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Masonry bricks reinforced with human hairs as innovative building products

Vafa Morsali*[1], Farzad Babamohammadi[2], Somaye Malmir[3]

[1] Department of Civil Engineering, Saghez Branch, Islamic Azad University, Saghez, Iran.
[2] Department of Civil Engineering, West Tehran Branch, Islamic Azad University, Tehran, Iran.
[3] Department of Physics, Payame Noor University, Tehran, Iran.

ABSTRACT: In this article, clay was mixed with sand, cement, lime, and stone powder in different ratios without using brick firing with the purpose of achieving the minimum resistance required by the standards in terms of compressive strength. An average compressive strength of 8.36 N/mm^2 was obtained on the bricks having the highest levels of resistance. A comparison was also made with brick samples available on the market (Gary), which are manufactured in brick kilns. A comparison of the compressive strength of bricks made of different raw materials revealed that they were lower in compressive strength than Gary bricks. In order to solve this resistance gap, it was necessary to strengthen the bricks; this study refers to the technique known as strengthening bricks with hair fibers (SBHF). Here, human hairs were used as natural tensile fibers to achieve this resistance. Based on the combination of different percentages of hair with bricks obtained from the best combination of materials, the compressive strength of the samples varied between 9.22 N/mm^2 and 15.13 N/mm^2. In this study, more than 300 bricks were produced without the use of brick kilns, which consume a significant amount of energy and contribute to environmental pollution. In the experiment campaign, it was found that bricks reinforced with 2% human hair, which are waste materials and pollute the environment, had a higher compressive strength than bricks currently available on the market. Additionally, the SBHF method also resulted in increasing compressive strength of prisms, satisfactory water absorption, and a reduction of 30% in production cost compared to samples found on the market.

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1- Introduction

Masonry buildings are among the most vulnerable structures when subjected to earthquakes. These constructions are made of masonry walls sustaining vertical and lateral loads, roofs, and partitions. Buildings constructed with steel and concrete frames are increasingly common, but masonry structures remain popular in many parts of the world due to their favorable characteristics. In Iran, the number of permits issued for residential masonry building constructions in urban areas from 1990 to 2020 is approximately 40 percent. Including construction in villages, this will be above 40% [1]. Schools are another type of masonry structure in Iran. In accordance with [2], approximately 90 percent of Iran's schools are made of masonry structures and contain a large student population. Approximately 90% of Iran's area lies within the Alpine-Himalayan earthquake belt, which is among the world's most seismically active regions. This area has experienced a series of catastrophic earthquakes, resulting in significant economic and social damage. Almost 126,000 people have been killed as a result of earthquakes that occurred in Iran during the 20th century, including 14 earthquakes of magnitude 7.0, and 51 earthquakes of magnitude between 6.0 and 6.9. During this period, nine cities were destroyed [3,4]. Furthermore, materials with appropriate resistance should be used, rather than designing and constructing principles. Bricks are naturally a major component of masonry buildings. The traditional method of making bricks consists of preparing raw material, drying, and firing them at high temperatures in kilns. In this instance, the mixture of clay and water is transferred to the brick kilns after drying, and then heated in kilns like the Hoffman kiln to a temperature of approximately 1000 degrees Celsius [5]. There are approximately 7000 active factories in Iran producing annually more than 50 million tons of masonry bricks. Most of these factories produce traditional bricks, machine bricks, and blocks using old technology, which consumes a significant amount of energy during production. Non-metallic minerals consume 39% of the total fuel in the industry sector. Brick industries consume 21% of the total industrial fuel consumption in this group on a national level. Considering this information, the importance of paying attention to environmental issues is highlighted [6]. As well as consuming a significant amount of energy, the high-temperature kiln firing releases a large amount of greenhouse gases [7,8]. Clay bricks, on average,

*Corresponding author's email: vafa.morsali1@gmail.com

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have an embodied energy of approximately 2.0 kWh and release about 0.41 kg of carbon dioxide (CO2) per brick [9,10]. Furthermore, many parts of the world are experiencing a shortage of clay. Some countries, such as China, have begun to limit the use of clay bricks in order to protect the clay resource and the environment [11-13]. As an alternative to traditional methods, new technologies are suggested as a way to avoid environmental hazards. As with many technologies, they require initial investments, high costs of setting up a production line, and the use of skilled labor. However, the use of new kilns requires energy sources, such as natural gas, and this results in air pollution, even at small scales. Optimization of energy consumption was the subject of many studies [14-18]. In these studies, there were different types of alternative energy consumption and the reduction of pollution in all stages of making bricks, like raw material acquisition, industrial production, packaging, and transportation. In addition to reducing energy consumption, the solution also reduced air pollution. In spite of all these efforts, energy consumption, particularly during brick preparation and production, and harmful outputs from the devices remained. The construction industry faced a growing number of environmental concerns. Resource efficiency, energy efficiency, pollution control, waste minimization, and indoor air quality were among the areas of concern. By identifying environmentally friendly, healthy building materials, the green building movement attempted to minimize the impact on the environment and the health of building occupants.

Masonry structures often suffer from various forms of deterioration, such as cracking, deformation, and loss of load-carrying capacity. To address these issues and ensure the long-term stability and safety of masonry structures, various strengthening methods have been developed and employed. These methods include both traditional and innovative approaches. Traditional techniques such as repointing, grouting, steel reinforcement, and fiber reinforced polymers (FRPs) involve filling the cracks and gaps in the masonry with mortar, cement, or epoxy, inserting metal rods or plates across the cracks to improve the cohesion and integrity of the walls, and applying thin layers of composite materials made of fibers (such as glass, carbon, or basalt) and resin on the surface of the walls. As well as innovative approaches such as textile-reinforced mortar (TRM) or fabric-reinforced cementitious matrix (FRCM), which involve applying thin layers of composite materials made of fibers (such as glass, carbon, or basalt) and resin on the surface of the walls, or a composite material that consists of a cementitious matrix reinforced with high-strength fabric, such as carbon or glass fibers. [19-25].

One of the methods used to improve the physical and structural properties of masonry materials is the use of fibers for making bricks. Fiber-reinforced bricks are a type of construction material that combines traditional brick-manufacturing techniques with the addition of reinforcing fibers. These fibers, usually made of materials such as glass, carbon, or synthetic polymers, are mixed into the brick mixture to enhance their mechanical properties and improve their overall durability. The concept of using fibers to reinforce building materials is not new, as it has been applied in various industries for decades. However, incorporating fibers into brick production has gained significant attention in recent years due to the numerous benefits it offers. The fibers used in the fiber-reinforced bricks act as a reinforcement medium, providing enhanced tensile strength and crack resistance. In addition to improved mechanical properties, fiber-reinforced bricks also exhibit enhanced thermal and acoustic insulation characteristics. Some of the beneficial features of this type of brick include increasing abrasion resistance, increasing shear strength and flexural strength, decreasing cracking and shrinkage, and being sustainable and eco-friendly [26-29]. Many studies [30-32] considered the ecological impact of a building based on the materials used in its construction. Building construction was analysed in a number of ways in order to ensure that environmental control standards are satisfied. The majority of these studies identified several sources of greenhouse gas emissions associated with building construction, including the containment, manufacturing, and transportation of building materials; energy consumption of construction equipment; energy consumption of processing resources; and disposal of construction waste, and then established a method for calculating greenhouse gas emissions. Thus, using waste and materials that cause environmental damage can be one method of preventing environmental pollution. There have been numerous waste materials studied, including fly ash, mine tailings, wood sawdust, cotton waste, limestone powder, rice husk ash, and cement kiln dust [33-44]. A general classification of studies conducted in this field can be made into three different subcategories: firing, cementing, and geopolymerization. In terms of energy and environmental concerns, geopolymerization is the preferred method of producing bricks from waste materials [45]. Another environmental challenge involves human hair. In many countries, human hair is considered a potential biowaste, and improper disposal can lead to a variety of environmental issues. As a result of their unique characteristics, human waste hairs can be effectively utilized for a wide variety of purposes [46]. Hair threads are natural fibers composed of keratin, a protein containing sulphur originating from cystine. A hair's physical and mechanical properties are mainly determined by its geometry; these include elasticity, smoothness, volume, shine, and softness as a result of both significant cuticle scale adhering and movement control. Hair exhibits a high tensile strength, from 150 to 270 MPa, which is significantly dependent on strain rate and humidity. The large tensile extension affects the internal cortex and the surface cuticle [47,48]. The use of human hair as waste material in concrete is being investigated by many researchers in the area of concrete technology. These studies examined the effect of human hair fibers on the fresh, physical, and mechanical properties of concrete. According to them, the compressive strength, tensile strength, and flexural strength of concrete samples were improved [49-52]. Adding human hair fibers to concrete can significantly increase its strength and durability over traditional concrete, with a 2% inclusion leading to

notable improvements in the strength of the concrete in terms of compressive, tensile, and flexural properties as compared to conventional concrete [53], Masterbuilder, (2013) showed that, by adding human hair fiber, the bricks became stronger and less prone to water absorption, and human hair fiber provides a sustainable building material while reducing environmental pollution[54]. M. Manjunatha et al. (2021) reported on an experimental study on the use of human hair for enhancing concrete performance [55]. They resulted that the optimal dosage of human hair is found to be 2.5% by weight of cement for M40 grade concrete and incorporating human hair improves the strength, durability, and workability of concrete, reducing water absorption and microcracks.

Despite these advances, limited research has addressed the application of human hair fibers in the production of masonry bricks, particularly non-fired masonry units. Moreover, the combined effects of hair content on compressive strength, failure behavior, masonry prism performance, and water absorption characteristics have not been comprehensively investigated. Therefore, this study aims to experimentally evaluate the feasibility of producing non-fired masonry bricks reinforced with human hair fibers as a low-energy and sustainable alternative to conventional fired bricks. The objectives of the research are to: (i) identify optimal material combinations for non-fired brick production, (ii) assess the influence of varying human hair content on the mechanical properties of brick units, (iii) evaluate the compressive behavior of masonry prisms constructed using the proposed bricks, and (iv) examine water absorption characteristics in accordance with relevant standards. The proposed approach is intended primarily for low-rise construction, rural housing, and regions with limited access to industrial brick manufacturing facilities.

2- Brick-making methodology

It is common for many countries, including Iran, to continuously alter their standard criteria, such as those contained in the Iranian Standard No. 7965 [56], for the consumption of energy in industries, such as that used for brick production. Therefore, to maintain synchronization and coordination with national and international developments in the field of industries, it is necessary to revise the standards as required. Today, it is clear that processes in the industry that promote optimal fuel consumption and are environmentally friendly are receiving attention and are being welcomed. The brick industry is no exception, as change is an integral part of its operations.

In this research, the aim is to determine the compressive strength of the unfired masonry bricks made by reinforcing with human hairs, so the determination of other parameters is omitted. The dimensions of bricks have undergone many changes from the past until now. In the market, compressive bricks or Gary bricks are one of the oldest types of masonry blocks. The dimensions of these bricks are 5.5×11×22 cm, which are also available in the size of 7×10×21 cm, and their weight is approximately 2.5 kg.

2- 1- Methods of making samples

In general, the method used for the production of bricks in this study is divided into two categories. 1- Unreinforced bricks (without using human hairs). 2- reinforced bricks (with human hairs). The raw materials and their chemical compositions used in this study are listed in Table 1, and the ratios used are outlined in sections 2.1.1 and 2.1.2.

2- 1- 1- Unreinforced masonry bricks

In this research, these types of bricks are divided into two categories according to the type of materials used in their

Table 1. The raw materials and their chemical compositions used for making bricks.

Clay (60-85%)	Cement (Type II) (14-20%)	Lime (4-15%)	Stone powder (4-15%)	Sand (14-20%)	Human Hairs (0.6-4.5%)
(SiO_2): ~50-60% (Al_2O_3): ~15-25% (Fe_2O_3): ~3-10% (CaO): ~0.1-1% (MgO): ~0.5-3% (Na_2O): ~0.1-2% (K_2O): ~1-3%	(CaO): ~60-65% (SiO_2): ~18-22% (Al_2O_3): ~4-6% (Fe_2O_3): ~2-4% (MgO): ~1-4% (SO_3): ~2-4% (Na_2O + K_2O): ~0.2-1%	(CaO): ~90-95% (MgO): ~1-5% (SiO_2): ~0.5-1.5% (Al_2O_3): ~0.1-1% (Fe_2O_3): ~0.1-0.5%	($CaCO_3$): ~95-98% $MgCO_3$): ~1-3% (SiO_2): <1% (Fe_2O_3): ~0.1-0.5% (Al_2O_3): ~0.1-0.5%	(SiO_2): ~70-95% (Al_2O_3): ~1-2% (Fe_2O_3): ~0.5-1.5% (CaO): ~0.1-1.5% (MgO): ~0.1-0.5% (Na_2O): ~0.1-0.6% (K_2O): ~0.1-0.5%	Keratin (Protein): ~65-95% (C): ~50-55% (O): ~20-25% (N): ~15-18% (H): ~6-7% (S): ~3-5% Minerals: <1%

Table 2. The brick specifications of Category 1.

Types	Clay (%)	Cement (%)	Lime (%)	Stone powder (%)
Type 1	78	14	4	4
Type 2	72	16	6	6
Type 3	66	18	8	8
Type 4	60	20	10	10
Type 5	86	14	-	-
Type 6	84	16	-	-
Type 7	82	18	-	-
Type 8	80	20	-	-
Type 9	80	-	10	10
Type 10	85	-	-	15
Type 11	85	-	15	-

construction. 1- Bricks made using clay, lime, stone powder, Portland cement and water 2- Bricks are made from clay, sand, cement, and water. Based on experience, the water amount needed for a mixture is 20% to 25% of the sample's dry weight.

2.1.1.1. Category 1

A basic mix of bricks is formed by combining raw materials, including clay, lime, stone powder, Portland cement, and water, according to the percentage quantities of Table 2. Materials are placed into brick molds and are allowed to dry in the ambient air. It was determined that the manufactured samples must dry completely for about 20 days before they can be tested for compressive strength assessment. In this method, the dough obtained from the raw materials should be uniform and without lumps. Several tests were conducted in the experimental campaign carried out. As a result of these tests, the dry weight of bricks obtained by this method is approximately 2200 kilograms. Additionally, approximately 22% to 28% water is required to prepare the initial dough. The amount of water added in this study was about 25%.

Primary raw materials are fine-grained, and clay must be sieved. Moreover, the maximum diameter of the sand grains in this study is 2.36 mm, which is equivalent to the ASTM grade 8 sieve. As a matter of fact, in the traditional method of producing bricks, the dried sample is transferred to brick kilns and heated at high temperatures for about 10 to 15 days. It is not necessary to use brick kilns in the method proposed in this study. Therefore, after drying, the samples are subjected to a pressure test to determine their strength. Table 2 shows the specifications of the 11 types of samples investigated.

Fig. 1 and 3 show pictures of Category 1 bricks ranging from type 1 to type 11.

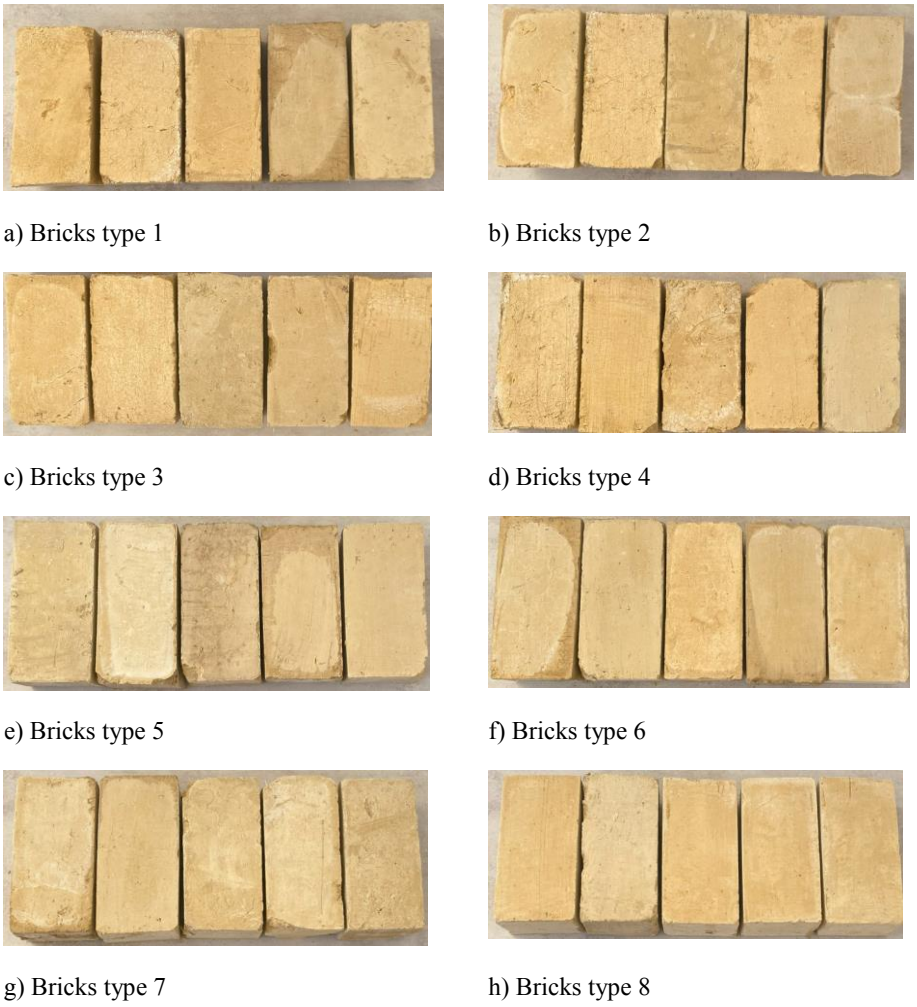
Figure 1 shows that the samples are free of cracks and can be tested for compressive strength. In Figure 2, the results of the compression tests on the first eight samples obtained in accordance with Table 2 are presented. In order to investigate this issue, the numerical average of the compressive strength of the samples was calculated.

As for other bricks made from types 9, 10 and 11, they had large cracks and are not subjected to the compressive strength test. Figure 3 shows pictures of the mentioned samples.

According to the ASTM C62-13a standard [57], compressive masonry bricks must meet the following minimum requirements before they can be used for construction. The minimum compressive strength of a brick should be greater than 8.43 N/mm2, and the minimum average compressive strength of 5 bricks should be greater than 10.1 N/mm2. On the basis of the diagram shown in Figure 2, it can be seen that none of the proposed samples are expected to meet these requirements. Consequently, these bricks are not suitable to be used as structural materials. The solution proposed in this study is to choose the best combination of the brick constituents and then mix them with sand, as discussed in Section 2.1.1.2. As seen from Figure 2 above, type 8 bricks have the best performance, so this type is chosen as the masonry block to be strengthened.

2.1.1.1. Category 2

In this section, bricks are made by mixing sand, cement, and clay with water in the proportions shown in Table 3. As in Section 2.1.1.1, 20 days are considered for complete drying of the samples. This brick consists primarily of Iranian high-quality clay, which is suitable for making these building components. The constitutive materials of bricks are combined based on different weight ratios. Finally, the most optimal combination is selected to be strengthened with



a) Bricks type 1 b) Bricks type 2

c) Bricks type 3 d) Bricks type 4

e) Bricks type 5 f) Bricks type 6

g) Bricks type 7 h) Bricks type 8

Fig. 1. Unreinforced masonry bricks of Category 1 (made of clay, lime, stone powder, Portland cement, and water) ready for testing.

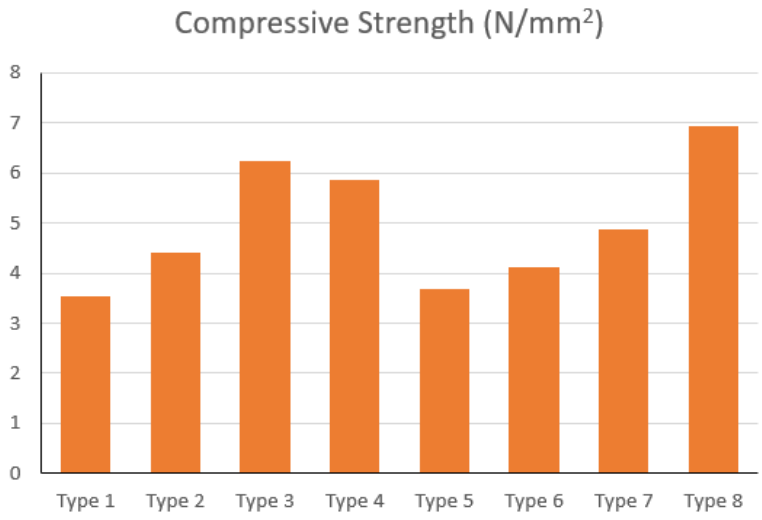


Fig. 2. Numerical average of the compressive strength of the Category 1 samples from type 1 to type 8.

a) Bricks type 9 b) Bricks type 10 c) Bricks type11

Fig. 3. Unreinforced Masonry Bricks of Category 1 (made of clay, lime, stone powder, Portland cement, and water) are not suitable for testing.

Table 3. Specifications of Category 2 bricks.

Types	Clay (%)	Cement (%)	Sand (%)
Type 12	72	14	14
Type 13	68	16	16
Type 14	64	18	18
Type 15	60	20	20

Fig. 4. Unreinforced masonry bricks made of clay, sand, cement, and water.

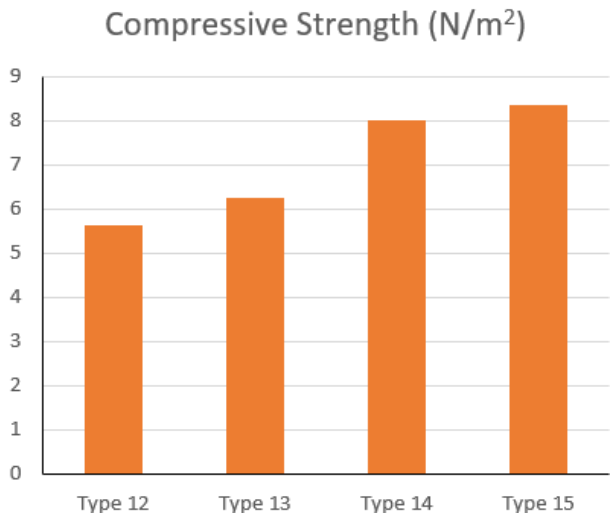


Fig. 5. Numerical average of the compressive strength of the Category 2 samples.

human hair and evaluated under compression tests.

Figure 4 shows an example of these bricks, which are made from sand grains with a maximum diameter of 2.36 mm. Accordingly, this number was chosen based on the construction and evaluation of different samples made using grade 4 and 8 sieves.

As can be seen, the appearance of this brick is free from cracks, so to be completely suitable for testing. In Figure 5, the average compressive strength of the samples of Table 3 after performing the compressive tests is shown.

Figure 5 shows that the average compressive strength of the samples has increased appropriately. However, the extracted average compressive strength is less than the minimum requirement provided by the ASTM C62-13a standard. As a result, type 16 is selected as the most appropriate brick. Therefore, it will be reinforced by human hair as a natural fiber, and its performance will be evaluated in the next section.

2- 1- 2- Reinforced masonry bricks

As a result of Sections 2.1.1.1 and 2.1.1.2, the most optimal composition is that of Type 16 brick, which is chosen as the main material to be reinforced. Most parts of the world consider human hair to be waste material, and its accumulation in waste streams can have detrimental effects

a) Hair Fibers b) Dry mixture

Fig. 6. Illustration of the dry mixture and hair fibers.

Table 4. Reinforced bricks with human hair as mixture additives.

Types	Clay (%)	Cement (%)	Sand (%)	Human Hair (% by dry weight of bricks)
Type 16	60	20	20	0.6
Type 17	60	20	20	0.8
Type 18	60	20	20	1
Type 19	60	20	20	1.2
Type 20	60	20	20	1.6
Type 21	60	20	20	2
Type 22	60	20	20	3
Type 23	60	20	20	4.5

on the environment. Using hair as a reinforcing fiber in the bricks can help reduce environmental pollution. In addition, bricks reinforced by human hair can be used in the construction of masonry buildings. In Section 2.1.2.1, the brick type 16 is reinforced and examined using human hairs. Different standards have proposed various characteristics for checking masonry bricks. In this research, the compressive strength test of brick units, the flexural strength test of brick units, the compressive strength test of masonry prisms, and the water absorption percentage test were performed on the samples, and their performance was investigated. Adding more fibers can usually cause clumping or uneven distribution, which complicates the mixing process. In order to achieve uniform dispersion of the hair fibers throughout the mixture, mixing time, speed, and technique need to be carefully controlled. Adjustments such as optimizing the mixing order (e.g., adding fibers gradually) or utilizing specialized mixers designed specifically for fiber-reinforced materials may be required in order to overcome these challenges. Additionally, the fiber length and quantity should be controlled to ensure workability without compromising the mechanical properties of the masonry bricks. These factors are essential for maintaining the quality of the mix as well as ease of handling during the production process. Raw materials are mixed using a mixer. Additionally, the fibers used in the mixture were hairdressing waste. The maximum fiber length was 7 cm. An illustration of the dry mixture and hair fibers is shown in Figure 6.

2.1.2.1 Compressive strength of reinforced masonry brick units

As a next step, Type 16 brick is reinforced using eight different percentages of human hairs as mixture additives, as shown in Table 4, and the compressive strength of the resulting eight brick types has been experimentally evaluated. In accordance with the large number of tests carried out, the amounts of human hair fibers less than 0.6 percent and greater than 4.5 percent were found to have a negative effect on the compressive strength of the samples. Experiments were conducted using the ratios shown in Table 4.

Figure 7 shows an example of these bricks containing 2% and 3% of human hair.

Figure 8 shows the compression properties of these bricks made from the combination of the basic materials with hair after undergoing a pressure test. Due to the presence of hair

Fig. 7. Reinforced masonry bricks.

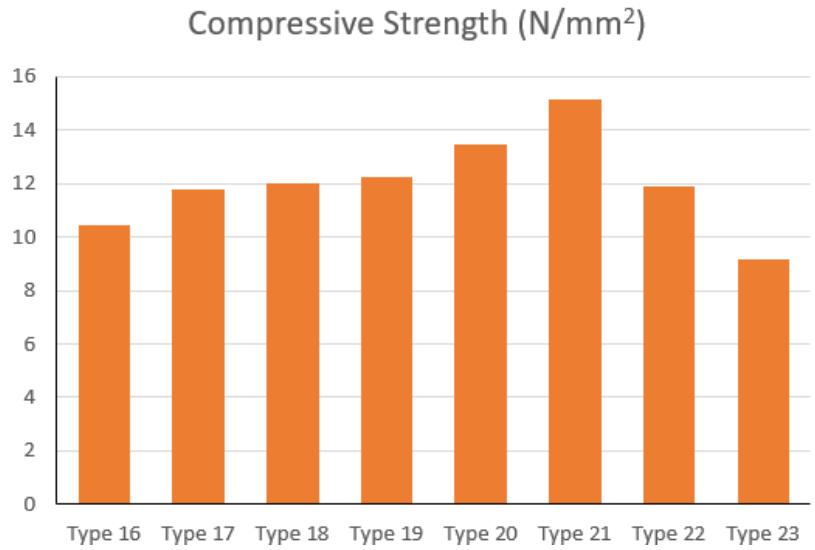


Fig. 8. Numerical average of the compressive strength of the reinforced samples.

fibers, this type of brick has no initial cracks and has not suffered shrinkage. Furthermore, the appearance of the bricks is very regular and free of cracks.

As can be seen in the diagram of Figure 8, the average resistance of the samples has increased significantly. Specifically, the average compressive strength increased from approximately 10.5 MPa for the unreinforced control specimens to about 15.0 MPa for bricks reinforced with 2.0% human hair fibers, corresponding to an improvement of approximately 43%. In other words, depending on the amount of human hair, the average compressive strength has increased compared to samples without hair. Moreover, all single-made samples reinforced with hair fibers have a compressive strength of more than 8.43 N/mm2 and also an average compressive strength (evaluated on 5 bricks) of all types, except type 23, greater than the minimum value of 10.1 N/mm2. Based on Figure 8, it can be seen that the process of increasing compressive strength was not continuous, and after an upward trend, it began to decline. In Figure 9, the average compressive strengths of the samples reinforced with hair fibers are shown in terms of the percentage of hair used. This enhancement can be attributed to the crack-bridging effect of randomly distributed human hair fibers, which restrain the initiation and propagation of microcracks and improve stress redistribution within the brick matrix under compressive loading. It should be noted that the proposed empirical relationship is valid only within the investigated fiber content range (0.6–4.5%), and extrapolation beyond this range may lead to unreliable predictions.

According to Figure 9, the highest average compressive strength was obtained for 2% of human hairs, and with an increase in hair, the average compressive strength decreased significantly. Therefore, the compressive strength of the samples with hair is approximately the same as that of the samples without hair at 4.5%. This indicates that the addition of hair to the samples is not always considered a positive factor. Instead, it is imperative to determine the optimal number of hairs to be added to the samples. A value of 2% is considered to be the most appropriate value here. In this research, using regression analysis, a transient optimal curve was estimated from the points displayed in Figure 9 and shown in Figure 10 using SPSS software [58].

Equation 1 shows the relationship extracted from Figure 10 between the percentage of human hairs used and

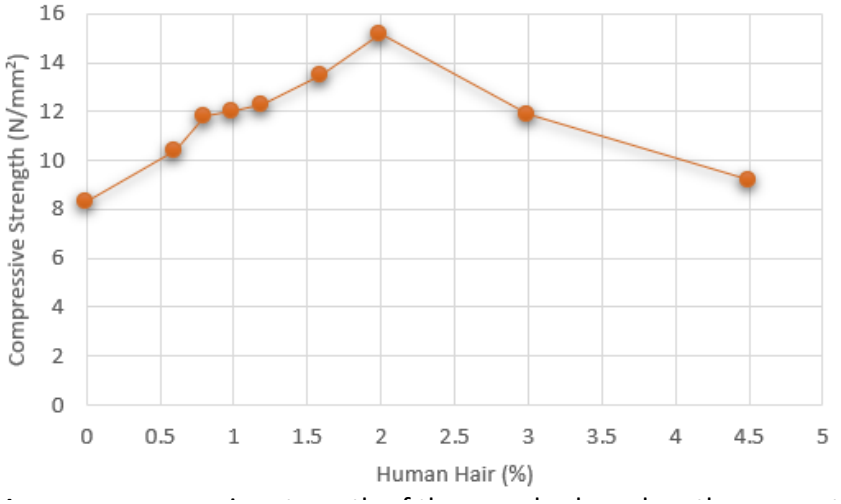


Fig. 9. Average compressive strength of the samples based on the percentage of hairs used (type 16- type 23).

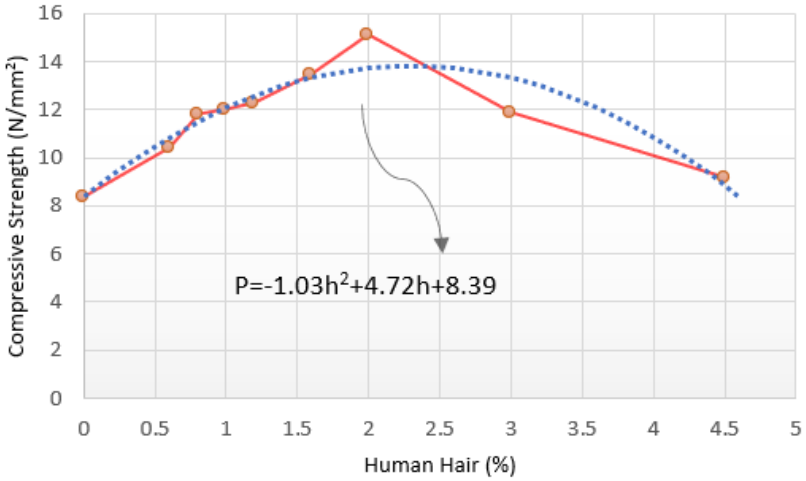


Fig. 10. Comparison of the original diagram and the traced scatterplot of compressive strength versus the percentage of human hairs.

the average compressive strength of bricks made with the proposed wastes in this research. Hence, the compressive strength can be determined from this equation by considering the hair percentage as follows:

$$P = -1.03h^2 + 4.72h + 8.39 \quad (1)$$

In the above relationship, P represents the average compressive strength of the samples, and h represents the percentage of hairs used in the samples. Based on a comparison between the graph obtained from this equation and the actual graph of the samples, we can conclude that the results of this equation are usable, since only a 10% error in the worst-case scenario is provided. For the purpose of comparing the proposed bricks with bricks currently available on the market, bricks made in Fars province of Iran have been used. The average compressive strength of 5 of these bricks is 13.63 N/mm2. It is evident from the comparison of this resistance to the values shown in Figure 7 that the average compressive strength of types 20 and 21 exceeds this value, so that they are suitable for construction purposes. A very important aspect of these bricks is how they break. Figure 10 illustrates broken samples under net compression for comparison.

It can be seen from Figure 10 that when the fractures of proposed samples and those of Gary bricks are compared to each other, the former blocks have a very favorable fracture pattern and did not undergo brittle failure. As masonry

Fig. 11. Broken samples under net compression.

structures typically experience sudden failures during earthquakes, this can be a desirable feature. Moreover, the cost of producing each brick is another advantage of this type of product. It is estimated that the SBHF method will reduce brick costs by about 40% when compared to the cost of construction and transportation to the project site. This significant cost reduction for establishing environmentally friendly local businesses is one of the positive aspects of this research methodology.

2.1.2.2 Flexural strength of reinforced masonry bricks

The flexural strength of materials is another measure of load resistance characteristic. This test is also performed in accordance with ASTM C67. Therefore, in this section, 5 samples of the proposed reinforced bricks are tested using the flexural strength measuring instrument for masonry bricks, as shown in Figure 11, and their average value is extracted.

To provide a comparison, Gary bricks' bending strength has also been calculated. A comparison has been made between this value and the value obtained for the proposed bricks in Table 5.

According to Table 5, the average flexural strength of the proposed bricks is approximately 35.3 % lower than the corresponding value for Gary bricks. Since human hairs are uniformly distributed throughout the entire volume of the proposed bricks, the compressive strength of the proposed bricks has been increased. However, in the flexural test, there is only one part of the hair used in the compressive part of the brick cross-section, and another part in the tensile part, and as human hairs are most effective in the compressive part, bricks' flexural capacity has been reduced compared to Gary bricks. Unlike synthetic fibers with controlled orientation, randomly dispersed human hair fibers do not effectively align along the tensile stress trajectory, which explains the reduced flexural performance observed.

2.1.2.3 Compressive strength of reinforced masonry prisms

Due to the fact that a masonry structure is comprised of bricks and mortar, its behavior under vertical and seismic loads will be influenced by the characteristics of its constituent components. Therefore, a compressive strength test of the

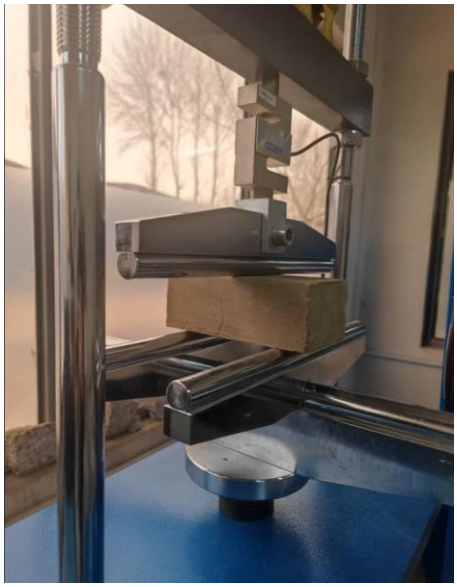


Fig. 12. Flexural strength test of reinforced masonry bricks.

masonry prism has also been carried out in this research. For this purpose, according to ASTM C1314, a masonry prism is constructed using 4 bricks and 3 layers of 10 to 12 mm thick mortar. To evaluate the effectiveness of bricks reinforced with 2% human hairs, their compressive strength is compared with the compressive strength of Gary brick prisms. Making mortar with the right materials and mixing ratios plays an important role in the compressive strength of masonry prisms. For this purpose, in this research, fine sand with a diameter of 2.36 mm, which is within the range of the ASTM C144 standard [7], was used in conjunction with Portland cement type 2 with a mixing ratio of sand to cement of 1:3. Figure 12 illustrates an example of this type of prism. In this study, three samples of masonry prisms were made, and the prism's compressive strength was determined by the numerical average of the samples' compressive strengths. Also, 3. Finally, the average compressive strength is considered as

Table 5. Flexural strength of bricks.

Type of Brocks	Flexural Strength (N/mm2)	Coefficient of variation (C.O.V.)
Proposed Bricks	2.67	14.97 %
Gary Bricks	3.61	

Table 6. Flexural strength of masonry prisms.

Type of prisms	Compressive Strength (N/mm2)	Coefficient of variation (C.O.V.) [%]
Proposed Bricks	5.22	6.1 %
Gary Bricks	4.62	

Fig. 13. Masonry prism is constructed using 4 bricks and 3 layers of mortar.

the compressive strength of the prism obtained from Gary bricks. Table 6 shows numerical results. The improved prism strength indicates enhanced brick–mortar interaction and suggests better load redistribution capacity at the assemblage level, which is critical for masonry performance under seismic loading.

Based on Table 6, it is evident that the average compressive strength of prisms made with the SBHF method is 12.95% higher than the average compressive strength of prisms made with Gary bricks. In which the SBHF method is shown to produce bricks with the proper performance.

2.1.2.4 Water Absorption of Reinforced Masonry Bricks

Water absorption is one of the criteria used to determine the standard performance of a brick. For different geographical conditions, this criterion may have a different value. In the event that the brick has a very limited ability to absorb moisture, the mortar becomes weak, and because there is insufficient water for the hydraulic reaction of the cement, there is no good contact between the brick and the mortar, and as a result, the strength of the structure is reduced. Additionally, if a lot of water is absorbed by the brick, the strength and durability of the structure will be adversely affected. Depending on the weather conditions, different countries have suggested different numbers as appropriate ranges. To control this issue, the method of boiling for 5 hours was used according to the national standard of Iran (INSO 7, 2017). In this method, samples are dried first, and their dry weight is determined. Following this, the samples should be placed in water so that the water can freely flow over their entire surface. Following the placement of the samples in the tank, the water should be heated to boiling within one hour, and then maintained at boiling for five hours. Following this period, the sample should be removed from the heat source so that the sample will reach room temperature by natural heat loss over the following 16 to 19 hours. After the samples have been removed from the water tank, the saturated weight is determined, and the water absorption percentage is calculated. This standard specifies that masonry bricks should absorb no more than 25% and no less than 6% of water. In this research, as shown in Figure 13, 5 bricks made by the SBHF method were selected and tested. According to the obtained results, the water absorption percentages of the samples were 24.72, 23.8, 22.41, 23.56, and 22.84. The presence of hair fibers likely interrupts continuous pore channels, limiting excessive water ingress while maintaining sufficient absorption for proper mortar bonding. As a result, it can be concluded that

Fig. 14. Water absorption test on hair reinforced masonry bricks.

the bricks performed satisfactorily from a water absorption standpoint.

Considering that in this research, human hair fibers were used in a city in Iran, it is possible that the properties of human hair in other regions differ from those used in this research. This phenomenon could change the optimal percentage of hair fiber selection based on compressive and flexural strength. Due to the fact that these bricks were dried naturally, the time needed for the bricks to reach their final strength can vary depending on their geographical location. Another parameter that affects the results to some extent is the type of clay used in different areas.

3- Conclusions

A novel method of reducing energy consumption and utilizing waste materials in brick manufacturing is presented in this article due to the high level of energy consumption and environmental pollution involved in the manufacture of masonry-fired bricks. Various raw materials were used to prepare samples for testing, and the following results were obtained.

1. Bricks reinforced with 2% human hair have a higher compressive strength than traditional bricks (Gary bricks) available on the market. It should be noted that this amount of human hair was not necessarily the maximum amount of waste to be used.
2. No need for skilled labor to produce these bricks.
3. By comparing the broken samples of bricks manufactured by existing methods with those manufactured by the proposed wastes in this article, it was observed that traditional bricks are extremely brittle, and the destruction of walls constructed with these bricks will be instantaneous. Despite this, the broken brick samples produced by the proposed wastes remained intact and were not completely broken.
4. The compressive strength of the produced samples meets the minimum standards. In comparison to the fired samples based on the percentage of hair used, the strength of the samples increased.
5. Since human hair is an environmental pollutant, these waste products entered the production cycle and were used suitably.
6. A masonry prism constructed from the proposed bricks performed satisfactorily in the compressive test compared to the Gary bricks.
7. As it explained in section 2.1.2.2, the flexural strength of the proposed bricks is lower than the corresponding value for Gary bricks. Because, in a flexural test, the brick is subjected to both tension and compression forces. It is important to note that human hair is only useful in support zones, so the tensile areas of the brick are not adequately reinforced, which decreases the brick's ability to resist bending as compared to Gary bricks. C.O.V equal to 14.97 % was obtained in this case.
8. As shown in section 2.1.2.3, it is evident that the average compressive strength of prisms made with the SBHF method is 12.95% higher than the average compressive strength of prisms made with Gary bricks. As masonry structures' behavior is a function of their masonry bricks' combined behavior, this feature demonstrates the superiority of the proposed bricks. This case results in a C.O.V coefficient of 6.1 %.
9. Water absorption by bricks reinforced with human hair falls within the standard range of regulations.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Presidency of the I.R.I. Plan and Budget Organization, Statistical data and official reports, https://www.amar.

org.ir (accessed 2024).

[2] Ministry of Education, State Organization of Schools Renovation, Report on retrofit procedure of school buildings in the Islamic Republic of Iran, Tehran, May 2011.

[3] M. Berberian, 100 years; 126,000 deaths, Encyclopaedia Iranica, 1997, http://iranian.com/Iranica/June97/Earthquake/Text2.html.

[4] Y. Gholipour, Y. Bozorgnia, M. Rahnama, M. Berberian, J. Shojataheri, Probabilistic seismic hazard analysis, Phase I: Greater Tehran Regions, Faculty of Engineering, University of Tehran, 2008.

[5] Y. Chen, Y. Zhang, T. Chen, Y. Zhao, S. Bao, Preparation of eco-friendly construction bricks from hematite tailings, Construction and Building Materials, 25(4) (2011) 2107-2111.

[6] Iranian Fuel Conservation Company, National energy efficiency reports, http://www.ifco.ir (accessed 2024).

[7] P. Quinteiro, A. Araujo, A.C. Dias, B. Oliveira, L. Arroja, Allocation of energy consumption and greenhouse gas emissions in the production of earthenware ceramic pieces, Journal of Cleaner Production, 31 (2012) 14-21.

[8] P. Quinteiro, A. Araujo, B. Oliveira, A.C. Dias, L. Arroja, The carbon footprint and energy consumption of a commercially produced earthenware ceramic piece, Journal of the European Ceramic Society, 32(10) (2012) 2087-2094.

[9] B.V.V. Reddy, K.S. Jagadish, Embodied energy of common and alternative building materials and technologies, Energy and Buildings, 35 (2003) 129-137.

[10] B.C. Lippiatt, BEES 4.0: Building for environmental and economic sustainability, Technical manual and user guide, NISTIR 7423, 2007.

[11] China Economic Trade Committee, Tenth five-year program of building materials industry, China Build Mater, 7 (2001) 7-10.

[12] Y. Chen, Y. Zhang, T. Chen, Y. Zhao, S. Bao, Preparation of eco-friendly construction bricks from hematite tailings, Construction and Building Materials, 25(4) (2011) 2107-2111.

[13] X. Lingling, G. Wei, W. Tao, Y. Nanru, Study on fired bricks with replacing clay by fly ash in high volume ratio, Construction and Building Materials, 19 (2005) 243-247.

[14] D. García, A.N. Klein, D. Hotza, Advanced ceramics with dense and fine-grained microstructures through fast firing, Reviews on Advanced Materials Science, 30(3) (2012) 273-281.

[15] I.Z. Bribián, A.V. Capilla, A.A. Usón, Life cycle assessment of building materials: comparative analysis of energy and environmental impacts, Building and Environment, 46(5) (2011) 1133-1140.

[16] G. Elmi, Fast firing technology in the brick and tile industry: a technical evaluation, Brick Tile Industry International, 46(3) (1993) 168-170.

[17] C. Koroneos, A. Dompros, Environmental assessment of brick production in Greece, Building and Environment, 42(5) (2007) 2114-2123.

[18] M.D. Bovea, E. Díaz-Albo, A. Gallardo, F.J. Colomer, J. Serrano, Environmental performance of ceramic tiles: improvement proposals, Materials and Design, 31(1) (2010) 35-41.

[19] F. Da Porto, M.R. Valluzzi, M. Munari, C. Modena, A. Arêde, A. Costa, Strengthening of stone and brick masonry buildings, Strengthening and Retrofitting of Existing Structures, 2017, 59-84.

[20] E. Vintzileou, Strengthening techniques: masonry and heritage structures, Encyclopedia of Earthquake Engineering, 2015, 3577-3604.

[21] L.A.S. Kouris, T.C. Triantafillou, State-of-the-art on strengthening of masonry structures with textile reinforced mortar, Construction and Building Materials, 188 (2018) 1221-1233.

[22] Z. Dong, M. Deng, J. Dai, P. Ma, Diagonal compressive behavior of unreinforced masonry walls strengthened with textile reinforced mortar added with short PVA fibers, Engineering Structures, 246 (2021) 113034.

[23] I. Boem, Masonry elements strengthened through textile-reinforced mortar: application of detailed level modelling with a free open-source finite-element code, Construction and Building Materials, 357 (2022) 129333.

[24] F.A. Kariou, S.P. Triantafyllou, D.A. Bournas, L.N. Koutas, Out-of-plane response of masonry walls strengthened using textile-mortar system, Construction and Building Materials, 165 (2018) 769-781.

[25] G.P. Lignola, C. Caggegi, F. Ceroni, S. De Santis, P. Krajewski, P.B. Lourenço, M. Morganti, C. Papanicolaou, C. Pellegrino, A. Prota, Performance assessment of basalt FRCM for retrofit applications on masonry, Composite Part B: Engineering, 128 (2017) 1-18.

[26] F. Parisi, D. Asprone, L. Fenu, A. Prota, Experimental characterization of Italian composite adobe bricks reinforced with straw fibers, Composite Structures, 122 (2015) 300-307.

[27] O.A. Ademati, A.A. Akinwande, O.A. Balogun, V. Romanovski, Optimization of bamboo fiber-reinforced composite-clay bricks for low-cost farm settlements, Journal of Materials in Civil Engineering, 34(12) (2022) 04022338.

[28] P. Prathyusha, K. Ramujee, The development and study of fiber reinforced fly ash bricks, Advances in Civil Engineering, 2020 (2020) 177-187.

[29] M. Mahgoub, I.S. Adelaja, M.S. Imbabi, Critical review of recent development in fiber reinforced adobe bricks, Frontiers of Structural and Civil Engineering, 14 (2020) 839-854.

[30] D.J. Harris, A quantitative approach to the assessment of the environmental impact of building materials, Building and Environment, 34(6) (1999) 751-758.

[31] M. Medineckiene, Z. Turskis, E.K. Zavadskas, Sustainable construction taking into account the building impact on the environment, Journal of Environmental Engineering and Landscape Management, 18(2) (2010) 118-127.

[32] H. Yan, Q. Shen, L.C.H. Fan, Y. Wang, L. Zhang, Greenhouse gas emissions in building construction: a case study of One Peking in Hong Kong, Building and Environment, 45(4) (2010) 949-955.

[33] X. Lingling, G. Wei, W. Tao, Y. Nanru, Study on fired bricks with replacing clay by fly ash in high volume ratio, Construction and Building Materials, 19 (2005) 243-247.

[34] S. Kute, S.V. Deodhar, Effect of fly ash and temperature on properties of burnt clay bricks, Journal of Civil Engineering, 84 (2003) 82-85.

[35] M.I. Chou, V. Patel, C.J. Laird, K.K. Ho, Chemical and engineering properties of fired bricks containing 50 wt% Class F fly ash, Energy Sources, 23 (2001) 665-673.

[36] M.I. Chou, S.F. Chou, V. Patel, M.D. Pickering, J.W. Stucki, Manufacturing fired bricks with Class F fly ash from Illinois basin coals, Final report, 2006.

[37] O. Kayali, High performance bricks from fly ash, Proc World of Coal Ash (WOCA), Lexington, USA, 2005.

[38] Y. Chen, Y. Zhang, T. Chen, Y. Zhao, S. Bao, Preparation of eco-friendly construction bricks from hematite tailings, Construction and Building Materials, 25(4) (2011) 2107-2111.

[39] P. Turgut, H.M. Algin, Limestone dust and wood sawdust as brick material, Building and Environment, 42 (2007) 3399-3403.

[40] H.M. Algin, P. Turgut, Cotton and limestone powder wastes as brick material, Construction and Building Materials, 22(6) (2008) 1074-1080.

[41] P. Turgut, Artificial limestone composites with cotton waste, Jordan Journal of Civil Engineering, 7(1) (2013) 126-131.

[42] J. He, Y. Jie, J. Zhang, Y. Yu, G. Zhang, Synthesis and characterization of red mud and rice husk ash-based geopolymer composites, Cement and Concrete Composites, 37 (2013) 108-118.

[43] S.M.S. Kazmi, S. Abbas, M.J. Munir, A. Khitab, Exploratory study on waste rice husk and sugarcane bagasse ashes in burnt clay bricks, Journal of Building Engineering, 7 (2016) 372-378.

[44] S. Ahmari, L. Zhang, Utilization of cement kiln dust to enhance mine tailings-based geopolymer bricks, Construction and Building Materials, 40 (2013) 1002-1011.

[45] L. Zhang, Production of bricks from waste materials: a review, Construction and Building Materials, 47 (2013) 643-655.

[46] K.K. Mondal, S. Banerjee, S. Dhar, M. Sudarshan, P. Bhattacharjee, Environmental impact of human waste hair reprocessing: a case study from rural West Bengal, Environmental Geochemistry and Health, 42(10) (2020) 3157-3170.

[47] Y. Yang, W. Yang, B. Wang, M.A. Meyers, Structure and mechanical behavior of human hair, Materials Science and Engineering C, 73 (2017) 152-163.

[48] M.V.R. Velasco, T.C.D.S. Dias, A.Z. de Freitas, N.D. Vieira Jr, C.A.S.O. Pinto, T.M. Kaneko, et al., Hair fiber characteristics and methods to evaluate physical and mechanical properties, Brazilian Journal of Pharmaceutical Sciences, 45(1) (2009) 153-162.

[49] N.D. Bheel, S.A. Abbasi, S.L. Meghwar, F.A. Shaikh, Effect of human hair fibers in cement concrete, Proc Int Conf Sustainable Development in Civil Engineering, 2017, 67-72.

[50] D. Jain, A. Kothari, Hair fiber reinforced concrete, Research Journal of Recent Sciences, 1 (2012) 128-133.

[51] S.L. Meghwar, G.B. Kheskheli, A. Kumar, R.B. Mahar, Recycling of human scalp hair in cement concrete, Proc 4th Int Conf Energy, Environment and Sustainable Development, 2016.

[52] N. Bheel, P. Awoyera, O. Aluko, S. Mahro, A. Viloria, C.A.S. Sierra, Sustainable composite development using human hair fibers in concrete, Case Studies in Construction Materials, 13 (2020) e00412.

[53] N. Ramya, J. Anitha, S. Pradeepa, N. Tamilselvi, G.D. Subhadra, Experimental study on mechanical behaviour of human hair reinforced concrete, Tuijin Jishu, 44(5) (2023).

[54] The Masterbuilder, Use of human hair as a natural fiber for fly ash bricks, Masterbuilder, 15(8) (2013) 68-70.

[55] M. Manjunatha, B. KVGD, J. Vengala, L.R. Manjunatha, K. Shankara, C.K. Patnaikuni, Experimental study on the use of human hair fibers in concrete, Materials Today: Proceedings, 47 (2021) 3966-3972.

[56] Iranian National Standardization Organization, Standard No. 7965, Tehran, 2011.

[57] ASTM C62-17, Standard specification for building brick (solid masonry units made from clay or shale), ASTM International, 2017.

[58] IBM Corp, IBM SPSS Statistics for Windows, Version 28.0, Armonk, NY, 2021.

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