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An Experimental Study on Mechanical Properties of Human Hair Fibre Reinforced Concrete (M-40 Grade)

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Abstract: *Since the ancient times, many researches and advancements were carried to enhance the physical and mechanical properties of concrete. Fibre reinforced concrete is one among those advancements which offers a convenient, practical and economical method for overcoming micro cracks and similar type of deficiencies. Since concrete is weak in tension hence some measures must be adopted to overcome this deficiency. Human hair is generally strong in tension; hence it can be used as a fibre reinforcement material. Human hair Fibre is an alternative non-degradable matter available in abundance and at cheap cost. It also creates environmental problem for its decomposition. Present work has been undertaken to study the effect of human hair on plain cement concrete of M-40 grade on the basis of its mechanical properties which include compressive, flexural and split tensile strength and also to reduce environmental problems. Experiments were conducted on Concrete cubes, beams and cylinders of standard sizes with addition of various percentages of Human Hair fibre i.e., 1%, 1.5%, 2%, 2.5% and 3% by weight of cement and results were compared with those of plain cement concrete of M-40 grade. For each percentage of human hair added in concrete, six cubes, three beams and three cylinders were tested for their respective mechanical properties at curing periods of 7 days, 14 days and 28days. The change in mechanical properties of concrete is determined and analyzed. The results obtained show us that the optimum content of human hair fibre to be added to M-40 grade of concrete is 1.5% by weight of cement and consequently there has been a significant increase in mechanical properties of concrete. Also addition of human hair fibres enhances the binding properties, micro cracking control, imparts ductility and also increases spalling resistance. The experimental findings in our studies would encourage future research in this direction for long term performance to extending this cost effective type of fibres for use in structural applications.*
Keywords: *Fibre reinforced concrete, human hair fibre, compressive strength, flexural strength, split tensile strength.*

I. Introduction

Fibre Reinforced Concrete (FRC) is concrete containing fibrous material which increases its structural integrity and is gaining importance. It contains short discrete fibres that are uniformly distributed and randomly oriented. The concept of using fibres as reinforcement is not new. Fibres have been used as reinforcement since ancient times. Historically, horsehair was used in mortar and straw in mud bricks. In the early 1900s, asbestos fibres were used in concrete, and in the 1950s the concept of composite materials came into being and fibre reinforced concrete was one of the topics of interest. Later, the use of asbestos for concrete reinforcement was discouraged due to the associated health risks. New materials like steel, glass, and synthetic fibres replaced asbestos for reinforcement. Active research is still in progress on this important technology, and research into new fibre reinforced concretes continues today.

Basically, it can be defined as a composite material consisting of mixtures of cement, mortar or concrete and discontinuous, discrete, uniformly dispersed suitable fibres. Continuous meshes, woven fabrics and long wires or rods are not considered to be discrete fibres. Fibres include steel fibres, glass fibres, synthetic fibres and natural fibres.

What is a fibre ?

A Fibre is a small piece of reinforcing material possessing certain characteristics properties. Addition of fibres to concrete influences its mechanical properties which significantly depend on the type and percentage of fibre. The properties of fibre reinforced concrete is influenced mainly by the physical and mechanical properties of the fibre. A good fibre should have good adhesion within the matrix and adaptable elasticity modulus. It must be compatible with the binder, which shouldn't be attacked or destroyed in the long term. It should be short, fine and flexible to permit mixing, transporting and placing and also strong enough to withstand the mixing process.

Why fibres are used in concrete ?

Generally, Concrete is weak in tension and has a brittle character. Hence fibres are added to increase its tensile strength and improve the characteristics of construction materials. Addition of fibres to concrete makes it a homogeneous and isotropic material. When concrete cracks, the randomly oriented fibres start functioning, arrest crack formation and propagation, and thus improve strength and ductility. Fibres are usually used in concrete for the following reasons:

i. To control cracking due to both plastic shrinkage and drying shrinkage.
ii. They also reduce the permeability of concrete and thus reduce bleeding of water.
iii. Some types of fibres also produce greater impact, abrasion and shatter resistance in concrete.
iv. The fineness of the fibres allows them to reinforce the mortar fraction of the concrete, delaying crack formation and propagation. This fineness also inhibits bleeding in the concrete, thereby reducing permeability and improving the surface characteristics of the hardened surface.

What are the factors effecting properties of FRC ?

Properties of Concrete are affected by many factors like Properties of Cement, Fine aggregate and Coarse aggregate. Other than this Fibre reinforced concrete is affected by following factors:

- **Types of Fibre** : A good fibre should have good adhesion within the matrix and adaptable elasticity modulus. It must be compatible with the binder, which shouldn't be attacked or destroyed in the long term. It should be short, fine and flexible to permit mixing, transporting and placing and also strong enough to withstand the mixing process.

- **Aspect Ratio** : 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. Its value varies for different fibres.

- **Quantity of Fibre** : The amount of fibres added to a concrete mix is measured as a percentage of the total volume of the composite (concrete and fibres) termed as volume fraction (V_f). V_f typically ranges from 0.1 to 3%. Also it can be taken as percentage by weight of cement that is used in preparing concrete. The increase in the volume of fibres, increase approximately linearly, the tensile strength and toughness of the composite. But use of higher percentage of fibre is likely to cause segregation and harshness of concrete and mortar.

- **Orientation of Fibre** : One of the differences between conventional reinforcement and fibre reinforcement is that in conventional reinforcement, bars are oriented in the direction desired while fibres are randomly oriented. It was observed that the fibres aligned parallel to the applied load offered more tensile strength and toughness than randomly distributed or perpendicular fibres.

- **Relative Fibre Matrix Stiffness :** The modulus of elasticity of matrix must be much lower than that of fibre for efficient stress transfer. The Interfacial bond between the matrix and the fibre also determine the effectiveness of stress transfer, from the matrix to the fibre. A good bond is essential for improving tensile strength of the composite.

Effects on mechanical properties of FRC

Addition of fibres to concrete influences its mechanical properties which significantly depend on the type and percentage of fibre. Fibres with end anchorage and Properties and Applications of Fibre Reinforced Concrete with high aspect ratio were found to have improved effectiveness. Below are cited some properties of FRC determined by different researchers.

Compressive Strength : The fibre effect will be minor on the improvement of compressive strength values (0 to 15 percent).

Modulus of Elasticity : For each 1 percent increase in fibre content by volume there is an increase of 3 percent in the modulus of elasticity approximately.

Flexure : The flexural strength was reported to be increased by 2.5 times using 4 percent fibres.

Toughness : For FRC, toughness is about 10 to 40 times that of plain concrete.

Splitting Tensile Strength : The presence of 3 percent fibre by volume was reported to increase the splitting tensile strength of mortar about 2.5 times that of the unreinforced one.

Impact Resistance : The impact strength for fibrous concrete is generally 5 to 10 times that of plain concrete depending on the volume of fibres

Fatigue Strength : The addition of fibres increases fatigue strength of about 90 percent and 70 percent of the static strength at 2 x 106 cycles for non-reverse and full reversal of loading, respectively.

Human Hair

As a Innovation to the field of Fibre Reinforced Concrete, usage of Human Hair as a Fibre gained its importance. Chemically, about 80% of human hair is formed by a protein known as keratin, with a high grade of sulfur – coming from the amino acid cysteine – which is the characteristic to distinguish it from other proteins. Keratin is a laminated complex formed by different structures, which gives the hair strength, flexibility, durability, and functionality. Basically, the hair thread has a cylindrical structure, highly organized, formed by inert cells, most of them keratinized and distributed following a very precise and pre-defined design. Hair forms a very rigid structure in the molecular level, which is able to offer the thread both flexibility and mechanical resistance. Human hair has about 65-95% of its weight in proteins, 32% of water, lipid pigments and other components.

Human Hair fibre is composed by three main structures: cuticle, cortex and medulla. Proteins with α-helix structure which are winded in the hair have long filaments of unknown micro fibres which link to each other to form bigger structures, in order to produce cortex cells. This enchained structure offers the capillary fibre more strength and elasticity. The main factor to be considered in the human hair is the high amount of the amino acid cysteine, which may be degraded and afterwards may be re-oxidated under a disulphidic bounding form. Hair is surprisingly strong. Cortex keratin is responsible for this propriety and its long chains are compressed to form a regular structure which, besides being strong, is flexible. The physical proprieties of hair involve: resistance to stretching, elasticity and hydrophilic power.

Why Human Hair as a Fibre?

Hair is used as a fibre reinforcing material in concrete for the following reasons:

i. It has a high tensile strength which is equal to that of a copper wire with similar diameter.
ii. Hair, a non-degradable matter is creating an environmental problem so its use as a fibro reinforcing material can minimize the problem.
iii. It is also available in abundance and at a very low cost.
iv. It reinforces the mortar and prevents it from spalling.

In this experimental study, human hair fibres are incorporated into concrete at content of 1.0%, 1.5%, 2.0%, 2.5% and 3% by weight of cement. Cubes, beams and cylindrical specimens are casted and cured properly for evaluating various mechanical properties. These specimens made of human hair fibre reinforced concrete are tested at different curing periods (i.e., 7days, 14 days and 28 days) respectively and the change in mechanical properties when compared to plain cement concrete is observed.

II. Literature Review

Review of work done by various researchers discusses the mechanism of fibre-matrix interaction, where various models are used to compute the bonding between the fibres and cement matrix. As the bonding of fibre and the matrix plays a major role in the composite behavior.

Dr.Sinan Abdulkhaleq Yaseen - University of Salahaddin **[1]** published a paper on “An Experimental Investigation into the Mechanical Properties of New Natural Fibre Reinforced Mortar” in 2013. This paper highlights use of human hair fibre (HHF) as a reinforced material in cementitious material. Tests were carried to study the influence of fibre content on the compressive strength, splitting tensile strength, flexural strength and load deflection was presented for two w/c ratios (0.6 and 0.7). An improvement in the energy absorption capacity due to the fibre addition was observed, and the optimum fibre volume fracture was seen to be 0.8%. Energy absorption capacity and ductility factor were improved considerably with fibre content increased, which makes using the HHF suitable for seismic force resistant structures.

Darsh Belani, Prof. Jayeshkumar Pitroda & Dr F S Umrigar - B.V.M Engineering College, Gujarat **[2]** published a paper on “Use of Human Hair as Natural Fibre for Fly Ash Bricks” in August 2013. It states that the human hair waste can be recycled by incorporating in brick-making. In this study, 8 different mixes of fibre fly ash bricks were tested for parameters like: crushing strength, weight, water absorption and cost. It was observed that there was enhancement in properties of fly ash bricks corresponding to the percentages of human hair fibre by weight and was found to be cost effective.

Renju.R.Pillai & Ayothiraman Ramanathan - IIT Delhi **[3]** published an article titled "An Innovative Technique of Improving the Soil Using Human Hair Fibre" in 2012. It presented a laboratory scale study on the influences of soil properties with the inclusion of human hair as fibre. Several laboratory tests were carried out such as consistency limit tests, compaction tests and unconfined compression tests. It was seen that maximum dry density initially reduces lightly and optimum moisture content increases marginally due to moisture absorption of hair fibres. Plasticity of soil increased, thereby enhancing engineering properties. Also with addition of 2.0% fibres by weight, the unconfined compressive strength increased up to 2 times that of unreinforced soil. This clearly indicated that the human hair fibre could be used in the improvement of cohesive soils.

Tomas U. Ganiron Jr. Australian Institute of Geoscientists, Qassim University **[4]** in Buraydah City, Saudi Arabia published a paper titled "Effects of Human Hair Additives in Compressive Strength of Asphalt Cement Mixture" in 2014. This experimental study presented the effects of human hair additives in compressive strength of asphalt cement mixture as potential binder in road pavement. It stated that the elastic property of the hair fibre reinforced in asphalt pavement may produce better stand on traffic loading i.e., increases the strength by the same fundamental mechanism of transferring the high intensity forces imparted at the surface by the wheel loads to lower levels that the subgrade can accommodate without deforming.

But it also faced the problem of uniform distribution of hair as they tend to "ball" in the mix and create workability problems. To avoid this problem, they have adopted the manual method of distribution of hair.

III. Experimental Programme

3.1 Materials Used

Cement : It is mixture of calcareous, siliceous, aluminous substances and crushing the clinkers of a fine powder. The ordinary Portland cement of 43 Grade is used. The specific gravity of cement is 3.15. For ordinary Portland cement, the initial setting time is 45 minutes and the final setting time is 600 minutes. The oxide contents are as follows : 60-67% CaO, 17-25% SiO_2, 3-8% Al_2O_3, 0.5-0.6% Fe_2O_3 and 0.1-0.4% MgO.

Fine Aggregate : The sand used for the experimental programme was locally procured and confirmed to grading zone II. The sand was sieved first through 4.75mm sieve to remove any particles greater than 4.75mm and was then washed to remove dust. The properties of fine aggregates are as follows : Specific gravity – 2.65 and Fineness Modulus – 3.35.

Coarse Aggregate : The material whose particles are of size as are retained on I.S. Sieve No. 480 (4.75 mm) is termed as Coarse Aggregate. The size of coarse aggregate depends upon the nature of work. The coarse aggregate used in this experimental investigation are of 20mm (60%), 16mm (20%) and 12mm (20%) sizes, crushed angular in shape. The aggregates are made free from dust before being used in the concrete. Its specific gravity is 2.74.

Human Hair Fibres : The properties of human hair are tabulated below :

PROPERTY	VALUE
Hair diameter	100 to 120 μm
Hair length	60mm
Aspect ratio	500 – 600
Tensile strength of Human Hair fibre	380 MPa
Ultimate Tensile Strain	50.16%

Water : Water used in the experimental work is conformed to IS: 456-2000 for mixing as well as curing of Concrete specimens.

3.2 Mix Design

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 designed as per IS 10262:2009 to achieve a target compressive strength of 40 MPa. Design mix proportions of M-40 grade are tabulated below :

Concrete Mix Proportions

Ingredient	Cement	Water	Fine aggregate	Coarse aggregate	Water-Cement Ratio
Weight	448 kg/m^3	197 lit	687.126 kg/ m^3	1108 kg/ m^3	0.44

The human hair fibres were added at percent variation of 1 %, 1.5 %, 2 %, 2.5% and 3 % by weight of cement in M - 40 Grade concrete and was compared to plain cement concrete.

3.3 Preparation and Details of Test Specimens

Casting and testing of cubical specimens of size 150mm×150mm×150mm for compressive strength and beam specimens of size 150mm×150mm×700mm for flexural 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.

In the present experimental investigation, the total number of specimens casted were 72. The cubes casted were totally 36 in number, of which each set of 6 cubes were meant for each percentage of hair (i.e., 0%, 1%, 1.5%, 2%, 2.5% and 3%). Out of 6 cubes, 2 cubes were tested for 7 day strength, 2 cubes were tested for 14 day strength and remaining 2 cubes were tested for 28 day strength. Similarly 18 beams and 18 cylinders were casted, of which each set of 3 beams and 3 cylinders were meant for each percentage of hair. In these, each beam and each cylinder were tested for 7 day strength, 14 day strength and 28 day strength respectively.

3.4 Workability Tests

The most general standard workability tests i.e., Slump test and Compaction factor test are carried out as per specifications provided in IS 1199:1959 to determine the workability of fresh concrete. It has been observed that the workability of concrete has been reduced consistently with the increase in the percentage of human hair in concrete. The compaction factor was found to be 0.82 and slump value of 90mm for concrete mix prepared. The reduction was slighter till 1.5% hair reinforced concrete but dropped suddenly thereafter 3% hair reinforced concrete was found to be unworkable. It is found that concrete reinforced with 1.5% of human hair fibres was found to have ideal workable conditions.

3.5 Tests on Hardened Concrete
3.5.1 Compressive Strength Test

This test was conducted as per IS 516:1959. The cubes specimens of standard size 150mm ×150mm × 150mm were use to find the compressive strength of concrete. Specimens were placed on the bearing surface of UTM of capacity 100 tonnes without eccentricity as shown in Fig. 3.1. A uniform rate of loading 550 kg/cm^2 per minute was applied till the failure of the cube. The maximum load was noted and the compressive strength was calculated.

Cube compressive strength (f_{ck}) in MPa, $\boldsymbol{\sigma} = \frac{P}{A}$

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)

Fig.3.1: Compressive Strength Test

3.5.2 Flexural Strength Test

This test was carried out as per IS 516:1959 specifications. Normal concrete beams and human hair reinforced concrete beams of size 150mm ×150mm ×700mm are tested using a flexure testing machine. The specimen is simply supported on the two rollers of the machine which are 600mm apart, with a bearing of 50 mm from each support as shown in Fig. 3.2. The load shall be applied on the beam from two roller which are placed above the beam with a spacing of 200mm. The load is applied at a uniform rate such that the extreme fibres stress increases at 0.7 N/mm^2/min i.e, the rate of loading shall be 4KN/min. The load is increased till the specimen fails. The maximum value of the load applied is noted down.

The modulus of rupture is calculated using the formula $\sigma_b = \frac{PL}{bd^2}$

Fig. 3.2 : Flexural Strength Test

Where,

P= Breaking load in N at which specimen fails
L= length in mm of the span on which the specimen is supported (600)
b= measured width in mm of the specimen (150)
d= measured depth in mm of the specimen at point of failure (150)

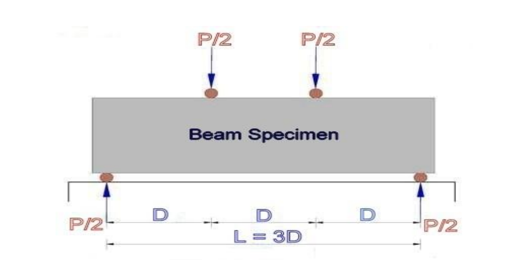


Fig. 3.3 : Flexure Test Setup

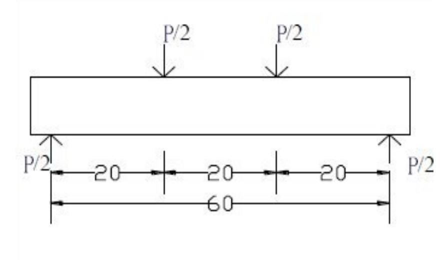


Fig. 3.4 : Loading Pattern

3.5.3 Splitting Tensile Strength Test

This test was carried out as per IS 5819:1999 specifications. Normal cylinders and human hair reinforced concrete cylinders of size 150mm(dia) ×300mm (height) are casted and cured. The test is carried out by placing a cylindrical specimen horizontally between the loading surface of a compression testing machine and the load applied until the failure of the cylinder, along the vertical diameter as shown in Fig. 3.5. When the load is applied along the generatrix, an element on the vertical diameter of the cylinder is subjected to a horizontal stress of $\frac{2P}{\pi Ld}$

Where , P = compressive load on the cylinder in N
L = length of the cylinder in mm (300)
d = diameter of the cylinder in mm (150)

Fig. 3.5 : Split tensile Strength Test

IV. Results And Discussions

The experimental studies to assess the mechanical properties of a human hair fibre Reinforced Concrete (M-40 Grade) were conducted in the concrete laboratory of the college during January-April 2015. The experimental results are shown vide Table 4.1, Table 4.2 and Table 4.3 and relevant graphs are also presented vide Fig.4.1, Fig.4.2 and Fig.4.3.

The mechanical properties included in the studies are Compressive Strength, Flexural Strength and Splitting Tensile Strength, tested on specimens made by M-40 grade concrete with and without human hair as fibre reinforcement. The percentage of human hair fibre is varying from 1% to 3% with an increase of 0.5% in each iteration. And the tests were conducted for different curing periods, i.e. 7, 14 and 28 days (ultimate) to study the impact of curing periods on the test samples.

During the casting of test samples, it was observed that mixing of human hair in the concrete to achieve homogeneity is a problem at concentration above 1.5% of human hair, resulting in balling and lumping of hair fibres which will ultimately affect the mechanical properties of the concrete which are considered for the study.

There has been a gradual increase in the mechanical properties up to 1.5% of human hair and subsequently shown declining trend up to 3% concentration for different curing periods as shown in Fig.4.1, Fig.4.2 and Fig.4.3. This declining phenomenon may be attributed to balling and lumping which will affect the mechanical properties as observed from the results. The rate of increase of flexural strength (23-27%) and Split tensile strength (17-29%) is more when compared to Compressive strength which is in the range of 7-8%. This observation is in tune with the behavior of the concrete with the addition of reinforced fibres like human hair.

The results are briefly tabulated and comparison between human hair fibre reinforced concrete and plain cement concrete is shown in graphs below :

Table 4.1 : Average Compressive Strength at different curing periods with Human Hair percent Variation for M-40 Grade of Concrete

S.No.	% Human Hair	Compressive Strength at different Curing Periods in MPa					
		7 Days		14 Days		28 Days	
		Average Load(KN)	Compressive strength(MPa)	Average Load(KN)	Compressive strength(MPa)	Average Load(KN)	Compressive strength(MPa)
1	0	603.80	26.84	766.90	34.08	918.25	40.80
2	1.0	615.90	27.43	788.95	35.06	947.25	42.10
3	1.5	646.95	28.78	822.15	36.54	993.25	44.14
4	2.0	630.45	27.93	802.10	35.65	956.20	42.50
5	2.5	620.10	27.55	780.20	34.67	929.10	39.05
6	3.0	609.10	27.06	766.30	34.06	901.85	38.31

Fig. 4.1 : Graph showing variation between Average Compressive Strength at different curing periods with human hair percent variation in M-40 Grade of Concrete

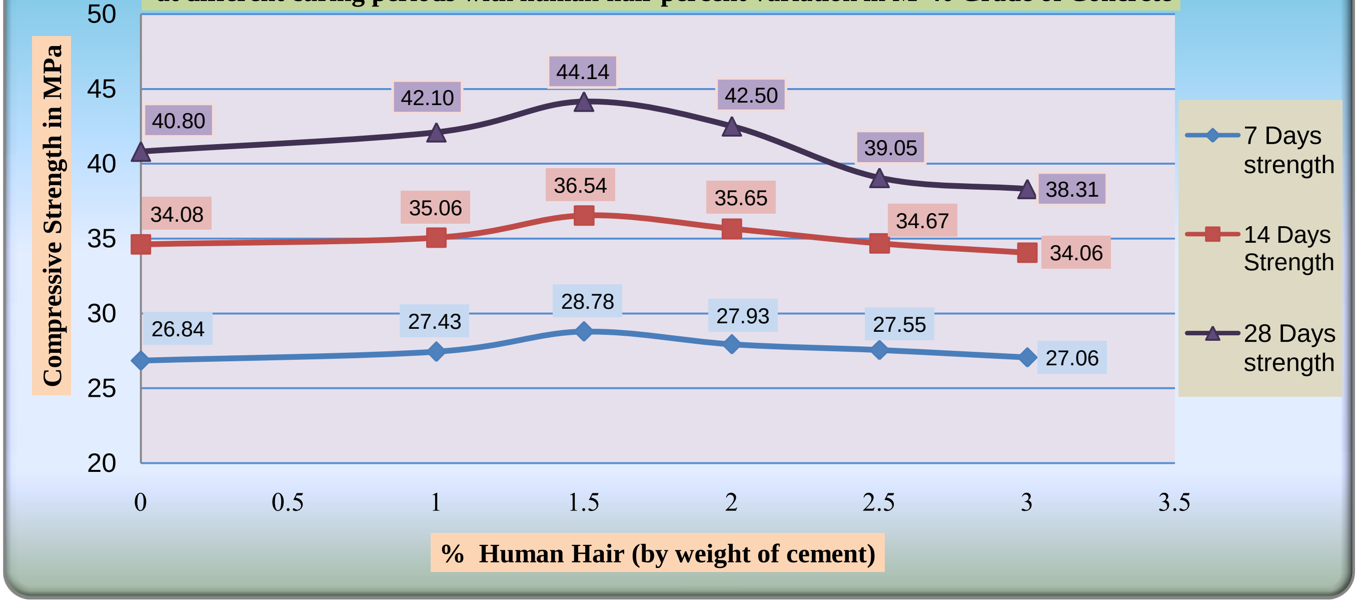


Table 4.2 : Average Flexural Strength at different curing periods with Human Hair percentage Variation for M-40 Grade of Concrete

S.No.	%HumanHair	Flexural Strength at different curing periods in MPa					
		7 Days		14 Days		28 Day Strength	
		Average Load(KN)	Flexural strength(MPa)	Average Load(KN)	Flexural strength(MPa)	Average Load(KN)	Flexural strength(MPa)
1.	0	14.5	2.58	21.5	3.82	25.5	4.53
2.	1.0	16.5	2.93	23.5	4.18	28.5	5.07
3.	1.5	18.5	3.29	26.0	4.62	31.5	5.60
4.	2.0	16.0	2.84	23.0	4.09	29.5	5.24
5.	2.5	15.5	2.75	22.0	3.91	27.0	4.80
6.	3.0	14.0	2.48	21.0	3.73	24.0	4.27

Fig. 4.2: Graph showing variation between Average Flexural Strength at different curing periods with human hair percent variation in M-40 Grade of Concrete

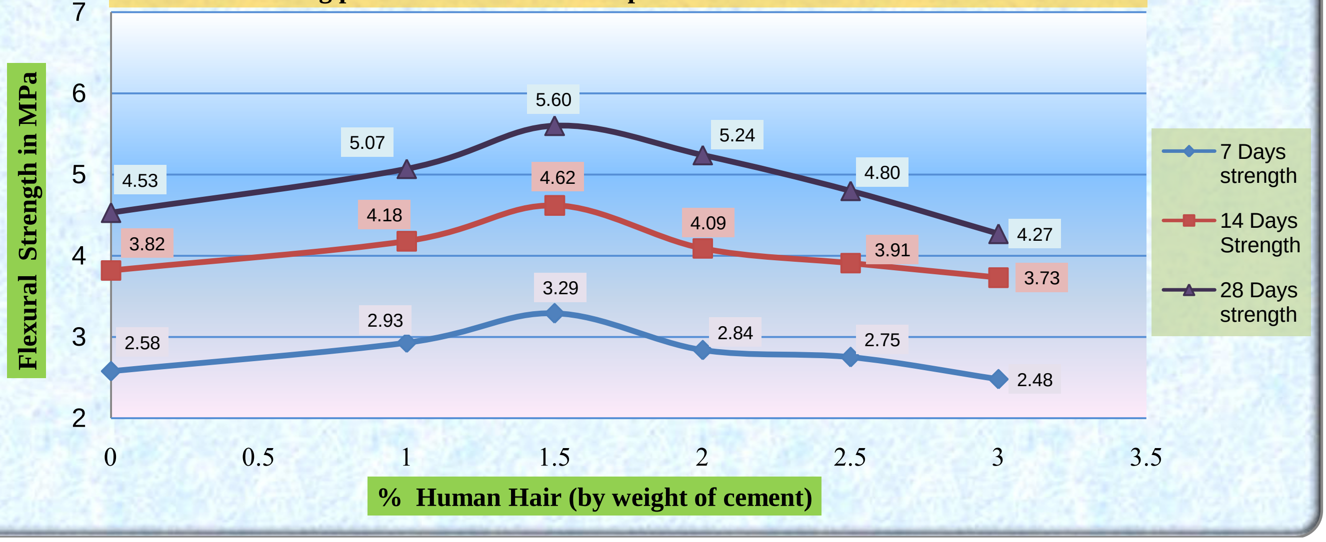
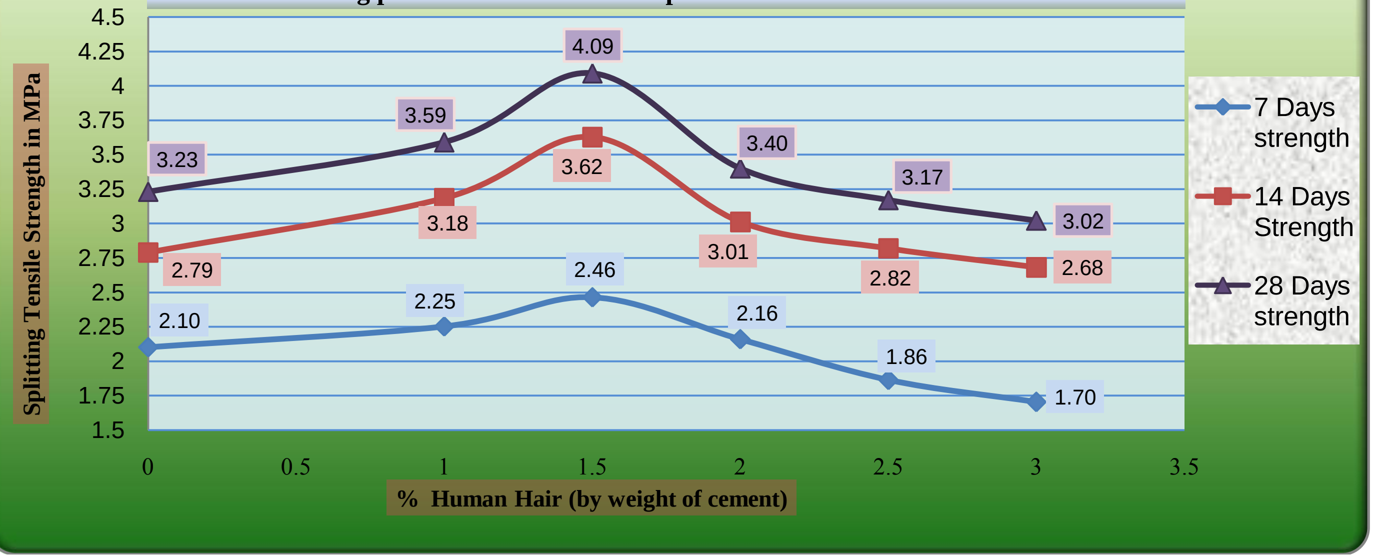


Table 4.3 : Average Splitting tensile Strength at different curing periods with Human Hair percentage Variation for M-40 Grade of Concrete

S.No.	%Human Hair	Splitting Tensile Strength at different curing periods in MPa					
		7 Day Strength		14 Day Strength		28 Day Strength	
		Average Load (KN)	Split Tensile strength (MPa)	Average Load (KN)	Split Tensile strength (MPa)	Average Load (KN)	Split Tensile strength (MPa)
1.	0	148.5	2.10	197.3	2.79	228.4	3.23
2.	1.0	159.3	2.25	225.2	3.18	253.8	3.59
3.	1.5	174.2	2.46	256.4	3.63	289.2	4.09
4.	2.0	152.7	2.16	212.9	3.01	240.4	3.40
5.	2.5	131.8	1.86	199.3	2.82	224.2	3.17
6.	3.0	120.4	1.70	189.6	2.68	213.6	3.02

Fig. 4.3 : Graph showing variation between Average Split Tensile strength at different curing periods with human hair percent variation in M-40 Grade of Concrete



V. Conclusions

From this experimental study, it is found that the optimum content of human hair fibre to be added to M-40 grade of concrete is 1.5%. It is observed that there has been improvement in the properties of M-40 grade of concrete in terms of its compressive strength, flexural strength and split tensile strength corresponding to the percentages of hair by weight of cement in concrete.

The experimental results indicated the following salient features of M-40 Grade concrete with the addition of HHF.

- It was found that M-40 grade concrete with 1.5% human hair fibre shown an increase in compressive strength of 7.22%, 7.21% and 8.18% at curing periods of 7 days, 14 days and 28 days respectively when compared with the plain cement concrete (i.e., values corresponding to 0% human hair fibre in Fig.4.1, Fig.4.2 and Fig.4.3).
- Increase in the flexural strength was in the order of 27.60%, 20.93% and 23.56% for the same experimental conditions at curing periods of 7 days, 14 days and 28 days respectively.
- Similarly the split tensile strength recorded an increase of 17.26%, 29.98% and 26.60% for the same experimental conditions at curing periods of 7 days, 14 days and 28 days respectively.

Other than the mechanical properties of concrete, it has enhanced the following physical properties :

- The addition of human hairs to the concrete not only modifies various properties of concrete like tensile strength, compressive strength but also enhances the binding properties, micro cracking control and also increases spalling resistance. The crack width is reduced to a greater extent.
- It imparts ductility to a certain extent which can be seen in experimental testing of beams. It tends the beam to bend and thus warning well before failure thereby enhancing safety.
- As the percentage of human hair increases, the strength increased upto 1.5% itself and then decreased. Its basically the tendency of human hair that has a water absorption capacity of about 30% of its own weight. And, it is in impure nature, the percentage may increase to 45-50% of its weight. Thus, we add to concrete is not sufficiently utilized by the cement, thereby percentage of unhydrated cement increases much more. Hence it weakens the structure and strength gets reduced.

Problems Encountered

The practical difficulties encountered are summarized below:

- The phenomenon of balling and lumping of fibres is generally encountered in field problems due to the addition of a fixed percentage of fibres directly to the ingredients of concrete during mixing. In order to avoid the occurrence of balling and lumping, it was proposed to add the fibres uniformly with proper mixing.
- The addition of fibres was taken up in three to five layers with approximately equal depths of layers and equal quantity of fibre in each layer. This results in improper or difficulty in penetration of aggregates in the void spaces. Also, it was noticed that 2% human hair fibres onwards further aggravated this problem.

Future Scope

The use of waste human hair as a fibre reinforcement in concrete widens the door for further research in the given field. They are as follows:

- The study of admixtures and super plasticizer which could distribute the hairs without affecting the properties of concrete.
- The distribution matrix of hair in concrete which affects the properties of resultant matrix.
- The study and type of human hair which can be used based on different age groups, its keratin properties etc.
- The use of human hair as nano material in the advanced nanotechnology in concrete.

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