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Compressive Behavior of Coir Fiber Reinforced Concrete in Elevated Thermal Condition

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ABSTRACT
Concrete, the second most used material in the world after water, plays a critical role in modern construction due to its durability, strength, and sustainability. However, fire outbreaks in buildings have emerged as a significant concern, as the integrity of concrete is often compromised under high temperatures, leading to a considerable reduction in its strength. Various strategies have been explored to address this issue and enhance the fire resistance of concrete. This study investigates the compressive strength behavior of regular concrete (0% coconut fiber) and coconut fiber-reinforced concrete with varying fiber contents (0.25%, 0.5%, and 1% by weight of cement) under conditions simulating exposure to fire. The findings reveal that concrete reinforced with an optimum percentage of coconut fiber demonstrates superior fire resistance compared to standard concrete. This improvement is attributed to the unique properties of coconut fibers, including the bridging effect, pyrolysis, and buffering effect, which arise from the low thermal conductivity of the fibers. These results highlight the potential of coconut fiber as an effective additive for enhancing the fire performance of concrete.
Keywords: *Fiber Reinforced Concrete, Coconut Fiber, Strength Test, Bridging Effect, High Temperature.*

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I. INTRODUCTION

Concrete has four essential elements: coarse aggregate, fine aggregate, water, and cement. Fibers have recently been introduced with steel to meet the design tensile strength requirements. Several kinds of fibers are used in concrete, such as glass fiber, carbon fiber, coconut fiber (natural fiber), steel fiber, etc. In high temperatures, the compressive strength of concrete gets reduced. Still, fibers with low thermal conductivity (e.g., coconut fiber) can help increase the compressive strength of concrete to withstand high-temperature conditions (Gideon Bamigboye, 2020). This study shows that coconut fiber is being used with the variation of cement, and the proper variation was found to be 0.5% to get maximum compressive strength under high temperatures. Lau and Anson conducted another experiment; this study deals with high-performance steel fiber-reinforced concrete with temperature variations ranging from 105ºC to 1200ºC. In this experiment, the effect of high temperature on SFRC was investigated. Their finding shows that temperatures below 400ºC give comparatively lower loss in compressive strength. However, above 400ºC, the loss is considerably high (Lau & Anson, 2006). The strength and durability test of coconut-fiber-reinforced concrete was conducted by Mahyuddin Ramli et al. in three different aggressive environments. In approximately all cases, 0.6% CF was the most appropriate. This proportion can enhance the performance of concrete exposed to tropical climates by 12% (Mahyuddin Ramli, 2013). The influence of 1%, 2%, 3%, and 5% fiber contents by mass of cement and fiber lengths of 2.5, 5, and 7.5 cm is investigated by Majid Ali and his team, the CFRC with 5 cm long fibers having 5% fiber content has an increased σ, T_c, MOR, and TTI up to 4%, 21%, 2%, and 910%, respectively, and decreased E_{static}, STS, and density up to 6%, 2%, and 3%, respectively, as compared to that of plain concrete (Majid Ali, 2011). M. Adamu et al. conducted tests on predicting the strengths of date palm fiber-reinforced concrete (DPFRC) exposed to elevated temperatures using artificial neural networks (ANN) and Weibull distribution. Their findings indicate that the residual compressive strength (RCS) and relative strength (RS) of DPFRC decreased with the addition of date palm fiber (DPF) at any temperature. However, silica fume improved both RCS and RS when heated up to 400°C (Musa Adamu, 2023). J. Novák and A. Kohoutková conducted tests on fiber-reinforced concrete exposed to elevated temperatures, gathering data on steel fiber-reinforced concrete (SFRC), synthetic fiber-reinforced concrete, and hybrid (steel + synthetic) fiber-reinforced concrete from various published contributions. Their findings show that the melting and ignition points of fibers are the main mechanical properties that affect the performance of fiber cement composites. Steel fibers are beneficial to preheat for enhanced toughness in a concrete mixture, whereas synthetic fibers are positive in post-heated residual mechanical properties, spalling resistance, and ductility. The addition of synthetic fibers mainly improves spalling resistance, whereas the addition of steel fibers improves not only mechanical properties but also thermal resistance (J Novák, 2017). M. Avubothu et al. investigated the effect of high temperatures on coconut fiber-reinforced concrete (CFRC). Specimens with coconut fibers were prepared and cured using an M20 mix design in the experiment. The temperature used was in the range of 200 °C, and the strength variations were evaluated by comparing these samples with control samples. The inclusion of coconut fibers confirmed a beneficial improvement in splitting tensile strength of CFRC at both ambient and high temperatures, as revealed by the study. However, the compressive strength of CFRC was slightly enhanced. The results indicated that the split tensile strength of CFRC was higher than the conventional concrete at room temperature and elevated temperature at the testing period of 7 and 28 days. However, the decline in compressive strength of CFRC and conventional concrete upon exposure to 200°C showed that high temperature can cause deterioration even with fiber inclusion. Similarly, a reduction in splitting tensile strength was observed in both CFRC and conventional concrete under high temperature conditions (Maheshwari Avubothu, 2022). The workability of fresh coconut Fiber concrete measured by the slump test reduces as the coconut fiber content increases. Therefore, coconut fiber makes concrete less workable, which helps control the bleeding of concrete and avoids segregation of the ingredients of the concrete mix (Osuji & Ukeme, 2024). The study found that adding coconut fibers to concrete improved its strength, but the best results were achieved with lower fiber contents. After 28 days, compressive strength increased by up to 38.13% at 0.5% fiber content, while flexural strength improved by 28.82% at 0.25% fiber content. However, beyond 0.5%, the benefits started to decrease. These results suggest that coconut fibers can be a cost-effective and sustainable way to enhance concrete properties (Ede & Agbede, 2015). This study investigated the use of coconut fibers to increase the compressive strength of recycled aggregate (RA) concrete. The study showed that adding 5% coconut fibers helped recover strength while increasing RA decreased it. The highest strength was attained for 50% RA with 5% fibers and a 0.3 water-cement ratio. Concrete with 25% RA and 5% fibers was as strong as ordinary concrete. According to the findings, 5% coconut fibers offer the best balance for enhancing concrete's performance, making it a sustainable substitute. (Lage et al., 2024). Coconut fiber is considered waste and is widely available in Bangladesh. The compressive behavior of coconut fiber reinforced concrete is investigated in this study, particularly its performance under ambient and elevated temperatures. The aim is to understand how the compressive strength of concrete mix imparts under normal conditions and investigate how the material behaves and retains its strength at high temperatures when exposed to the environment. The research addresses these questions in order to gain useful information on the possibilities of using coconut fiber improved concrete as sustainable construction materials.

II. MATERIAL AND METHODS

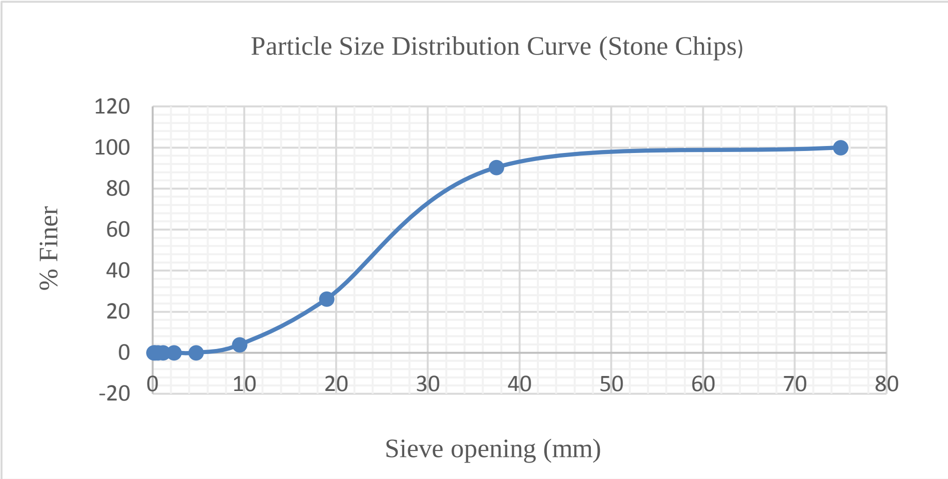
Materials selected for the experimentation are based on optimal fiber content and sustainability. For our natural reinforcement, we chose Coconut Fiber, or coir fiber, as it is abundant and eco-friendly. It is a natural fiber extracted from the husk of coconuts (Cocos nucifera). Coir fiber is extracted from the coconut husk (mesocarp), usually regarded as agricultural waste. Coconut fiber consists of 37% cellulose, 42% lignin, 11.36% moisture, and 30.45% microfibrillar angle (Chokshi et al., 2022). Coir fiber used in the testing was procured from the local market and dehusked to obtain 75-mm-long fibers. The fibers were treated by submerging them in warm water and then oven drying. This preparation process removes additional dust particles from the fiber, ensuring improved cleanliness and casting integrity. (Bamigboye et al., 2020). Coconut fiber was incorporated as a natural reinforcement to enhance the composites's mechanical as well as thermal properties of the composite. The coarse and fine aggregates were selected for bulk and structural strength. Two types of aggregates were used: stone chips as coarse aggregate and Sylhet sand as fine aggregate. The origin of stone chips is from the UAE. The properties of these aggregates were tested, and the values are shown in Table 1.

Table 1: Properties of Aggregates

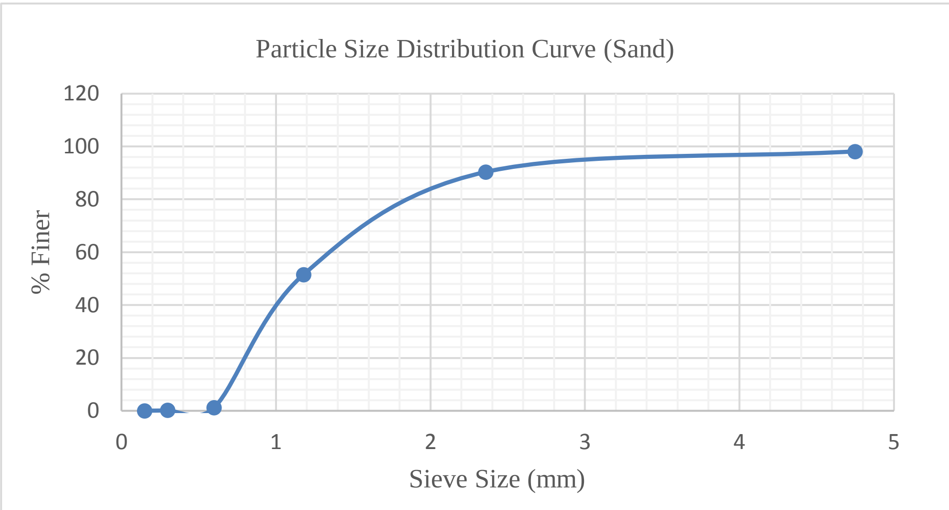
Properties of Stone Chips	Values
Bulk Sp. Gr. (OD)	2.71
Fineness Modulus	7.776
Absorption Capacity (%)	1.91
Unit wt. in SSD (kg/m^3)	1474.3
% Void	39.21
AIV (%)	11.04

Properties of Sylhet Sand	Values
Bulk Sp. Gr. (OD)	2.18
Fineness Modulus	3.58
Absorption Capacity (%)	12.5

The particle size distribution of the sand sample is analyzed through a series of experiments, allowing us to construct a detailed particle distribution curve that illustrates the varying sizes of the sand particles in the sample, shown in Figure 2



(a)



(b)

Figure 2: Particle Size Distribution Curve (a)Stone Chips (b) Sand

The particle size distribution curve of two aggregates shown in Figure 2 indicates that these curves are well-graded. Different sizes of particles are present, and with this distribution, maximum strength can be achieved because voids are minimal. Cement was used as the primary binder to bind these aggregates effectively. Cement ensures cohesion among the particles, forming a solid and durable matrix when combined with water. Portland composite cement branded as SHAH cement was used in this study. SHAH cement complies with Bangladesh standard BDS EN 197 – 1:2003 and American standard ASTM C 150 type-1. By ASTM C 150, the results of this test were justified. The concrete mix design was prepared by weight, following a proportion of 1:1.5:3 (cement: fine aggregate: coarse aggregate). The fiber content was deployed into the mix at varying percentages of 0%, 0.25%, 0.5%, and 1% by weight of cement. W/C remained constant for all of the variations. The following table illustrates the progression of testing, showcasing the different amounts of fibers and materials incorporated into each batch of the mixture.

Table 3: Mix proportions of the concrete used in the experimental works

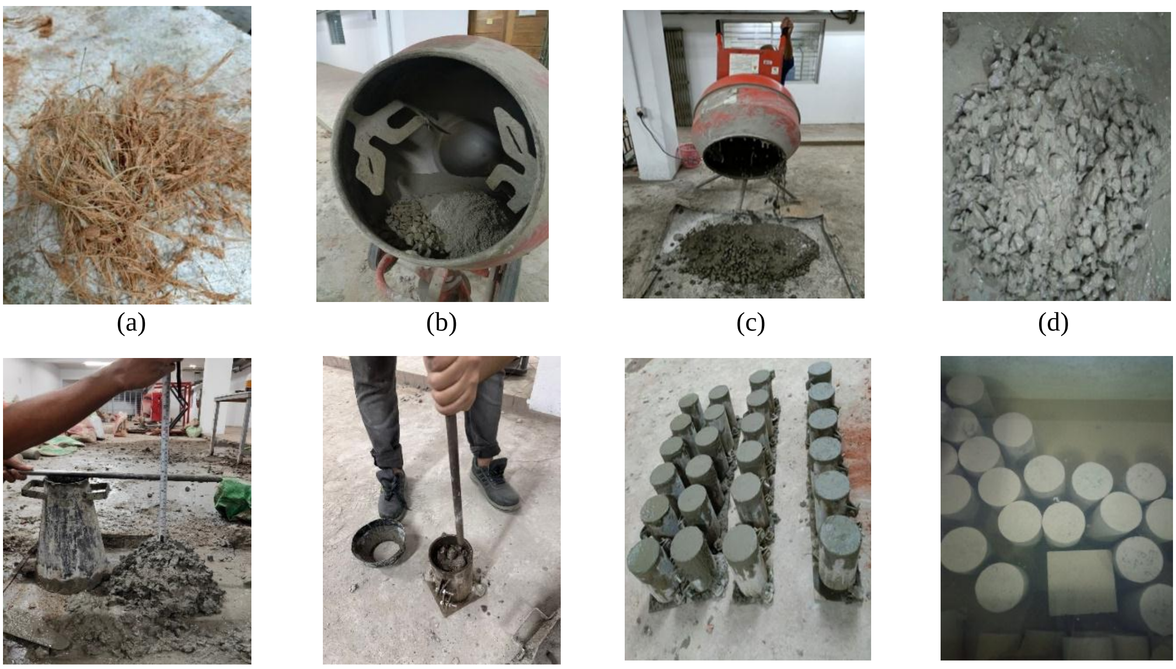
Fiber (kg)	Water(kg)	Cement(kg)	Fine Aggregate(kg)	Coarse Aggregate(kg)
0	0.259	4.51	8.051	16.5

0.011	0.259	4.49	8.051	16.5
0.0225	0.259	4.48	8.051	16.5
0.0451	0.259	4.46	8.051	16.5

Twenty-four cylindrical molds (200mm*100mm) were prepared, with six specimens for each fiber content, divided equally for testing at room temperature, 150^{o}C, and 250^{o}C. Materials were distributed manually in each mix with an even distribution of coir fibers. A workability test was performed before the freshly poured concrete was placed into cylinders following ASTM C143/C143M. After that, the freshly cast concrete was poured into the cylinders lubricated earlier to prevent the concrete from adhering to the mold's inner surface. The freshly prepared concrete mix was poured into cylinders in three layers, with each layer compacted thoroughly using a tamping rod to eliminate voids and ensure proper compaction. Concrete curing was conducted to promote hydration and achieve proper strength. The cylindrical specimens were dried for twenty-four hours after casting. Following 24 hours, the mold was eliminated, and the samples were cured by the ponding method to guarantee sufficient moisture levels per the specifications of ASTM C192M-02 and C192M. Specimens were tested after 7 and 28 days of curing. After curing for 7 days and 28 days, the compressive strength of the specimens was tested. But before the test, 12 concrete specimens were heated at elevated temperatures ($150\ ^{0}$ C and $250\ ^{0}$ C) for about an hour by using an oven. Then, the specimens were tested at normal temperatures, $150\ ^{0}$ C and $250\ ^{0}$ C, to check the strength variation of conventional concrete and CFRC. Afterward, a total of 24 cylinders were tested for compressive strength. Rubber pads were placed at both ends of each cylinder to improve grip during testing. The compressive strength tests were conducted using a Universal Testing Machine (UTM) following the ASTM C39/C39M standard (Concrete & Aggregates, 2014). The maximum load applied to each specimen was recorded, and the compressive strength was determined by dividing the failure load by the specimen's cross-sectional area. The calculation for compressive strength was as follows:

$C = P/A$; where $A = \pi D^2/4$

Where, C = Compressive strength, MPa [psi], P = Maximum applied load, N [lb.], D = Diameter of the specimen, mm [in]



(a) (b) (c) (d)

(e) (f) (g) (h)

Figure 4: (a) Coconut Fiber, (b) Mixing dry materials, (c) Concrete Mixing Machine, (d) Freshly Poured Concrete, (e) Slump Test, (f) Temping, (g) Concrete Cylinder Making, (h) Curing

III. RESULT AND DISCUSSION

Fresh Concrete Test:

Fresh concrete refers to concrete that has been recently mixed and is in a state that is still workable and moldable. It has not yet hardened or set, allowing it to be poured, shaped, and finished according to the desired form or structure. In this study, the slump test serves as a key component in assessing the overall workability of CFRC.

The slump test results ranged between 90 and 120 mm, indicating the workability of the concrete mix. The slump value varies with the percentage of coir added to the concrete, as coir fibers absorb some of the water content, resulting in a reduced slump. This reduction typically leads to a true slump, as the graph shows.

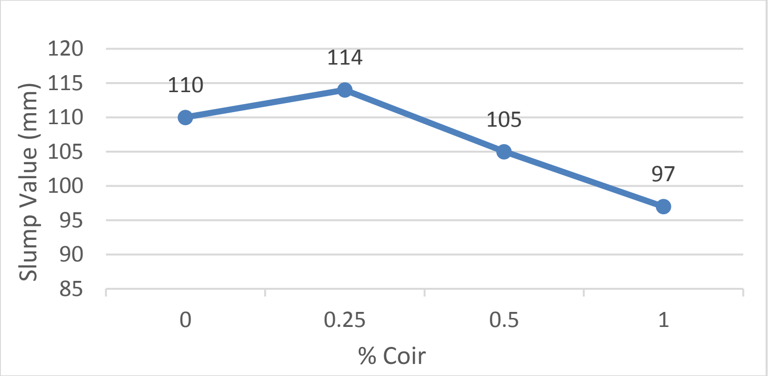


Figure 9: Slump values of fresh concrete

Harden Concrete Test:

The compressive strength of concrete specimens refers to the maximum load per unit area that the concrete can withstand under compression. In this study, 24 concrete cylindrical specimens were prepared by varying the percentages of coir (0%, 0.25%, 0.5%, 1%). The concrete cylinders were tested under the specifications provided in ASTM C 39. The compressive strength was investigated after 7 and 28 days of curing age with a design strength of 20 MPa (2900 psi) for cylindrical specimens.

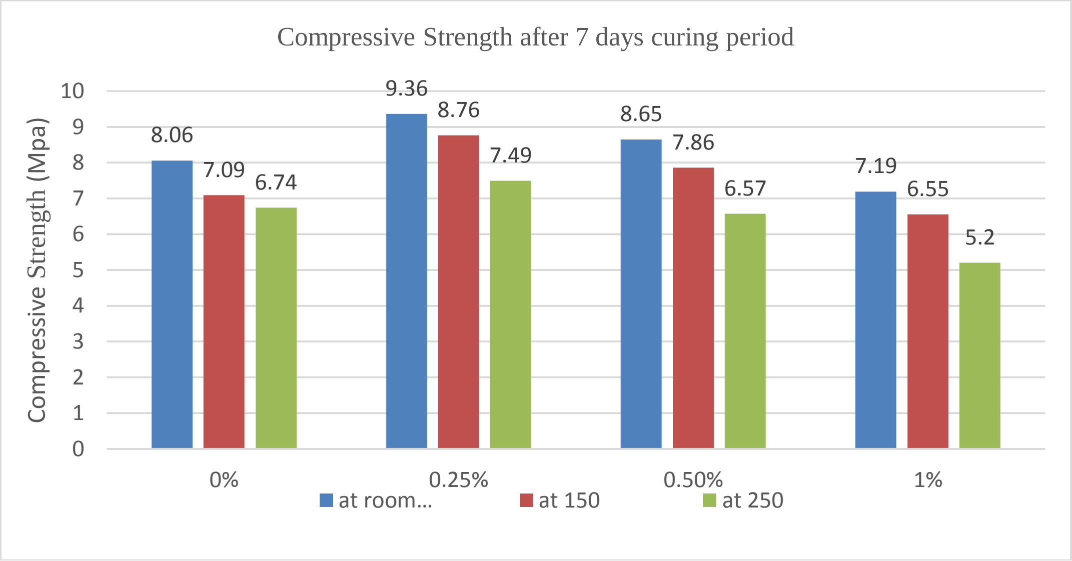


Figure 10: Compressive strength variations with different fiber content after 7 days of curing period

This graph illustrates a gradual decline in the compressive strength of concrete as the coir fiber content and heat increase.

Heat affects the compressive strength of plain concrete, but coconut fiber reinforced concrete showed higher strength of up to 0.25% fiber content under similar conditions. Beyond this, strength decreased due to reduced bond and matrix strength between the fibers and concrete.

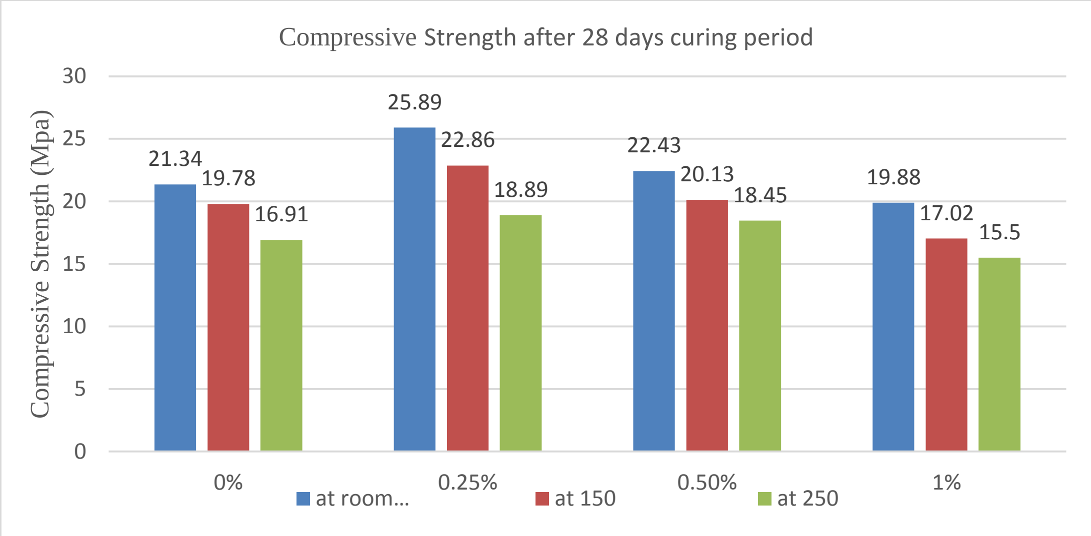


Figure 11: Compressive strength variations with different fiber content after 28 days of curing period

The graph shows similar patterns, with the compressive strength initially higher after 28 days of curing.

Heat reduces the compressive strength of plain concrete, but coconut fiber-reinforced concrete showed higher strength up to 0.25% fiber content, with the highest strength observed at this level. Beyond 0.25%, strength declined due to reduced bond and matrix strength. Coconut fibers improve both compressive and flexural strength, enhancing ductility and preventing brittle failure by holding the concrete together after crushing. So, it can be stated that an optimal percentage of coir in concrete can enhance its strength at elevated temperatures.

IV. CONCLUSION

Varying percentages of coir fiber were utilized as a reinforcing element in concrete in this experiment to evaluate its impact on the material's mechanical properties. The experimental results highlighted the following key findings:

1. At 0% fiber content, the concrete shows a normal slump value, which increases at 0.25% fiber, improving workability ranging between 90 and 120 mm of slump value. However, further increases in fiber content reduce the slump, indicating that optimum fiber content is essential for balancing strength and workability.
2. After 7 days of curing, 12 samples were tested under loading at elevated temperatures. At an ambient temperature of 28°C, 0.25% coir content gave the maximum strength of 9.86 MPa. However, an inverse relation was noticed between strength and both fiber content and temperature exposure, with strength dropping to 5.2 MPa for 1% coir content at 250°C.
3. After curing for 28 days, the remaining 12 samples were tested in the same condition. An ambient temperature of 28°C resulted in a maximum strength of 25.93 MPa with 0.25% coir content exceeding the target strength of 20 MPa. However, increased fiber content and temperature led to a reduction in strength to 15.5 MPa at 250°C for 1% coir.

In Conclusion, this study shows that adding coir fiber to concrete in the right proportions improves its strength and fire resistance performance over conventional concrete. It is also a cost-effective and environmentally sustainable alternative to traditional construction materials.

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