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Develop an optimum mix design of fabric waste reinforced concrete for enhance thermal comfort

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Abstract*— Construction industry is widely focusing on sustainable construction materials to mitigate the environmental impact while improving building performance. Simultaneously, textile industry produces thousand tons of textile wastage per year, and it has become a significant environmental challenge. Incorporating fabric waste into concrete offers a promising solution by enhancing thermal performance while promoting circular economy principles. This study experimentally investigating on the effects of textile fiber on the fresh, mechanical, and thermal properties of the concrete to develop the optimum mix design for improved thermal comfort. Three different types of fabric waste were selected based on their performance reviewed by literature. Cotton, Polyester, and denim with varying fabric content of 0.5%, 1.0% and 1.5% partially replacement of fine aggregate and grade 25 concrete as control mixed were tested experimentally. Mechanical performance and thermal performance were evaluated through slump test, compressive strength, flexural strength and thermal conductivity. Fiber length was maintained 10-20mm. The control mix achieved compressive strengths of 23.60 MPa and 28.88 MPa at 7 and 14 days, and 33.50 MPa at 28 days. Strength generally reduced with higher fiber content, with cotton at 1.5% showing the lowest 28-day strength (28.40 MPa). Flexural strength improved with fiber addition, and the highest value was obtained for denim at 1.0% replacement (4.55 MPa) compared to the control (4.10 MPa). Thermal conductivity decreased from 1.65 W/m·K (control) to 1.34 W/m·K for cotton at 1.5%, representing an 18.8% reduction. All three fabric types exhibited distinct characteristics: cotton showed the best thermal performance, polyester maintained higher strength, and denim provided superior flexural behavior. An optimum replacement level of about 1.0% is recommended, as it achieves a balanced performance between mechanical properties and thermal comfort, making it suitable for practical applications.

Key words: Fabric waste fibers; Textile waste recycling; Grade 25 concrete; Thermal conductivity; Guarded hot plate method; Thermal comfort.

I. INTRODUCTION

The construction industry is one of the most important sectors that supports economic development and improves the quality of life of people. Buildings provide shelter, safety, and space for human activities. Among all construction materials, concrete is the most widely used due to its high compressive strength, durability, availability of raw materials, and relatively low cost. Reinforced concrete is commonly used for structural elements such as beams, columns, slabs, and walls in residential and commercial buildings. However, conventional concrete has some disadvantages related to thermal performance. Concrete has relatively high thermal conductivity, which allows heat to pass easily through building components. In tropical countries like Sri Lanka, high outdoor temperatures, and strong solar radiation cause buildings to absorb and store large amounts of heat during the daytime. This heat is later released into indoor spaces, resulting in uncomfortable indoor conditions, especially during the evening and night. As a result, occupants rely heavily on mechanical cooling systems such as fans and air conditioners, which increases electricity consumption and energy costs. At the same time, rapid urbanization and industrialization have led to a substantial increase in solid waste generation, particularly textile waste. Millions of tonnes of textile waste are discarded annually due to fast fashion, industrial off-cuts, and post-consumer clothing, with a significant proportion ending up in landfills or being incinerated. These disposal practices create serious environmental concerns, including land degradation, greenhouse gas emissions, and the inefficient use of valuable resources (Rahman et al., 2022).

Therefore, developing sustainable applications for textile waste has become an important research priority within the framework of the circular economy.
Previous studies have demonstrated that textile waste fibres can reduce the thermal conductivity of cementitious materials by interrupting heat transfer

pathways and increasing internal air voids within the cement matrix (Sadrolodabaee et al., 2021). Furthermore, textile fibres have been reported to enhance flexural behaviour and crack resistance through fibre bridging mechanisms (Spadea et al., 2015; Gamage et al., 2024). However, excessive fibre incorporation often leads to reduced workability, increased porosity, and lower compressive strength (Tang et al., 2023). These findings indicate that the performance of textile waste-reinforced concrete is highly dependent on fibre type, geometry, and dosage (Bartulović et al., 2022). Although numerous studies have examined the influence of textile waste on individual mechanical or thermal properties, comprehensive investigations aimed at identifying an optimum mix design remain limited. In particular, there is insufficient information regarding the effects of different fabric waste types on both thermal and mechanical performance. Most previous studies have focused on a single fibre type or a single performance indicator, making it difficult to determine a practical mixture that satisfies both structural and thermal requirements for building applications. This knowledge gap highlights the need for systematic experimental studies that evaluate multiple performance parameters simultaneously.

The present study addresses this research gap by experimentally investigating the influence of three commonly available fabric waste fibres—cotton, polyester, and denim—on the fresh, mechanical, and thermal properties of concrete. Concrete mixtures containing different fibre contents were prepared and evaluated through slump, compressive strength, flexural strength, and thermal conductivity tests. The results were analysed to identify an optimum mix that provides the best balance between thermal insulation and mechanical performance.

The outcomes of this research contribute to the development of sustainable concrete materials that utilize recycled textile waste while improving the thermal efficiency of buildings. By diverting textile waste from landfill disposal and incorporating it into concrete, this study supports circular economy principles and promotes environmentally responsible construction practices. The findings are expected to provide practical guidance for engineers, researchers, and the construction industry in developing thermally efficient and sustainable concrete suitable for tropical climates.

II. METHODOLOGY

Ordinary Portland Cement (OPC) conforming to the relevant standards was used as the primary binding material. Natural river sand with a maximum particle size of 4.75 mm was used as the fine aggregate, while crushed granite with a nominal maximum size of 20 mm served as the coarse aggregate. Potable water was used for concrete mixing and curing.



Figure 1. Fabric Samples

Three types of recycled fabric waste fibres—cotton, polyester, and denim—were selected due to their abundance in the textile industry and their potential to improve the thermal performance of concrete. The collected fabric waste was cleaned, dried, and manually cut into fibres ranging from 10 to 20 mm in length to ensure uniform dispersion within the concrete matrix. Concrete mixtures were designed to achieve a characteristic compressive strength of 25 MPa (M25) using the Department of Environment (DOE) mix design method. A control mix without fibres and nine fibre-reinforced mixes were prepared using cotton, polyester, and denim fibres at 0.5%, 1.0%, and 1.5% replacement levels by weight of fine aggregate. The water-to-cement ratio and all other mix constituents were maintained constant throughout the study to isolate the effect of fabric waste incorporation.

Table 1.Fabric replacement levels

Mix ID	Fibre Type	Fibre Length (mm)	Replacement (% by weight of fine aggregate)
CM	None	–	0
C0.5	Cotton	10–20	0.5
C1.0	Cotton	10–20	1.0
C1.5	Cotton	10–20	1.5
P0.5	Polyester	10–20	0.5
P1.0	Polyester	10–20	1.0
P1.5	Polyester	10–20	1.5
D0.5	Denim	10–20	0.5
D1.0	Denim	10–20	1.0
D1.5	Denim	10–20	1.5

The concrete constituents were dry mixed to obtain a uniform distribution of cement, aggregates, and fabric fibres. Water was then added gradually while mixing continued until a homogeneous concrete mixture was achieved. Particular attention was given to fibre dispersion to minimize fibre balling and ensure uniform distribution throughout the concrete.

Fresh concrete was tested immediately for workability using the slump test. The concrete was then cast into standard steel moulds and compacted using a vibrating table to eliminate entrapped air. After casting,

the specimens were covered and kept at room temperature for 24 hours before demoulding. All specimens were subsequently cured in clean water until the specified testing ages.
The experiments evaluated both the fresh and hardened properties of fabric waste-reinforced concrete.

Workability was assessed using the slump test in accordance with the relevant standard procedures. Compressive strength tests were conducted on concrete cube specimens after 7, 14, and 28 days of curing using a universal compression testing machine. Flexural strength was determined at 28 days using prism specimens subjected to three-point loading.
The thermal performance of the concrete mixtures was evaluated by determining the thermal conductivity of hardened specimens using the Guarded Hot Plate (GHP) method, which is widely recognized as a reliable steady-state technique for measuring the thermal conductivity of construction materials. This method provides an accurate assessment of heat transfer through concrete and enables comparison of the insulating performance of different fibre-reinforced mixtures.

The experimental results obtained for workability, compressive strength, flexural strength, and thermal conductivity were compared with those of the control concrete. The influence of fibre type and replacement level on concrete performance was analysed to identify the optimum mix capable of providing enhanced thermal insulation while maintaining satisfactory mechanical properties. The optimum mixture was selected by considering the combined performance of thermal conductivity, compressive strength, flexural strength, and workability.

III. RESULT AND DISCUSSION



Figure 2. fresh concrete behavior

The slump test results indicated that the incorporation of fabric waste fibres reduced the workability of fresh concrete, with the reduction becoming more pronounced as the fibre replacement level increased. The control mix recorded a slump of 90 mm, whereas cotton fibre mixes showed the greatest reduction, decreasing to 45 mm at 1.5% replacement. Polyester mixes retained the highest workability, while denim exhibited intermediate behaviour.

The reduction in slump is primarily attributed to the increased internal friction created by randomly distributed fibres and the absorption of mixing water by the fabric waste, particularly cotton fibres. Cotton possesses a rough surface texture and high moisture absorption capacity, reducing the amount of free water available for lubrication within the concrete matrix. Polyester fibres, in contrast, absorb little water and therefore maintained better workability.
Although workability decreased with increasing fibre content, all mixtures remained suitable for casting when a superplasticizer was used. These findings agree with previous studies, which reported that textile fibres reduce concrete flowability because they obstruct aggregate movement and increase interparticle friction. Therefore, moderate fibre contents are recommended to achieve acceptable workability without compromising construction practicality.

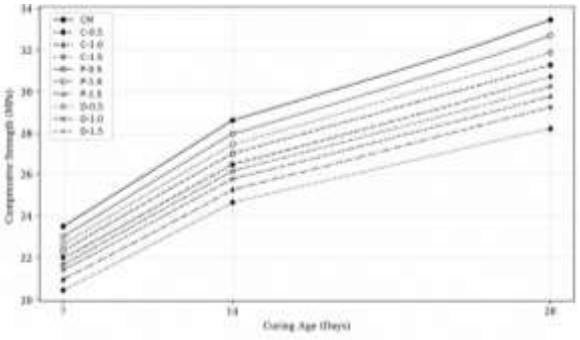


Figure 3. Compressive strength results

The compressive strength of all concrete mixtures increased with curing age, confirming normal cement hydration. However, increasing the fabric waste replacement level from 0.5% to 1.5% gradually reduced compressive strength irrespective of fibre type. The control mix achieved a 28-day compressive strength of 33.50 MPa, whereas the lowest value (28.40 MPa) was recorded for the cotton mix containing 1.5% fibres. Polyester-reinforced concrete consistently retained compressive strength closer to the control mix than cotton and denim mixtures.

The reduction in compressive strength can be attributed to the lower stiffness of textile fibres compared with natural fine aggregates, together with increased entrapped air and weaker fibre–matrix interfaces. As fibre content increased, additional voids were introduced into the concrete, reducing density and load-carrying capacity. Cotton fibres produced the largest strength reduction due to their higher water absorption and rougher surface, which affected the quality of the cement matrix. Polyester fibres showed comparatively better strength retention because of their lower water absorption and greater dimensional stability during mixing.

Despite these reductions, all mixtures satisfied the characteristic compressive strength requirements for Grade 25 concrete, demonstrating that fabric waste can be incorporated without significantly compromising structural performance when used at moderate replacement levels.

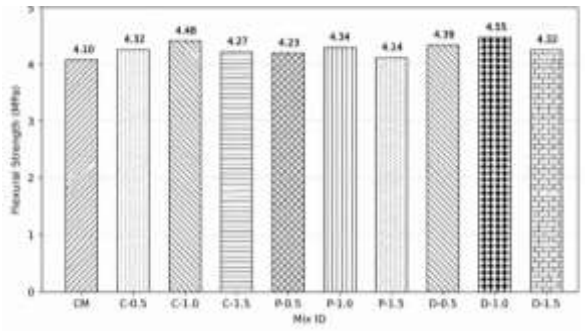


Figure 4. Flexural Strength results

Unlike compressive strength, flexural strength generally improved following the incorporation of fabric waste fibres. The control concrete achieved a flexural strength of 4.10 MPa, while most fibre-reinforced mixtures exhibited higher values, with the highest performance obtained for denim fibres at 1.0% replacement (4.55 MPa).

The improvement in flexural performance is attributed to the crack-bridging action of the fibres. During loading, the fibres transferred tensile stresses across developing cracks, delaying crack propagation and increasing the energy absorption capacity of the concrete. Denim fibres demonstrated the greatest improvement because of their comparatively thicker and stronger fibre structure, which provided better resistance against tensile cracking.

However, increasing the fibre content to 1.5**%** resulted in a slight reduction in flexural strength for all fibre types. This behaviour is likely due to fibre agglomeration, reduced workability, and increased void formation, which weakened the fibre–matrix bond. Consequently, the results suggest that approximately 1.0% fibre replacement provides the optimum level for improving flexural performance while maintaining good concrete quality.

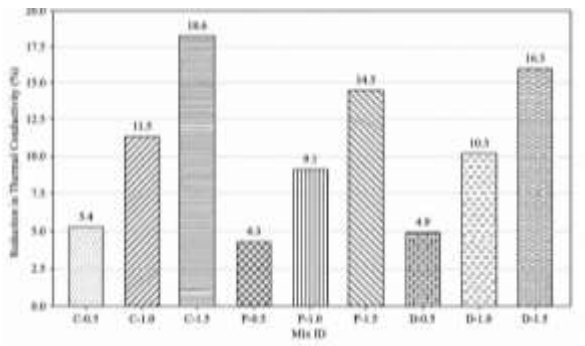


Figure 5. Thermal Conductivity results

Thermal conductivity measurements obtained using the guarded hot plate method demonstrated that incorporating fabric waste significantly improved the thermal insulation performance of concrete. The control concrete exhibited a thermal conductivity of 1.65 W/m·K, while all fibre-reinforced mixtures showed progressively lower values as the replacement percentage increased. Cotton fibres produced the greatest reduction, reaching 1.34 W/m·K at 1.5% replacement, representing an 18.8% reduction compared with the control concrete. Polyester and denim fibres also reduced thermal conductivity, although to a lesser extent.

The reduction in thermal conductivity is mainly associated with two mechanisms. First, textile fibres possess considerably lower thermal conductivity than mineral aggregates. Second, the incorporation of fibres introduces additional microscopic air voids within the concrete matrix, disrupting continuous heat-transfer pathways. Because air has a much lower thermal conductivity than concrete, these voids increase the overall thermal resistance of the material.

Cotton fibres achieved the greatest thermal improvement due to their highly porous structure and superior insulating characteristics. Polyester fibres produced comparatively smaller reductions because of their denser structure and lower porosity, while denim exhibited intermediate performance. These observations are consistent with previous studies reporting that natural textile fibres generally provide better thermal insulation than synthetic fibres because of their greater capacity to trap air within their fibrous structure. The improved thermal performance demonstrates the potential of fabric waste-reinforced concrete for reducing heat transfer through building envelopes, thereby contributing to improved indoor thermal comfort and lower cooling energy demand, particularly in tropical climates. The optimum concrete mixture was selected by simultaneously considering workability, compressive strength, flexural strength, and thermal conductivity. Although the 1.5% cotton mixture exhibited the lowest thermal conductivity, it also experienced the greatest reduction in workability and compressive strength. Conversely, lower replacement levels produced only modest thermal improvements.

Based on the combined performance of all test parameters, 1.0% fibre replacement is recommended as the optimum level for fabric waste-reinforced concrete. At this replacement level, the concrete maintained satisfactory workability and compressive strength while providing improved flexural performance and a substantial reduction in thermal conductivity. Among the three fibre types, cotton offered the greatest thermal insulation, polyester retained the highest compressive strength, and denim provided the highest flexural strength. Therefore, the selection of fibre type may be

tailored according to the primary performance requirement of the intended application.

IV. CONCLUSIONS AND RECOMMENDATIONS

This study experimentally evaluated the effects of recycled cotton, polyester, and denim fabric waste fibres on the workability, mechanical properties, and thermal conductivity of M25 concrete. Based on the experimental findings, the following conclusions can be drawn:

The incorporation of fabric waste fibres reduced the workability of fresh concrete, with the reduction becoming more significant as the fibre replacement level increased. Cotton fibre mixtures exhibited the lowest slump due to their high-water absorption capacity.The compressive strength of concrete decreased with increasing fibre content. However, all mixtures achieved compressive strengths exceeding the characteristic strength requirement of Grade 25 concrete, indicating that structural performance was maintained within acceptable limits.Fabric waste fibres enhanced the flexural strength of concrete through their crack-bridging effect. Denim fibre-reinforced concrete exhibited the highest flexural strength, demonstrating its effectiveness in improving tensile behaviour. Thermal conductivity decreased with increasing fibre content for all fibre types. Cotton fibres produced the greatest reduction in thermal conductivity owing to their porous structure and superior thermal insulation characteristics.

Considering workability, compressive strength, flexural strength, and thermal performance collectively, a 1.0% fibre replacement by weight of fine aggregate was identified as the optimum level. This replacement provided a balanced improvement in thermal insulation while maintaining satisfactory mechanical properties. The results demonstrate that recycled fabric waste can be successfully incorporated into concrete as a sustainable construction material. Its application can contribute to reducing textile waste disposal while improving the thermal performance of buildings, supporting environmentally responsible and energy-efficient construction practices.

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