

# Enhancing Mechanical and Thermal Performance of M30 Concrete with Carbon Fibre Reinforcement

K.V.G. D Prasad <sup>1,\*</sup>, A.Aravindan <sup>2</sup>, Nadigatla Naveen Kumar <sup>3</sup>

## Abstract

*This study examines the influence of carbon fibre incorporation on the mechanical properties of M30-grade concrete. A series of experimental investigations were conducted to assess the effects of varying carbon fibre content on compressive, split tensile, and flexural strengths. The results indicate a significant enhancement in mechanical performance with the inclusion of carbon fibres, with the optimum fibre dosage identified as 0.75%. At this content, the concrete achieved a peak compressive strength of 37.76 N/mm<sup>2</sup> at 7 days and 57.51 N/mm<sup>2</sup> at 28 days, demonstrating substantial improvements over conventional M30 concrete. Furthermore, the thermal performance of carbon fibre-reinforced concrete was evaluated by subjecting specimens to a temperature of 100°C. The heated samples exhibited superior mechanical properties, attaining a maximum 28-day compressive strength of 64.84 N/mm<sup>2</sup>, split tensile strength of 10.64 N/mm<sup>2</sup>, and flexural strength of 17.39 N/mm<sup>2</sup>. These findings suggest that carbon fibre reinforcement enhances both strength and thermal resistance, making it highly suitable for structural applications exposed to elevated temperatures and high-stress conditions. The study underscores the potential of carbon fibre-reinforced concrete in modern construction, particularly for infrastructure requiring enhanced durability and resilience. Its superior mechanical properties and thermal stability position it as a promising material for use in high-performance structures, including industrial facilities, transportation infrastructure, and fire-resistant buildings. Future research should further explore the long-term durability and microstructural behaviour of carbon fibre-reinforced concrete under extreme environmental conditions.*

**Keywords:** Carbon fiber reinforced concrete (CFRC), compressive strength, split tensile strength, flexural strength, high-temperature durability

## INTRODUCTION

Concrete remains one of the most widely used construction materials worldwide, valued for its versatility, durability, and cost-effectiveness. Its extensive application spans infrastructure, residential, and commercial projects, owing to its ability to withstand significant compressive loads. However, despite its many advantages, conventional concrete has inherent limitations, particularly in tensile strength, resistance to cracking, and overall performance under extreme environmental and mechanical conditions. These weaknesses can lead to structural degradation over time, compromising safety and longevity [9]. To address these issues, researchers and engineers have explored various strategies to enhance concrete's mechanical properties, including the incorporation of supplementary materials and reinforcement techniques. Among these, fibre reinforcement has emerged as one of the most effective solutions, significantly improving the structural integrity of concrete and extending its lifespan.

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strength, resistance to cracking, and overall performance under extreme environmental and mechanical conditions. These weaknesses can lead to structural degradation over time, compromising safety and longevity [9]. To address these issues, researchers and engineers have explored various strategies to enhance concrete's mechanical properties, including the incorporation of supplementary materials and reinforcement techniques. Among these, fibre reinforcement has emerged as one of the most effective solutions, significantly improving the structural integrity of concrete and extending its lifespan.

The use of fibres in concrete reinforcement has gained increasing attention due to its potential to

mitigate cracking, enhance load-bearing capacity, and improve durability under various stress conditions. Different types of fibres, including steel, glass, synthetic, and natural fibres, have been studied for their effectiveness in modifying the performance characteristics of concrete. Among these, carbon fibres have demonstrated exceptional promise due to their high tensile strength, stiffness, low density, and superior thermal resistance. Their ability to improve the mechanical properties of concrete while maintaining a relatively low weight makes them particularly attractive for high-performance structural applications.

Carbon Fibre Reinforced Concrete (CFRC) is an advanced composite material that integrates carbon fibres into the concrete matrix to enhance its mechanical and durability properties. Unlike traditional reinforcement methods, which primarily address compressive strength, CFRC improves tensile and flexural strength while also reducing the risk of cracking [12]. As a result, this material has been identified as a viable solution for infrastructure projects requiring high strength, long-term durability, and resistance to adverse environmental conditions. Applications of CFRC include high-rise buildings, bridges, tunnels, and industrial structures where enhanced mechanical performance is critical [13]. Additionally, its lightweight nature contributes to reducing overall structural loads, which is particularly beneficial in seismic-prone regions.

This study aims to investigate the mechanical properties of CFRC, with a specific focus on compressive strength, split tensile strength, and flexural strength. A key objective is to determine how varying percentages of carbon fibres influence the structural behaviour of concrete. Furthermore, the research examines the performance of CFRC under elevated temperature conditions (50°C, 100°C, and 150°C) to assess its suitability for use in environments subject to thermal stress, such as industrial facilities, fire-prone structures, and regions experiencing extreme temperature fluctuations.

To achieve these objectives, experimental investigations were conducted on concrete samples with different carbon fibre concentrations. The mechanical properties were evaluated at two key curing periods—7 days and 28 days—allowing for a comprehensive assessment of strength development over time. Comparative analysis with conventional concrete was performed to quantify the improvements achieved with carbon fibre incorporation. Preliminary results indicate that an optimal carbon fibre content of 0.75% enhances the compressive strength to 57.51 MPa after 28 days of curing, significantly surpassing the strength of standard concrete mixtures. However, fibre additions beyond this percentage exhibited diminishing returns, suggesting that an optimal balance must be maintained to achieve maximum efficiency.

The findings of this research contribute to the growing body of knowledge on fibre-reinforced concrete and provide valuable insights into the practical applications of CFRC in modern construction. By demonstrating the advantages of carbon fibre reinforcement, particularly in terms of strength enhancement, crack resistance, and thermal stability, this study underscores the potential of CFRC as a high-performance construction material. The implications of this research extend to infrastructure development, where the demand for durable, resilient, and sustainable materials continues to rise. Ultimately, the integration of carbon fibres in concrete presents an opportunity to improve the longevity and reliability of structures, reducing maintenance costs and enhancing safety across various engineering applications.

## LITERATURE REVIEW

The incorporation of carbon fibers into concrete has been widely studied due to its potential to enhance the mechanical properties and durability of concrete composites. This review highlights significant findings from various studies regarding the effects of carbon fibers on concrete, focusing on mechanical properties, durability, and application in structural strengthening.

Carbon fiber incorporation has been shown to significantly influence the mechanical properties of different concrete mixes. Thakur and Singh [1] reviewed various studies that explored the impact of

carbon fibers on concrete, concluding that the fibers improve the compressive, tensile, and flexural strength. Similarly, Khalil and Abdulrazaq [2,17] investigated high-performance carbon fiber concrete and reported enhancements in mechanical strength, indicating the effectiveness of carbon fibers in reinforcing concrete structures. Kinayekar et al. [3,16] also demonstrated that adding carbon fibers to high-strength concrete results in noticeable improvements in compressive and tensile strength.

Ji et al. [5] focused on the development of carbon fiber conductive concrete and explored its mechanical and heating properties, highlighting its dual functionality as a structural and conductive material. The study by Wei et al. [10] also delved into the effects of different fibers, including carbon fibers, on high-strength lightweight aggregate concrete, revealing improvements in mechanical properties and providing insights into the micro-mechanisms involved.

The long-term durability of carbon-reinforced concrete is a critical aspect when considering its application in construction. Spelter et al. [11] provided a comprehensive overview of carbon-reinforced concrete's durability, presenting experimental investigations that suggest carbon fibers significantly enhance the material's resistance to environmental degradation.

Klyuev et al. [4] discussed the use of composite materials based on carbon fibers for strengthening concrete structures, emphasizing the material's ability to maintain its integrity over extended periods under various loading conditions. This focus on long-term performance is crucial for infrastructure applications where durability is a primary concern.

One of the notable applications of carbon fiber in concrete is in the seismic retrofitting of structures. Ozcan et al. [6] demonstrated that carbon fiber-reinforced polymers (CFRP) could be used effectively to enhance the seismic performance of deficient reinforced concrete columns[18]. Their study highlighted the ability of CFRP to increase the load-bearing capacity and ductility of these columns, making them more resilient during seismic events.

Chuang et al. [8] investigated the dispersion of chopped carbon fibers in a cement matrix, emphasizing the importance of proper mixing techniques to ensure uniform fiber distribution, which directly impacts the composite's structural properties. This study aligns with findings from Branco et al. [13], who also noted that uniform fiber distribution is crucial for maximizing the reinforcing benefits of carbon fibers in concrete [20].

The control and modification of the interfacial characteristics between carbon fibers and polymer composites are essential for optimizing their reinforcing capabilities. Liu et al. [12] explored these aspects, focusing on the chemical interactions at the fiber-matrix interface, which play a significant role in the mechanical performance of the composite [19].

Recent research by Bhandari and Nam [14] reviewed the use of recycled carbon fibers in concrete, presenting a sustainable approach to enhance concrete properties. This study highlights the environmental benefits of reusing carbon fibers, which aligns with modern sustainable construction practices[21].

Innovations in concrete reinforcement using carbon fibers have led to the development of new composite materials with enhanced properties. Aljalawi and Al-Jelawy [15] examined the potential of using carbon fiber-reinforced concrete in construction, identifying its advantages in terms of increased strength and reduced weight compared to traditional concrete.

Kinetic modelling and post-treatment evaluations in the context of carbon fiber use in industrial wastewater treatment have also been studied by Liu et al. [7]. Although not directly related to concrete reinforcement, these studies provide insights into the versatility of carbon fibers in various engineering applications.

### Objective

1. To determine the optimum percentage of carbon fibers required to achieve maximum compressive strength in M30 grade concrete.
2. To evaluate the compressive strength of M30 grade concrete at both 7 days and 28 days with the incorporation of carbon fibers.
3. To study the effect of heating on the 28-day compressive, split tensile, and flexural strength of M30 concrete with carbon fibers.
4. To compare the mechanical properties (compressive, split tensile, and flexural strength) of M30 concrete with carbon fibers before and after heating to 100°C.

### Scope

1. *Material analysis:* The study focuses on the performance of carbon fiber-reinforced M30 concrete, aiming to identify the optimum percentage of carbon fibers for enhancing the mechanical properties of the concrete.
2. *Strength evaluation:* The scope includes analysing the compressive, split tensile, and flexural strengths of M30 concrete, particularly emphasizing the strength variations when subjected to a specific heating condition (100°C).
3. *Performance enhancement:* The research will provide insights into the potential of carbon fibers in improving the mechanical properties of M30 grade concrete, which can be beneficial for applications where higher strength and thermal resistance are required.
4. *Practical applications:* The results of this study could contribute to the development of high-strength and durable concrete for use in various construction projects, especially in environments exposed to elevated temperatures.

## RESULTS

The experimental investigation was conducted to assess the mechanical properties of concrete under varying conditions, including the incorporation of carbon fibers and the influence of temperature. The results provide valuable insights into the compressive strength, split tensile strength, and flexural strength of concrete, as outlined in the subsequent tables.

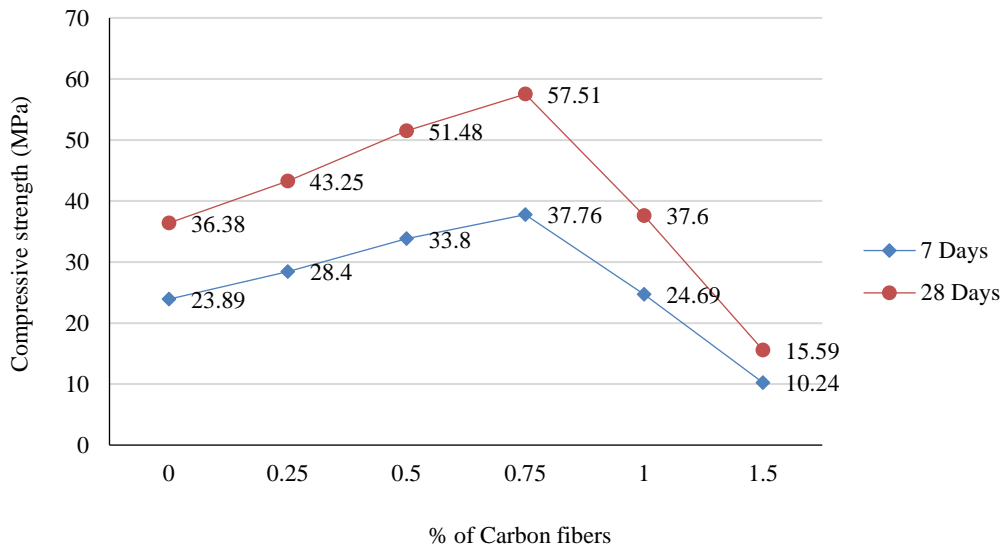
Table 1 presents the nominal values of concrete, serving as a reference for comparison with modified mixtures. The impact of carbon fiber reinforcement on compressive strength is illustrated in Table 2, where an optimal dosage of 0.75% carbon fibers resulted in the highest strength at both 7 and 28 days. However, beyond this percentage, a decline in strength was observed, indicating a possible threshold for fiber reinforcement effectiveness.

**Table 1.** Nominal concrete values.

Days	Compressive strength (N/mm <sup>2</sup> )	Split tensile strength (N/mm <sup>2</sup> )	Flexural strength (N/mm <sup>2</sup> )
7	37.76	4.35	8.78
28	57.51	6.62	13.37

**Table 2.** Compressive strength of concrete with % of Carbon Fibers.

Mix	% of fibers	Compressive strength (N/Mm <sup>2</sup> )	
		7 Days	28 Days
1	0	23.89	36.38
2	0.25	28.4	43.25
3	0.5	33.8	51.48
4	0.75	37.76	57.51
5	1	24.69	37.60
6	1.5	10.24	15.59

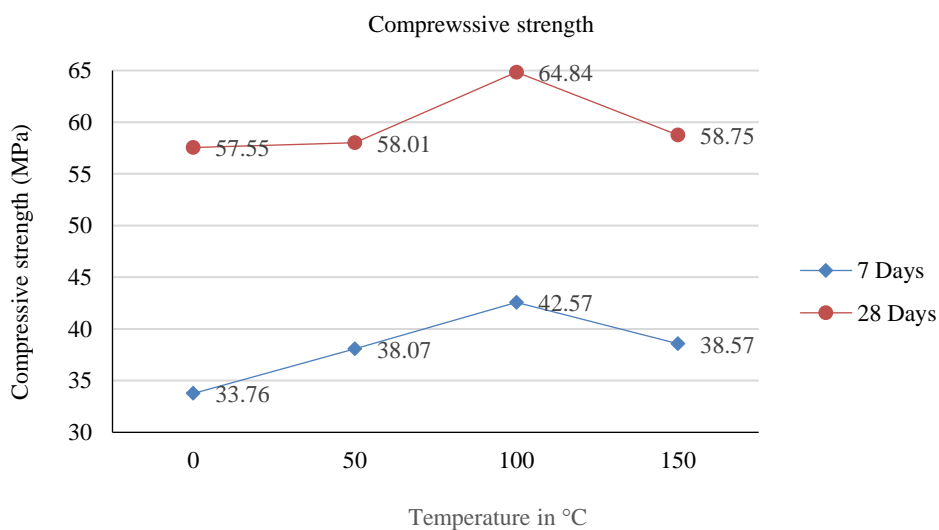


**Figure 1.** The variation of compressive strength of concrete with % of carbon fibers.

Furthermore, the effect of temperature variations on compressive strength is documented in Table 3. An increase in curing temperature up to 100°C led to enhanced compressive strength, suggesting accelerated hydration and improved matrix bonding. However, at 150°C, a slight reduction was recorded, likely due to thermal degradation effects. Similarly, Table 4 presents the split tensile strength trends under different temperature conditions, highlighting a peak at 100°C, followed by a decrease at higher temperatures. A comparable pattern is observed in Table 5, where flexural strength increases up to 100°C before stabilizing at higher temperatures as shown in Figure 1,2 and 3.

**Table 3.** Compressive strength of concrete with temperature (°c).

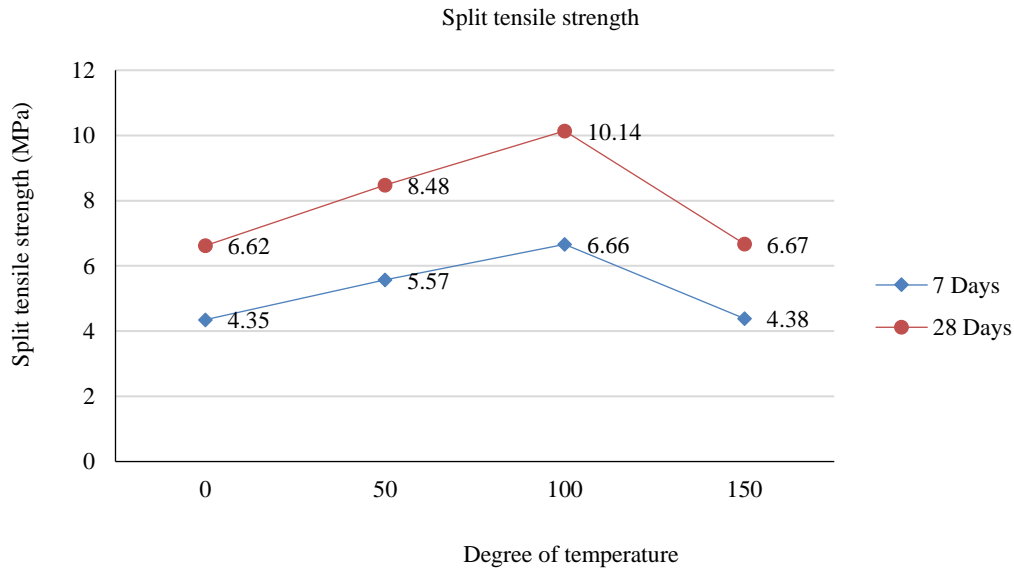
S N	Temperature (°C)	Compressive strength (N/mm <sup>2</sup> )	
		7 days	28 days
1	0	37.76	57.55
2	50	38.07	58.01
3	100	42.57	64.84
4	150	38.57	58.753



**Figure 2.** Variation of compressive strength of concrete with temperature (°c).

**Table 4.** Split tensile strength of concrete with temperature (°c).

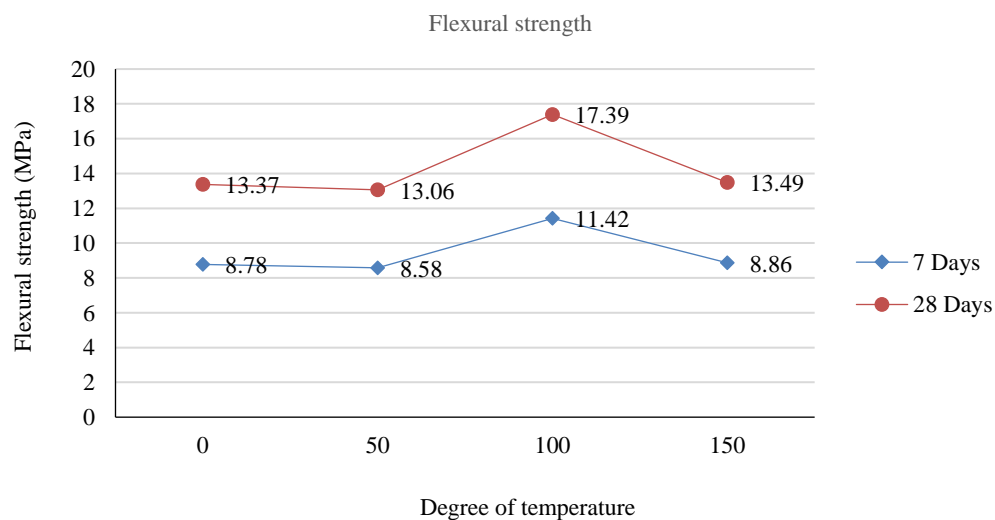
S N	Degree of temp	Split tensile (N/mm <sup>2</sup> )	
		7 Days	28 Days
1	0	4.35	6.62
2	50	5.57	8.48
3	100	6.66	10.14
4	150	4.38	6.67



**Figure 3.** Variation of split tensile strength of concrete with temperature (°c).

**Table 5.** Flexural strength of concrete with temperature (°c).

S N	Degree of temp	Flexural strength	
		7 Days	28 Days
1	0	8.78	13.37
2	50	8.58	13.06
3	100	11.42	17.39
4	150	8.86	13.49



**Figure 4.** Variation Of Flexural Strength of Concrete with Temperature (°c)

These findings emphasize the significance of fiber dosage optimization and thermal exposure considerations in concrete applications, particularly in environments subject to elevated temperatures. The subsequent sections provide a detailed analysis of these observations, supported by graphical representations in Figure 4.

## CONCLUSION

The experimental findings unequivocally demonstrate that the incorporation of carbon fibres into M30-grade concrete significantly enhances its mechanical properties, including compressive, split tensile, and flexural strengths. The optimum carbon fibre content for achieving superior performance was determined to be 0.75%, yielding a maximum 7-day compressive strength of 37.76 N/mm<sup>2</sup> and an optimal 28-day compressive strength of 57.51 N/mm<sup>2</sup>. Furthermore, when the concrete was exposed to an elevated temperature of 100°C, its mechanical properties exhibited further enhancement, with the 28-day compressive strength increasing to 64.84 N/mm<sup>2</sup>, the split tensile strength reaching 10.64 N/mm<sup>2</sup>, and the flexural strength attaining 17.39 N/mm<sup>2</sup>.

These results highlight the effectiveness of carbon fibre reinforcement in improving the structural integrity and durability of concrete under both ambient and elevated temperatures. The enhanced mechanical performance observed suggests that carbon fibre-reinforced concrete is a promising material for advanced construction applications, particularly in environments where high strength, resilience, and thermal durability are critical. Future research could explore the long-term durability and sustainability aspects of such composites to further validate their suitability for large-scale infrastructure projects.

## RECOMMENDATIONS

1. *Optimisation of carbon fibre content:* Further research should be conducted to refine the optimal dosage of carbon fibres in different concrete grades and mix proportions to achieve maximum strength and durability.
2. *Long-term performance evaluation:* Studies on the long-term durability of carbon fibre-reinforced concrete, including its resistance to environmental factors such as moisture, freeze-thaw cycles, and chemical exposure, should be undertaken to assess its suitability for various construction applications.
3. *Impact of higher temperatures:* Since heating at 100°C further enhanced the mechanical properties, future investigations should examine the effects of higher temperatures to determine the thermal stability limits of carbon fibre-reinforced concrete.
4. *Structural applications:* The practical application of carbon fibre-reinforced concrete in structural elements such as beams, columns, and slabs should be explored through large-scale experimental studies and field trials to validate its real-world performance.
5. *Sustainability and cost analysis:* A comprehensive assessment of the economic feasibility and environmental impact of using carbon fibres in concrete should be conducted, considering factors such as production costs, carbon footprint, and recyclability.
6. *Hybrid fibre reinforcement:* The potential benefits of combining carbon fibres with other fibres, such as steel or polypropylene, should be investigated to enhance mechanical performance and crack resistance further.
7. *Workability and mix design improvement:* Modifications to the concrete mix design should be explored to improve the workability of carbon fibre-reinforced concrete without compromising its mechanical properties, as fibre addition can sometimes lead to reduced workability.
8. *Numerical modelling and simulation:* Advanced computational techniques, such as finite element modelling, should be employed to simulate the behaviour of carbon fibre-reinforced concrete under different loading and environmental conditions, providing deeper insights into its performance characteristics.

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