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MECHANICAL PROPERTIES OF KEVLAR FIBRE REINFORCED CONCRETE: AN EXPERIMENTAL STUDY

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Abstract

The study investigates the impact of Kevlar fibres on concrete's mechanical properties. Concrete specimens with varying Kevlar fibre content were subjected to two curing periods of 7 and 28 days. The study found a significant relationship between Kevlar fibre content and concrete's compressive strength. As the percentage of Kevlar fibres increased, compressive strength increased significantly. The optimal fibre content range was identified as 12% to 14%, allowing for maximum compressive strength, and the study also explored flexural strength, particularly in prisms. The proportion of Kevlar fibres significantly improved concrete's flexural strength, with the rate of strength gain accelerating with higher fibre percentages. The study also examined split tensile strength, revealing that increased fibre content led to a substantial enhancement in concrete's tensile strength. This makes fibre-reinforced concrete formulations suitable for applications requiring robust resistance against tensile forces.

Keywords: Kevlar Fibre, Compressive Strength, Flexural Strength, Split Tensile Strength, Fibre Reinforced Concrete.

1. INTRODUCTION

Concrete stands as the preeminent artificial material, playing a pivotal role in the realm of civil engineering worldwide. It emerges as a solid mass resulting from the meticulous blending of cement, sand, gravel, and water in precise proportions. These constituent elements coalesce to create a malleable substance capable of taking on virtually any desired shape. Fibre-reinforced concrete (FRC) represents a modern twist on traditional concrete formulations. FRC primarily comprises hydraulic cements, aggregates, and discrete reinforcing fibers. This innovation is a relatively recent addition to the material landscape. One particularly versatile variant of FRC is Kevlar Fibre Reinforced Concrete (KFRC), which has garnered acclaim among architects and engineers for its wide-ranging utility. KFRC is primarily composed of cement, sand, aggregate and Kevlar fibers. These materials yield a thin yet remarkably robust concrete with diverse applications in the construction industry. The inclusion of fibres within the cement-based matrix serves a critical role by acting as crack arresters. This means that these fibres inhibit the expansion of flaws within the matrix, preventing them from developing into full-fledged cracks under the influence of external loads. Ultimately, this attribute safeguards the

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structural integrity of the material and prevents premature failure. Nataraja et al. [1] experimentally produced the stress-strain curve of steel-fibre-reinforced concrete with varying compressive strengths. Ding and Kusterle [2] found that adding fibres to SFRC increases its shear force, and SFRC showed better performance in terms of stress before and after reaching peak load. Pazdera et al. [3] discovered that acoustic emission can detect cracks in both concrete and FRC. Marcalikova et al. [4] studied the mechanical properties of fibre-reinforced concrete with various fibre dosages. Song and Hwang [5] evaluated the impact of a high steel fibre volume on concrete's mechanical properties. Duzgun et al. [6] proposed the use of pumice aggregate to produce light-weight concrete and found that reinforcing LWC with steel fibre enhances its properties. Tassew and lubell [7] enhanced the mechanical properties of ceramic concrete by using chopped glass fibre with magnesium potassium phosphate. Kizilkanat et al. [8] analysed and compared the mechanical properties of reinforced concrete. And kumar et al. [9] found that reducing water content can improve compressive strength. Finally, Yuan and Jia [10] discovered that low glass fibre content can control crack expansion, but increasing fibre content weakens the bonding between the fibre and matrix. Mirza and Soroushian [11] found that glass fibre reinforcement effectively controls shrinkage cracking in light-weight concrete and increases flexural strength at elevated temperatures. Dias and Thaumaturago [12] investigated the fracture toughness of geopolymer concrete with basalt and found that fibre addition improved tensile strength and flexural strength but reduced workability. Arslan [13] elevated the fracture energy and mechanical properties of basalt and glass fibre-reinforced concrete, finding that fibre addition improved failure resistance. Branston et al. [14] evaluated the mechanical behaviour of basalt fibre-reinforced concrete through flexural and impact testing. Ramesh and Eswari [15] studied the mechanical behaviour of basalt fibre-reinforced concrete and found that it is a sustainable and natural fibre option. Fasil mohi u din [16] investigated the suitability of Kevlar fibre in concrete. Halvaei et al. [17] investigated the impact of carbon short fibres on the flexural properties of engineered cementitious composites and found that they improved first crack resistance and energy absorption. Hossaian and Abdul et al. [18] investigated the flexural behaviour of the cement-based matrices using different fibre sizes and percentages and found that carbon fibre improves bearing capacity, ductility, and young's modulus. De Souza et al. [19] found that adding carbon fibre waste to concrete improves compressive and tensile strength but reduces the modulus of elasticity. Meng and Khayat et al. [20] found that adding nano plates and carbon nano fibers to ultra-high-performance concrete improves mechanical properties, particularly compressive and flexural strength and bond strength. Rangeloy et al. [21] investigated the use of cured carbon fibre composite material (CCFCM) to improve the hydraulic and mechanical properties of pervious concrete (PC). Tabatabaei et al. [22] compared the impact resistance of plain concrete, steel-reinforced concrete, and four different types of long carbon fibre reinforced concrete (LCFRC) panels. Dhanesh et al. [23] explored the use of aramid fibres and chopped carbon fibres to enhance the mechanical properties of plain concrete. Palanisamy and Ramasamy [24] examined the mechanical durability characteristics of hybrid fibre concrete (HFC) created with polypropylene fibre (PP), sisal fibre (SF), and banana fibre (BF). Han et al. [25] examined the mechanical and electrical properties of cement mortar by adding carbon fibres with hydrophilic surface modifications. Ganta et al. [26] investigated the effect of fibre type and aggregate

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content on the hardening and durability properties of self-compacting concrete (SCC). Wei and Meyer [27] investigated the durability of sisal fibre-reinforced cement composites exposed to wetting and drying cycles. Teja prathipati et al. [28] developed hybrid fibre-reinforced concrete (HYFRC) by incorporating two types of fibres in a graded form. Qian and stroeven [29] investigated the optimisation of fibre size, fibre content, and fly ash content in hybrid polypropylene-steel fibre concrete with low fibre content. Zhong and Zhang [30] provided a comprehensive understanding of the effect of hybrid steel-polypropylene fibre reinforcement on the engineering properties of concrete. Naraganti et al. [31] found that hybrid fibre-reinforced concrete showed better impact resistance than monofibres. Balcikanli and sevim [32] observed that hybrid fibres, such as steel and polypropylene fibres, increased flexural strength but decreased compressive strength and increased abrasion resistance when exposed to elevated temperatures. Shi et al. [33] discovered that by adding basalt and macro-polypropylene fibres, they increased compressive strength but decreased workability. Chaturvedi et al. [34] found that the addition of polypropylene fibres increased split tensile strength and compressive strength, as well as fire resistance capability. Hari, and venkata Das [35] discusses the comparison between the built-up section and the conventional concrete beam. Li et al. [36] observed that increasing carbon fibre length decreased compressive strength but increased flexural strength in CFRM and CFRC, which could be utilised for repair work in reinforced concrete structures. Li et al. [37] discovered that adding steel fibres to HFRC improved strength and toughness, and combining steel and basalt fibres resulted in better outcomes. Wang et al. [38] studied the mechanical properties of high-performance concrete HPC reinforced with basalt and polypropylene fibres. They found that increasing fibre content improved flexural and tensile strength but not compressive strength. Polypropylene fibres outperformed basalt fibres, and the combination of both fibres had mixed effects. Li et al. [39] investigated using MAP technology to recycle resin from a CFRP bicycle frame into carbon fibre for fibre-reinforced concrete and found that adding carbon fibre improved mechanical properties, and recycled carbon fibre had better impact resistance than normal carbon fibre. Higher carbon fibre content increased flexural strength and impact resistance; recycled carbon fibre performed similarly to normal carbon fibre in carbon-reinforced concrete. The present study involves extensive experimental research aimed at investigating the influence of Kevlar fibre on the mechanical properties of concrete. Kevlar (K49) was utilized in four distinct volume fractions.

2. EXPERIMENTAL METHOD AND MATERIALS

Kevlar fibre, renowned for its exceptional strength-to-weight ratio, finds extensive application in the production of various products. This material possesses robust strength characteristics, exhibits reduced brittleness, and benefits from cost-effective raw materials. When finely integrated into concrete, Kevlar fibres offer a multitude of advantages, including the creation of crack-free surfaces and the enhancement of both the static and dynamic properties of the concrete. However, it's important to note that Kevlar fibre-reinforced concrete, in its fresh state, tends to be stiff and less workable. To address this, admixtures are introduced to reduce the water content while maintaining the desired properties. In this study, an experimental

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programme was meticulously planned to investigate the strength properties of concrete reinforced with Aramid Fibre Polymer (AFP), commonly referred to as Kevlar. The research focused on designing concrete mixes with a target strength of 25N/mm^2 while incorporating varying percentages of Kevlar fibre reinforcement, ranging from 0% to 14%. The Fig. 1 explains the processes involved in the production of the concrete mix.

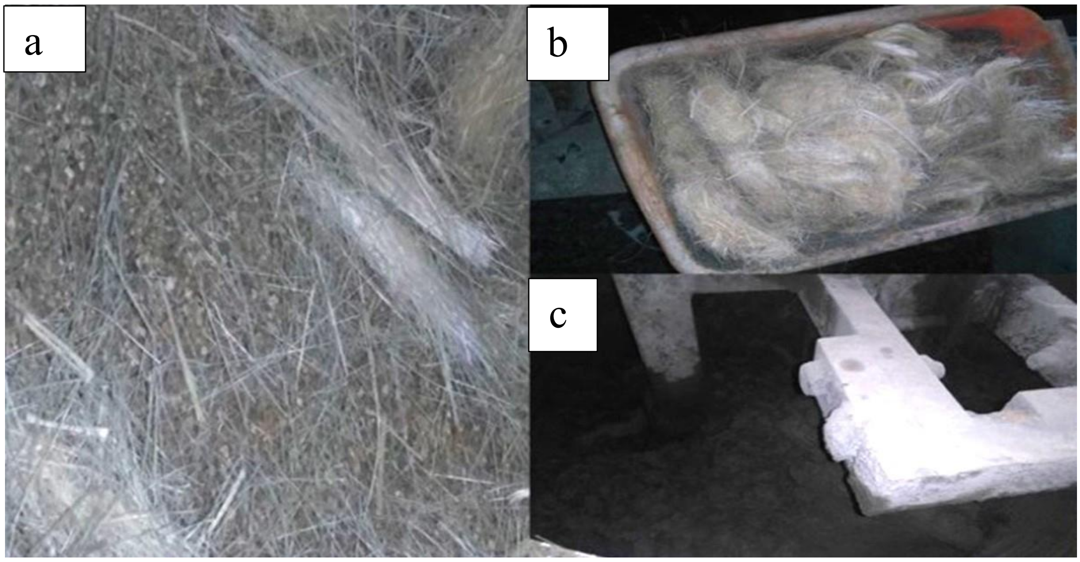

Fig 1: (a) Fibre spread over Dry mix, (b) Chopped Kevlar fibre, (c) Wet Concrete Mix

The dimensions of all the test specimens were standardized, with cross-sectional dimensions measuring 100mm x 100mm x 100mm.For testing purposes, 21 cubes were cast for assessing properties at 7 days, and an additional 21 csubes were cast for extended testing at 28 days. The first three cubes were cast without fibre, representing the controlled samples. Subsequently, cubes were incorporated with fibre at different percentages, such as 2%, 4%, 6%, 8%, 10%, 12%, and 14%.

The properties of the concrete were evaluated in its hardened state. This included testing for the compressive strength of the cubes, the split tensile strength of cylinders, and the flexural tensile strength of the prisms according to Indian codal provisions. These assessments aimed to comprehensively explore the impact of Kevlar fibre reinforcement on the concrete's mechanical properties.

3. RESULTS AND DISCUSSIONS

3.1. Compression test result

In the realm of concrete properties, two attributes stand out prominently: compressive strength and durability. The aim of this research was to investigate the influence of fibres on concrete's compressive strength through a meticulous testing protocol involving 100-mm cubes. These cubes underwent precise casting and were subjected to assessments at two critical time points: 7 days and 28 days of curing, with thorough documentation of any strength variations observed

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during this period. Adhering to the guidelines outlined in IS 516-1959, titled "Methods of Testing for Strength of Concrete," we conducted a comprehensive examination of the concrete's compressive strength.The aggregates were sourced locally for the concrete mix, and no additional admixtures were added to the mix design. Additionally, the mix's workability was monitored to ensure that no excess water was added, thus maintaining the desired consistency.

The cube casting process employed moulds measuring 100mm × 100mm × 100mm. A total of 24 cubes were cast for testing, with 12 cubes designated for the 7-day assessment and the remaining 12 tested at the 28-day mark. This approach provided a comprehensive assessment of how the inclusion of fibres impacts the compressive strength of the concrete specimens. Fig. 2 outlines the compressive strength of concrete specimens, measured in kilonewtons per square millimeter (kN/mm^2), at various percentages of fibre reinforcement and two distinct curing periods: 7 days and 28 days. The detailed analysis makes it evident that there is a clear positive correlation between the percentage of fibre reinforcement and compressive strength. As the fibre content increases from 0% (represented as C/S, serving as the control specimen) to 14%, there is a consistent and pronounced increase in compressive strength at both the 7-day and 28-day curing periods.

This trend strongly suggests that the incorporation of Kevlar fibres into the concrete mix enhances its compressive strength. Furthermore, when considering the influence of time on compressive strength, it's noteworthy that there is a significant gain in strength as the curing period extends from 7 days to 28 days for all fibre percentages. This aligns with the typical behaviour of concrete, which continues to hydrate and strengthen over time. The increase in compressive strength over the 21-day interval underscores the importance of allowing concrete to mature to achieve its full-strength potential. Another key observation is the rate at which compressive strength increases with varying fibre content.

While the experimental observations indicate a positive relationship between fibre content and strength, the rate of strength gain appears to accelerate as the fibre percentage rises. For instance, the increase in strength between 0% and 2% fibre content is relatively moderate, but as the fibre content surpasses 4%, the strength gains between the two curing periods become more substantial. The obtained data implies that there may be an optimal range of fibre content for maximising compressive strength.

This range seems to fall between 12% and 14% fibre content, where the rate of strength increase is most prominent. Beyond this range, the rate of strength gain seems to plateau or exhibit slight diminishing returns, suggesting that excessively high fibre content may not yield significant additional strength benefits.

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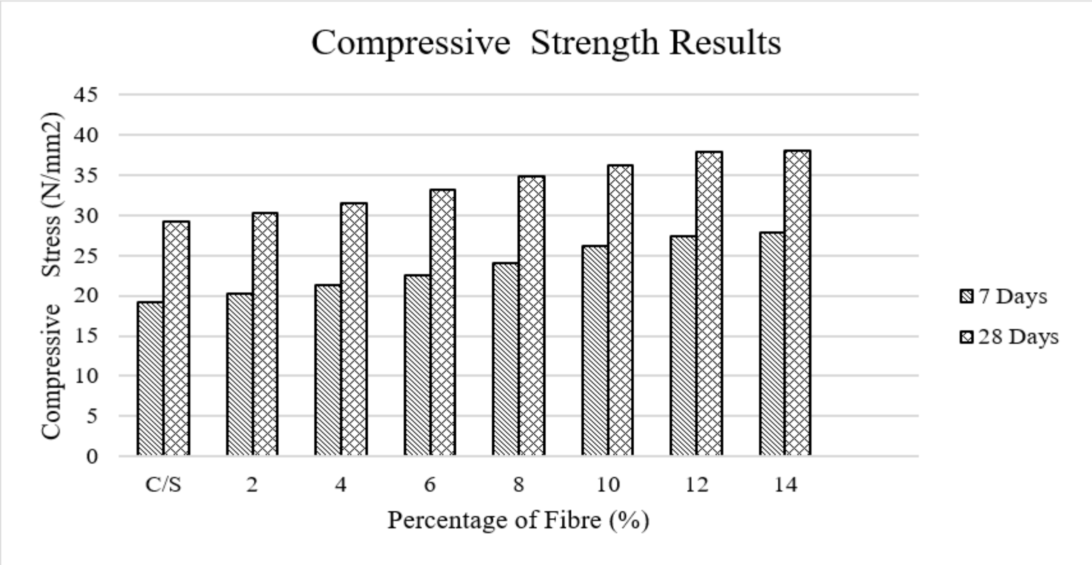

Fig 2: Compression test results for Kevlar Fibre reinforced Concrete

3.2 Four Point Flexural test

Flexural strength serves as a critical indicator of a concrete's ability to withstand tensile forces when subjected to practical scenarios, particularly in structures like beams. Beams, by nature, are members designed to withstand flexural stresses. In this context, moulds sized at 500mm × 100mm × 100mm were employed, and a total of 24 beams were cast for evaluation at both 7 days and 28 days, with strength assessments conducted following IS 516-1959 guidelines.

The data obtained from the experimental investigation sheds light on the flexural strength of these concrete prisms, measured in kN/mm^2, across varying levels of fibre reinforcement. Fig. 3 unravels the effects of fibre content and curing time on flexural strength. The analysis of flexural strength data for concrete specimens with varying percentages of fibre reinforcement at 7 days and 28 days of curing reveals important insights into the impact of fibre content and curing time on this mechanical property.

There is a clear and consistent trend indicating that flexural strength increases with higher percentages of fibre reinforcement. Commencing with the control specimen (C/S) at 0% fibre content, which exhibited a flexural strength of 0.9 kN/mm2 at 7 days and 3.1 kN/mm2 at 28 days, there is a discernible and progressive augmentation in flexural strength as the fibre content rises. This pattern underscores the effectiveness of incorporating Kevlar fibres into the concrete mix to enhance its resistance to bending and tensile forces.

Extending the curing time from 7 days to 28 days leads to a substantial improvement in flexural strength for all fibre percentages. This aligns with the typical behaviour of concrete, which continues to gain strength over time as the hydration process progresses.

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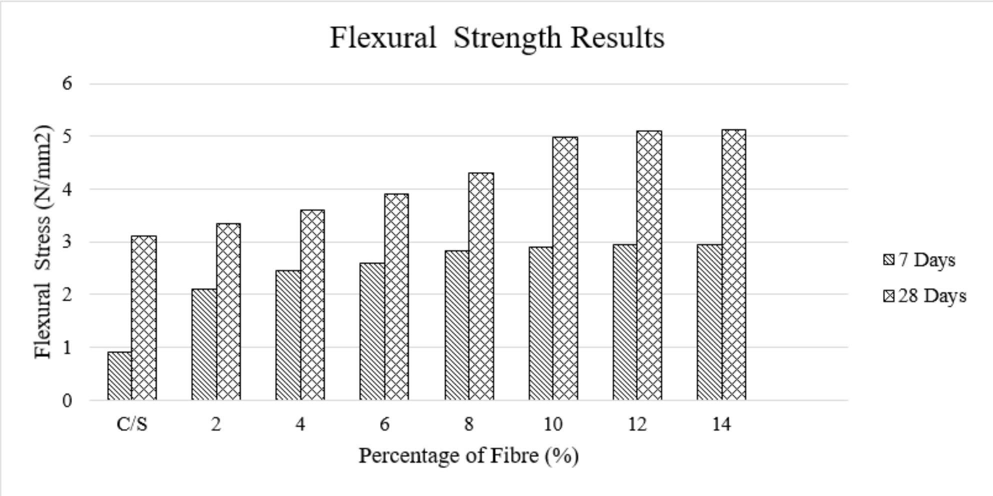

Fig 3: Flexural test results for Kevlar Fibre reinforced Concrete

The obtained data emphasises the importance of allowing concrete sufficient time to reach its full potential in terms of flexural strength, especially when concrete elements are subject to bending stresses. When examining the relationship between fibre content and the rate of strength gain, an interesting trend emerges. The rate of increase in flexural strength appears to accelerate as the fibre percentage increases. While the initial increments in strength between 0% and 2% fibre content are relatively modest, the strength gains become notably more substantial as fibre content exceeds 4%. This observation suggests that higher levels of fibre content contribute significantly to augmenting the flexural strength of concrete specimens, making them more resilient to bending forces.

3.3 Split Tensile test

Concrete is typically weak in tension, but there are situations, albeit rare, where it may be subjected to tensile forces. In such cases, it becomes crucial to determine the load at which cracking will occur. The tensile strength of concrete is notably lower when compared to its compressive strength, often hovering at just 10% to 15% of the compressive strength. To assess this property, cylindrical concrete specimens are loaded along their length, resulting in the development of tensile stresses along the central diameter in the lateral direction. When these stresses reach the limiting tensile strength, the specimen splits, and this value can be quantified. The moulds used for this purpose are 200 mm in length and 100 mm in diameter. A total of 24 cylinders are carefully cast, with 12 designated for testing at 7 days of curing and the remaining 12 for evaluation at the 28-day mark. The assessment of tensile strength follows the IS 516-1959 guideline. The split tensile strength of concrete is a crucial mechanical property that reflects its resistance to tensile forces, making it especially relevant in structural applications where concrete elements might be subjected to bending or flexural stresses. Fig 4 includes data on split tensile strength (measured in kN/mm^2) at 7 days and 28 days of curing for various percentages of fibre reinforcement (ranging from 0% to 14%). Examining the relationship between fibre content and split tensile strength, it is evident that there is a consistent and

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gradual increase in split tensile strength as the percentage of fibre reinforcement increases. Starting with the control sample (C/S) at 0% fibre content, which exhibited a split tensile strength of 1.86 kN/mm^2 at 7 days and 2.83 kN/mm^2 at 28 days, there is a clear and sustained improvement in split tensile strength with increasing fibre content. This trend underscores the positive influence of incorporating Kevlar fibres into the concrete mix, effectively enhancing its resistance to tensile forces that lead to splitting. Moreover, the obtained data indicates the significant impact of curing time on split tensile strength. A substantial increase in strength is observed as the concrete matures from 7 days to 28 days. This observation aligns with the typical behaviour of concrete, which continues to gain strength as the hydration and curing processes progress. Therefore, this emphasises the importance of allowing concrete adequate time to develop its full split tensile strength potential. When analysing the rate of strength gain concerning varying fibre content, it becomes apparent that the rate of increase in split tensile strength remains relatively consistent as the fibre percentage increases. While the initial strength increments between 0% and 2% fibre content are relatively modest, the strength gains become more substantial as fibre content exceeds 4%. This suggests that higher fibre percentages contribute more significantly to improving split tensile strength.

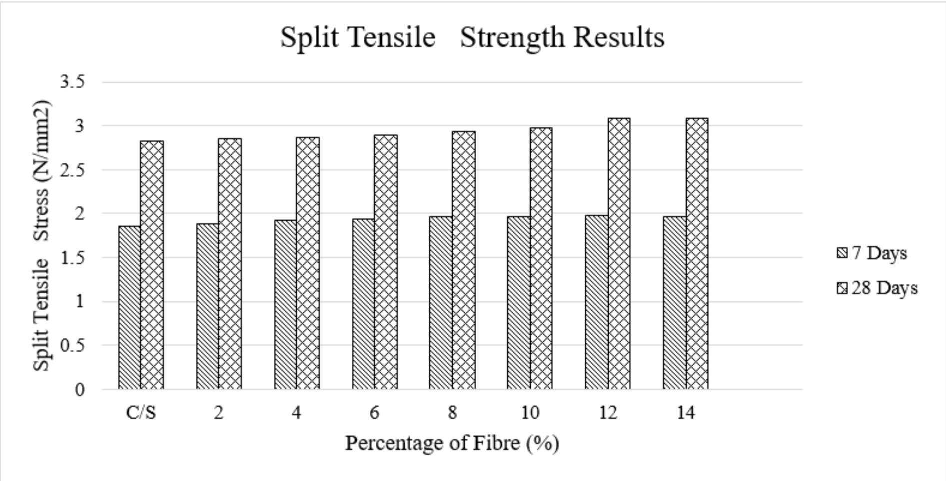

Fig 4: Split tensile test results for Kevlar Fibre reinforced Concrete

4. CONCLUSIONS

This research paper reports the outcomes of a comprehensive experimental investigation into the influence of Kevlar fibre on various mechanical properties of concrete. The study encompassed different combinations of Kevlar fibre percentages (ranging from 0% to 12%) and curing durations (7 days and 28 days) in the production of concrete specimens. The key findings can be summarised as follows:

Compressive Strength: The research demonstrates a direct correlation between increased Kevlar fibre content and enhanced compressive strength in concrete. Moreover, prolonging the curing period results in improved strength. The study identifies an optimal fibre content range, notably between 12% and 14%, for maximising compressive strength.

Flexural Strength: The investigation reveals that a higher percentage of Kevlar fibres in concrete significantly bolsters its flexural strength, a critical attribute for structures like beams. Furthermore, the rate of strength gain accelerates as fiber content increases, emphasizing the potential of fiber-reinforced concrete for applications demanding superior resistance to bending forces.

Split Tensile Strength: The study indicates that an increased fibre content, particularly Kevlar fibres, enhances the concrete's tensile strength. This effect becomes more pronounced with extended curing periods. These findings highlight the efficacy of higher fiber percentages in enhancing split tensile strength, making such concrete mixtures suitable for applications requiring resistance to tensile forces.

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