ORIGINAL RESEARCH

Experimental investigation on the mechanical properties of goat hair fiber reinforced concrete

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Abstract:

One of the disadvantages of concrete is low tensile strength and poor crack resistance. The use of fibers in the concrete mixing design is an effective and practical method to increase ductility and energy absorption capacity, reduce cracking and enhance the tensile strength of concrete. Using natural fibers in concrete is always recommended with the aim of saving non-renewable resources and using sustainable materials. In this research, the effect of using goat hair as an example of natural fibers on the mechanical properties of concrete was investigated. To achieve this goal, concrete samples were made with different percentages of 0, 0.25, 0.5, 0.75 and 1% goat hair with a length of 13-22 cm and diameter of 50-60 microns. To assess the effectiveness of this fiber, plain concrete properties were used. The results indicated that the addition of goat hair fibers increases the compressive and tensile strength of concrete samples at ages 7 and 28-day. This fact was more evident in the samples containing 0.5% goat hair with respect to the weight of cement. For example, at the age of 28-day the improvements in compressive and tensile strength was 18.2% and 83.4%, respectively. Also, by adding goat hair fibers to concrete, workability was reduced and concrete samples containing 0.75% or less fibers had acceptable workability. In general, the use of 0.5% of goat hair fibers is recommended as the optimal percentage in reinforced concrete due to its effect on the mechanical properties of concrete and economic efficiency.

Keywords:
Goat hair, Fiber reinforced concrete, Compressive strength, Tensile strength, Workability

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1. Introduction

Concrete is considered as the most widely used material in the construction industry. The weakness of concrete against tensile stress can be improved by adding special materials and fibers to concrete mixes, which has led to the growth of the concrete admixture industry in the last 50 years and lots of research has been carried out in this field. The first use of fibers in brittle matrix materials is in the form of straw in sun dried bricks and has a long history dating back to 7000 BC in the city of Jericho in southern Turkey. The use of fibers in the concrete production process is one of the effective methods to reduce cracking, increase ductility and energy absorption capacity and enhance the tensile strength of concrete which can reduce the risk of structural damage, especially in earthquake-prone areas.

So far, many researchers have investigated the effect of using natural fibers such as coconut [1], sisal [2], sugarcane bagasse [3,4], bamboo [5], hemp [6], abaca [7], banana [8,9] and kenaf [10] fibers in concrete (Figure 1).

Although the results were encouraging, weaknesses in durability were observed that were caused by the interaction between cement paste and fibers. Despite this problem, environmentalists have always supported the replacement of chemical fibers with natural fibers in concrete to support renewable sources [11-14]. Now a number of researchers are looking for a solution to improve the durability of this type of concrete [15, 16]. Often, the bridge that plants fibers put on both sides of the crack to prevent concrete failure is not strong, and when the fibers are broken or pulled out of the concrete mortar, it causes the concrete to fail [17,18].

Goat hair fiber have unique properties that make it suitable for concrete mixes. These fibers are chemically neutral and have very high resistance in alkaline environments, which makes them more important in underground structures that are exposed to water, moisture and corrosion. On the other hand, goat hair fibers have very low weight and high elastic properties compared to steel fibers. Today, goat hair fibers are produced in different shapes and sizes and can be used as single strands, bundles or interconnected strips in reinforced concrete.

Fig. 1. Examples of natural fibers used in reinforced concrete

For the first time in 1847, Joseph Lambot, a French engineer, produced a new building material by adding continuous fibers in the form of wires into concrete [18]. Porter conducted a research in 1910 with the aim of strengthening concrete and increased the tensile strength of the concrete by adding cut nails in the concrete [19].

In 1914, William Fickley conducted an experimental study on a series of concrete specimens using various tortuous shaped pieces of steel reinforcement into concrete and concluded that toughness and cracking resistance were improved but mentioned that no increase in compressive and tensile strengths of concrete was observed [20]. The results show that in order to achieve a better performance of fiber concrete, if the fibers are placed perpendicularly to the edges of the cracks, by bridging the fibers between the cracks, the integrity of the concrete is maintained until large deformations and causes to increase flexural and tensile strength. Also, with the random distribution of fibers at distances much smaller than the distance between the reinforcements, the size of the cracks is reduced, and as a result, permeability and stability of concrete in aggressive environments decrease [21]. In 2010, Singh et al. casted cubic, cylindrical and rectangular cube samples and conducted numerous tests and concluded that the best combination of steel fibers and polypropylene is 75% steel fibers and 25% polypropylene fibers [22]. Ali et al. (2012) mixed concrete with natural coconut fibers at 1% to 5% by mass of cement and lengths of 2.5, 5, and 7.5 cm and concluded that coconut fibers improve the dynamic and static behavior of concrete. The greatest effect on properties of concrete was observed in 5% fibers with a length of 5 cm [23]. In 2014, Kumar investigated the mechanical properties of epoxy composites reinforced with human hair fibers and indicated that the best results for the mechanical properties of fiber reinforced concrete such as flexural, tensile and impact occurs in 20% fiber with a length of 1.5 cm [24]. Another research in 2018 investigated the effect of different percentages of sugarcane bagasse and goat hair in concrete slabs in controlling cracks. The results showed that 1-2% of sugarcane bagasse fiber and 1% of goat hair fiber were the best percentage to reduce the plastic shrinkage cracks and can be effective in controlling the corrosion of reinforcements in humid areas or in the vicinity of salty water [25].

In this research, an initial attempt was made to investigate the effect of goat hair fiber on workability and slump value of fresh concrete by considering different percentages of fibers. In the next step, the mechanical properties of fiber reinforced concrete were explored in the hardened state. To achieve this goal, compressive and tensile strength tests were conducted on 25 cubic and 25 cylindrical samples of concrete reinforced with various amount of goat hair fibers. Finally, the results were analyzed to obtain the most optimum amount of goat hair fibers for the reinforced concrete mixture.

2. Experimental Program

2-1- Materials

In this study, the materials used for the nonfibrous concrete mixture consisted of certain proportions of fine aggregate, coarse aggregate, broken sand, cement, water and superplasticizer based on ASTM standards [26-28]. In the ACI standard titled "Guide for Specifying, Proportioning, Mixing, Placing, and Finishing Steel Fiber Reinforced Concrete" [29], it is recommended that in fiber reinforced concrete, the maximum aggregates size should be 19 mm. Type II Portland cement was selected with water to cement ratio of 0.53. Natural broken sand and semi crushed coarse and fine aggregate were used to prepare the specimens. It is worth noting that the Portland cement type 2 (chemical properties are given in Table 1) manufactured by Dashtestan Cement Factory and the goat hair fibers donated by a local livestock farming, were used in the mixture.

The mix proportions of benchmark concrete are given in Table 2.

Table 1. Chemical composition of cement

Component	SiO2	CaO	MgO	Fe2O3	SO3	FCaO	C3A
Content (%)	21±0.5	3.7±0.2	62±0.5	4.6±0.3	2.4±0.3	1.5±0.3	6±0.5

Table 2. Mixture proportions of benchmark concrete (kg/m3)

Coarse aggregate (kg)	Fine aggregate (kg)	Broken sand (kg)	Cement (kg)	Water (kg)	Water/cement ratio
378	350	1150	350	186	0.53

In the testing program, the variable was the amount of goat hair fiber and other parameters were kept constant. The goat hair fibers had a various length between 13-22 cm and diameters of 50-60 microns (Figure 2).

Fig. 2. Weighing of goat hair fibers

2-2- Preparation of samples

For the production of concrete, dry mixing of coarse and fine aggregates was started. After 1 minutes, cement was added and dry mixing stage continued for another 1 minutes. Certain amount of goat hair fiber was added slowly to avoid fibers balling and ensure uniform distribution of fibers throughout the concrete and produce high quality concrete. Finally, water was poured into the mixture. It worth noting that goat hair fiber percentage varied from 0, 0.25, 0.5, 0.75 and 1% by weight of cement.

The freshly mix concrete was poured into 150×150×150 mm cubic and 100×200 mm cylinder molds. 25 cubic specimens were employed to evaluate the compressive strength and 25 cylindrical specimens were used for splitting tensile strength test. After 24 hours, samples were removed from the molds and were submerged into water for 7 and 28 days. Figure 3 shows some photos of experimental program of this research.

One of the important and practical physical characteristics of fresh concrete is workability that affects strength, durability, as well as labor costs and the appearance of the final product. The studies show that, in general, adding any type of fiber to plain concrete decreases workability and the amount of this reduction depends on the volume of fibers. Since the presence of fibers in concrete greatly decrease the slump of the fresh concrete, it is recommended to use the slump test [30] for measuring the workability of fiber reinforced concrete. The outcomes of using slump test in different percentages of

goat hair fibers has been presented in the results section.

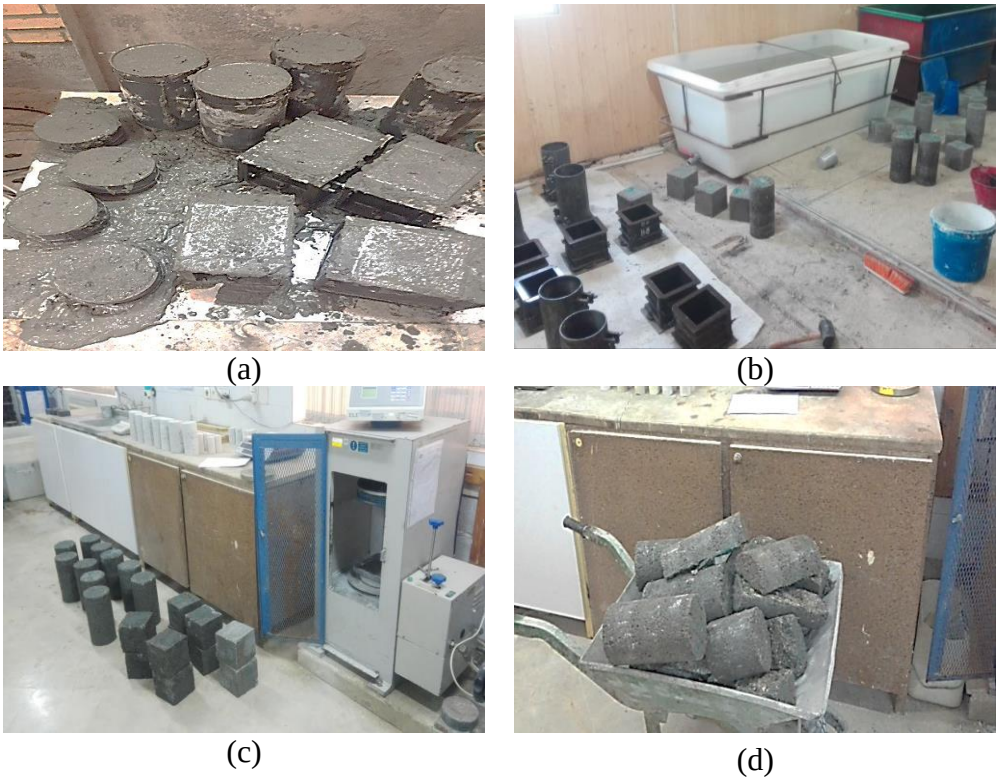

Fig. 3. a) concrete placing in moulds, b) curing of samples, c) cylindrical and cubic samples before test, d) failure mode of cylindrical samples

2-3- Test methods

As mentioned above, from the total number of 50 samples, 25 cubic specimens for compressive test and 25 cylindrical specimens for splitting tensile strength were considered. For each of the percentages of goat hair fiber (0, 0.25, 0.5, 0.75 and 1%), two and three samples were examined at the age of 7 days 28 days, respectively. Then, the average strength of samples were reported as the final results.

To evaluate the compressive strength, cubic samples at target age were placed in the testing machine under a load rate of 0.3 MPa/s until failure [31]. To determine the tensile strength, the Brazilian test was performed on cylindrical samples as per ASTM C496 standard test method for splitting tensile strength of cylindrical concrete specimens [32]. First, the exact diameter and height of samples were accurately measured. Two thick steel plates were used on the top and bottom of the samples for uniform load distribution. Then, the specimens were placed into the testing machine. The continuous load was applied constantly at a rate of 0.15 MPa/s and caused to increase the tension in the direction perpendicular to the applied load until the specimens failed. At this time, the maximum load was recorded to derive the tensile strength using the equation 1.

$$T=2P/\pi ld \quad (1)$$

Where :
T = splitting tensile strength
P = maximum load applied by the testing machine
l = height of specimen
d = diameter of specimen

3. Results and discussion

3-1- Slump

Workability of concrete can be determine by Concrete Slump Test that has been used since

1922. The apparatus consists of a cone in which fresh concrete is placed in 4 compacted layers. Then the cone is vertically raised and vertical distance between the displaced top surface and original concrete level is measured as the slump value. The results of the Slump Test can be classified as [33]:

- Very low workability: Slump value 0-25mm
- Low workability: Slump value 25-50mm
- Medium workability: Slump value 50-100mm
- High workability: Slump value 100-175mm

Figure 4 shows the results of concrete workability in different percentages of goat hair fibers. As expected, increasing the goat hair fibers decreased the slump and workability of fresh concrete, so that for plain concrete, the slump was 9.1 cm with medium degree of workability and by adding 1% fiber, the slump reduced to 4.2 cm and degree of workability changes to low level. This reduction in the workability of concrete in high percentages of goat hair fiber could cause problems for the construction team during concreting or make formworks not to be filled with concrete. According to the following Table, it seems that the best workability is in concrete with a maximum amount of 0.75% goat hair fiber.

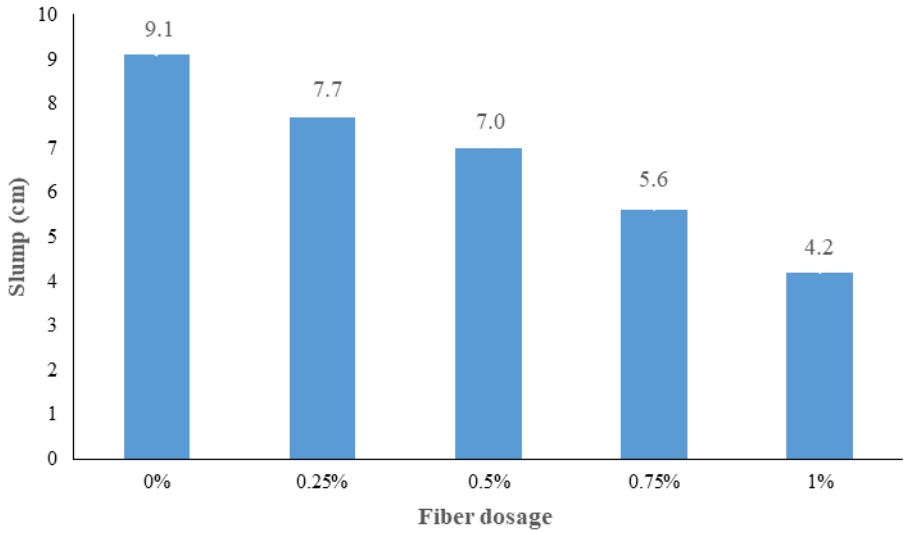

Fig. 4. Effect of fiber dosage on workability of fresh concrete

Table 3. Workability of fresh concrete for various percentages of goat hair fiber

Fiber dosage	0% (benchmark concrete)	0.25%	0.5%	0.75%	1%
Slump (cm)	9.1	7.7	7.0	5.6	4.2
Reduction in workability	-	15.4%	23.1%	38.5%	53.8%
workability	**Medium**	**Medium**	**Medium**	**Medium**	**Low**

3-2- Compressive strength

The average values of the compressive strength of the samples were measured at the age of 7 and 28-day and presented in Figure 5 and Table 4. It is worth to mention that the samples with no goat hair fibers used as benchmark specimens.

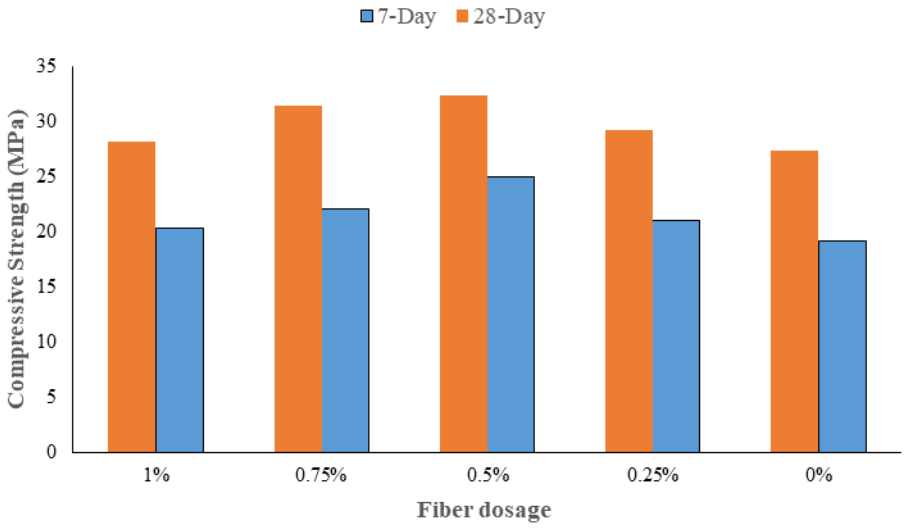

Fig. 5. Effect of fiber dosage on compressive strength of concrete

Table 4. Compressive strength results of specimens

Fiber dosage	7-day compressive strength			28-day compressive strength		
	No. of specimens	Average strength (Mpa)	Increase amount	No. of specimens	Average strength (Mpa)	Increase amount
0%	2	19.2	-	3	27.4	-
0.25%	2	21.0	9.4%	3	29.2	6.6%
0. 5%	2	25.0	30.2%	3	32.4	18.2%
0.75%	2	22.1	15.1%	3	31.4	14.6%
1%	2	20.3	5.7%	3	28.2	2.9%

According to Table 4, it can be seen that adding goat hair fibers to concrete increases the compressive strength of concrete. The greatest increase in the compressive strength of 7 days and 28 days is equal to 30.2% and 18.2%, respectively, and corresponded to 0.5% of fibers. In other words, this percentage can be considered as the most optimal value in terms of compressive strength. The lowest effect on compressive strength among different percentages of goat hair fibers is related to samples with 1% fibers, which is only 5.7% and 2.9% increase for 7 and 28-day, respectively.

3-3- Tensile splitting strength

The average values of the tensile splitting strength of the samples were calculated using maximum applied test load and equation 1 at the age of 7 and 28 days and illustrated in Figure 6 and Table 5.

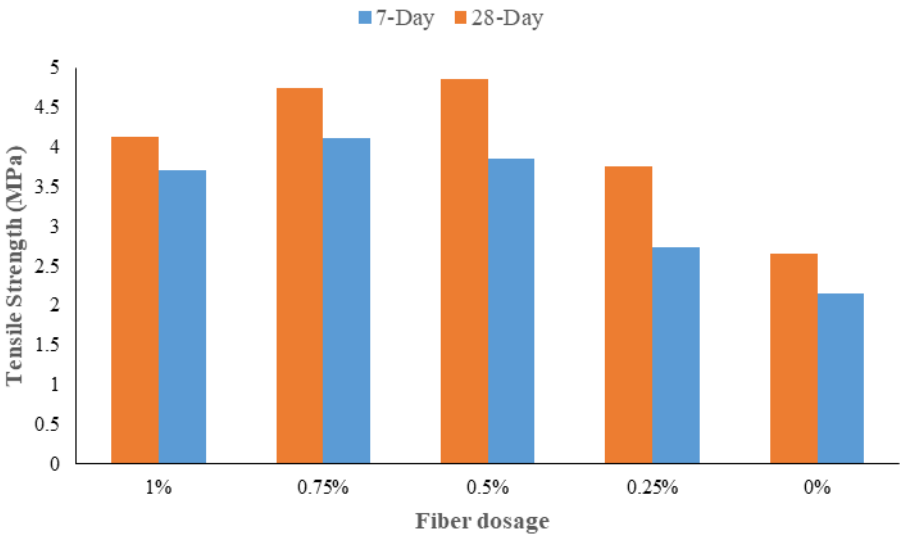

Fig. 6. Effect of fiber dosage on tensile strength of concrete

Table 5. Tensile splitting strength results of specimens

Fiber dosage	7-day tensile strength			28-day tensile strength		
	No. of specimens	Average strength (MPa)	Increase amount	No. of specimens	Average strength (MPa)	Increase amount
0%	2	2.16	-	3	2.65	-
0.25%	2	2.73	26.4%	3	3.76	41.9%
0. 5%	2	3.85	78.2%	3	4.86	83.4%
0.75%	2	4.11	90.3%	3	4.75	79.2%
1%	2	3.71	71.8%	3	4.13	55.8%

Similar to the results of the compressive strength test, adding goat hair fibers to concrete increased the tensile strength of concrete, but the enhancement in tensile strength was much higher than the compressive strength. For the 7-day samples, the concrete containing 0.75% goat hair fibers had a higher tensile strength and had grown by 90.3% compared to the benchmark sample, while for the age of 28-day, the tensile strength of the specimens with 0.5% goat hair fibers had the highest value (4.86 MPa) and this means a 79.2% increase in tensile strength compared to the benchmark sample of the same age. The lowest increase in tensile strength was related to the sample containing 0.25% goat hair fibers, which is 26.4% and 41.9% for the age of 7 and 28 days, respectively. Even though all the examined values of tensile splitting strength increased, by considering the importance of tensile strength at older ages of concrete, it should be said that adding 0.5% of goat hair fibers is the most optimal percentage in terms of tensile strength.

It seems that the decrease in tensile strength in 1% ratio compared to lower percentages is due to the balling effect which occurs due to the use of large and incorrect amounts of fibers and causes obstruction in concrete and practically eliminates the effect of fibers.

In addition, the outcomes of tensile splitting test of fiber concrete specimens showed that failure occurred due to pulling out of fibers or

loss of cohesion. As a result, unlike plain concrete, fiber reinforced concrete specimens did not fail immediately after the first cracks.

3-4- Optimum percentage of goat hair fiber

Summarized results of slump tests, compressive strength and tensile strength are given in Table 6. Considering that the percentage of optimum fibers for 7 and 28 days tensile strength is equal to 0.75% and 0.5%, respectively, but since the strength at older ages is more important, 0.5% of fiber was selected as optimum percentage for tensile strength. On the other hands, the optimum percentage of fiber for compressive strength was 0.5% and the medium degree of workability obtained for percentage less than or equal to 0.75%. According to the mentioned results, 0.5% of goat hair fibers are recommended for reinforced concrete.

Table 6. Optimum percentage of goat hair fiber for mechanical properties of concrete

Mechanical properties of concrete	Age of specimen	Optimum percentage of fiber
Compressive strength	**7-day**	0.5%
	28-day	0.5%
Tensile splitting strength	**7-day**	0.75%
	28-day	0.5%
Workability	**During molding**	$\leq 0.75\%$

4. Conclusions

In the present research the workability, tensile splitting strength and compressive strength of concrete reinforced with various percentages of goat hair fibers (0, 250, 0.5, 0.75 and 1 percent by weight of cement) were investigated experimentally. The summarized results are stated below:

- By increasing the percentage of goat hair fibers, the workability of concrete specimens decreased. In high percentages of fibers, reduction in the workability of concrete can cause problems for the construction team during concreting and afford the formwork not to be filled with concrete. For example, the decrement in concrete slump with 1% goat hair fibers compared to the benchmark specimen was 53.8%.
- Adding goat hair fibers to concrete for all the mentioned percentages increased the compressive strength of concrete specimens at target ages. The highest compressive strength was related to the samples containing 0.5% goat hair fibers, which was equal to 30.2% and 18.2% for the age of 7-day and 28-day, respectively.
- Addition of goat hair fibers to concrete for all the stated percentages caused a significant increase in the tensile splitting strength of concrete samples at tested ages. For 7-day concrete, the highest tensile strength corresponded to 0.75 percent of fibers, which showed an increase of 90.3%, while the maximum increase in tensile strength of 28-day occurred in concrete containing 0.5% of goat hair fiber.
- The results of workability tests, tensile and compressive strength of 7 and 28 days and economic efficiency stated that the most optimal percentage occurred for concrete containing 0.5% goat hair fibers.

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