



Enhancing cement concrete strength by incorporating synthetic human hair waste as fibre: The case of Musanze District in Rwanda

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Abstract

This study examined the use of synthetic human hair waste as reinforcement in concrete to improve its mechanical properties to mitigate micro-cracking. Specifically, the research evaluated the effect of fibre inclusion on concrete workability, compared the compressive strength of conventional concrete with fibre-reinforced concrete, and determined the optimal fibre content required to achieve improved overall performance in terms of both strength and workability. The experiments, including sieve analysis, slump test and compressive strength test, were conducted according to IS 383-1970, American standard ASTM C143 and IS 456:2000, respectively. The study incorporated synthetic human hair waste into concrete at various percentages, ranging from 0% to 4.5% by weight of the cement for the slump test, and from 0% to 3% for the compressive strength test. The results showed that the addition of fibres slightly improved the workability of concrete, with slump values increasing from 5.2 cm to 5.8 cm up to 3% fibre content, before slightly decreasing at 4.5%. In terms of mechanical performance, 1.5% synthetic human hair waste fibres significantly enhanced compressive strength by 16.56% at 7 days and 27.23% at 28 days, whereas a higher content (3%) caused a notable reduction in strength. Therefore, 1.5% fibre content was identified as the optimal proportion for improving concrete performance. This study recommended that synthetic human hair waste fibre can be incorporated at an optimal dosage of 1.5% by weight of cement to enhance the mechanical performance and strength characteristics of concrete, as higher fibre contents negatively affect compressive strength. Further studies are required to evaluate long-term durability and to establish its practical applicability in sustainable construction.

Key words: *Compressive strength; Mechanical properties of concrete; Slump test; Sustainability; Synthetic human hair waste; Waste management; Workability*

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Introduction

Concrete is a fundamental construction material composed of water, a binding agent (typically cement), coarse and fine aggregates, and, when needed, admixtures valued for its durability and resistance (Xing *et al.*, 2024). However, conventional concrete exhibits inherent weaknesses, such as low tensile strength and susceptibility to cracks (Kumar *et al.*, 2024). To address these limitations, researchers have explored various additives to enhance the crack susceptibility performance of concrete (Zhang *et al.*, 2024). Fibre reinforcement is one such approach that has gained attention due to its ability to improve toughness and ductility (Samani *et al.*, 2015). The beauty industry generates significant synthetic human hair waste, which presents disposal challenges due to its non-biodegradable nature (Moshood *et al.*, 2022). Finding sustainable solutions for using synthetic human hair waste is imperative to mitigate environmental impacts (Kathiresan and Meenakshisundaram, 2022). Integrating synthetic human hair waste as fibres in concrete production not only addresses waste management issues but also has the potential to enhance the mechanical properties of concrete. Synthetic human hair waste contributes to pollution, as the fibres are made from polymers that release harmful gases when burned (Gupta, 2014).

The disposal of synthetic hair waste contributes significantly to environmental pollution. When these materials are burned or thermally decomposed, they release carbon-based gases such as carbon monoxide (CO) and carbon dioxide (CO₂). These emissions contribute to environmental problems including global warming, ozone layer depletion, and acid rain formation (Şanal, 2018). Furthermore, synthetic hair waste is rarely recycled and tends to accumulate in landfills, where it persists for long periods due to its non-biodegradable nature. This leads to increased land pollution and inefficient waste management. Therefore, finding alternative uses for synthetic hair waste, such as incorporating it into cement concrete, can help reduce environmental impacts while

improving material performance (Iravani and Ravari, 2020). Specifically, hair fibres made from nylon can take 30–40 years to decompose, while those made from polyester may take over 200 years. As a result, land pollution occurs, which can lead to water pollution when contaminated soil is eroded into nearby water bodies (Ayothiraman *et al.*, 2022). These wastes can also lead to respiratory illnesses due to the inhalation of hair dust and the harmful gases they emit (Zhang *et al.*, 2022). To overcome these limitations, researchers have investigated various additives to enhance concrete performance (Ferreira *et al.*, 2000). Among these, fibre reinforcement has gained significant attention for its ability to improve the material's toughness and ductility (Ferreira *et al.*, 2000). As an alternative to traditional reinforcement methods, incorporating discrete fibres into plain or reinforced concrete presents a promising solution to mitigate issues such as steel corrosion caused by cracking. Interestingly, synthetic hair commonly discarded as waste by many beauty salons in Rwanda offers a potential source of such fibres. Utilizing this waste material in fibre-reinforced concrete not only addresses environmental concerns but also enhances the performance of the concrete itself. Fibre-reinforced concrete is widely recognized for improving the flexibility of traditionally brittle concrete, with notable benefits including increased ductility, strength, and resistance to crack formation. These improvements largely depend on the type, length, and proportion of fibres used. When properly incorporated, fibres contribute to greater impact resistance and durability, making the concrete more resilient and long-lasting (Kang *et al.*, 2015).

This study explored innovative ways to enhance the strength of concrete while promoting sustainability by reusing synthetic human hair waste as fibres in plain concrete. The primary objective was to investigate the potential of synthetic human hair waste as reinforcement in cement concrete to improve its mechanical properties particularly strength and to address the issue of micro-cracks.

The investigation into the use of synthetic human hair waste as fibre reinforcement has

significantly contributed to both academic and professional growth, advancing knowledge in materials engineering and sustainable construction practices. At the academic level, this research enhances the field of civil engineering, contributing to the expansion of expertise in sustainable building materials. The findings of this study have the potential to attract funding opportunities, foster collaborations with industry partners, and encourage partnerships with other academic institutions, creating a culture of interdisciplinary research and knowledge exchange.

By repurposing synthetic human hair waste in concrete production, this research helps reduce the environmental impact of hair waste disposal, mitigates pollution, and supports the principles of a circular economy. The development of sustainable construction materials also offers broader societal benefits, including improved infrastructure resilience and a higher quality of life for communities. This study specifically focuses on the design and production of cement concrete incorporating synthetic human hair waste as fibre reinforcement. It examines the influence of varying fibre content and length on the mechanical and durability properties of the concrete. However, it does not explore the chemical composition of synthetic human hair fibres or their long-term performance in real-world construction applications.

This study aimed to investigate the potential of synthetic human hair waste as a reinforcing material in cement concrete to enhance its mechanical properties, particularly strength, and to mitigate micro-cracking. Specifically, the research evaluated the effect of fibre inclusion on concrete workability, compared the compressive strength of conventional concrete with fibre-reinforced concrete, and determined the optimal fibre content required to achieve improved overall performance in terms of both strength and workability.

Materials and methods

In this study, concrete mixtures were prepared using a combination of coarse and fine

aggregates, along with cement and water. The coarse aggregates comprised crushed granite stones with particle sizes ranging from over 4.75 mm to a maximum of 20 mm, while fine aggregates consisted of clean, locally available, well-graded river sand passing through a 4.75 mm sieve. Potable tap water, free from impurities and suitable for both mixing and curing, was consistently used throughout the experiment. Ordinary Portland Cement (OPC) of grade 32.5, conforming to IS: 8112-1989 standards, served as the primary binding material in the concrete mix. Synthetic human hair waste used in this study was collected from local salons, thoroughly washed using a mild detergent and clean water to remove impurities, sun-dried for 3 hours, and manually cut into uniform lengths of 10 cm.

The experimental program was designed using a single-factor completely randomized design, where the percentage of synthetic hair fibre was the only variable, investigated at four levels (0%, 1.5%, 3%, and 4.5% by weight of cement). A conventional M20 grade concrete mix, proportioned at 1:1.5:3 in accordance with IS: 10262-2019, was used as the control mix. Synthetic hair fibres were incorporated into the concrete in the specified proportions to evaluate their influence on mechanical properties and determine the optimal fibre content.

The mixing process involved thoroughly blending the dry materials cement, fine aggregate, and coarse aggregate in a concrete mixer. Synthetic hair fibres were gradually introduced into the dry mix to ensure uniform dispersion and prevent clumping. Water was then added slowly while mixing continued until a consistent and workable mix was achieved. Concrete specimens were cast in standard moulds, demoulded after 24 hours, and cured in clean water for periods of 7 and 28 days.

To evaluate performance, laboratory tests were conducted in accordance with relevant standards. Sieve analysis was performed as per IS: 383-1970 to determine aggregate gradation. Workability was assessed using the slump test following IS: 456-2000 and ASTM C143. Compressive strength tests were conducted in accordance with IS: 456-2000 on at least two

specimens per mix, and the average values were recorded to ensure accuracy and reliability.

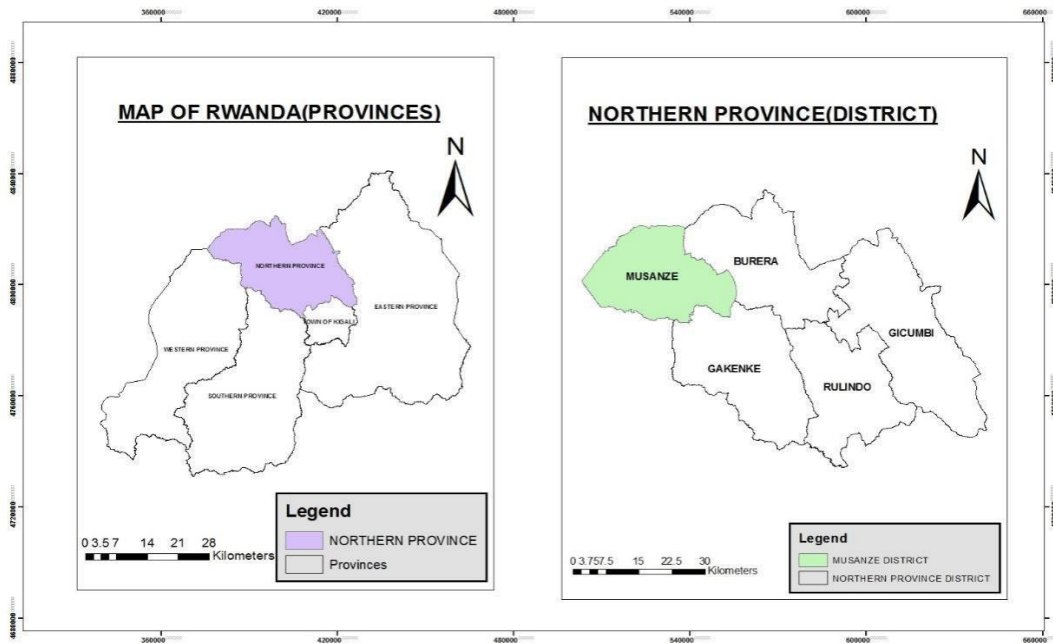
Description of the case study

The case study is situated in Musanze District, located in the Northern Province of Rwanda. Musanze is the second largest city in Rwanda, after Kigali, the capital. It is known for its fertile soil, which has a positive impact on agricultural cultivation. As a popular tourist destination, attracted by the presence of volcanoes and gorillas, Musanze has seen an influx of migrants. This has led to an increased demand for fashion services, including hairstyling, resulting in a higher number of salons and shops. Consequently, the amount of synthetic hair waste has also risen. When discarded in the soil, its non-biodegradable nature leads to long-term waste build up, which, if not managed properly, can harm the farm's soil. The beauty industry contributes significantly to the accumulation of synthetic human hair waste, which poses considerable disposal challenges due to its non-biodegradable composition. Synthetic

human hair waste contributes significantly to environmental pollution due to its polymer-based composition. When these synthetic fibres are incinerated, they release harmful gases such as carbon monoxide and carbon dioxide both of which are major contributors to global warming, ozone layer depletion, and acid rain. In addition to atmospheric pollution, the release of fine hair dust and toxic fumes during combustion poses serious health risks, including respiratory disorders when inhaled by humans. Addressing this issue through sustainable waste management practices is crucial for minimizing its environmental impact. One promising solution is the incorporation of synthetic human hair waste as fibre reinforcement in concrete. This innovative approach not only offers a practical method for managing waste but also has the potential to improve the mechanical performance of concrete, including its strength and durability. The map location of Musanze district is shown in Figure 1.

Figure 1

The map location of Musanze district, Rwanda



Sample collection and preparation

Synthetic human hair waste gathered from various salons and dump sites in the Musanze District, along with coarse aggregates (gravel) and fine aggregates (sand) sourced from the Kimonyi quarry, were used. The cement used was PRIME cement (Ordinary Portland Cement (OPC) of grade 32.5), which was purchased from a hardware store in Musanze.

The collected synthetic human hair fibres were thoroughly cleaned to remove any impurities that could potentially harm the concrete. The fibres were gently washed with distilled water to eliminate contaminants that could affect the quality of the concrete mix. After washing, the fibres were dried by exposing them to sunlight for 3 hours to ensure the removal of moisture, preventing any increase in the water content of the concrete. Once dried, the fibres were carefully cut into 10 cm lengths using a ruler and scissors, preparing them for use in the concrete mixture.

Batching and mixing

The concrete components were measured using a weighing scale of 1:1.5:3 mix ratio as specified in the Indian Standard IS 456:2000 for M20 grade concrete. During the mixing process, the fine and coarse aggregates were first combined with cement to form a homogeneous mixture. Synthetic hair was then added and thoroughly mixed in, followed by the addition of water at the final stage of the process. The mixture was prepared on a plate using a trowel resulted in

freshly mixed concrete ready for placement. The mixing was carried out in four stages, corresponding to different percentages of synthetic fibres (0%, 1.5%, 3%, and 4.5%) incorporated into the concrete.

After one day in cube moulds to achieve a sufficient level of hardness, the concrete was taken out of the moulds and allowed to cure in a curing tank (basin) for a total of 7 days and 28 days before being tested for compressive strength.

Calculation on mixing process

The mix design calculations for the concrete specimens were carried out using standard volumetric and weight relationships to ensure accuracy and consistency in material proportions, as summarized in Equations (1) to (14) shown in Table 1. The process involved determining the wet and dry volumes of concrete required for casting the specimens, followed by the calculation of individual material quantities based on the specified mix ratio of 1:1.5:3. Appropriate conversion factors were applied to account for voids and bulking in aggregates. The quantities of cement, fine aggregates, coarse aggregates, and water were computed using established formulas, while the addition of synthetic hair fibres was determined as a percentage of cement weight.

Table 1*Equations for Material Quantity Calculations in Concrete Mixing Process*

Eq. No.	Description	Equation
(1)	Wet concrete volume of cube	$V=L \times l \times h$
(2)	Total wet volume	$V_{total}=V \times \text{number of cubes}$
(3)	Dry concrete volume	$V_{dry}=1.54 \times V_{total}$
(4)	Volume of cement	$V_c = \frac{1}{\text{sum of ratios}} \times V_{dry}$
(5)	Volume of fine aggregates	$V_{fa} = \frac{1.3}{\text{sum of ratios}} \times V_{dry}$
(6)	Volume of coarse aggregates	$V_{ca} = \frac{3}{\text{sum of ratios}} \times V_{dry}$
(7)	Weight of cement (general form)	$W_c = V \times \text{unit weight of cement}$
(8)	Weight of cement (from dry volume)	$W_c = V_{dry} \times \text{unit weight of cement}$
(9)	Weight of fine aggregates	$W_{fa} = 1.5 \times W_c$
(10)	Weight of coarse aggregates	$W_{ca} = 3 \times W_c$
(11)	Weight of water	$W_w = (W/C) \times W_c$
(12)	Fibre weight (1.5%)	$W_f = 1.5\% \times W_c$
(13)	Fibre weight (3%)	$W_f = 3\% \times W_c$
(14)	Fibre weight (4.5%)	$W_f = 4.5\% \times W_c$

Casting of specimens

The casting of specimen was performed in three cases.

Case 1: The casting of 4 concrete specimen that contains 0% of synthetic human hair fibres by the weight of the cement of hair fibres (normal concrete).

Case 2: Casting of 4 concrete specimen containing 1.5% of synthetic human hair fibres by the weight of the cement,

Case 3: Casting of 4 concrete specimen containing 3% of synthetic human hair fibres by cement weight.

For case 1, 2 and 3, the concrete was casted following the procedures of casting for obtaining M20 grade. The concrete which was used for determining the slump test, was reused after the same concrete was casted into 3 moulds of 15cmx15cmx15cm for compressive strength test.

Curing

After being left in the cube moulds for one day to achieve adequate hardness, the concrete was removed and placed in a curing tank. It was then allowed to cure for 7 days and 28 days, ensuring optimal strength development (Memon *et al.*, 2018). Once the curing periods were completed, the concrete samples were tested for compressive strength.

Laboratory test

Sieve analysis

The sieve analysis test involved using a stack of sieves with progressively finer mesh sizes, with the material placed at the top sieve and shaken to allow particles to pass through. The amount of material that passed through each sieve was collected and weighed to provide information on the particle size distribution. The process involved preparing the sieves, preparing the sample, shaking the stack, collecting and weighing particles, calculating the percentage retained, creating a particle size distribution

curve, and interpreting results to interpret the material's properties and behaviour. For both coarse and fine aggregates (gravel and sand), sieve analysis was conducted. In order to avoid potential obstruction caused by moisture, the sample for fine aggregates (sand) was sun-dried for a duration of 5 hours. A 2 kg sample of the dried material was weighed using a weighing scale, then passed through a series of sieves arranged in order of decreasing aperture size. The largest sieve, with an aperture size of 75 mm, was placed at the top, followed by progressively smaller sieves, with the smallest having an aperture size of 0.075 mm. The sieving process was done manually. The weight of each sample retained on each sieve was recorded. This process was repeated for the coarse aggregates, with sieving performed for a duration of ten minutes.

Slump test

The slump test evaluated the workability and consistency of freshly mixed concrete. This test was conducted on the fresh concrete. The truncated cone was filled in multiple layers. For the first layer, the cone was filled to one-third of its height and then tapped 25 times with a tapping rod to ensure proper compaction. The compaction was applied with sufficient force to ensure that the rod penetrated the full depth of the material. The remaining two layers were compacted in the same manner. After compacting the top layer, the cone was filled to the top and levelled with a hand trowel. The cone was then carefully removed, and the slump of the mix was measured as the vertical settlement of the cone. This test was conducted in accordance with the American standard ASTM C143 and IS 456:2000. The slump value was determined by measuring the height difference between the slumped concrete and the original height of the cone using a ruler, as shown in Figure 2.

Figure 2

Slump Test for Fresh Concrete



Compressive strength

The compressive strength test was conducted on different concrete cubes after 7 and 28 days of curing using a compressive strength machine. The fibre content varied in the cubes: 4 cubes contained normal concrete with 0% fibre, 4 cubes contained 1.5% fibre, and 4 cubes contained 3% fibre. Two cubes were tested for each curing age, and the average compressive strength value was then calculated. The cubes were removed from the curing basin (tank) and placed outside to air-dry for a duration not exceeding 5 minutes. Afterward, the cubes were weighed on a balance, and the weight was recorded. The cubes were properly positioned in the compressive strength machine. The start button was pressed to activate the machine and begin loading the cubes. Once the curve on the screen stabilized, the maximum load was recorded. The stop button was then pressed to turn off the machine.

Results

Batching calculations

The batching results for the concrete mix were determined based on the standard mix design procedure outlined in Table 2. A total of nine concrete cubes, each measuring $15 \times 15 \times 15$ cm, were prepared, resulting in a combined wet concrete volume of 0.030375 m^3 . Considering the M20 mix ratio of 1:1.5:3 and a dry volume factor of 1.54, the required quantities of cement, fine aggregates, and coarse aggregates were calculated. Using the unit weight of cement, the corresponding weights of each material were derived, along with the required water content based on a water-cement ratio of 0.48. Additionally, synthetic human hair fibres were incorporated into the mix at varying percentages (1.5%, 3%, and 4.5%) by weight of cement to evaluate their effect on the concrete properties.

Table 2*Concrete Batching Calculations*

Concrete Volume Calculation for Cube Specimens				
Parameter	Calculation			Result
Size of cube	15 × 15 × 15 cm			–
Volume of one cube	$(15 \times 15 \times 15) \text{ cm}^3 = (3.375 \times 10^{-3}) \text{ m}^3$			0.003375 m ³
Number of cubes	–			9
Total wet concrete volume	(0.003375×9)			0.030375 m ³
Dry concrete volume factor	(0.030375×1.54)			0.0467775 m ³
Mix Ratio and Volume Distribution (M20 Concrete)				
Component	Mix Ratio	Calculation	Volume (m³)	Weight
Cement	1	$(1/5.5 \times 0.0467775)$	0.008505	9.74757 kg
Fine Aggregate	1.5	$(1.5/5.5 \times 0.0467775)$	0.012755	14.621355 kg
Coarse Aggregate	3	$(3/5.5 \times 0.0467775)$	0.025517	29.24271 kg
Water		(0.48×9.74757)	4.6788	4.6788 L
Total Ratio	1 : 1.5 : 3		Sum = 5.5	
Calculation of Synthetic Human Hair Fibre Content				
Fibre Percentage (%)	Calculation		Weight of Fibres (g)	
1.5%	$(1.5\% \times 9.74757) \{ \text{kg} \}$		146.21 g	
3%	$(3\% \times 9.74757) \{ \text{kg} \}$		292.42 g	
4.5%	$(4.5\% \times 9.74757) \{ \text{kg} \}$		438.46 g	
Total Fibre Weight	$(146.21 + 292.42 + 438.46)$		877.09 g	

Fine Aggregates

The particle size distribution curve of fine aggregate (sand) was an S-shape as required for the good particle size distribution. The coarse sand (2mm to 4.75mm) weighed 235 grams, constituting 11.75% of the sample. The medium sand (0.425mm to 2mm) weighed 1204 grams, representing 60.2% of the sample. The fine sand (0.425mm to 0.075mm) weighed 529 grams, making up 26.45% of the sample. The fine materials (<0.075mm) weighed 32 grams, accounting for 1.6% of the sample. The sieve analysis results of the fine aggregate indicated that it was highly workable and suitable for use in mortar or concrete production, in accordance with IS 383-1970.

Coarse aggregate

The grading curve of coarse aggregate (gravel

was an S-shape as required for the good particle size distribution this was indication of a workable material according to the IS 383:1970.

Slump test result

As shown in Table 3, the slump test results indicated that the slump value increased from 5.2 cm to 5.8 cm with the addition of 0% to 3% synthetic hair fibres. However, the slump value decreased to 5.6 cm with a 4.5% hair fibre content. The workability of the concrete improved with increasing synthetic hair fibre content from 0% to 3%, as a higher slump value corresponds to greater workability. The optimum water-to-cement ratio at which the slump was achieved was 0.48. Figure 3 shows the variation of slump values for the fresh concrete in form of curve.

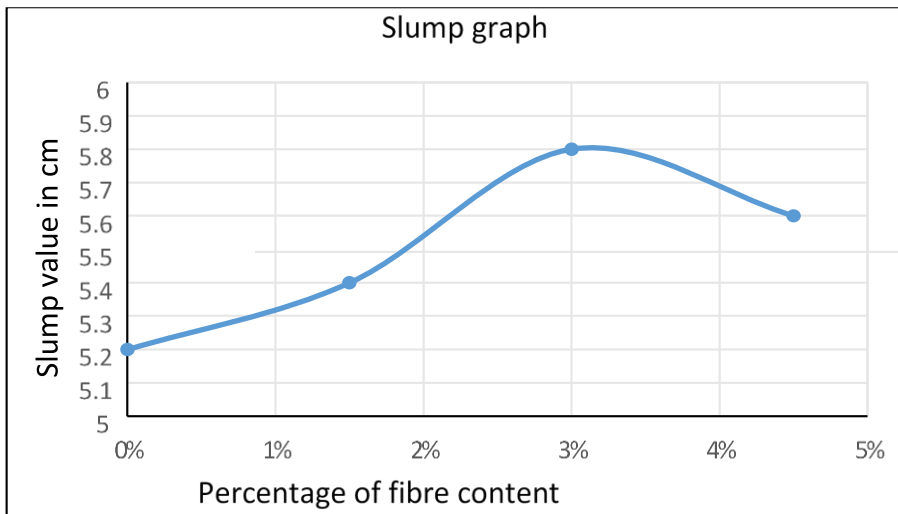
Table 3

Concrete slump test values

Fibre content	Slump value (cm)
0%	5.2
1.5%	5.4
3%	5.8
4.5%	5.6

Figure 3

Fresh concrete Slump curve



Compressive strength test

The correlation between the compressive strength and percentage of hair fibre at different curing ages as shown in Figure 4 and 5 respectively for 7 days and 28 days curing age, and with different percentage of fibre content for 0%, 1.5% and 3%. Two cubes were tested for each case and the average values were calculated for the obtained weight, load and compressive strength. As shown in Figure 4, the compressive strength of concrete increased with both the curing age and the

addition of synthetic human hair fibres, ranging from 0% to 1.5%. However, at 3% fibre content, the compressive strength began to decrease as the fibre content increased. As shown in Figure 5, the compressive strength values at 28 days for different fibre percentages (0%, 1.5%, and 3%) were 21.905 MPa, 27.87 MPa, and 15.73 MPa, respectively. The results demonstrated that compressive strength increased from 0% to 1.5%, but decreased at 3%.

Figure 4

Compression strength of concrete at 7 days curing age

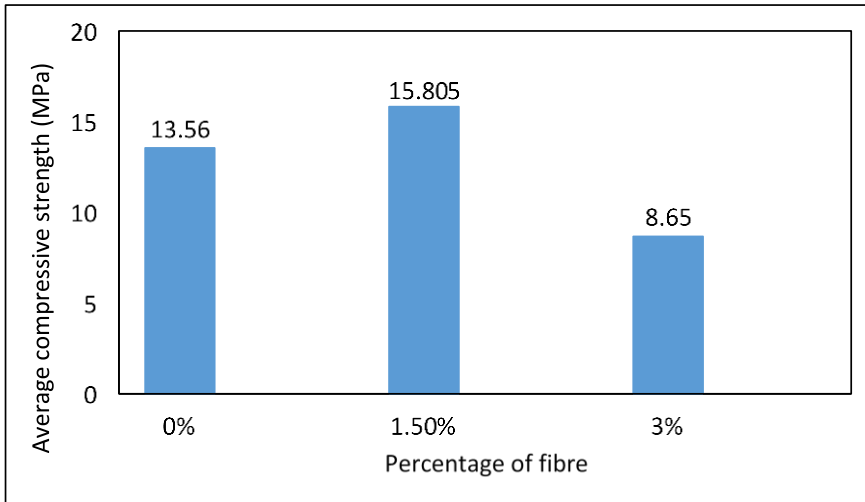
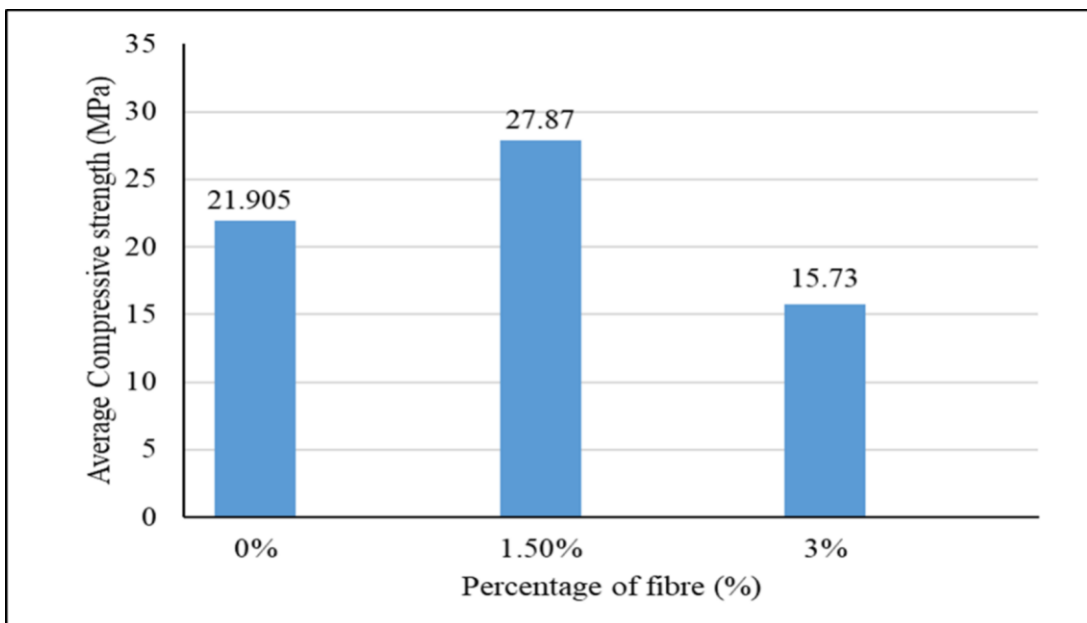


Figure 5

Compressive strength of concrete at 28 days curing age



Discussion

Sieve Analysis

Fine Aggregates

After revising the mass of fine aggregate retained on individual sieves, cumulative and percentage passing values were computed to evaluate the particle size distribution and gradation characteristics of the sand. Based on the results found, the fine aggregate was classified as Grading Zone II in accordance with IS 383:1970, indicating a medium-grade material suitable for structural concrete due to its balanced workability, good compaction, and adequate strength. The added value of this research lies in integrating this well-graded aggregate with synthetic human hair waste as fibre reinforcement, ensuring that the concrete matrix is optimized prior to fibre inclusion. This is particularly important because many previous studies on human hair fibre-reinforced concrete have primarily focused on fibre dosage while paying limited attention to the influence of aggregate gradation on fibre dispersion and bonding performance (Soomro *et al.*, 2025). By contrast, the present study demonstrates that a properly graded Zone II fine aggregate promotes improved fibre-matrix interaction, enabling more effective stress transfer, crack-bridging, and enhanced ductility (Abd *et al.*, 2020). Earlier investigations have reported that incorporating human hair fibres can increase compressive strength by approximately 8% at around 1% fibre content, while tensile and flexural strengths improve at slightly higher dosages; however, excessive fibre addition often reduces workability and leads to clustering (Bheel *et al.*, 2020). Furthermore, most existing works do not explicitly relate aggregate grading characteristics to fibre efficiency (Akbar *et al.*, 2023). Therefore, this study contributes to the field by addressing this gap, showing that the combination of controlled aggregate gradation and optimized synthetic hair fibre incorporation can significantly improve the mechanical performance and sustainability of concrete.

Coarse aggregate

The results indicated that the coarse aggregate (gravel) conformed to the grading requirements specified in IS 383:1970, demonstrating a well-graded distribution. This confirms that the aggregate possesses adequate workability characteristics and is suitable for concrete

production. Proper grading is essential, as it minimizes voids, reduces cement paste demand, and enhances overall concrete strength findings that are consistent with established concrete technology principles.

The previous studies on fibre-reinforced concrete, particularly those incorporating unconventional waste materials, the quality of aggregate grading played a crucial role in ensuring that the effects of fibre addition are accurately reflected (Rukmangadha *et al.*, 2000). For instance, studies involving polypropylene, steel, and natural fibres (such as coconut coir or sisal) have shown that poorly graded aggregates can mask the reinforcing benefits of fibres due to reduced compaction and increased porosity (Manaf and Varghese, 2017). In contrast, the well-graded aggregates observed in this study provide a stable matrix that allows the influence of synthetic human hair fibres to be more effectively evaluated.

Furthermore, research on waste fibre incorporation such as plastic fibres or textile waste has emphasized that the interaction between fibres and the cement matrix is highly dependent on the surrounding aggregate structure (Mishra *et al.*, 2025). In this context, the compliance of the coarse aggregate with IS 383:1970 ensures uniform stress distribution and improved bonding conditions, which are critical for fibre bridging and crack resistance. This aligns with findings from similar works where optimal aggregate grading enhanced fibre dispersion and improved mechanical performance.

The added value of this study lies in its integration of synthetic human hair waste as a fibre material within a properly graded concrete system. While previous studies have explored various waste fibres, limited research has focused specifically on synthetic human hair (Petrounias *et al.*, 2021). By ensuring that the aggregate meets standard grading requirements, this study isolates the effect of hair fibres more reliably, thereby contributing clearer insights into their role in enhancing concrete strength and durability.

Slump test

As shown in Table 2 and Figure 3, the slump test results reveal a gradual increase in slump value

from 5.2 cm (0% fibre) to 5.8 cm (3% synthetic human hair fibre), followed by a slight reduction to 5.6 cm at 4.5% fibre content. This trend indicates that the workability of concrete improved with increasing fibre content up to an optimum level (3%), beyond which it began to decline. The optimum water-cement ratio corresponding to this behaviour was 0.48, which provided sufficient lubrication for proper mixing and placement.

The previous studies on fibre-reinforced concrete, this behaviour showed both similarities and notable differences (Hassan and Saeed, 2024). Research involving conventional fibres such as polypropylene and steel fibres typically reports a decrease in workability with increasing fibre content, primarily due to fibre entanglement, increased internal friction, and reduced flow ability of the mix (Huang *et al.*, 2025). Similarly, studies on natural fibres such as coconut coir, sisal, and even natural human hair often indicate reduced slump values as fibre dosage increases, since these fibres tend to absorb water and create a denser, less workable.

However, the results of the present study contrast with the findings of previous research in the initial stages of fibre addition (0–3%), where an increase in slump value was observed. This variation can be attributed to the distinct physical properties of synthetic human hair fibres, which differ significantly from conventional natural and synthetic fibres. In particular, their lower water absorption capacity allows more free water to remain available in the concrete mix, while their smoother surface texture reduces internal friction between particles. Additionally, the flexible and lightweight nature of these fibres promotes better dispersion throughout the matrix. Collectively, these characteristics enhance the flow ability of the mix and reduce resistance during mixing, resulting in an increase in slump value up to the optimum fibre content.

The subsequent decrease in slump at 4.5% fibre content aligns with trends reported in other fibre studies, where excessive fibre addition leads to balling effects, poor dispersion, and increased interlocking, ultimately reducing workability. This suggests that, like other fibre types, synthetic human hair also has a threshold limit, beyond which its benefits diminish (Hassan and Saeed, 2024).

Compressive strength

The findings of this study on enhancing concrete strength through the incorporation of synthetic human hair fibres showed a trend that was consistent with, yet distinct from previous research on fibre-reinforced concrete. Similar to studies involving steel, polypropylene, and natural fibres, the compressive strength increased with fibre addition up to an optimum level, beyond which a decline was observed due to fibre clustering and poor bonding. In this study, the optimum fibre content was found to be 1.5%, at which the compressive strength reached 15.805 MPa at 7 days and 27.87 MPa at 28 days. These values not only exceed the minimum requirements specified by IS 456:2000 for M20 concrete (13.5 MPa at 7 days and 20 MPa at 28 days), but also demonstrate the effectiveness of synthetic human hair as a reinforcing material. Compared to conventional fibres, the added value of this research lies in the use of a low-cost, lightweight, and waste-derived material that contributes to sustainability while maintaining adequate mechanical performance. Furthermore, unlike many natural fibres that suffer from high water absorption and durability issues, synthetic human hair offers improved consistency and durability, making it a promising alternative for non-structural and light structural applications such as pavements, walkways, and residential construction.

Conclusion

This research aimed to investigate the effect of synthetic human hair waste fibre on the strength characteristics and mechanical properties of concrete. The results showed that both the compressive and tensile strength, as well as the workability, improved with the use of synthetic human hair waste fibre. Specifically, the study found that adding 1.5% synthetic human hair fibre by weight of cement increased the compressive strength of the concrete by 16.56% and 27.23% at 7 and 28 days of curing, respectively. However, adding 3% fibre led to a decrease in compressive strength by 36.21% and 28.19% at the same curing ages.

Regarding workability, the study found that adding 1.5%, 3%, and 4.5% synthetic human hair waste fibre by weight of cement increased the

workability by 3.71%, 11.54%, and 7.69%, respectively. The optimum workability was achieved with 3% fibre addition, as the workability decreased by 3.85% when the fibre content was increased to 4.5%. Based on these findings, the optimum synthetic human hair waste fibre content for concrete is 1.5% by the weight of the cement, as it provided the best overall results across all experimental tests performed.

The incorporation of synthetic human hair waste fibre at an optimal dosage of 1.5% by weight of cement was recommended for improving the mechanical performance and strength characteristics of concrete, as higher fibre contents were found to adversely affect compressive strength. Further research is needed to assess long-term durability and practical application in sustainable construction.

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Conflict of Interest

The authors declare that there are no known financial, professional, or personal conflicts of interest that could have influenced the work reported in this study.

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