Original Research Article

The Use of Waste Synthetic Hair Fibre in Cement Mortar

ABSTRACT

Cement mortar has low tensile strength and fracture strain; therefore, fibres are used to reinforce cement mortar. Synthetic hair is one of the most neglected of all the residual wastes that cause environmental problems in many developing countries. Therefore, this study used waste synthetic hair fibre in cement mortar production as a way to reduce the environmental effect generated by waste, and also to enhance the strength of the mortar for construction application. The study aimed to investigate the properties of cement mortar reinforced with waste synthetic hair fibres. 0, 2.5, 5, and 7.5% of synthetic hair fibre were used as a replacement for cement by weight in mortar. 100 × 100 × 100 mm cube, and 100mm diameter and 200mm length cylinder specimens were prepared, cured, and tested at ages 7, 14, and 28 days for tensile and compressive strengths, density, and water absorption. The highest compressive strength for the synthetic waste hair fibre reinforced mortar was 8.57N/mm^2 as compared to 10.84N/mm^2 achieved for the control at 28 days of curing. The synthetic waste hair fibre reinforced mortar achieved the highest tensile strength of 1.80N/mm^2 as compared to 1.67N/mm^2 achieved by the control at 28 days of curing, representing an increase of about 11% in tensile strength of the synthetic hair fibre reinforced mortar over the control. The highest density for the synthetic hair fibre reinforced mortar was 2114 kg/m^3 as compared to the control of 2144 kg/m^3. The lowest water absorption for the synthetic hair fibre reinforced mortar was 2.48% as compared to the control of 2.04%, respectively.It is concluded that the properties of cement mortar reinforced with waste synthetic hair fibres are acceptable for construction application and recommended that practitioners use 2.5% waste synthetic hair as a partial replacement for cement in producing mortar.

Keywords: Cement mortar, compressive strength, density, synthetic hair fibres, tensile strength, water absorption

1. INTRODUCTION

Cement mortar is a building material that is made with sand, cement, and water, and sometimes additives are added to improve the properties. It is used in a paste to fill the joints between blocks, bricks and stones in walls, plaster walls, screed floors, and for moulding blocks, bricks and pavement units. It is one of the most often used building materials. Cement mortar, unlike concrete, is not known for its durability and cannot be used as a solo building material [1]. While the compressive strength of cement mortar is typically satisfactory, its tensile strength is significantly lower, accounting for just approximately 10% of its compressive strength [2]. This weakness causes difficulties including shrinking and cracking, which are affected by a variety of factors like as the chemicals used, temperature, and relative humidity [3]. Reinforced fibres are used to overcome these difficulties and increase the strength of the mortar used in construction to enhance mortar's overall performance [2, 4-6].The improvement of the properties of mortar with fibres is an old construction technique.

Technological improvements have resulted in the introduction of fibre-reinforcement, which improves the mechanical properties of mortar. Fibre reinforced mortar has shown to be more dependable and effective, with widespread applicability across a variety of sectors. A study by Akbar et al. [7], has proven that fibre-reinforced mortar greatly outperforms standard mortar. This marks a considerable advance in building materials. Different types of fibres effectively limit the formation and development of cracks in structures and the fibres prevent the rapid and uncontrolled progression of cracks to the entire matrix with their bridging effect [8].In ancient times, the technique of using hair or fibres has traditionally been used as reinforcement in lime renders as a means of improving tensile strength and reducing shrinkage cracking.

Hairs, both natural and synthetic, are being investigated as fibre reinforcing elements in mortar to determine their effects on compressive, crushing, and flexural strength, as well as fracture control. The use of hair intends not only to improve mortar performance but also to minimize costs and address environmental concerns related to hair decomposition [9]. Synthetic hair, in particular, shows promise as a reinforcing fibre due to its high tensile strength. It is a non-biodegradable material that is commonly available at low to no cost and creates environmental risks when decomposed. By incorporating synthetic hair into mortar, its high tensile strength can be leveraged to improve the material's properties, offering an economical and environmentally friendly solution [10].

In Ghana, synthetic hair is considered a waste substance, commonly discovered in waste streams and contributing considerably to environmental problems. The combustion of human hair or garbage piles containing it produces foul aromas and harmful gasses. Open hair dumps can produce hair dust, which irritates neighboring inhabitants and can cause serious respiratory issues. Araya-Letelier et al. [11] said that trash disposal is a global issue owing to its environmental consequences. To address these challenges, incorporating synthetic hair into cement mortar offers a dual benefit: it not only enhances the mechanical properties of the mortar but also reduces environmental impacts and contributes to the economic system by providing an affordable construction material. Utilizing synthetic hair fibres in this way presents an effective and environmentally friendly solution, turning waste into a valuable resource for construction applications.

Synthetic hairs are being investigated as a fibre-reinforcing material in cement mortar to determine their effects on compressive, tensile, density, and water absorption. This strategy seeks to reduce the cost of mortar while also addressing environmental issues caused by hair degradation [12]. Synthetic hairs, sometimes known as false hair, weaves, or extensions, are widely utilized by women to improve their look [12]. These synthetic hairs allow women to acquire longer, thicker, or different-colored hair without affecting their natural hair. Women utilize synthetic hair to create complicated hairstyles like buns, which would be impossible to achieve with insufficient natural hair volume. Furthermore, synthetic hair allows women to get a temporary color change without having to dye their genuine hair [13]. After use of the synthetic hair for some time, it is usually removed and dumped in a refuse, or burnt which contributes to carbon dioxide (CO_2) in the atmosphere. Incorporating waste synthetic hair into building materials not only improves the mechanical qualities of mortar but also reduces the environmental effect of synthetic hair waste. This novel application of synthetic hair provides a sustainable and cost-effective option in the building sector.

Senthilnathan et al. [13] state that the high elasticity of synthetic hair is similar to that of a copper wire of the same diameter, making it a suitable material for fibre reinforcement. Because of the ecological issues this non-biodegradable substance presents, using it in mortar is not only a greener way to improve building materials but also a way to reinforce them. Because synthetic hair is widely available and reasonably priced, it improves mortar and keeps it from spalling. In a study by Araya-Letelier et al. [11], they found that the amount of pig hair added to mortar determined how much the mortar's characteristics improved. Pig hair improved binding qualities, micro-crack management, compressive strength, tensile strength, and spalling resistance [11]. Additional research by Araya-Letelier et al. [14] verified that adding fibres to cement-based composites enhanced their ability to withstand damage and operate mechanically. These fibres improved impact resistance, toughness, tensile and flexural strength, delayed fracture development, and narrowed crack widths.

Several studies have incorporated fibres in concrete production for construction applications. A study by Adedokun et al. [15] found that the compressive strength of concrete rises with both curing age and the percentage of human hair fibre in concrete. They also found that as the percentage of hair fibres increased, the density of concrete decreased. Bheel et al. [16] uncovered a distinct trend when researching the usage of human hair as a fibre in concrete. They discovered that while adding modest amounts of human hair initially boosts compressive strength, the strength falls when the hair fibre content increases beyond a certain point. They further found an increase in water absorption as the percentage of human hair increased. Jain and Kothari [17] study found the largest gain of 5 to 15% in compressive and flexural strengths of concrete reinforced with hair fibre over the control mortar. Similarly, Agrawal and Shrivastav [18] discovered a maximum improvement of 6.82% in flexural strength of concrete reinforced with human fibre at 7 days of curing and a 6.95% improvement at 28 days of curing over the control. Meghwar et al. [19] investigated the flexural strength of mortar mixed with human scalp hair fibre and found an increase of 7.4 and 6% at mix ratios of 1:2:4 and 1:1.5:3, respectively. They also found that the density of concrete decreased as the percentage of hair fibres increased. Sreevani and Ajitha [20] investigated the impact of human hair fibres added to concrete and found that the addition did not only improve properties such as tensile and compressive strengths but also enhanced the binding properties and micro-crack control. In a study by Chinnadurai and Anuradha [21], the effect of human hair fibres on splitting tensile strength of concrete was examined, and it was observed that the addition of human hair fibres led to an increase in strength characteristics.

From the foregoing, it can be observed that natural human hair in concrete production has been studied widely. However, the same cannot be said about the use of hair in mortar production, particularly about waste synthetic hair fibres. There is a gap in the research on using synthetic hair fibre as cement replacement in mortar, which requires a study to explore the potential of using synthetic hair fibre in building materials for construction applications.This gap underscores the need to use waste synthetic hair fibres to enhance the properties of cement mortar, particularly in mitigating tensile strength deficiencies. The use of waste synthetic fibre in mortar could also reduce the environmental effect of burning waste synthetic hair and further provides a sustainable and alternate building material for construction applications. This approach aligns with the goals of sustainable construction by utilizing waste materials and minimizing environmental impact.This study, therefore, aimed at investigating the properties of cement mortar reinforced with waste synthetic hair fibres. Waste synthetic hair was used as a replacement for cement in mortar to prepare cube and cylinder specimens and was cured and tested for tensile and compressive strengths, density, and water absorption.

2. MATERIAL AND METHODS

This study utilized an experimental research design to investigate the mechanical and physical properties of mortar incorporating waste synthetic hair fibres. The primary focus was on assessing key parameters including compressive strength, density, and water absorption characteristics. Data on compressive strength, density, and water absorption properties were systematically collected and analyzed.

2.1 Materials

Ordinary Portland Cement (OPC) class 32.5R produced by Ghana cement (GHACEM)conforming to IS 269:2013 [22] was used for the production of mortar. The chemical compound of the class 32.5R GHACEM OPC cement is presented in Table 1 as was investigated by Akyen and Kankam [23]. It was obtained from a market in Kumasi, Ghana. Natural pit sand which passed through a 4.75mm sieve with a specific gravity range between 2.5 and 2.8 was used as fine aggregate in the experimental work. Tap water was used for mixing mortar. In addition, waste synthetic hair fibre (Figure 1a) obtained from dumping sites, hairdresser's salons, and beauty parlors in Takoradi, Ghana was used as a partial substitution for cement in the mortar. The characteristics of waste synthetic hair fibres encompass various properties such as fibre diameter, length, aspect ratio, tensile strength, and ultimate tensile strain as presented in Table 2.

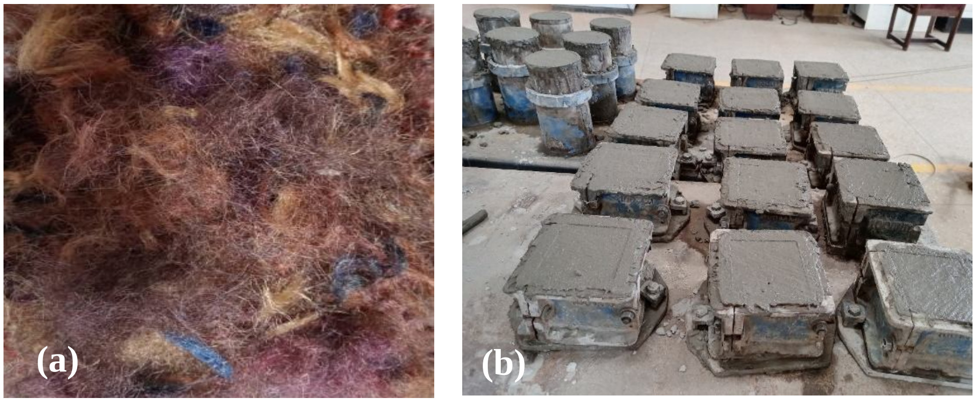

Figure 1: Material preparation: (a) waste synthetic hair fibre, (b) moulding of cube specimens

Table 1: Chemical compound of cement

Chemical compound	Value
SiO_2	22.90
Fe_2O_3	4.55
CaO	58.00
Al_2O_3	5.80
MgO	3.34
SO_3	3.46
Na_2O	0.00
K_2O	0.61
Insoluble residue and LOI	1.34

Table 2: Properties of waste synthetic hair fibres

Properties	Value
Average length	25cm
Diameter range	90 to 120 µm
Aspect ratio	450 – 500
Average tensile strength	350 MPa
Ultimate tensile strain	50.11%

2.2 Specimen Preparation

A mix ratio of 1:6 of cement to sand with a water-cement ratio of 0.5 was used for preparing the mortar. Waste synthetic hair fibre was used as a substitution for cement in varying quantities of 0, 2.5, 5, and 7.5% by weight of cement. These proportions were chosen to systematically evaluate the influence of waste synthetic hair on the mortar's properties. To ensure uniform distribution and to prevent clustering, the required quantities of cement, sand, and waste synthetic hair fibre were mechanically mixed in a pan mixer for 5 minutes before adding water. This step was crucial to achieving homogeneous mortar mixtures with consistent fibre dispersion. After mixing, the mortar was used to prepare 100 × 100 × 100 mm cube, and 100mm diameter and 200mm length of cylinder specimens (Figure 1b). These specimens were then carefully preserved in a sealed condition for 24 hours to facilitate setting and early strength development. The specimens were demoulded and cured under saturated conditions by covering the specimens with jute sacks and sprinkling water on them twice daily at an average temperature of 22°C. This environment was maintained throughout the curing period, which extended from 7 to 28 days before testing.

2.3 Determination of the various properties of Reinforced Mortar

2.3.1 Compressive Strength

The compressive strength test was conducted in line with IS 516:1959 with cube specimens. Each specimen was carefully positioned on the compression testing machine's bearing surface to ensure uniform loading conditions (Figure 2a). A controlled and uniform rate of loading was applied to the specimen until it fractured under the pressure. Throughout the test, the maximum loads at which the specimens fractured were recorded. The compressive strength (σ) of the mortar specimen was computed as the load (kN) at which the specimen fractured divided by the cross-sectional area (mm^2) of the specimen where the load was applied.

Figure 2: Testing of specimens; (a) compressive strength, (b) tensile strength

2.3.2 Splitting tensile strength

The splitting tensile strength test was conducted in line with IS 5816:1999 [24] specifications, following the casting and curing of synthetic hair reinforced mortar specimens. The objective was to evaluate the material's resistance to tensile stresses. A cylindrical specimen was used for the test. The specimen was carefully positioned horizontally on the test machine's loading surfaces so that the load would be applied along its vertical diameter (Figure 3). A load was gradually applied to the cylindrical specimen until it fractured under tension. The load application was used for determining the splitting tensile strength, which measures the ability of the mortar to resist tensile stresses perpendicular to its axis.

2.3.3 Density

To determine the density of the waste synthetic hair-reinforced mortar specimens was determined in line with IS 2250:1981 [25]specification. The specimens were oven-dried and the specimen's weight was measured using an electronic weighing balance. The dimensions of the specimens were recorded and used to calculate their respective volumes. The density of each specimen was calculated by dividing the dried weight (kg) by the volume (m^3) of the specimens.

2.3.4 Water absorption

The water absorption of the waste synthetic hair-reinforced mortar specimens was determined in line with IS 2250:1981 [25] specification. Initially, specimens were oven-dried and weighed using an electronic weighing balance to determine their dried weight. Subsequently, the specimens were immersed in a basin containing water for a period of 24 hours, after which the specimens were removed from the water, the excess surface water was gently removed, and their wet weight was measured. The percentage water of absorption (%) was calculated and then calculated.

3. RESULTS AND DISCUSSION

The average results of the tests conducted are presented in a summary Table 3. The tests include compressive, tensile, density, and water absorption.

Table 3: Summary results of waste synthetic hair fibre mortar

Curing age	Fibre content (%)	Compressive strength (N/mm^2)	Tensile strength (N/mm^2)	Density (kg/m^3)	Water absorption (%)
7	0	7.26	1.32	2127	-
	2.5	5.60	1.33	2081	-
	5	5.42	1.29	2020	-
	7.5	4.32	0.82	2001	-
14	0	9.17	1.56	2144	-
	2.5	6.59	1.65	2114	-
	5	6.42	1.50	2101	-
	7.5	5.68	0.91	2041	-
28	0	10.84	1.67	2128	2.04
	2.5	8.57	1.80	2111	2.06
	5	7.13	1.39	2101	2.13
	7.5	6.62	0.97	2094	2.48

3.1 Mechanical properties of mortar produced with synthetic hair fibre

3.1.1 Compressive strength of mortar produced with synthetic hair fibre

The investigation involved conducting compressive strength tests on mortar samples at intervals of 7, 14, and 28 days, where synthetic hair fibre was used as a partial replacement for cement. The results of these tests, detailing the average compressive strength values, are presented in Table 2 and summarized in Figure 3. The compressive strength results range between 4.32 and 10.84N/mm^2. The results indicate that the highest compressive strength of reinforced mortar was 8.57 N/mm^2 with 2.5% hair fibre replacement at curing day 28 as compared with the control of 10.84N/mm^2.This represents a decrease of about 19% in compressive strength of the synthetic hair fibre mortar. Compressive strength further reduced beyond 2.5% hair fibre replacement for all the curing days. Though the compressive strength of the waste hair fibre mortar was lower than the control, all the strength values were better than 4 N/mm^2 (M4) and 6N/mm^2 (M6) recommended by the BS EN 998-2 [26]. This outcome aligns with the findings of Bheel et al. [16], supporting the fact that compressive strength diminishes with an increase in hair fibre content. The consensus on this trend extends to the studies of Chinnadurai and Anuradh [21], Nila and Raijan[27], and Agrawal and Shrivastav [18], all reporting that an increase in compressive strength was observed at lower percentages of hair fibre content, while strength declined beyond these limits.

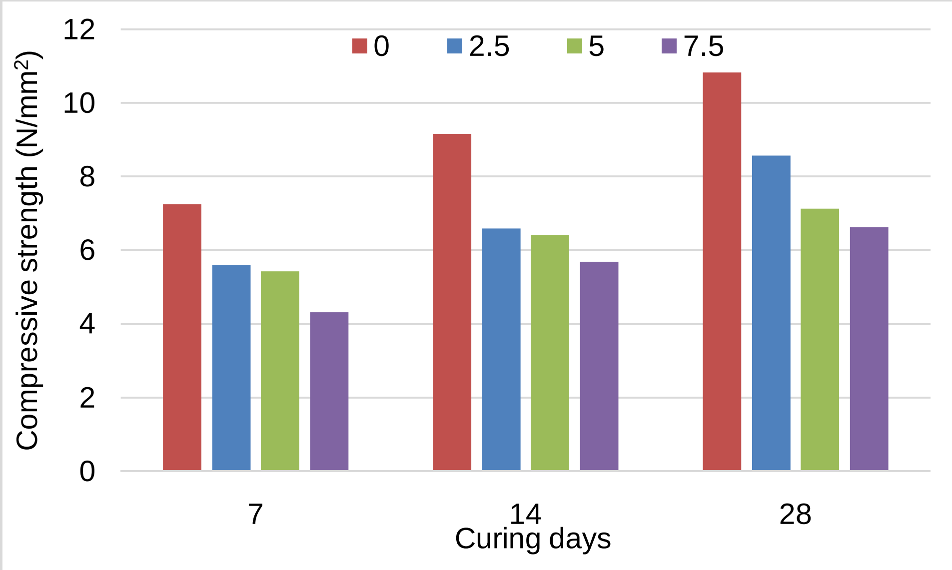

Figure 3. Compressive strength result

3.1.2 Tensile strength of mortar produced with synthetic hair fibre

In the examination of the tensile strength of the mortar produced with synthetic hair fibre as a partial replacement for cement, the average values of the tensile strength results are documented in Table 2 and further illustrated in Figure 4. The mortar's average results indicated a range of split tensile strength from 0.91 to 1.80 N/mm^2 for curing durations of 7, 21, and 28 days. Out of the replacements, 2.5% synthetic hair fibre produced the highest split tensile strength of 1.80N/mm^2 at the curing day 28 while the control recorded 1.67N/mm^2. This represents an increase of about 11% in tensile strength of the synthetic hair fibre reinforced mortar over the control. Fibres have better tensile properties which resulted in the better tensile strength at the right mix quantity.The result shows a gradual decrease in tensile strength with a further increase in synthetic hair fibre beyond 2.5%. These results indicate a notable decrease in tensile strength as the proportion of synthetic hair fibre replacing cement increases. Interestingly, it was found that incorporating 2.5% synthetic hair fibre replacement of cement exhibited the highest strength performance. This finding aligns with the observations of Adedokun et al. [15], who noted that additions of hair fibre at a certain level record an optimum strength, however, further increase leads to a decline in mortar tensile strength. It underscores the potential of waste synthetic hair fibre to initially enhance mortar tensile strength, beyond which its effectiveness diminishes, impacting the material's overall strength. Moreover, the research resonates with the findings of Sreevani and Ajitha [20], who similarly reported improved split tensile strength in mortar when supplemented with human hair fibres. Their investigation consistently demonstrated that while lower concentrations of hair fibres contributed positively to tensile properties, higher percentages resulted in decreased tensile strength. This trend underscores the significant influence of synthetic hair fibres on mortar's mechanical characteristics, emphasizing the need for careful dosage optimization to achieve optimal strength enhancements.

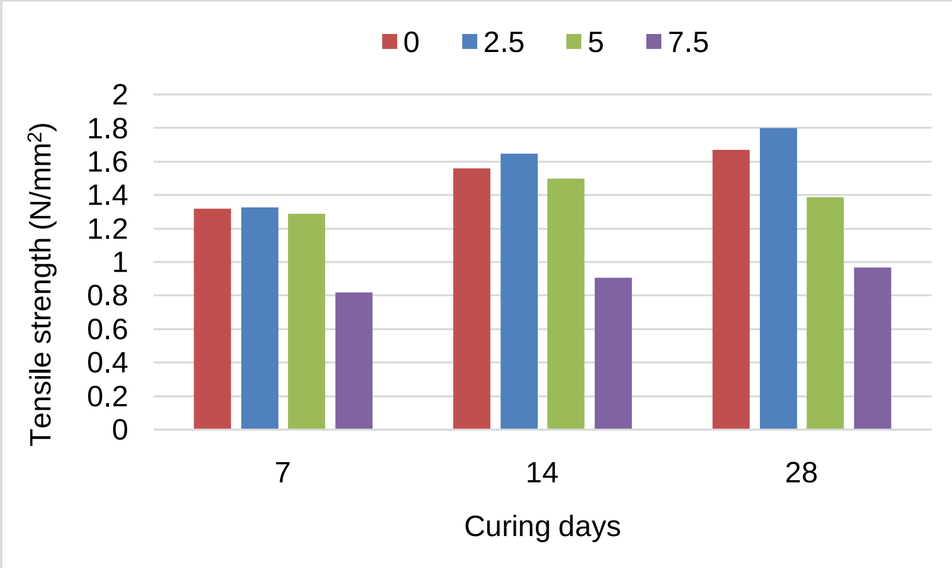

Figure 4. Tensile strength result

3.2 Physical properties of mortar produced with synthetic hair fibre

3.2.1 Density of mortar produced with synthetic hair fibre

The average density test results are presented in Table 2 and summarized in Figure 5. The recorded densities range from 2001 to 2144kg/m^3. At 7 days of curing, the minimum density was recorded at 2001kg/m^3 for 7.5% replacement, while the maximum density of 2127kg/m^3 was noted at 0% replacement. Moving to the 14-day curing period, the minimum density was 2041kg/m^3 at 0% hair fibre replacement, and the maximum density was 2144kg/m^3 at 0% hair fibre replacement. Similarly, at 28 days, the minimum density was 2094kg/m^3 for hair fibre replacement at 7.5%, while the maximum density was 2128kg/m^3 at 0% replacement. These values are higher than the recommended density of 1700-1900kg/m^3 by ASTM C270:2019[28]. As reported by Cellulose [29] the density of cement mortar is required to be no less than 1900kg/m^3, and that of cement composite mortar should be no less than 1800kg/m^3. The density values obtained in this study meet the requirement and are lower than those of Bheel et al. [16], whose values ranged from 2422 to 0% to 2368kg/m^3 for mortar with human hair fibre. The trend of the result suggests a consistent decrease in density with an increase in the percentage of synthetic hair fibre as a partial replacement for cement. A similar trend was found in a study conducted by Adedokun et al. [15], where it was demonstrated that the density of concrete decreases with an increase in the percentage of the synthetic hair fibre. The reduction in the density of the mortar with increased waste synthetic hair fibre as a partial replacement for cement can be attributed to the light weight of the hair fibres as compared with the weight of the cement. A similar finding was made in studies of reinforcing cement mortar with natural fibres [30, 31].

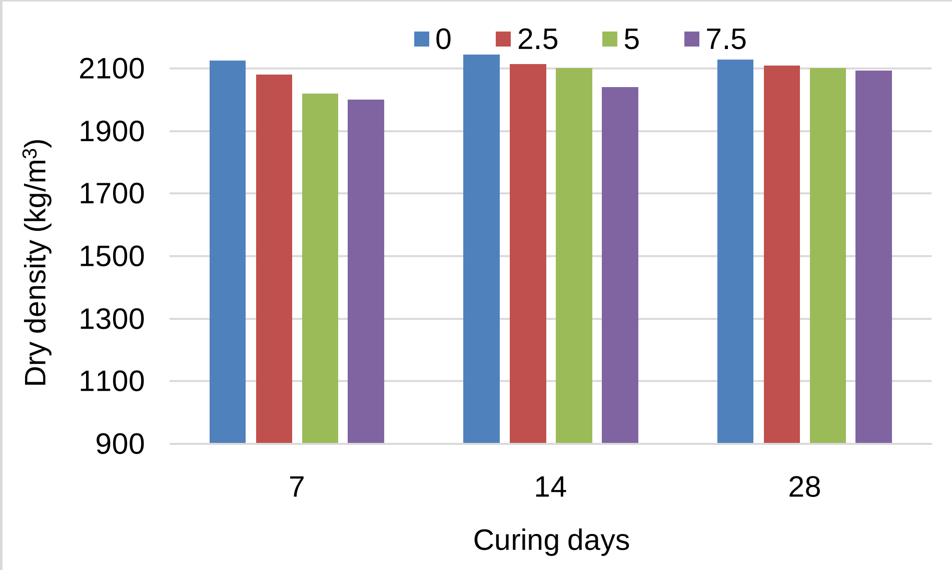

Figure 5. Dry density result

3.2. Water absorption of mortar produced with synthetic hair fibre

The 28-day curing water absorption test results are presented in Table 2 and summarized in Figure 6. The results range from 2.04 to 2.48% respectively for 0% and 7.5% of synthetic hair fibre replacement. There was about 1% increase in water absorption of 2.5% synthetic hair fibre mortar as compared the control. Furthermore, there was a progressive water absorption increase in the mortar as the synthetic hair fibre replacement increased. This indicates that the water uptake of the mortar surges with the increase in the synthetic hair fibre. The findings of this study align with those of Bheel et al. [16], who reported that the maximum water absorption in the mortar of 3.07% was observed with human hair fibre after 28 days. Additional support for this trend is found in studies conducted by Kumar et al. [32] and Reddy et al. [33], both confirming that water absorption values in concrete increase with an increasing proportion of hair fibre as a partial replacement for cement. According to ASTM C1403:2022 [34], good mortar should not absorb water more than 10% by mass. This implies that although the water absorption levels of the synthetic hair fibre mortar were more than the control, they were all within the acceptable requirement by ASTM C1403:2022 [34].

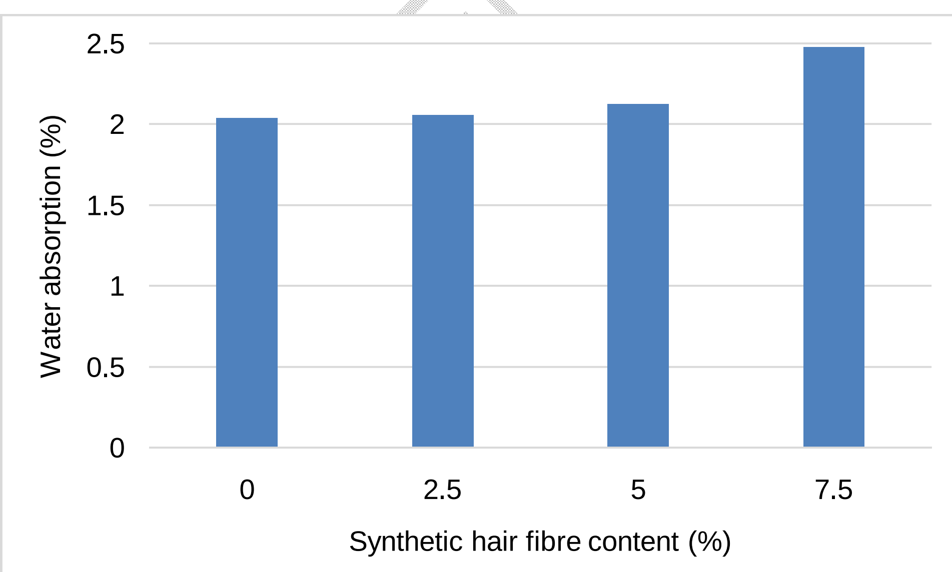

Figure 6. Water absorption result

4. CONCLUSION

The study aimed at investigating the properties of cement mortar reinforced with waste synthetic hair fibres as a replacement for cement. The findings of the study include:

- The compressive strength of the waste synthetic hair fibre mortar was lower than the control mortar. However, the strength values of the fibre-reinforced mortar were found to be better than the minimum recommended strength.
- The waste synthetic hair fibre mortar produced the highest split tensile strength at 2.5% replacement of cement.This represented an increase of about 11% in tensile strength of the synthetic hair fibre reinforced mortar over the control.
- There was a consistent decrease in the density of mortar with as increase of synthetic hair fibre content in the mortar as a partial replacement for cement. However, the density values obtained from the fibre-reinforced mortar were acceptable.
- Although the water absorption of the waste synthetic hair fibre mortar was higher than the control, it was below the maximum recommended value.

The study, therefore, concludes that the properties of cement mortar reinforced with waste synthetic hair fibres are acceptable for construction application. The study recommends that incorporating synthetic hair as a partial replacement for cement, specifically at a 2.5% substitution rate, can produce acceptable mortar for construction application. The use of waste synthetic hair fibre in cement mortar does not only allows for a substantial reduction in cement usage but also promotes the development of eco-friendly mortar solutions. By adopting such practices, the construction industry can align with Sustainable Development Goals (SDG 12) related to responsible consumption and production. Furthermore, embracing synthetic hair in mortar production supports a circular economy model by efficiently utilizing waste materials and minimizing environmental impact throughout the construction lifecycle. These findings underscore the potential of synthetic hair as a viable alternative in enhancing sustainability practices within the building sector.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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