stress at the tip of the cracks, changes the direction of cracks and also the growth rate of the cracks is also delayed. Table VI shows that the cube and hollow block compressive strength increases from 9% to 22% for various percentages of nylon fibre added to the concrete. Similarly, when different percentages of steel fibres were added to concrete the cube and hollow block compressive strength increases from 6.3% to 37.2%. In order to improve the compressive strength in concrete, the same table also reveals that the consequence

Table- VI: Compressive strength, Split tensile Strength and Flexural Strength Test Results

Mix No.	Mixture ID	Cube Compressive Strength (MPa)		Hollow Block Compressive Strength (MPa)		Split Tensile Strength (MPa)		Flexural Strength (MPa)	
		28 days	% increase	28 days	% increase	28 days	% increase	28 days	% increase
1	Plain	19.2		3.8		2.19		2.81	
2	NF0.5	21.1	9.9	4.16	9.5	2.43	11	3.26	16
3	NF0.75	21.9	14.1	4.43	16.6	2.62	19.6	3.65	29.9
4	NF1.0	23.41	21.9	4.6	21.1	2.95	34.7	3.87	37.7
5	NF1.25	21.43	11.6	4.31	13.4	2.41	10	3.7	31.7
6	NF1.5	20.94	9.1	4.14	8.9	2.29	4.6	3.34	18.9
7	SF2.5	21.71	12.4	4.27	13.1	2.47	12.8	3.31	17.8
8	SF2.75	24.31	26.6	4.81	26.6	2.76	26	3.65	29.9
9	SF3.0	26.34	37.1	5.21	37.2	3.08	40.6	4.11	46.3
10	SF3.25	23.4	21.6	4.62	21.9	2.66	21.5	3.68	31
11	SF3.5	20.43	6.3	4.04	6.4	2.44	11.4	3.25	15.7
12	SF2.25NF0.75	25.19	31	4.98	31.2	3.16	44.3	4.27	49.1
13	SF1.5NF1.5	24.39	26.8	4.82	27	2.86	30.6	3.96	40.9

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of adding steel fibres was more significant than adding nylon fibres. The reason for showing this improvement in the compressive strength is mainly because of the higher strength and modulus of elasticity of steel fibres when compared with nylon fibres. As a result, the efficiency of bridging the macro-cracks has increased which in turn increased the strength in compression.

Table VI also shows that when a small percentage of nylon fibres is added along with the steel fibres, the cube and the hollow block compressive strength attain 31.2% more than that of the concrete without any fibres depending on the replacement level of nylon and steel fibres. The results obtained indicate that the compressive strength is decreased when a portion of steel fibres is substituted with nylon fibres. The mix which gave the best performance was the concrete added with 3% steel fibres, which attained a cube and hollow block compressive strength of 26.34N/mm^2 and 5.21N/mm^2 respectively at the end of curing period.

34.7% compared to the reference concrete when different percentages of nylon fibres were added to concrete. The maximum value was obtained as 2.95N/mm^2 for the optimum fibre content of 1%. When different percentages of steel fibres were added to concrete, the strength is increased from 12.8% to 40.6%. The maximum value of 3.08N/mm^2 was obtained for the optimum fibre content of 3%. The results of the hybrid fibre included concrete indicates a superior increase of strength than concrete added with single fibre or concrete made without fibres. Table VI indicates that Mix 12 gave a higher split tensile strength of 3.16N/mm^2, 44.3% higher than the strength of reference concrete. In comparison with reference concrete, the table also demonstrates that the other samples of concrete with the combination of any type of fibres, exhibit better performance in the matter of strength.

In the investigation of flexural strength also, a similar strength variation as that of split tensile strength can be seen. The flexural strength increases from 16% to 37.7% and 15.7% to 46.3% for different percentage addition of nylon and steel fibres in concrete respectively. The maximum value of 3.87N/mm^2 is obtained when an optimum nylon fibre content of 1% is added and 4.11N/mm^2 is obtained when 3% of steel fibre is added to concrete.

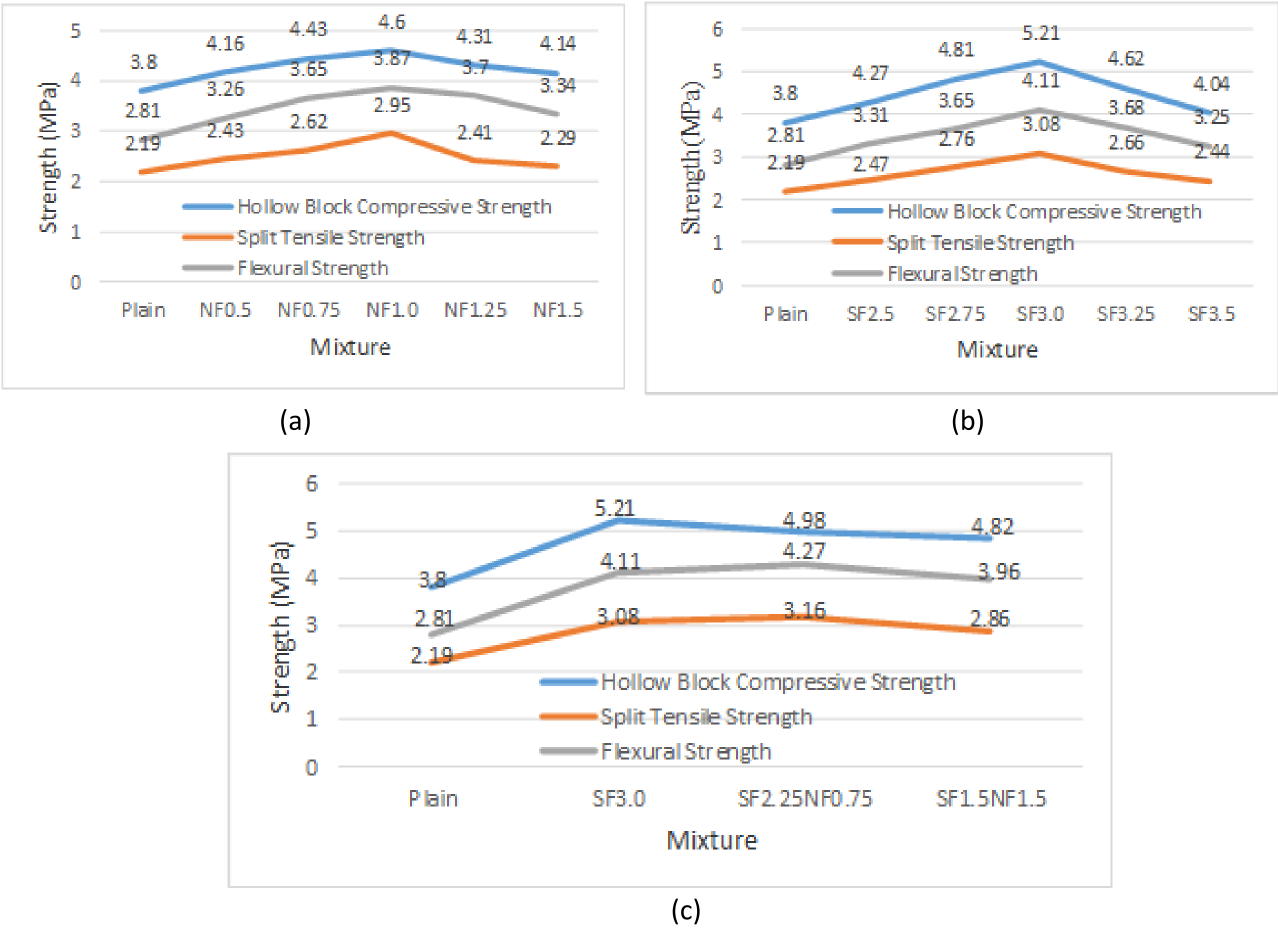

Fig. 3. Strengths of different fibre reinforced concretes: a) Nylon fibre reinforced specimens b) Steel fibre reinforced specimens and (c) Hybrid fibre reinforced specimens

B. Split Tensile and Flexural Strengths

The variation of strength both in split and flexure of different fibre added to the concrete are shown in fig 3 and are presented in Table VI. The experimental results clearly indicate that out of the steel and nylon fibres used, the steel incorporated concrete gave a significant improvement in the tensile strength. The strength is increased from 4.6% to

Therefore, with an addition of steel fibres in concrete, the flexural strength achieved is of significant increase, as per results given in Table VI. At the end of a curing period of 28 days, the hybrid steel nylon fibre reinforced concrete results show that mix 12 obtains a higher value of 4.27N/mm^2 in terms of flexural strength which is 49.1% higher than that of concrete without fibres.

V. CONCLUSIONS

Conclusions given below are based on the analytical discussions of the test results in this study:

1) The values obtained from the compression test shows that the fibre included concrete perform better than the concrete without fibres due to the ability of fibres to resist the crack extension. This increase is mainly due to the ability of the fibres to restrain the extension of cracks.
2) The presence of fibres reduces the stress concentration at the tip of the cracks, changes the direction of cracks and also delay the growth rate of the cracks.
3) The optimum steel fibre content and nylon fibre content was obtained as 3% and 1% by weight of cement.
4) The maximum cube compressive strength and hollow concrete block compressive strength obtained on concrete added with nylon fibres was 23.41N/mm^2 and 4.6 N/mm^2 respectively which is 21.9% and 21.1% higher than the strength of concrete and hollow concrete block without adding any fibres.
5) The maximum value of steel fibre reinforced concrete cube and hollow concrete block compressive strength obtained was 26.34 N/mm^2 and 5.21N/mm^2 respectively which is 37.1% and 37.2% higher than the strength on reference concrete and reference hollow concrete block.
6) Out of the steel and nylon fibres used, steel fibre added concrete and hollow concrete blocks performed better because of two factors. They have higher tensile strength and higher value of modulus of elasticity.
7) The results of hybrid reinforced concrete and hollow concrete blocks shows that the substitution of steel fibres with nylon fibres reduces the compressive strength.
8) The maximum value of split tensile and flexural strength of nylon fibre reinforced concrete obtained are 2.95N/mm^2 and 3.87N/mm^2 respectively which gives an increase of 34.7% and 37.7% over the strength of concrete without the addition of fibres.
9) The steel fibre reinforced concrete attained a maximum value of split tensile and flexural strength as 3.08N/mm^2 and 4.11N/mm^2 with an increase of 40.6% and 46.3% when compared with the strength of concrete without fibres.
10) When 2.25% of steel fibres and 0.75% of nylon fibres were added to the concrete, the highest split tensile and flexural strength was obtained. The values obtained are 3.16N/mm^2 and 4.27N/mm^2 which shows an increase of 44.3% and 49.1% over the strength of concrete without adding any fibre content.

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