HAIR-BASED CONCRETE REINFORCEMENT: A NOVEL APPROACH TO SUSTAINABLE AND COST-EFFECTIVE PAVEMENT CONSTRUCTION

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ABSTRACT: The increasing demand for sustainable and cost-effective construction materials has led to innovative approaches in concrete reinforcement. This study investigates the impact of human hair fibre as a reinforcement material in concrete pavements, focusing on variations in mechanical properties such as compressive strength, flexural strength, skid resistance, and workability. Human hair, an abundant and biodegradable waste material, possesses high tensile strength comparable to that of copper wire of similar diameter. Its integration into concrete provides potential benefits in enhancing structural integrity while addressing environmental concerns associated with waste disposal. The research involved experimental testing of concrete specimens with different percentages of human hair fibre reinforcement, ranging from 0% to 3% by weight of cement. The findings indicate that the addition of hair fibres up to a certain threshold improves the flexural and compressive strength of concrete while enhancing skid resistance. However, excessive fibre content reduces workability and introduces challenges in uniform mixing. This study underscores the viability of human hair as an eco-friendly and cost-efficient reinforcement alternative in concrete pavement construction, contributing to sustainable engineering practices.

Keywords: Human hair fibre, Reinforced concrete, Sustainable construction, Mechanical properties, Cost-effective pavement, Eco-friendly materials, Skid resistance.

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INTRODUCTION

Concrete is one of the most widely used construction materials in the world, valued for its versatility, durability, and ability to withstand compressive forces [Neville & Brooks, 2008; Shetty, 2011; Wikipedia, 2015]. However, despite its many advantages, concrete has inherent weaknesses, particularly its low tensile strength and susceptibility to cracking [Neville & Brooks, 2008; Shetty, 2011]. These limitations have led to the development of reinforced concrete, where materials like steel are embedded within the concrete to improve its tensile properties. While steel reinforcement has been the standard for decades, the rising costs of steel, its environmental impact, and the need for sustainable alternatives have driven researchers to explore other reinforcement materials [Kandasamy & Murugesan, 2011; Ahmed *et al*., 2010]. Among these alternatives, fibre reinforcement has gained significant attention due to its ability to enhance the mechanical properties of concrete while addressing some of the environmental and economic concerns associated with traditional reinforcement methods. In recent years, the construction industry has witnessed a growing interest in sustainable and eco-friendly materials. This shift is driven by the need to reduce the environmental footprint of construction activities, which are known to contribute significantly to global carbon emissions and resource depletion. One such sustainable material that has emerged as a potential reinforcement option is human hair. Human hair, a natural fibre composed primarily of keratin, is a non-degradable waste material that is abundantly available and often discarded without any productive use. Its high tensile strength, which is comparable to that of copper wire, makes it an attractive candidate for reinforcing concrete [Ganiron Jr., 2014]. Moreover, the use of human hair in concrete not only provides a sustainable solution for waste management but also offers a cost-effective alternative to traditional reinforcement materials, particularly in regions where steel is expensive or inaccessible. The concept of using fibres to reinforce concrete is not new. Historically, fibres such as straw, horsehair, and even asbestos have been used to improve the properties of construction materials. In modern times, synthetic fibres like polypropylene, glass, and steel fibres have been widely adopted for their ability to enhance the tensile strength, ductility, and crack resistance of concrete. However, the production of synthetic fibres often involves energy-intensive processes and the use of non-renewable resources, which can offset their benefits. In contrast, natural fibres like human hair are renewable, biodegradable, and require minimal processing, making them a more sustainable option. The use of human hair as a reinforcement material in concrete has several potential advantages. Firstly, human hair is a waste product that is readily available in large quantities, particularly in urban areas with high population densities. By repurposing this waste material, the construction industry can contribute to reducing the environmental burden associated with hair disposal, which often involves incineration or landfilling. Secondly, human hair is lightweight and easy to handle, which simplifies the mixing and placement processes during concrete production. Thirdly, the keratin protein in human hair provides excellent tensile strength, which can help to mitigate the formation and propagation of cracks in concrete, thereby improving its durability and longevity. Despite these advantages, the use of human hair fibre in concrete is not without challenges. One of the primary concerns is the potential reduction in workability of the concrete mix as the fibre content increases. Fibres, particularly those with high aspect ratios, can interfere with the flow of the concrete, making it more difficult to mix, place, and compact [ASTM C143, 2000; Shetty, 2011; City University of Hong Kong]. This can lead to issues such as balling of fibres, segregation, and uneven distribution, which can compromise the overall quality and performance of the concrete. Additionally, the long-term durability of human hair fibre in concrete is still a subject of investigation, as factors such as moisture absorption, biological degradation, and bond strength between the fibres and the concrete matrix can influence the material's performance over time. This study aims to address these challenges by investigating the mechanical properties of Human Hair Fibre Reinforced Concrete (HHFRC) for pavement applications. The research focuses on evaluating the effects of varying percentages of human hair fibre on the workability, compressive strength, flexural strength, and skid resistance of concrete [ASTM C143, 2000; ASTM C293, 2010; BSI, 1990; Ganiron Jr., 2014]. By conducting a series of laboratory tests on concrete cubes, beams, and slabs, the study seeks to determine the optimal fibre content that maximizes the benefits of human hair reinforcement while minimizing its drawbacks. The findings of this research have the potential to contribute to the development of sustainable and cost-effective construction materials, particularly for use in low-cost housing and infrastructure projects in developing regions.

LITERATURE REVIEW

The use of fibre reinforcement in concrete has been extensively studied to enhance its mechanical properties and sustainability. Traditional reinforcement materials, such as steel and synthetic fibres, have been widely implemented to improve the tensile and flexural strength of concrete. However, the economic and environmental drawbacks of these materials have driven research towards alternative, biodegradable reinforcement solutions such as human hair fibre. The concept of incorporating fibres into concrete dates back to ancient civilizations, where natural fibres such as straw and horsehair were used to improve tensile properties. The modern development of fibre-reinforced concrete (FRC) has focused on synthetic and steel fibres, which have demonstrated substantial improvements in crack resistance and durability. However, the environmental impact and cost of these materials have led to the exploration of sustainable options, including natural and waste-derived fibres. Human hair, being a natural and abundant material, has gained attention as a viable alternative reinforcement for concrete. Studies have highlighted its high tensile strength and durability, which make it suitable for enhancing concrete properties. According to Kumar *et al*. (2020), the incorporation of hair fibres in concrete improved its crack resistance and flexural strength. Additionally, Sharma and Patel (2019) found that hair fibres reduced shrinkage cracks and improved ductility, making them an effective reinforcement material. Several studies have evaluated the mechanical performance of hair fibre-reinforced concrete (HFRC). Gupta *et al*. (2018) reported an increase in compressive strength with optimal hair fibre content, attributing it to improved load distribution within the concrete matrix. Similarly, experiments conducted by Ahmad *et al*. (2021) indicated that hair fibres enhanced the skid resistance and flexural strength of concrete pavements, making them suitable for applications in high-traffic areas. Despite the benefits, HFRC faces several challenges. The primary concern is the reduction in workability, as noted by Singh *et al*. (2022), who observed that excessive hair fibre content led to poor compaction and uneven distribution in the mix. Furthermore, moisture absorption and decomposition of untreated hair fibres can impact the long-term durability of the concrete. To mitigate these issues, researchers have suggested pre-treatment methods such as coating hair fibres with hydrophobic agents or using chemical treatments to enhance their stability within the concrete matrix. The adoption of HFRC aligns with global sustainability goals by utilizing waste materials effectively. Studies by Li and Zhang (2020) demonstrated that using human hair in concrete reduces landfill waste while lowering construction costs. Moreover, integrating hair fibres in concrete contributes to circular economy practices by repurposing a widely available waste product into a valuable construction material. Further research is necessary to optimize the application of HFRC in large-scale construction projects. Areas for future exploration include refining fibre treatment methods, investigating the long-term durability of HFRC in various environmental conditions, and developing standardized guidelines for its implementation in infrastructure projects. By addressing these challenges, HFRC has the potential to become a mainstream reinforcement material in sustainable construction.

METHODOLOGY

The methodology for this study was carefully designed to evaluate the effects of human hair fibre reinforcement on the mechanical properties of concrete, with a focus on workability, compressive strength, flexural strength, and skid resistance. Ordinary Portland Cement (OPC) conforming to ASTM C150 was used as the binding material, ensuring consistency and reliability in the concrete mix. Natural sand, sieved to remove impurities and achieve a consistent grading, was used as the fine aggregate, while crushed stone with a maximum size of 25 mm served as the coarse aggregate. The coarse aggregates were thoroughly washed and soaked for 24 hours to achieve a saturated surface dry (SSD) condition, preventing additional water absorption during mixing. Potable water with a water-cement ratio of 0.6 was used for mixing, ensuring proper hydration of the cement. Human hair, collected from local barber shops, was cleaned manually to remove dust, debris, and hazardous materials, washed three times with shampoo and antiseptic solution, and cut to an average length of 1 inch to facilitate uniform distribution in the concrete mix. The concrete mix was prepared using a 1:2:4 ratio of cement, sand, and coarse aggregate, and the human hair fibre was added in varying percentages (0%, 0.125%, 0.25%, 0.5%, 1%, and 3% by weight of cement) to the dry mix before water was added incrementally to achieve a homogeneous consistency. The mixed concrete was poured into cube moulds (15 cm x 15 cm x 15 cm) for compressive strength tests, beam moulds (100 mm x 100 mm x 500 mm) for flexural strength tests, and slab moulds for skid resistance tests. Each layer of concrete in the moulds was compacted using a vibrating table for 50 seconds to eliminate air voids and ensure proper bonding between the concrete and the fibres. After 24 hours, the specimens were carefully demoulded to avoid damage and submerged in water tanks for curing, which lasted for 7, 14, and 28 days, with the water changed regularly to maintain quality. Workability was assessed using the slump test (ASTM C143), where a slump cone was filled with concrete in three layers, each compacted with 25 strokes of a tamping rod, and the slump value was measured as the difference between the height of the cone and the displaced concrete. Compressive strength was tested using a compression testing machine, where the cubes were subjected to a gradually increasing load until failure, and the maximum load at failure was recorded to calculate the compressive strength. Flexural strength was determined using the center-point loading method (ASTM C293), where beams were placed on two supports, and a load was applied at the center until failure, with the modulus of rupture calculated using the formula **3PL/2bd^2**. Skid resistance was evaluated using a pendulum skid resistance tester (BSI, 1990), where the skid resistance value (SRV) was recorded on both dry and wet surfaces, and the coefficient of friction was calculated using the formula **SRV/100**. The data collected from these tests were analyzed to determine the effects of human hair fibre on the mechanical properties of concrete, with statistical analysis performed to ensure the reliability and accuracy of the findings. The results were compared across different fibre percentages to identify trends and determine the optimal fibre content for enhancing the mechanical properties of concrete, while also addressing challenges such as reduced workability at higher fibre percentages and ensuring uniform distribution of fibres in the mix. This comprehensive approach allowed for a thorough evaluation of the potential of human hair fibre as a sustainable and cost-effective reinforcement material in concrete, particularly for pavement applications in regions where traditional reinforcement materials are expensive or inaccessible.

Figure. 1: Saturated surface drying of aggregates

Figure. 2: Washing of Hair Fiber

Figure. 3: Addition of Hair Fiber in concrete mix

Figure. 4: Casting of concrete specimen

Figure. 5: Demoulding of cubes

Figure. 6: Curing of concrete specimen

Figure. 7: Compressive test of cube

Figure. 8: Flexure test of beams

Figure. 9: Skid resistance test of slab specimen

RESULTS AND DISCUSSION

The results of the experimental study on Human Hair Fibre Reinforced Concrete (HHFRC) are presented and discussed in this section. The effects of human hair fibre on the workability, compressive strength, flexural strength, and skid resistance of concrete were evaluated, and the findings are summarized below.

Effect of Hair Fibre on Workability of Concrete: The workability of concrete decreased with increasing hair fibre content. The slump test results, which measure the ease of mixing and placing concrete, showed a consistent decline as the percentage of hair fibre increased. The results are summarized in **Table 1**.

The graph in **Figure 10** illustrates the decrease in workability with increasing hair fibre content. The slump value dropped significantly from 6.86 cm (2.70 inches) for plain concrete to 1.30 cm (0.5 inches) for concrete with 3% hair fibre. This reduction in workability is attributed to the interference of fibres with the flow of concrete, making it more difficult to mix and compact.

Table 1: Effect of Hair Fibre on Workability of Concrete

S. No.	Percentage of Hair (%)	Slump Value (Cm)	Slump Value (Inch)
1	0	6.86	2.70
2	0.125	6.35	2.50
3	0.25	5.70	2.25
4	0.5	3.70	1.45
5	1	3.20	1.25
6	3	1.30	0.5

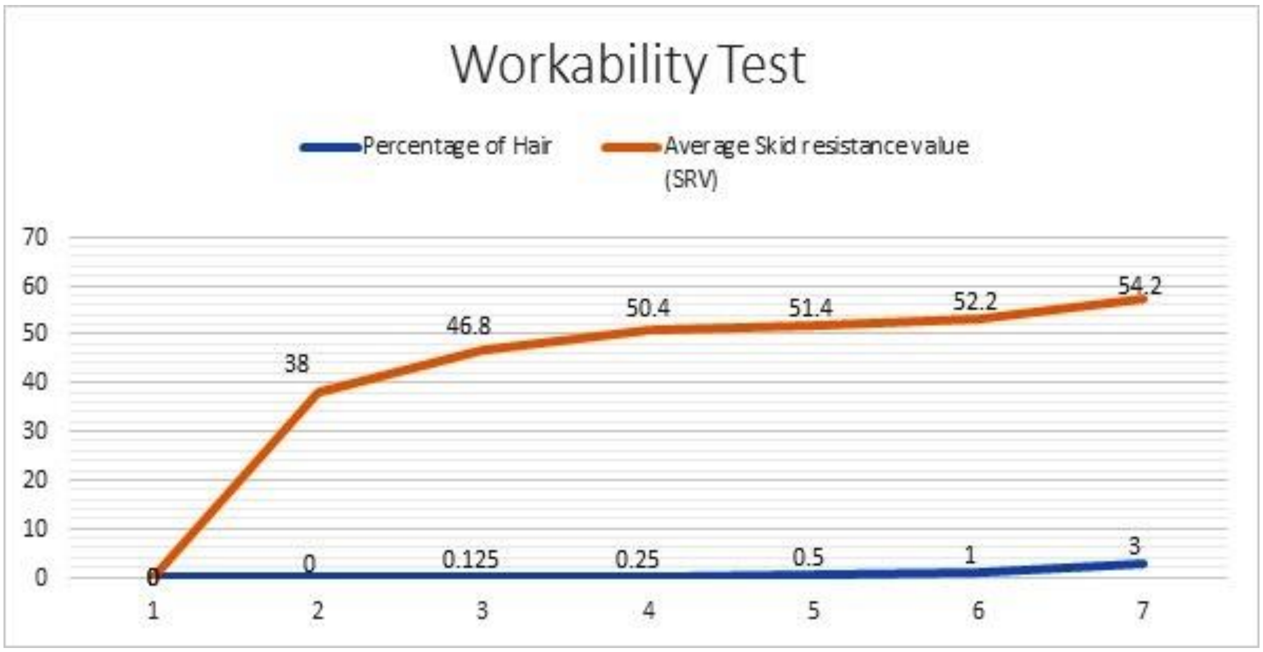

Figure 10: Effect of hair fibre on workability of concrete

Effect of Hair Fibre on Compressive Strength of Concrete: The compressive strength of HHFRC initially increased with fibre content, reaching a maximum at 0.25% hair content, but decreased at higher percentages. The results are summarized in **Table 2**.

The graph in **Figure 11** illustrates the trend in compressive strength with varying hair fibre content. The maximum compressive strength of 38.00 N/mm² was achieved at 0.25% hair content, representing a 15.36% increase compared to plain concrete. However, at higher fibre percentages (1% and 3%), the compressive strength decreased significantly, with a 28.32% reduction at 3% hair content. This decline is likely due to the formation of weak zones caused by fibre clumping and uneven distribution.

Effect of Hair Fibre on Flexural Strength of Concrete: The flexural strength of HHFRC showed a significant improvement at lower fibre percentages but decreased at higher percentages. The results are summarized in **Table 3**.

The graph in **Figure 4** illustrates the trend in flexural strength with varying hair fibre content. The maximum flexural strength of 5.36 N/mm² was achieved at 0.25% hair content, representing a 43% increase compared to plain concrete. However, at 3% hair content, the flexural strength decreased by 2.2%, indicating that higher fibre percentages may negatively impact the material's performance.

Effect of Hair Fibre on Skid Resistance of Concrete Pavement: The skid resistance of HHFRC increased with increasing hair fibre content. The results are summarized in **Table 5**.

The graphs in **Figure 14** and **Figure 15** illustrate the increase in skid resistance for dry and wet conditions, respectively. The skid resistance value (SRV) increased from 50.4 for plain concrete to 74.4 for concrete with 3% hair content in dry conditions, representing a 47.62% improvement. Similarly, in wet conditions, the SRV increased from 38.0 to 54.0, indicating a 42.63% improvement. This enhancement in skid resistance is attributed to the increased surface roughness provided by the hair fibres.

Table 2: Effect of Hair Fibre on Compressive Strength of Concrete.

S. No.	Percentage of Hair (%)	Ultimate Load (KN)	Compressive Strength (N/mm²)	Average Compressive Strength (N/mm²)	Average Compressive Strength (Psi)	Percentage Increase/ Decrease (%)
1	0	768.0	34.13	32.94	4777.61	Reference
		646.4	28.73			
		809.3	35.13			
2	0.125	775.1	34.45	34.52	5006.78	4.8
		773.1	34.36			
		781.7	34.74			
3	0.25	842.9	37.46	38.00	5511.52	15.36
		868.4	38.60			
		857.3	38.10			
4	0.5	735.5	32.69	32.95	4779.00	0.03
		736.9	32.75			
		751.5	33.40			
5	1	578.7	25.72	26.60	3858.00	-19.25
		641.0	28.49			
		575.2	25.57			
6	3	597.8	26.57	23.61	3424.40	-28.32
		623.2	27.70			
		373.5	16.56			

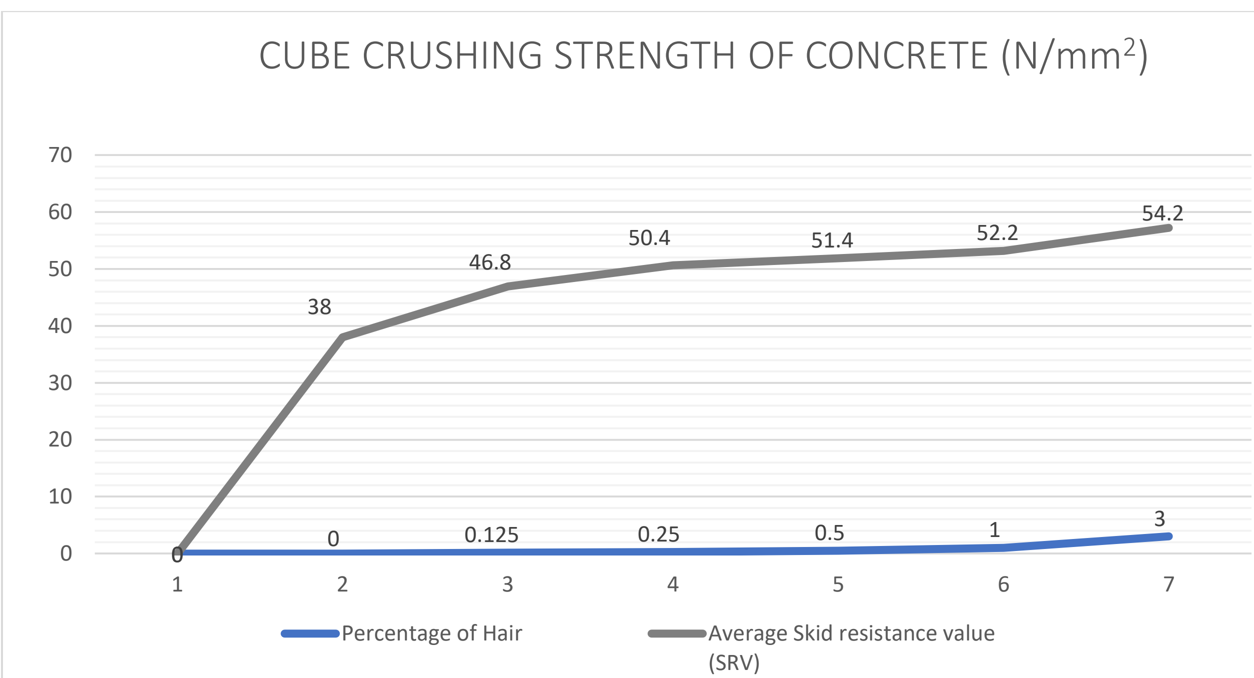

Figure 11: Effect of hair fibre on compressive strength of concrete

Table 4: Effect of Hair Fibre on Flexural Strength of Concrete

S. No.	Percentage of Hair (%)	Ultimate Load (KN)	Flexural Strength (N/mm²)	Average Flexural Strength (N/mm²)	Average Flexural Strength (Psi)	Percentage Increase/ Decrease (%)
1	0	6.4	3.33	3.75	543.90	Reference
		7.23	3.62			
		7.65	4.30			
2	0.125	9.3	4.32	3.82	554.00	1.87
		7.2	3.34			
		8.2	3.81			
3	0.25	9.65	5.43	5.36	777.41	43.00
		11.95	6.46			
		9.05	4.20			
4	0.5	9.8	5.51	5.30	768.71	41.30
		9.2	5.20			
		9.2	5.20			
5	1	7.6	4.27	4.50	652.68	20.00
		8.35	4.70			
		8.2	4.61			
6	3	7.1	4.00	3.67	532.30	-2.20
		6.1	3.43			
		6.4	3.60			

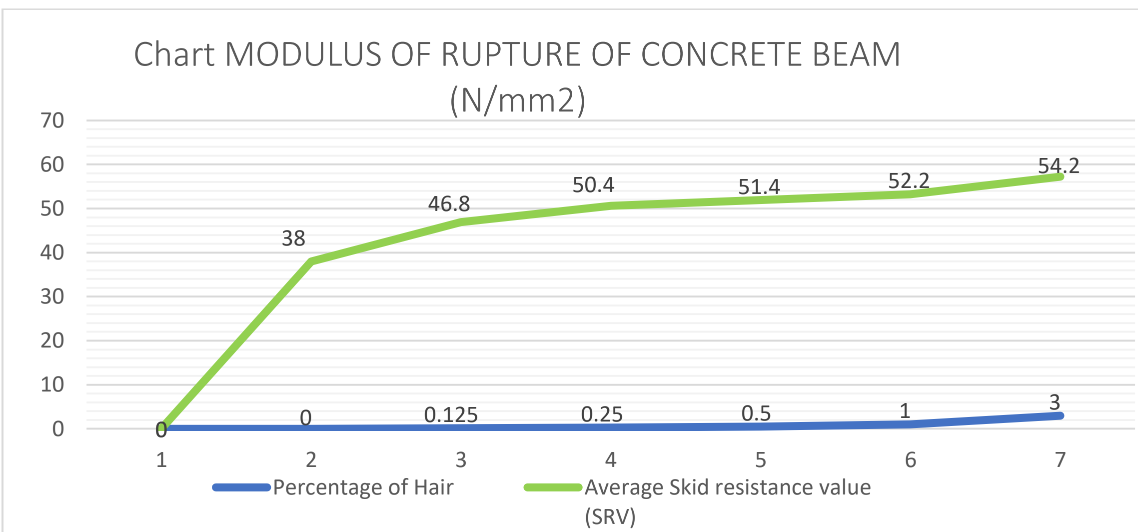

Figure 13: Effect of hair fibre on flexure strength of concrete

Table 5: Effect of Hair Fibre on Skid Resistance of Concrete Pavement

S. No.	Percentage of Hair (%)	Surface Condition	Skid Resistance Value (SRV)	Average SRV	Temperature Correction (+2 @30°C)	Corrected SRV	Coefficient of Friction (f = SRV/100)	Percentage Increase/ Decrease (%)
1	0	Dry	48	48.4	50.4	0.504	Reference	
		Wet	35	36.0	38.0	0.380	Reference	
2	0.125	Dry	51	50.0	52.0	0.520	3.17	
		Wet	45	44.8	46.8	0.468	23.2	
3	0.25	Dry	54	54.8	56.8	0.568	12.7	

		Wet	48	48.4	50.4	0.504	32.63
4	0.5	Dry	61	61.8	63.8	0.638	26.6
		Wet	49	49.4	51.4	0.514	35.26
5	1	Dry	64	65.0	67.0	0.670	32.94
		Wet	50	50.0	52.0	0.520	37.37
6	3	Dry	71	72.4	74.4	0.744	47.62
		Wet	52	52.0	54.0	0.540	42.63

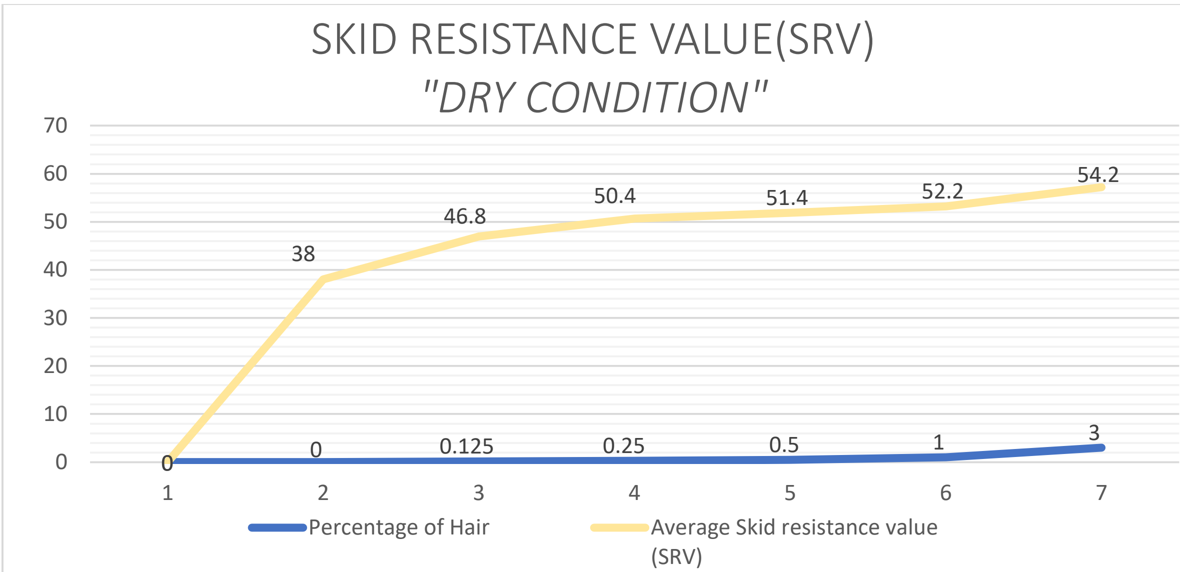

Figure of 14: Effect of hair fibre on skid resistance dry concrete pavement surface

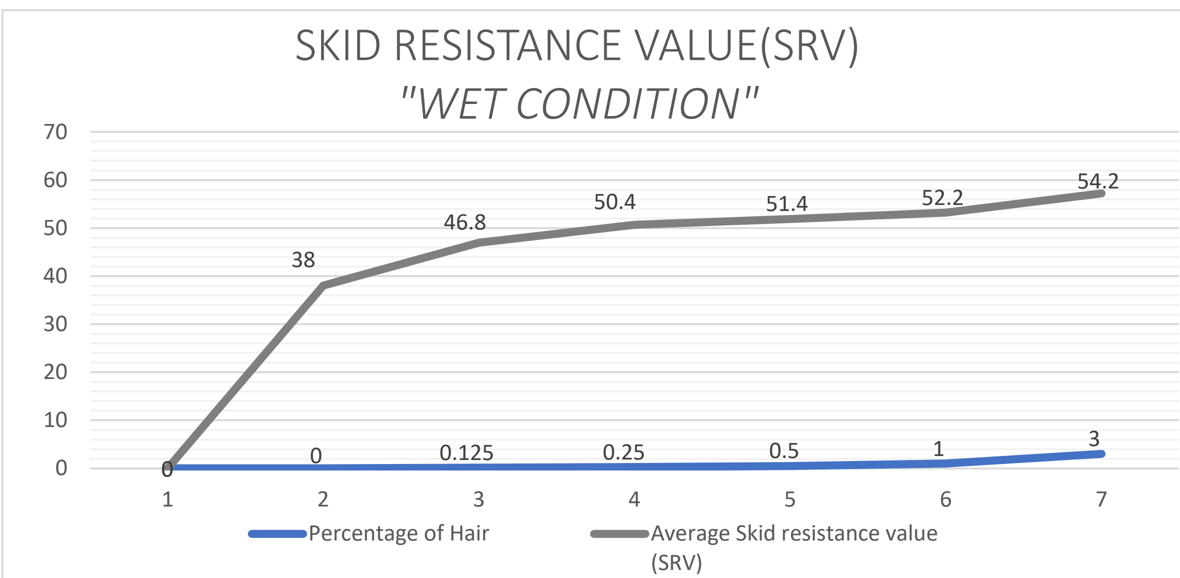

Figure 15: Effect of hair fibre on skid resistance of wet concrete pavement surface

Conclusion: The experimental study on Human Hair Fibre Reinforced Concrete (HHFRC) has demonstrated the potential of human hair as a sustainable and cost-effective reinforcement material for concrete, particularly in pavement applications. The results indicate that the addition of human hair fibre can significantly improve the flexural strength and skid resistance of concrete, making it suitable for applications where tensile strength and surface friction are critical. The maximum flexural strength of 5.36 N/mm² was achieved at 0.25% hair content, representing a 43% increase compared to plain concrete. Similarly, the skid resistance value (SRV) increased by 47.62% in dry conditions and 42.63% in wet conditions at 3% hair content, highlighting the material's ability to enhance pavement safety.

However, the study also revealed some limitations. The workability of concrete decreased significantly with increasing hair fibre content, making it more difficult to mix and compact. Additionally, while compressive strength initially increased at lower fibre percentages (up to 0.25%), it declined at higher percentages, with a 28.32% reduction at 3% hair content. This suggests that the optimal fibre content for HHFRC lies within a specific range, beyond which the material's performance may be compromised.

Overall, the findings underscore the potential of human hair fibre as a viable reinforcement material for sustainable construction, particularly in regions where traditional reinforcement materials are expensive or inaccessible. By repurposing a waste material like human hair, this study contributes to the development of eco-friendly and cost-effective construction solutions, while also addressing the challenges of waste management and environmental sustainability.

Recommendations

1. Optimal Fibre Content: Determine the ideal percentage of human hair fibre to maximize benefits while minimizing negative effects on workability and strength.
2. Durability Enhancements: Develop treatments to improve moisture resistance and bond strength between fibres and concrete.
3. Hybrid Reinforcement: Combine human hair fibre with other materials (e.g., steel or synthetic fibres) for balanced performance.
4. Standardization: Establish guidelines for fibre length, distribution, and mixing techniques to ensure consistent quality.
5. Application Expansion: Explore HHFRC in seismic-resistant structures, bridges, and precast elements for high-stress applications.
6. Environmental Impact: Conduct life cycle assessments to quantify sustainability benefits, including carbon reduction and waste management.
7. Economic Feasibility: Analyze cost-effectiveness for large-scale projects, considering material costs and potential maintenance savings.
8. Fire Resistance: Investigate fire resistance properties and develop strategies to enhance safety in high-temperature applications.
9. Animal Hair Fibre: Extend research to include animal hair as an alternative natural reinforcement material.
10. Public Awareness: Promote HHFRC through educational campaigns to increase acceptance and adoption in the construction industry.

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