Case Studies in Construction Materials 13 (2020) e00412

Contents lists available at ScienceDirect

Case Studies in Construction Materials

journal homepage: www.elsevier.com/locate/cscm

Case study

Sustainable composite development: Novel use of human hair as fiber in concrete

Naraindas Bheel[a], Paul Awoyera[b,*], Oluwatobi Aluko[c], Santosh Mahro[d], Amelec Viloria[e], Carlos Alberto Severiche Sierra[f,g]

[a] Civil Engineering Technology, Hyderabad College of Science and Technology, Hyderabad, Sindh, Pakistan
[b] Department of Civil Engineering, Covenant University, Ota, Nigeria
[c] Civil Engineering Department, M46, School of Civil Engineering, Universiti Teknologi, Malaysia
[d] Institute of Environmental Engineering & Management, Mehran University of Engineering and Technology, Jamshoro, Sindh, Pakistan
[e] Universidad de la Costa, Baranquilla, Colombia
[f] Grupo de investigacion GASST, Corporacion Universitaria Minuto de Dios – UNIMINUTO, Barraquilla, Colombia
[g] Grupo de investigacion GITEC, Corporacion Universitaria Rafael Nunez – CURN Cartagena de indias, Colombia

ARTICLE INFO

Article history:
Received 2 July 2020
Received in revised form 3 August 2020
Accepted 3 August 2020

Keywords:
Human hair
Fiber reinforcement
Mechanical properties
Environmental pollution
Waste reuse

ABSTRACT

In the present era, to recycle waste and to reduce environmental pollution is the main objectives of sustainable development. Many researchers are working on new techniques and thinking for innovation in the field of concrete technology by utilizing the waste material in concrete. This research aims to check the effect of a human hair (waste material) as fiber on the fresh, physical and mechanical properties of concrete with 0%, 1%, 2%, 3%, and 4% of human hair by volume of cement. In this regard, a total of 180 concrete specimens (cubes, cylinders, and prisms) was made and cured after 7th, 28th, and 90th day. The result indicated that the compressive strength was enhanced by 8.15 % at 1% human hair after 28 days as indirect tensile strength and flexural strength were improved by 21.83 % and 12.71 % at 2% of human hair after 28 days, respectively. Also, the density of concrete gets reduced with rising in the content of human hair, and water absorption is improved, as the content of human hair increases after 28 days, respectively. Besides, the modulus of elasticity increased with the inclusion of human hair after every curing period, and drying shrinkage of concrete is minimized with the addition of human hair as fibers in concrete at 40 days. The slump value was reduced as the content of human hair increased.

1. Introduction

Concrete is one of the most consumed human-made materials in the world [1–3]. Annually 10 billion tons of concrete are manufactured [4]. It is moldability, strength, and durability made it usable in building, roads, and other hydraulic constructions [5,6]. However, the demerit of concrete is that it is weak in tension but strong in compression [7], and different fibers like steel, synthetic natural fiber, are used to overcome this deficiency. Human hair fibers (HHF) have been used extensively in concrete, but in this research, a human hair is used as fiber in concrete by the volume of cement [8]. Sustainable development goals meet current needs and requirements without risk to future generations.

* Corresponding author.
E-mail address: paul.awoyera@covenantunivesity.edu.ng (P. Awoyera).

https://doi.org/10.1016/j.cscm.2020.e00412

Currently, tremendous population growth leads to produce a considerable quantity of human hair waste. Human hair waste is thrown into open storage facilities and is considered as municipal solid waste (MSW) in most of the regions, which are available in most urban cities as municipal waste streams throughout the world [9,10]. Human hairs are either incinerated with municipal solid waste or thrown down in the sewerage line through the toilet in most of the developing countries, which adversely affect the environment. When human hair is thrown into a household sewer pipe, it blocks the sewer pipe and increases the nitrogen concentration in the sewer water pipes, and finally, the sewage water will overflow across streets through utility holes. Open dumping of hair generates hair dust that can cause uneasiness in a nearby home. In sparsely populated areas, hair wastes are openly dumped, where it takes years to decompose. The combustion of Human hair creates unpleasant odors and produces hazardous gases like ammonia, carbonyl sulfide, hydrogen sulfide, sulfur dioxide, phenol, nitrite, pyrrole, and pyridine [11,12] that cause environmental degradation. The growth rate of hair on the head is around 12.7 mm monthly, and it weighs about 80−100 g per year [9]. Taking into account the total world population is 7.7 billion [13] that produced about 6.9×10^5 tons of hair per year.

On the other hand, in previous years, a similar amount of hair was dumped as municipal solid waste. Given this aspect, more and more attention is being paid to use it in construction work. The use of human hair waste not only saves the disposal cost besides it has many indirect advantages, like energy conservation and environmental safety. Adding to ordinary concrete reduces the brittleness of concrete fibers such as steel, synthetic fibers, and plastics. The use of discrete fibers for reinforcing brittle composites is an ancient concept. Still, the era of using fibers in concrete to increase ductility and bending strength began in the early 1900s [14,15]. Fibers in concrete can enhance tensile and bending strength [16–24], inhibits crack growth and increases toughness [11]. Fibers can control cracking caused by plastic shrinkage and drying shrinkage [24–26]. Fibers improve shear and impact resistance of concrete [27–29]. The microfibers can mitigate the growth of minor cracks, though macro fibers can enhance concrete performance after cracks [30,31]. Human hair strands have high tensile strength and friction coefficient. That is why in rural areas of Bangladesh, India, Syria [9,32] and European countries [33], human hair was used to strengthen clay structures with clay and other adhesives on the plastered walls of houses. More than 90 % of shrinkage value can be minimized with the inclusion of human hair in concrete [34]. The previous research studies conducted by Jain D. and Kotari A [34]. found during experiments that the addition of 1.5 % by volume of a human hair to regular concrete can increase concrete crushing strength to 22 % and bending strength to 8.60 %.

Similarly, Meghwar et al., [35] concluded that in the case of cement by weight ratio of 1:2:4 and 0.50 w/c, the addition of 1% HSH to the cement can increase the compressive strength by 26.8 %. Batebi et al. [36] believed that hair lengths of 15 mm and 60 mm could reduce the shrinkage of reinforced concrete when used with a solution weight of 0.4 %, 0.8 %, and 1.2 %. Physical properties of fibers, such as diameter and length, are directly related to various properties of concrete [37]. The smaller the fiber diameter, i.e., the higher the aspect ratio (aspect ratio), the more difficult it is to disperse the fibers in concrete. On the other hand, the shorter the fiber length, the smaller the aspect ratio, the easier it is to disperse the fiber in fresh concrete [38]. It is also noteworthy that fibers with higher aspect ratio would lead to higher tensile capability of concrete or fiber reinforced cement-based composites [39]. When the fiber placement is in one direction and parallel to the applied load, the best advantage can be obtained, while with a random orientation in three dimensions, the benefits obtained are smaller. Until now, due to the short fiber length, it is hard to have the distribution and arrangement of the fibers in one direction to get the maximum benefit [40–42].

This experimental investigation was conducted to identify the effect of human hair as fiber in concrete for determining the fresh, physical, and mechanical properties of concrete at different ratios of human hair by the volume of cement.

2. Materials and methods

The Portland cement (PC) was utilized as a binding ingredient in concrete for this research study. The setting time for cement was calculated by observing ASTM C191-19 [43]. Table 1 elaborates on the chemical composition of PC, while the physical properties for cement are summarized in Table 2. Human hair was collected from different Barbershops of the Hyderabad region. The properties of the human hairs utilized are: length 8–100 mm, diameter 0.04 – 0.12 mm, modulus of elasticity of about 4 GPa. With the observed properties, it is clear that the performance of the huma hair is somewhat comparable to the natural fibres. Considering that the quality control of human hair would be key issue for its application to concrete, and in addition, that human hair can be naturally decayed. The hair was adequately washed two times with washing powder to separate unwanted ingredients. Also, ensuring that there was greasy texture on the hair. Then it was

Table 1
Chemical composition of PC.

Compound	PC
SiO_2	20.78
Al_2O_3	5.11
Fe_2O_3	3.17
CaO	60.22
Na_2O	0.18
SO_3	2.86

Table 2
Properties of Cement.

S.No	Property	Cement
01	Normal Consistency	33 %
02	Initial Setting Time	48 min
03	Final Setting Time	260 min
02	Specific Gravity	3.15
04	Fineness Modulus	5%

spread for drying under the sunlight. After that, it was mixed thoroughly in concrete by the volume of cement. The hill sand was used as fine aggregates that passed through #4 sieve, and coarse aggregates were used of 20 mm in size in this research work. These materials were collected locally from the Hyderabad region. The sieve analysis of aggregates is calculating under the ASTM C136 [44]. The specific gravity of coarse aggregates (CA) and fine aggregates (FA) are computing under the code of ASTM C127-93 [45] and ASTM C128-93 [46] respectively. However, Bulk density of aggregates is obtained by using ASTM C29-97 [47], and water absorption of coarse and fine aggregates are found under the ASTM C127-93 [45] and ASTM C128-93 [46] code of conduct respectively. The properties of aggregates are shown in Table 3. The drinking water was utilized for mixing and curing of concrete.

3. Research methodology

This experimental study was conducted to check the effect of human hair as fiber in concrete so as to find fresh, Physical, and mechanical properties of concrete. A total of 180 concrete specimens were cast for investigating the mechanical properties of concrete. These concrete samples were cast by five proportions like 0%, 1%, 2%, 3%, and 4% of human hair by volume of cement. The water to binder ratio was maintained at 0.50, and the ratio between coarse aggregate and fine aggregate at 2. The detailed composition of each mixture evaluated is presented in Table 4.

4. Testing methods

4.1. Slump test

The slump test was done to know the workability of fresh concrete. The slump was determined immediately after preparing the mixture in line with the ASTM C143-90 [48].

4.2. Mechanical properties of concrete

The 150 mm cube specimens were used for investigating the compressive strength, as shown in Fig. 1. It is one of the fundamental properties of hardened concrete that provides the quality of concrete by obeying ASTM C39/C39 M [49], and split tensile strength was examined under ASTM C 496-90 [50] after 7, 28 and 90 days respectively. For the tests, triplicate samples were tested and the average of the results was noted as the strength values for each mix. Place the standard

Table 3
Properties of Aggregates.

Property	Fine aggregate	Coarse aggregate
Fineness Modulus	2.21	–
Specific Gravity	2.66	2.70
Absorption (%)	1.75	1.20
Bulk density (kg/m^3)	1890	1569

Table 4
Mixtures composition (kg/m^3).

Mixture ID	PC	Human Hair (%)	Water	Fine aggregate	Coarse aggregate
0HHF	375	0	190	560	1120
1HHF	375	1	190	560	1120
2HHF	375	2	190	560	1120
3 HHF	375	3	190	560	1120
4 HHF	375	4	190	560	1120

Fig. 1. Compressive Strength Test.

Fig. 2. Split Tensile Strength Test.

cylindrical specimen horizontally in the Universal Testing Machine (UTM) jaws and apply a load until it was divided into two parts, as given in Fig. 2. Similarly, the flexural strength was carried out following ASTM C293 / 293 M [51] (center load method) after 7, 28, and 90 days. Fig. 3 shows that the concrete prism is put in a simply supported assembly, and the load is applied through the UTM until it is divided into two parts, as summarized in Fig. 3. Also, concrete density is measured for every percent of human hair to understand the correlation between strength and density. Moreover, density is determined by weighing concrete samples with electronic weight balance under conditions of SSD (saturated surface drying). After curing, the concrete sample is placed in a cool place for 1 day to adapt to the conditions of the SSD. Then the weight is determined per ASTM C1754 / C1754 M [52] specifications and water absorption of concrete is calculated by observing ASTM C1585-13 [53]. Besides, the modulus of elasticity test was examined to know the stiffness of material with reference to code

Fig. 3. Flexural Strength Test.

Fig. 4. Concrete Specimens Curing Tank.

ASTM C 469 [54] after 7, 28, and 90 days respectively. However, the drying shrinkage of the hardened concrete was calculated following ASTM C426-07 [55] at 40 days (Fig. 4).

5. Results and discussions

5.1. Slump test

Fig. 5 shows the graphical demonstration of the variation in the slump values with rising in the content of human hair in concrete. Higher slump (65 mm) was obtained for concrete without hair fiber, but slump for hair fiber-reinforced mix was 22 mm, representing a 4% improvement in slump for hair reinforced concrete. This decrease may be due to a lower ratio of aggregate to cement and a lower specific surface area of the aggregate covered with cement mortar in the former mixture. Also, with an increase in the proportion of hair, workability is gradually reduced. This trend may be associated with a rise in the specific surface area of the material, more human hair in concrete to need more cement mortar to cover its area, thereby reducing the quantity of water needed for workability. Generally speaking, workability decreases as the fiber content of human hair in concrete increases. Similarly, the trend of reducing workability was also reported in a related study by Meghwar et al., [56].

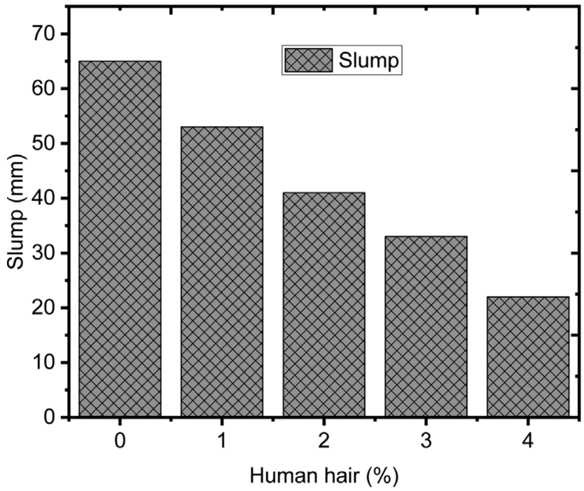

Fig. 5. Slump Test of Concrete.

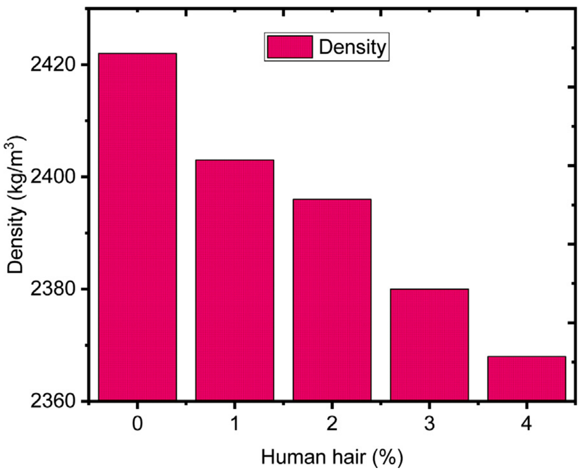

Fig. 6. Density of Concrete.

5.2. Density of concrete

Fig. 6 shows that with an increase in the percentage of hair, concrete density decreases. The maximum density is noted by 2422 kg/m^3 at 0% of Human hair, while minimum recorded by 2368 kg/m^3 at 4% of Human hair in concrete mix ratios. This decrease in density shows that the density of the hair is lower than that of other constituents of concrete, and hairs entrapped more air as compared to control mix concrete, these are two possible reasons for the decrease in the density and strength of concrete.

5.3. Water absorption of concrete

The concrete samples were utilized for investigating the water absorption of concrete. The maximum water absorption was noted by 3.07 % at 4%, and minimum water absorption was noted by 2.46 % at 0% after 28 days. Resultantly, water absorption of concrete was increased as the content of human hair increased, as presented in Fig. 7. This increment of water absorption in concrete may be human hair absorb more water as compared to control mix concrete.

5.4. Compressive strength

The standard 150 mm concrete cubes was used for this test. At each percentage of hair, three cubes were taken for crushing strength, and finally average of three is considered as the ultimate result. From experimental results presented in

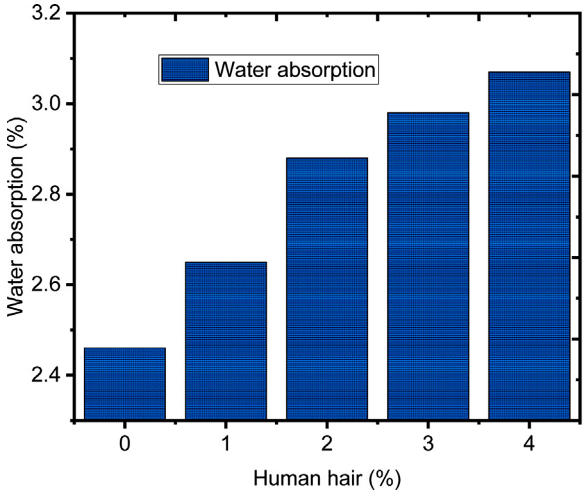

Fig. 7. Water Absorption of Concrete.

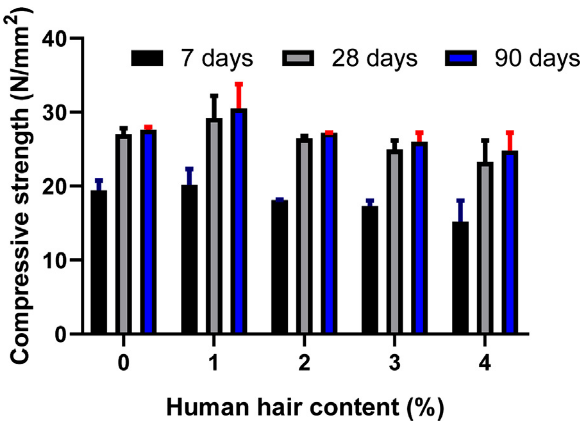

Fig. 8. Compressive Strength of Concrete.

Fig. 8, it was found that compressive strength reduced with increasing hair fiber content. The increase in compressive strength observed at 1% is 4%, 8.15 %, and 10.51 % after 7, 28, and 90 days respectively. Reduction in compressive strength is 21.6 %, 13.80 %, and 10.14 % at 4% addition of hair after 7, 28, and 90 days respectively. Maximum and minimum strength was notified at 1% and 4% of hair. This reduction in strength may be due to a decrease in the density of concrete with an increasing percentage of human hair. Also, when pouring concrete into the mold, there is free space in the fresh concrete. Concrete is compressed and placed into its shape by vibration or other methods to minimize these gaps. The gaps trapped in concrete reduce both the strength of concrete and cause the concrete to contain more gaps; as a result, concrete contains more voids, which complicates the impact of concrete on any external environment.

5.5. Splitting tensile strength

Fig. 9 represents a graphical demonstration of the variation in tensile strength. The splitting tensile strength enhances gradually, as the content of human hair increases in concrete mixes, till it reached the highest value of 17.5 %, 21.83 % and 22.1 % at 2% of human hair fiber after 7, 28 and 90 days respectively. And then it starts declines throughout at other proportions of human hair. The strength of concrete with the inclusion of human hair is higher than that of the control mix at 2%. This improvement in strength may be due to fiber strength, sufficient physical/ chemical bonding of human hair fibers with the matrix. Fibers can prevent the propagation of microcracks and ultimately enhance the tensile strength of concrete. As the augmentation is expected to be more significant when the percentage of human hair fibers is higher, but the opposite trend is observed in the concrete mix. The lower tensile strength during cracking may be due to the lower density of concrete at a higher fiber content, which can be observed in Fig. 6. When the fiber content is high, the density is low.

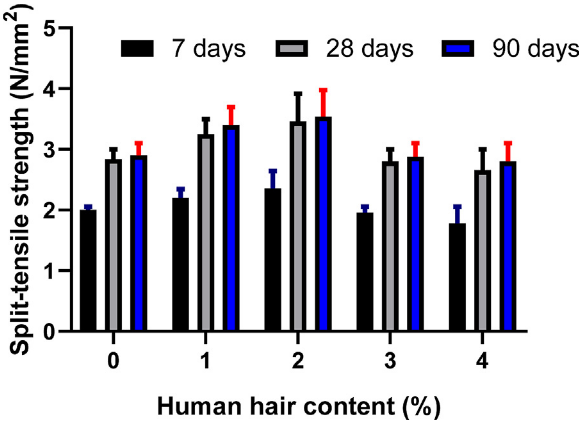

Fig. 9. Indirect Tensile Strength.

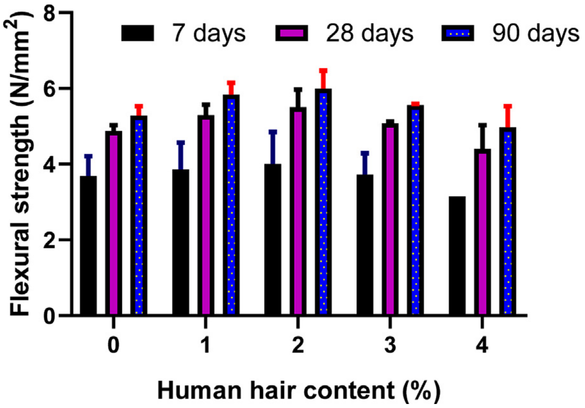

Fig. 10. Flexural Strength of Concrete.

5.6. Flexural strength

Fig. 10 shows the trend in bending strength for various proportions of human hair fibers. Here, variations in trends are observed: the intensity of strength reduces at 4% of human hair but increases at 2% of human hair. The enhancement is about 8.70 %, 12.71 %, and 13.64 % at 2% after 7, 28, and 90 days respectively. An adequate length of 2% of human hair may be

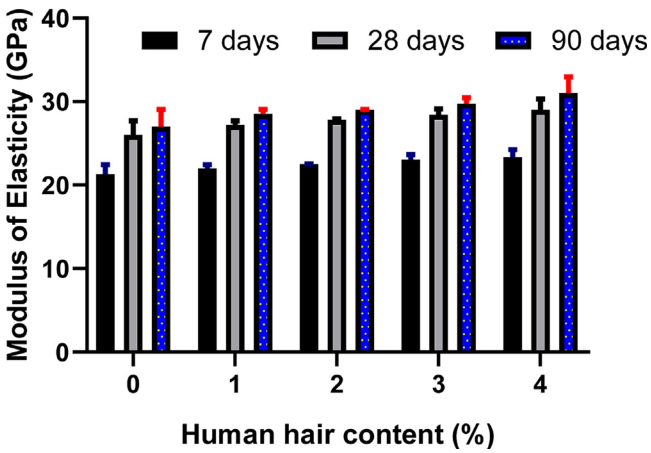

Fig. 11. Modulus of Elasticity of Concrete containing Human Hair.

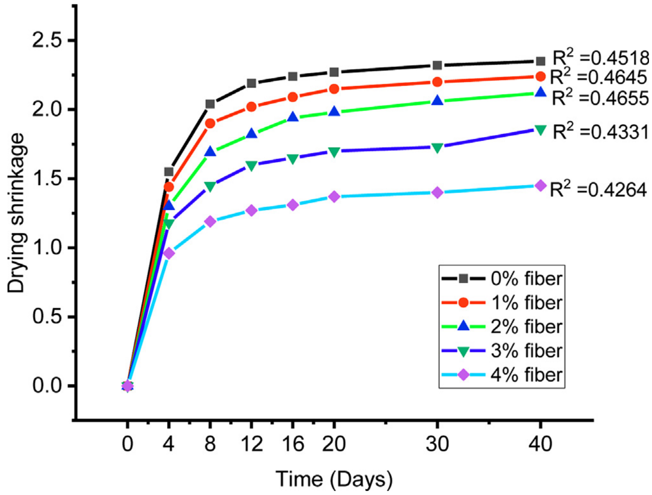

Fig. 12. Drying Shrinkage of Concrete containing Human Hair.

sufficient to maintain cracks, which leads to an increase in flexural strength. Other factors may be higher bond strength between the fiber and concrete, with more fibers perpendicular to the orientation of the crack that occurs during loading. If this is the reason, the strength would have been higher with a higher proportion of fibers, but the strength would be reduced at 4% of human hair. This lower strength may be associated with a change in the fiber length; it is possible that the fiber length of 4% may be shorter than other proportions. According to the results of visual observation in the process of mixing concrete, at 4% of human hair, the fibers become spherical, which makes it difficult to separate them. Therefore, the balling of fibers put adverse effects on any type of strength. This is the main reason for the high proportion of human hair, fibers acquired interlocked, which caused in amalgamation in concrete, and these fiber balls are similar to holes in concrete, which can reduce the flexural strength of concrete.

5.7. Modulus of elasticity

It is a measure of concrete resistance to elastic deformation. Elasticity module defines stiffness; higher elasticity modulus of the material, therefore, represents a stiffer one. Results of the investigation presented in Fig. 11 showed that human hair presence in concrete increased the Elasticity Modulus. The higher the percentage composition of human hair in concrete, the stiffer the concrete becomes. The modulus of elasticity of fiber-reinforced concrete usually relies on the type of fiber, its volume, and direction. Adding fibers to the concrete mix would delay the propagation of the crack and its propagation. Fig. 11 gives the modulus of elasticity of various concrete mixtures. The control concrete showed brittle failure, while a fiber sample of concrete showed plastic failure.

5.8. Drying shrinkage of concrete

Fig. 12 above reveals the drying shrinkage of concrete that contains human hair fiber decreases with an increase in percentage composition of human hair fibers at different curing days but increases with an increase in curing days for different percentages of human hair fibers. This results in a dramatic decrease in shrinkage at drying when human hair is used as fibers in concrete by the volume of cement, and this decrease is progressive with an increment in the percentage of human hair.

6. Conclusion

It has become pertinent to source for alternative concrete technology to preserve the natural material sources. This study presented sustainable composite development based on a novel use of human hair as fiber in concrete. The following under listed conclusions were drawn from the study:

i Workablity of concrete containing no fiber was higher than that of the fire reinforced mixture. This was as a result of gripping effect by the network of fibers. As the proportion of hair increased, then there was a subsequent drop in workability values.
ii The maximum density was noted by 2422 kg/m^3 at 0% of human hair, and minimum density was observed by 2368 kg/m^3 at 4% of human hair after the 28th day. Also, the maximum water absorption was measured at 3.07 % at 4% of human hair, and minimum water absorption was noted as 2.46 % at 0% of human hair after 28 days.

iii There was an increase in compressive strength observed by 4%, 8.15 %, and 10.51 % at 1% of the human hair fiber, and reduction value is 21.6 %, 19.33 %, and 13.80 % at 4% addition of hair after 7th, 28th, and 90th day respectively.
iv Maximum split tensile strength observed at 2% of human hair is 17.5 %, 21.83 %, and 22.1 %, and reduction in split tensile strength is noted as 11 % and 6.33 % and 3.45 % at 4% addition of hair after 7, 28 and 90 days respectively.
v The flexural strength was improved by 8.70 %, 12.71 %, and 13.64 % by using 2% of human hair fiber and the minimum value was recorded by 14.40 %, 9.83 % and 5.87 % at 4% of human hair fiber in concrete after 7, 28 and 90 days respectively. The modulus of elasticity was augmented, as the amount of human hair fiber increased in concrete after each curing period.

The drying shrinkage of concrete was reduced with an increase in the amount of human hair as fibers in concrete after 40 days.

Declaration of Competing Interest

The authors report no declarations of interest.

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