COMPARISON OF MECHANICAL PROPERTIES OF NORMAL AND FIBRE REINFORCED

Concrete (Grade M15)

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ABSTRACT

Concrete is weak in tension, hence some measures must be adopted to overcome this deficiency as well as to enhance physical and other mechanical properties but in more convenient and economical method. Through many research from the past, it has been observed that addition of different types of fibres has been more effective for this purpose. This report presents the work undertaken to study the effect of steel and hay fibre on normal cement concrete of M-15 Grade on the basis of its mechanical properties which include compressive and tensile strength test and slump test as well. Although hay fibres are abundantly available in Nepal, no research have been popularly conducted here regarding the use of hay fibres in concrete and the changes brought by it on concrete's mechanical properties. Experiments were conducted on concrete cubes and cylinders of standard sizes with addition of various percentages of steel and hay fibres i.e. 0.5%, 1% and 1.5% by weight of cement and results were compared with those of normal cement concrete of M-15 Grade. For each percentage of steel and hay fibre added in concrete, six cubes and six cylinders were tested for their respective mechanical properties at curing periods of 14 and 28 days. The results obtained show us that the optimum content of fibre to be added to M-15 grade of concrete is 0.5% steel fibre for compression and 0.5% hay fibre content for tension by weight of cement. Also, addition of steel and hay fibres enhanced the binding properties, micro cracking control and imparted ductility.

In addition to this, two residential buildings were modeled in SAP software, one with normal concrete and other with concrete containing 0.5% steel fibre. Difference in reinforcement requirements in each building was computed from SAP analysis and it was found that 489.736 Kg of reinforcement could be substituted by 158.036 kg of steel fibres and decrease in materials cost of building with 0.5% steel fibre reinforced concrete was found to be Rs. 32,100.

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1.   INTRODUCTION

FIBRE

- Fibre is a small piece of reinforcing material possessing certain characteristics properties.
- The fibre is often described by a convenient parameter called aspect ratio.
- The aspect ratio of the fibre is the ratio of its length to its diameter.
- Typical aspect ratio ranges from 30 to 150.
- Volume percent of fibre used (V_f = 0.1 to 3%)
- Fibers include steel fibers, glass fibers, synthetic fibers and natural fibers.
- Fibre reinforced concrete (FRC) may be defined as a composite materials made with Portland cement, aggregate, and incorporating discrete discontinuous fibres which are uniformly distributed and randomly oriented.
- It resists cracking and crack propagation. The transformation from a brittle to a ductile type of material would increase substantially the energy absorption characteristics of the fibre composite and its ability to withstand repeatedly applied, shock or impact loading.
- Within these different fibers, the character of fiber reinforced concrete changes with varying concrete ,fiber materials, geometries, distribution, orientation and densities.
- The role of randomly distributed discontinuous fibres is to bridge across the cracks that develop provides some post- cracking "ductility". If the fibres are sufficiently strong, sufficiently bonded to material, and permit the FRC to carry significant stresses over a relatively large strain capacity in the post-cracking stage.

WHY STEEL AND HAY FIBRES?

Steel fibres are most commonly used fibres and are proved to enhance flexural, impact and fatigue strength of concrete. They are widely used for-overlays of roads, airfield pavements, bridge decks. Hay fibres have high tensile strength and are abundantly available in Nepal, mostly the rural areas where maximum numbers of people are involved in agriculture. If they are found to enhance mechanical properties of concrete, it would be more economic and safer to construct building using hay as fibre.

ADVANTAGES OF FIBRE REINFORCED CONCRETE

a) Fibre reinforced concrete has started finding its place in many areas of civil infrastructure applications especially where the need for repairing, increased durability arises.

b) FRC is used in civil structures where corrosion is to be avoided at the maximum.

c) Fibre reinforced concrete is better suited to minimize cavitation /erosion damage in structures such as sluice-ways, navigational locks and bridge piers where high velocity flows are encountered.

d) A substantial weight saving can be realized using relatively thin FRC sections having the equivalent strength of thicker normal concrete sections.

e) When used in bridges it helps to avoid catastrophic failures. In the quake prone areas, the use of fibre reinforced concrete would certainly minimize the human casualties.

f) Fibres reduce internal forces by blocking microscopic cracks from forming within the concrete.

g) There may be other cheaper ways to increase strength rather than using fibres but use of fibres in concrete has following dominant features:

   1) Fibres increase toughness of concrete.

   2) They increase strain at peak load.

   3) They provide a great deal of energy absorption in post-peak portion of load vs. deflection curve.

DISADVANTAGES OF FIBRE REINFORCED CONCRETE

The fibres have to be uniformly mixed and spread throughout the concrete mix. At times, this is found to be a difficult process and time consuming. If this limitation has been overcome by new and effective methods of fabrication, fibre reinforced concrete is found to be more adaptable for common concreting works. The process of incorporating fibres into the cement matrix is labor intensive and costlier than the production of the normal concrete. The real advantages gained by the use of FRC overrides this disadvantage.

2.   OBJECTIVE OF RESEARCH

a) To find out the value of compressive strength and tensile strength of fiber reinforced concrete due to variation in percentage of fibers.

b) To compare these values with the results of tests on mechanical properties (compressive strength, tensile strength, slump value) of samples of conventional concrete.

c) To compare and choose the optimum percentage of fibre (Steel or Hay) contents in concrete structure respect to its compressive and tensile strength.

d) To compare the reinforcement requirement in a residential building using conventional and fibre reinforced concrete obtained from SAP analysis.

3. LIMITATIONS OF RESEARCH

a) Temperature was not taken into consideration during the specimen preparation and testing as well.

b) Length of the fibre was kept approximately constant.

c) Fibres were manually mixed and distributed in a random manner.

d) Fibres used were wastage of steel (scrap) brought from local grill and steel workshop.

4. EXPERIMENTAL SETUP

MATERIALS USED

- Cement:

  It is mixture of calcareous, siliceous, aluminous substances and crushing the clinkers of a fine powder. The ordinary Portland cement of 53 Grade is used. The specific gravity of cement is 3.15. For ordinary Portland cement, the initial setting time is 30 minutes and the final setting time is 600 minutes.

- Fine Aggregate:

  The aggregate whose particles pass through sieve of 4.75mm is called fine aggregate. The sand used for the experimental program was locally procured and confirmed to grading zone III. The properties of fine aggregates are: Specific gravity – 2.65 and Fineness Modulus – 1.958

- Coarse Aggregate:

  The material whose particles are of size as are retained on I.S. Sieve No. 480 is termed as Coarse Aggregate. The aggregates are made free from dust before using in the concrete. Its specific gravity is 2.74 and fineness modulus is 7.545.

- Fibres:

  Weight of fibers = 0.5%, 1 % & 1.5% by weight of cement

Type of fibers	Steel Fibers (scrap steel)			Hay Fibers (locally available)		
Percent of fibers	0.5%	1%	1.5%	0.5%	1%	1.5%
Weight of fibers(kg)	0.095	0.19	0.285	0.095	0.19	0.285

Fibers type	Steel fibers		Hay fibers
Length of fibers (cm):	6.7, 7, 6.65, 6.1, 5.5	5	
Average length(cm)	6.4		5
Thickness of fiber(cm)	0.07		0.07,0.08,0.07,0.09,0.08
Average thickness (cm)	0.07		0.078

- Water: Water used during the experimental work was clean tap water free of impurities.

EXPERIMENTAL WORK

The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing concrete of the required strength, durability, and workability as economically as possible is termed the concrete mix design. In this study, concrete mix was prepared to make concrete of Grade M15. Mix proportion for M15 is 1:2:4 (Cement: Fine aggregate: Coarse aggregate)

Concrete Mix Proportion;

Cement = 214.68 kg/m^3

Fine Aggregate = 457.62 kg/m^3

Coarse Aggregate = 971.73 kg/m^3

Water Cement ratio = 0.55

Water = 118.64 liter/m^3

The steel and hay fibres were added at percent variation of 0.5 %, 1 % and 1.5 % by weight of cement in M-15 Grade concrete and was compared to normal cement concrete.

PREPARATION AND DETAILS OF TEST SPECIMENS:

Casting and testing of cubical specimens of size 150mm×150mm×150mm for compressive strength was done as per IS 516:1959 specifications. Whereas casting and testing of cylindrical specimens of size 150mm diameter and 300mm length for splitting tensile strength was done as per IS 5816:1999 specifications. Compressive strength test was performed on 150mm cubes, tested at 28 days, with their specimen in each case and cured in the water tank completely immersed at ambient temperature until the test age. All the test specimens were demodulated after 24 hours of casting.

5.   METHODOLOGY

The methodology adopted to compare the mechanical properties between conventional concrete, steel fibre reinforced concrete and hay fibre reinforced concrete is governed by:

i)   COMPRESSIVE STRENGTH TEST

A number of cubical specimen were made using M15 Grade conventional concrete and FRC with varying percentage (0.5% , 1% and 1.5%) of different types of fibers (steel and hay). The samples after curing for 14 days and 28 days were loaded with compressive force in a UTM until the failure occurred. The ultimate strength at 28 days indicated the compressive strength of the respective sample. This test was conducted as per IS 516:1959.

Let,

P = maximum load carried by the cube before the failure A = area normal to the load

= maximum compressive stress (N/mm^2) Therefore,

Cube compressive strength (f_{ck}) in MPa,

$$\sigma = \quad /$$

where, P = Cube compression load in Newtons (N)

A = Area of the side of cube on which load is applied (i.e., 150×150=22500 mm^2)

ii) TENSILE STRENGTH TEST

A number of cylindrical specimen were made using M15 Grade conventional concrete and FRC with varying percentage (0.5% , 1% and 1.5%) of different types of fibers (steel and hay). The samples after curing for 14 days and 28 days were placed between the two plates of Universal Testing Machine with its axis horizontal. The load was increased until failure occurred by splitting along a vertical diameter. The ultimate strength of 28 days sample indicated the tensile strength of the respective sample. This test was carried out as per IS 5819:1999 specifications. Let,

P = maximum load carried by the cylinder before the failure A = area normal to the load

σ = maximum tensile stress (N/mm^2)

L= length of cylinder specimen (300mm) D= Diameter of cylinder (150mm) Therefore,

σ = (P/A) N/mm^2

= 2P/ () N/mm^2

iii) SLUMP TEST

Concrete slump test is to determine the workability or consistency of concrete mix prepared atthe laboratory or the construction site during the progress of the work. Concrete slump test is carried out from batch to batch to check the uniform quality of concrete during construction. After preparing M15 Grade concrete (for both conventional type and FRC), fresh concrete were poured in clean moulds in four layers, each layers being tamped by standard steel rod(16mm diameter and 0.6m long) for 25 times. The cone was lifted slowly and the decrease in the height of the slump formed prior to the lifting was determined in mm. From this, workability was obtained. Only a true slump is of any use in the test. A collapse slump will generally mean thatthe mix is too wet or that it is a high workability mix, for which the slump test is not appropriate. Very dry mixes; having slump 0 – 25 mm are used in road making, low workability mixes; having slump 10–40 mm are used for foundations with light reinforcement, medium workability mixes; 50-90 for normal reinforced concrete placed with vibration, high workability concrete >100 mm.

SAP ANALYSIS

A normal residential building (two and a half storey) was modeled in SAP software as shown in figure with size of each component (beam, column, slab, and staircase) as per the thumb rule of NBC (Nepal Building Code) using M15 concrete. After obtaining the results of cube tests, the percentage of fibre (hay or steel) at which maximum compressive strength was obtained was chosen to replace M15 concrete. Another similar building was modeled with same components size using this fibre. Reinforcement requirements in each component were calculated from results of SAP analysis and compared. Total reinforcement needed in each building was separately summed up and the difference in reinforcement requirement due to the replacement of conventional concrete by FRC was calculated. The size of building components used was:

Columns: 12" * 12"

Beams: 9" * 14"

Slabs: 5"

Steel Rebar: Fe500

Concrete   : Conventional M15.369 and FRC M18.055

Room Size: 5m * 5m

The loads on the building were taken as:

Live Loads (LL)   = 2 KN/m²

Floor Finish (FF) = 1.2 KN/m²

Wall load (WL)   = 12 KN/m

6.   RESULTS & ANALYSIS

The final average result of the experiment is summarized in the table below:

S.N	Concrete type	% of fibre	Slump (mm)	28 days average load in (KN)		28 days average strength in (N/mm²)	
				Tension	Compression	Tension	Compression
1	Normal	0	27	96.2	345.8	1.362	15.369
2	Steel fibre reinforced	0.5	20	101.6	406.23	1.438	18.055
		1	11	85.7	350.07	1.213	15.559
		1.5	9	102.77	344	1.455	15.289
3	Hay Fibre reinforced	0.5	14	104.6	333.43	1.547	14.819
		1	13	92.37	307.03	1.307	13.646
		1.5	11	78.4	274.03	1.11	12.179

i)   Slump Test
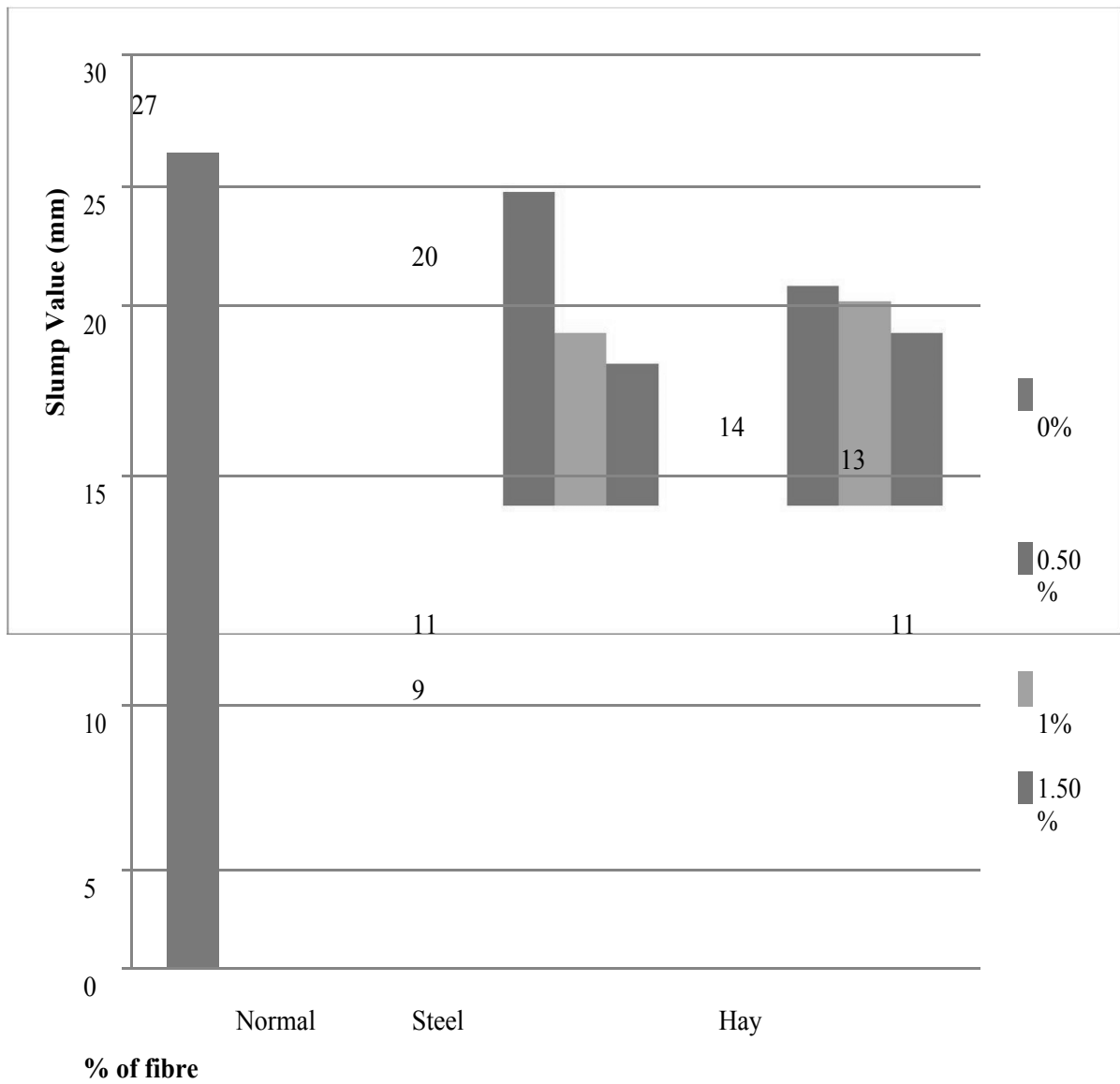
It was observed that the slump value gradually decreased with increase in fibre content. In steel fibre, the slump value reduced by 25.9 % , 59.3% and 66.7% for fibre content of 0.5% , 1% and 1.5% respectively in comparison to slump value of normal concrete. Similarly in hay fibre, the slump value reduced by 48.2 %, 51.9 % and 59.3% for fibre content of 0.5%, 1% and 1.5% respectively in comparison to slump value of normal concrete.

ii)   Compressive Strength Test

% of fibre
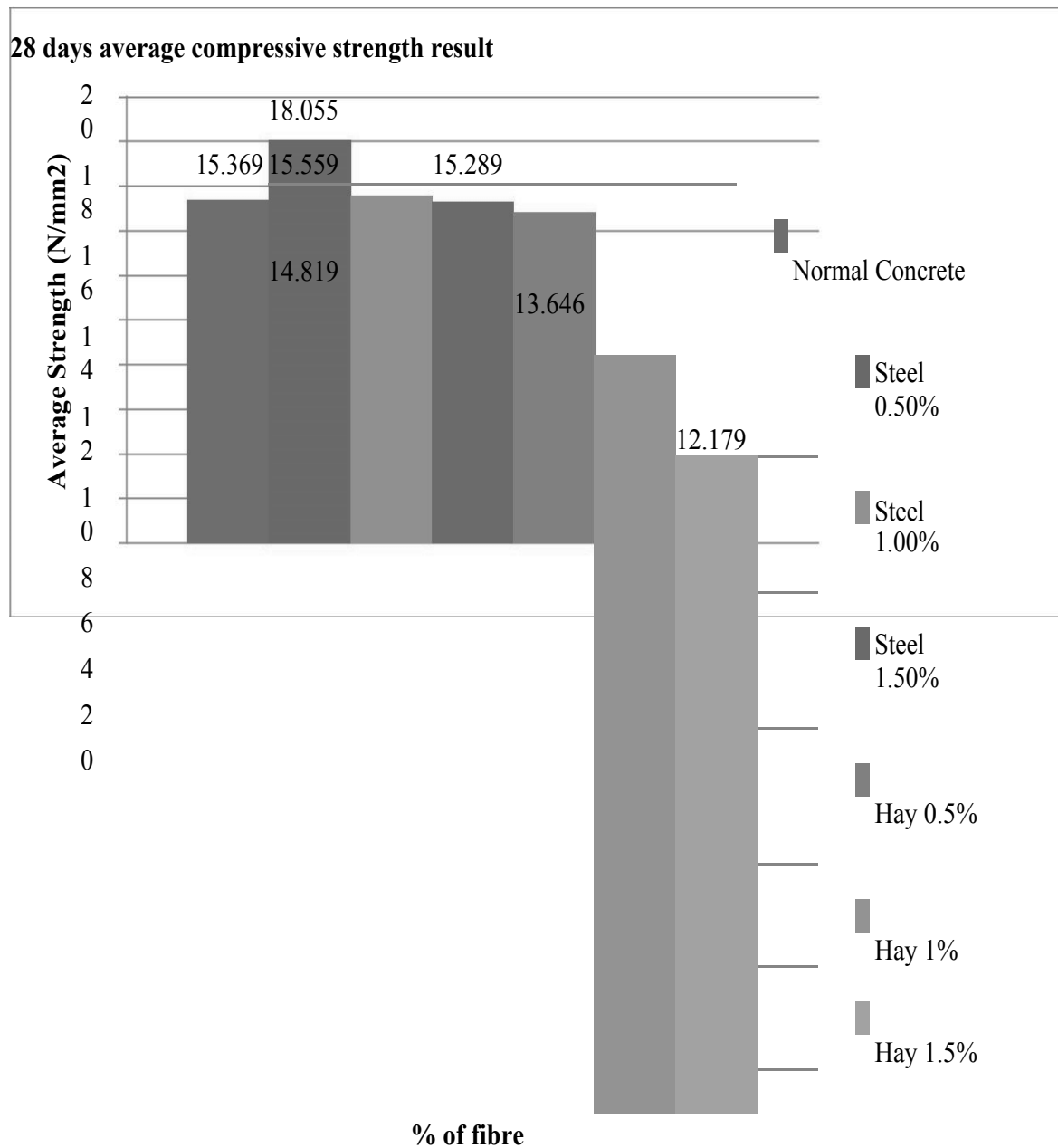
From the test results, it was observed that the 28 days average compressive strength of steel fibre increased by 17.5 % and 1.2%for fibre content 0.5% and 1% respectively while decreased by 0.52% for fibre content of 1.5% in comparison to that of normal concrete.

Similarly, 28 days average compressive strength of hay fibre reduced by 3.6 % , 11.2 % and 20.8 % for fibre content of 0.5% , 1% and 1.5% respectively in comparison to that of normal concrete.

iii)   Tensile Strength Test
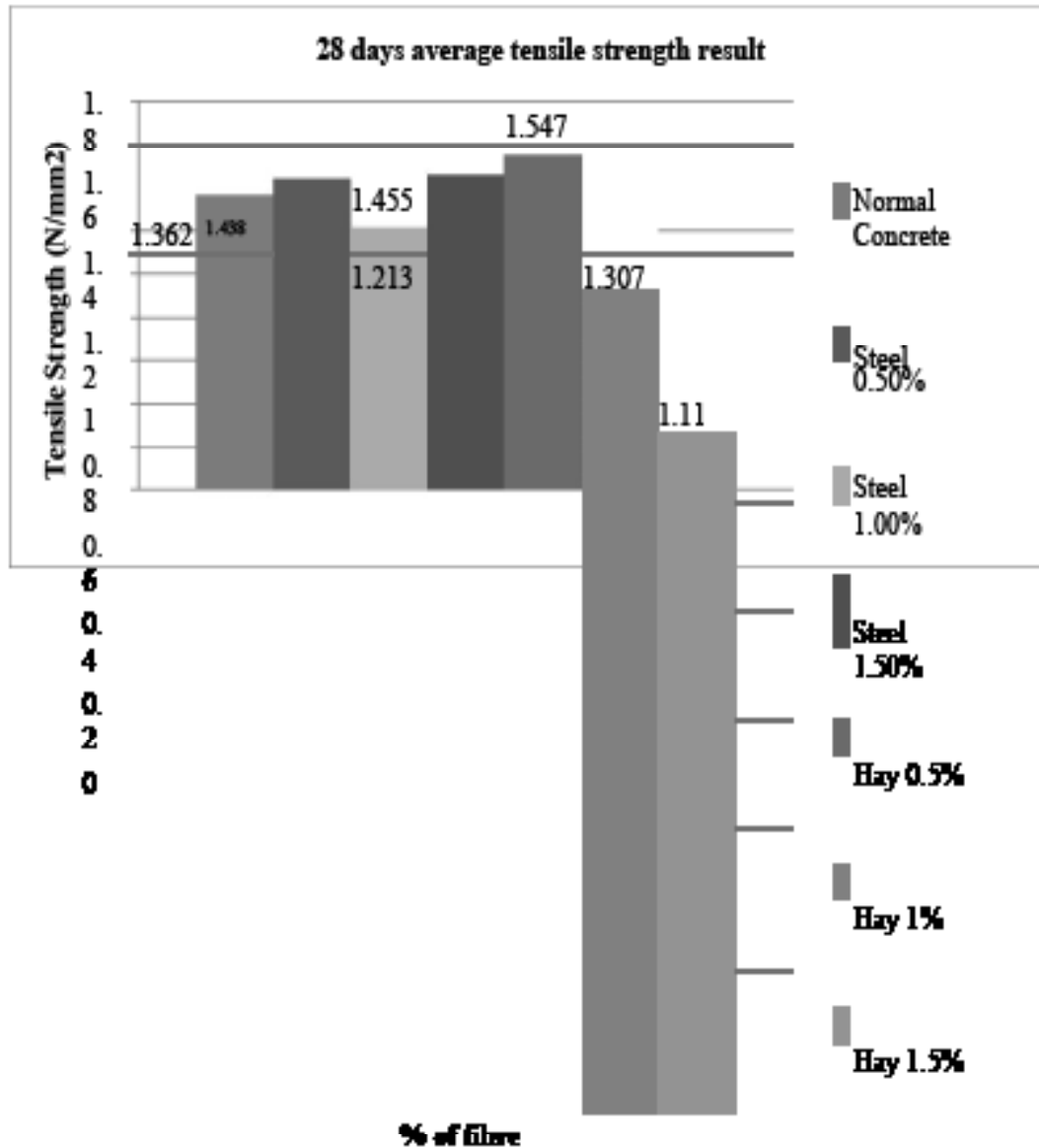
From the test results, it was observed that the 28 days average tensile strength of steel fibre increased by 5.6% and 6.8% for fibre content of 0.5% and 1.5% respectively and reduced by

10.9% for fibre content of 1% in comparison to that of normal concrete. Similarly, 28 days average tensile strength of hay fibre increased by 13.6 % for fibre content of 0.5% and decreased by 4% and 18.5% for fibre content of 1% and 1.5% respectively in comparison to that of normal concrete.

REINFORCEMENT CALCULATION FROM SAP OUTPUT

Requirements of reinforcement as per concrete type used;

	Conventional Concrete (Reinforcement in kg)	Fibre Reinforced Concrete (Reinforcement in kg)
Building Components:		
Columns	2458.785	2222.602
Beams	3912.865	3831.115
Slabs	1735.231	1720.265
Stair	812.959	656.121
Total reinforcement required	8919.84	8430.104

From SAP analysis results and calculations, it was observed that use of fibre reinforced concrete in place of conventional concrete reduces the amount of reinforcement requirement in different components of building. Here, the difference in reinforcement requirement = 489.736 kg

Profit in reinforcement = Rs 35,261 (Rs 72 per kg)

Fibre Amount   = 158.036 kg (0.5% of weight of cement)

Cost of steel fibre = Rs 3,160.72 (Rs 20 per kg)

Net profit in using fibre reinforced concrete = Profit in reinforcement – Loss in fibre

= Rs. 32,100

7.   CONCLUSION & RECOMMENDATIONS

From this experimental study, it is found that the optimum content of (steel or hay) fibre to be added to M15 grade of concrete is 0.5% steel fibre. The slump value is observed to be decreasing with increase in fibre content of both hay and steel.

In case of steel fibre reinforced concrete, maximum compressive strength was observed in 0.5% steel content i.e 18.055 N/mm^2 (increased by 17.5% comparing to normal concrete)and maximum tensile strength was observed in 1.5% steel content i.e 1.455N/mm^2 (increased by 6.8% compared to normal concrete).

In case of hay fibre reinforced concrete, maximum compressive strength was observed in 0.5% steel content i.e 14.819 N/mm^2 (decreased by 3.6% comparing to normal concrete)and maximum tensile strength was observed in 1.5% steel content i.e 1.547 N/mm^2 (increased by 13.6 % compared to normal concrete).

The net profit obtained by the replacement of normal concrete by 0.5% steel fibre reinforced concrete in a two and half storey residential building (from SAP analysis) considering total amount of reinforcement bars and fibre required is Rs. 32,100 (approx. $321) where difference in reinforcement requirement in two types of building is found to be 489.736 kg.

This research would have been more effective if the limitations were overcome considering temperature, orientation, aspect ratio etc.

Problems Encountered

- Uniform mixture of fibre becomes a challenge as balling and lumping of fibres is generally encountered in field problems. In order to avoid the occurrence of balling and lumping, it was proposed to add the fibres uniformly with proper mixing.

- Fibre could have given more strength if they were oriented in a particular direction. But orientation process was more complex and time consuming, so fibres were randomly mixed.

- Due to cold season, the complete setting of concrete after 24 hours of pouring into moulds was not easily achieved.

Future Scope

The use of hay and steel as reinforcement in concrete has opened a wide scope for further research in this particular field. They are:

1) Further study of hay and steel fibres with different length as fibre reinforced concrete and study of the modification in properties of concrete.

2) Extensive study of tensile strength properties of steel and hay reinforcement and its advantage in construction works.

3) The study of admixtures and super plasticizer which could distribute the fibres without affecting the properties of concrete.

4) Division of fibres or fibres content as per the slump test result and determining the construction works where they provide optimum benefits.

8.   ACKNOWLEDGEMENT

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