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Study of Kevlar Aramid Fiber in Improving Concrete Performance and Mitigating Pathologies

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Abstract. This study investigated the potential of Kevlar aramid fiber reinforcement to enhance the mechanical properties and mitigate pathologies in concrete structures. The objectives were to analyze improvements in flexural and compressive strengths and to evaluate the effectiveness of Kevlar in reducing pathological manifestations under the specific conditions and methodologies of this experiment. Experimental testing was conducted on prismatic and cylindrical concrete specimens, prepared following standard mix ratios and testing protocols. Kevlar fiber was applied to the specimens using an epoxy resin, ensuring adhesion and uniform reinforcement. The results, obtained under these controlled conditions, showed a 6.90% increase in flexural tensile strength, from 0.29 MPa to 0.31 MPa, and a 14% enhancement in compressive strength, from 14 MPa to 16 MPa. Pathological manifestations, such as crack propagation, were significantly mitigated in the reinforced specimens, demonstrating improved structural preservation and reduced degradation under tensile and compressive stresses. These findings, specific to the experimental parameters and standards employed, confirm the dual benefits of Kevlar reinforcement. The study highlights its effectiveness in improving durability, reducing maintenance demands, and extending the service life of concrete structures, reinforcing its potential as a viable solution for advanced civil construction applications.

Introduction

The demand for innovative materials in civil construction has driven the adoption of high-performance reinforcements, such as Kevlar aramid fiber, to enhance the durability and structural performance of concrete elements. Numerous studies have demonstrated the effectiveness of fiber reinforcements in improving concrete's mechanical properties and mitigating structural deficiencies. Kevlar, known for its exceptional mechanical properties such as high tensile strength, lightweight composition, and chemical resistance, has been increasingly applied in construction to address common structural issues [1,4]. These attributes make it an ideal reinforcement material for mitigating structural pathologies and improving the longevity of construction projects [5].

Chemically, Kevlar's molecular structure is characterized by aromatic polyamide chains, which provide its exceptional strength-to-weight ratio and thermal stability. The hydrogen bonds within its structure contribute to its remarkable tensile properties, while its resistance to environmental degradation ensures long-term performance in harsh conditions [6,8]. These characteristics are particularly advantageous in civil construction, where structures are frequently exposed to cyclic loads, environmental stressors, and other factors that induce damage over time [9,10].

Chemically, Kevlar's molecular structure consists of aromatic polyamide chains, which provide its strength-to-weight ratio and thermal stability. These properties contribute to its resistance to environmental degradation, making it an ideal reinforcement material in civil construction, where structures are exposed to cyclic loads and environmental stressors [6,8]. Research has shown that Kevlar-reinforced concrete exhibits significant improvements in flexural tensile and axial compression strengths, as well as a reduction in pathological manifestations such as cracks and delamination [11,15].

Beyond improving mechanical properties, the use of Kevlar also contributes to reducing common structural pathologies, such as cracks widening and material delamination [16,18]. Pathological manifestations are a primary concern in civil construction, as they can compromise the safety and functionality of structures. Kevlar's reinforcement capabilities enhance crack control, thereby mitigating damage and reducing the frequency and cost of maintenance. Despite its advantages, a gap persisted in the application of Kevlar to simultaneously enhance mechanical performance and mitigate pathologies in civil construction. This study addressed this gap by systematically evaluating the effects of Kevlar reinforcement on the mechanical properties and pathology mitigation of concrete structures. The objectives of the research were to analyze the improvements in flexural and compressive strengths and to evaluate the effectiveness of Kevlar reinforcement in reducing pathological manifestations in concrete [19,20].

The results revealed a 6.90% increase in flexural tensile strength, rising from 0.29 MPa to 0.31 MPa, and a 14% improvement in compressive strength, from 14 MPa to 16 MPa. Pathological phenomena, such as crack propagation, were significantly reduced in the reinforced specimens, highlighting superior structural integrity and reduced degradation under tensile and compressive stresses. This study highlights the dual benefits of Kevlar in civil construction: its ability to enhance mechanical performance and its role in minimizing structural pathologies [21,24]. These findings underscore the material's potential as a sustainable and efficient solution for improving the reliability, safety, and durability of concrete structures, particularly in applications requiring high-performance reinforcements.

Experimental

Materials. The materials used in the study were selected based on their specific technical properties, as described below. The binder employed was Portland cement CPII-E-32, supplied by the Mauá brand, whose composition meets Brazilian technical standards for the production of intermediate-grade concrete, characterized by a compressive strength of 32 MPa at 28 days, and having durability properties suitable for the proposed application. The coarse aggregate used was crushed stone 02, purchased from the Arckom brand, with a granulometry ranging from 4.8 to 9.5 mm, meeting the specifications of NBR 7211 [25] for coarse aggregates for concrete. This aggregate is classified as high-strength, with a compressive strength index greater than 40 MPa, ensuring the robustness and structural integrity of the concrete. The fine aggregate used was medium sand, also supplied by the Arckom brand, with a granulometry ranging from 0.3 to 0.6 mm, according to NBR 7211 [25]. The sand was selected for its good workability and adhesion characteristics, as well as its satisfactory abrasion resistance for the concrete mix. The water used for preparing the mixture came from the public water supply, meeting the quality criteria established by NBR 7222, ensuring the absence of impurities or harmful substances to the concrete. The release agent used for the test specimens was Desmol Cd 3.6 liters, supplied by Otto Baumgart, chosen for its high efficiency in demolding the concrete without compromising the surface integrity of the specimens. This product is characterized by its release properties suitable for high-strength concretes, not interfering with the curing process or the final properties of the concrete. The Kevlar aramid fibers used in the study were purchased from Tapcamp, with a tensile strength of 3.62 MPa and an elastic modulus of 120 GPa. The fibers had a length of 50 mm and a diameter of 12 micrometers. Kevlar was chosen for its exceptional mechanical strength and toughness properties, which contribute to improving the strength and durability characteristics of the concrete. The Kevlar fibers were added to the concrete to increase tensile strength and crack resistance, as well as to provide greater ductility to the material. The epoxy resin used was 4008, of low viscosity and ultra-clear, supplied by Redelease. This resin has ideal characteristics for fiber impregnation, with a transparency index greater than 95% and UV protection, ensuring the durability of the material when exposed to sunlight. The resin was accompanied by the hardener (715 g), which, when mixed with the resin, provided proper curing and the formation of a robust and durable compound.

The water and resin were carefully dosed to ensure the workability of the concrete and the effective adhesion of the fibers to the concrete matrix. The properties of each material were thoroughly analyzed to optimize the performance of the concrete reinforced with Kevlar fibers. Figure 1 illustrates the materials used in the preparation of the concrete, for later coating with Kevlar fiber, highlighting the composition aspects of the concrete and the fiber impregnation process.

Fig. 1. (A) materials used in preparing the concrete mix (crushed stone (a), sand (b), and cement (c)); (B) mixing materials in an electric concrete mixer.

Avaliation of Workability and Moldability of Samples. In the study conducted, a classic material proportion was used for concrete production, following the 1:2:3 mix ratio, corresponding to 1 part cement, 2 parts sand, and 3 parts gravel. This mix is widely applied in simple concrete applications, such as sidewalks and subfloors, as it offers a good balance between workability, strength, and cost. The water amount was adjusted based on a water-to-cement ratio of 0.5, ensuring proper consistency without compromising the material's strength. This proportion provides homogeneous concrete with good workability and durability for non-structural applications. The slump test was performed to evaluate the consistency and ensure the quality of the concrete. The test was conducted in accordance with the NBR 16889 standard [27], and the measured slump of the adopted concrete was 10 cm, as illustrated in Figure 2.A. Prior to the concrete placement, a coat of form release agent was applied to each mold to facilitate the demolding of the specimens. Subsequently, the CA-60 steel reinforcement was positioned within the prismatic molds using circular and chair spacers to ensure a nominal cover of 3 cm, as specified in the NBR 6118:2023 standard [28]. The flexural design calculation of the prismatic samples was based on the NBR 6118 standard [28] to ensure structural integrity. For this purpose, the minimum reinforcement calculation was employed, defined as the one where steel bars were placed in the tensile region, while the compressive region relied exclusively on the concrete to balance the compression forces. In the tensile zone, 1 ϕ 4.2 mm reinforcement with a spacing of 60 cm was used.

The concrete compaction was performed using an immersion vibrator with a 2.5 cm diameter hose for the prismatic samples and manually, using a metallic rod, for the cylindrical samples. The latter received 25 uniformly distributed strikes over the section of each concrete layer.

The samples were demolded and stored in a curing tank 24 hours after molding (Figure 2). It was observed that the concrete exhibited good appearance, with a uniform texture and no defects such as honeycombing, as illustrated in Figure 3.

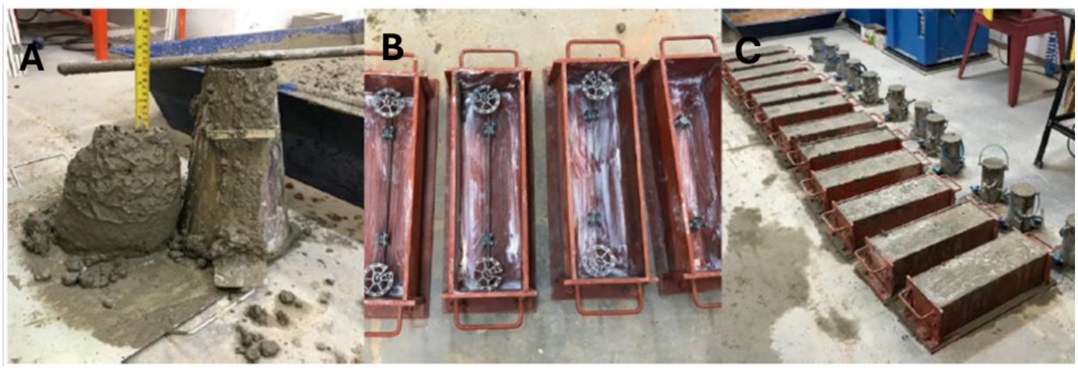

Fig. 2. (A) Slump test; (B) preparation of beam molds; (C) Specimens obtained from concrete beams.

These samples (Figure 3) remained submerged in water, maintained at a temperature of 23 ± 2 °C, in accordance with NBR 9479 [29]. After 28 days in the curing tank, the samples were removed for the subsequent research phase: the application of fiber to the matrix and the execution of strength tests.

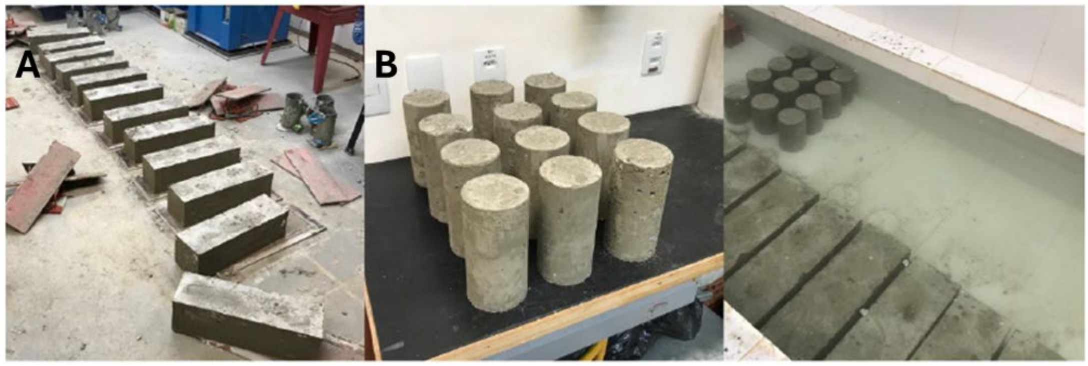

Fig. 3. Specimens immersed in a tank for wet curing. (A) flexural stren gth specimens; (B) compressive strength specimens.

Preparation of Concrete Specimens Reinforced with Kevlar Fiber. The selection of aramid fiber was based on its high-performance properties and lightness. The fiber fabrics were cut to the specific dimensions required to cover the bottom face of the prismatic samples and the lateral face of the cylindrical samples, both bonded longitudinally. To ensure adhesion to the matrix, an epoxy resin mixed with a hardener in a 2:1 ratio (two parts resin to one part hardener) was used, strictly following the manufacturer's specifications.

After the initial application of the fiber, an additional layer of resin was applied over the fabric, initiating the material's curing process. This process required 24 hours to achieve maximum resistance and stiffness properties. Figure 4 illustrates the coating applied to the test specimens.

Fig. 4. Coating of the specimens with Kevlar fiber for flexural and compressive strength tests.

Mechanical Tests of Materials. The flexural tensile strength test was performed in strict accordance with the procedural requirements outlined in NBR 12142 [30], which provides the standardized methodology for conducting such tests. A total of twelve prismatic specimens, each with dimensions of 50 × 15 × 15 cm, were selected, accurately numbered, and identified for testing. The specimens were segregated into two categories: reinforced concrete with fiber coating and unreinforced concrete. Markings were inscribed on the tensile surface and the opposite face of each specimen to ensure proper central alignment within the loading apparatus. Additionally, reference lines were drawn 5 cm from the edges and at the 25 cm mark along the length of the specimens, ensuring precise alignment of the loading apparatus along the span. Upon correct positioning, the samples were subjected to a progressively applied load, without any shock impact, at a rate of 0.9 MPa/min to 1.2 MPa/min, until failure was observed. The flexural tensile strength was evaluated based on the rupture occurring within the central third of the span between the supports, or alternatively, rupture occurring outside this region. Figure 5 illustrates the execution of the 3PB test using the INTERMETRIC universal mechanical testing machine, with a maximum capacity of 100 kN.

Fig. 5. Flexural strength test.

In the axial compression resistance test, twelve cylindrical samples were identified and numbered to initiate the experiment. These samples were divided into two groups: reinforced concrete and plain white concrete without fiber reinforcement. Subsequently, the samples were positioned between two compression plates that applied continuous and uniform loads without shocks. The loads were applied at a loading rate ranging from 0.3 MPa/s to 0.8 MPa/s until the specimens failed. Figure 6 illustrates the axial compression test performed on samples reinforced with Kevlar and on those without reinforcement.

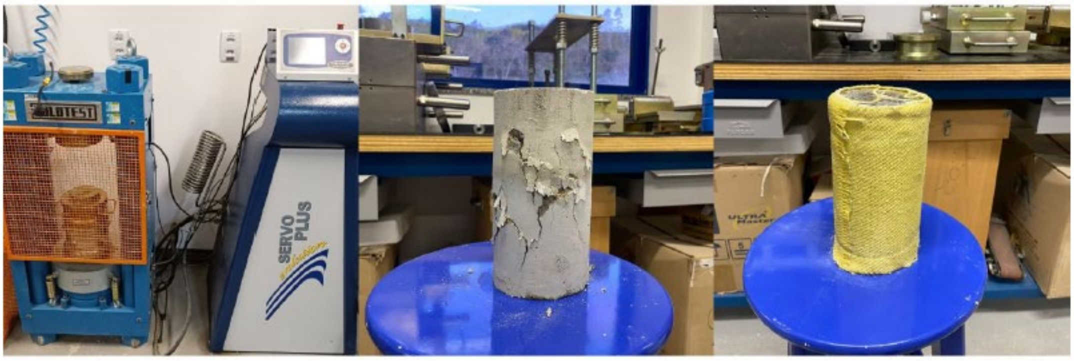

Fig. 6. Compressive strength tests.

Results and Discussion

Tensile Strength Test in Flexion. After the rupture of the uncoated samples, it was observed that the cracks caused by overload exhibited wider openings in the regions subjected to tensile stresses. The cracks observed in Figures 7.A and 7.B were characterized as predominantly vertical and located in the tensile zone of the samples, indicating the typical behavior of materials subjected to bending stresses. These cracks developed continuously, starting from the lower surface of the samples and propagating toward the central region, demonstrating the overcoming of the concrete's tensile strength. Additionally, signs of stress concentration were identified in areas near the cracks, suggesting a pattern of failure controlled by the mechanical stresses applied during the test. The flexural tensile strength test showed that Kevlar-reinforced prismatic samples exhibited an average resistance of 0.31 MPa compared to 0.29 MPa in uncoated samples, representing a 6.90% increase. This improvement is consistent with findings from similar studies, which reported enhanced stress distribution and reduced crack propagation in fiber-reinforced concrete [11,16]. Despite the occurrence of cracks in both groups, the reinforced samples demonstrated superior structural preservation, aligning with theories of improved energy absorption in fiber-reinforced materials [17,19].

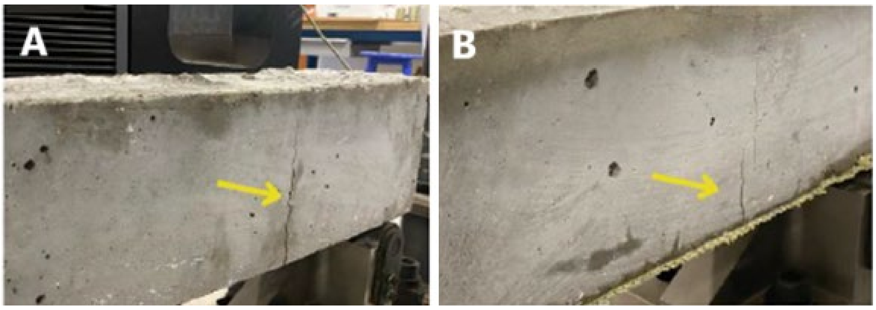

Fig. 7. Specimens after the flexural strength test. (A) Uncoated beam with fibe; (B) Beam with fiber coating.

Aramid fibers exhibit high tensile strength, enabling them to withstand significant stress before failure, thereby contributing to the preservation of structural integrity. In essence, the fibers act as a network that restricts the propagation of cracks, thereby enhancing the material's durability and strength.

Axial Compression Resistance Test. The uncoated cylindrical samples exhibited cracks with Type E – sheared and Type D – conical and sheared patterns on the external surface, as illustrated in Figure 8. The same procedure was performed on the cylindrical samples coated with aramid fiber. Due to the presence of fiber in the specimens, greater structural preservation was observed when subjected to axial compression strength tests (Figure 8). The axial compression tests revealed a 14% increase in strength for Kevlar-coated cylindrical samples, with average resistances of 16 MPa compared to 14 MPa in uncoated specimens. This finding corroborates past research indicating that fiber reinforcements enhance load distribution and prevent catastrophic failure under compressive stresses [12,18]. The Kevlar fibers minimized surface cracking and structural deformation, further supporting their utility in maintaining structural integrity under high loads.

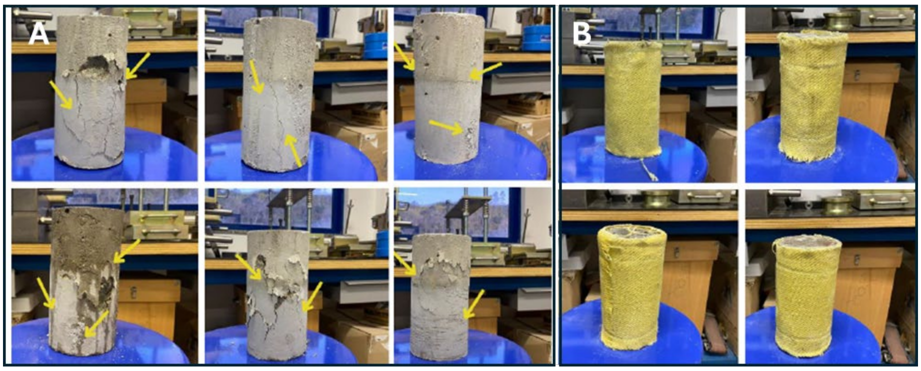

Fig. 8. Specimen fractured after the axial compression resistance test. (A) Uncoated beam with fibe; (B) Beam with fiber coating.

Comparative Analysis. The results align with existing literature, emphasizing the reinforcing effect of aramid fibers in improving both flexural and compressive strengths. The incorporation of Kevlar also addresses common construction pathologies, including crack widening and material delamination, as reported in previous studies [20,22]. Table 1 summarizes the mechanical performance improvements achieved with Kevlar reinforcement. The analysis of the data obtained from the flexural and compressive strength tests showed that the addition of Kevlar resulted in significant improvements in the material properties. Flexural strength increased from 0.29 MPa to 0.31 MPa, representing an improvement of approximately 7%, while compressive strength increased from 14 MPa to 16 MPa, resulting in a 14% increase.

Table 1. Mechanical Performance Improvements.

Property (MPa)	without Kevlar	with Kevlar	Improvement (%)
Flexural tensile	0.29	0.31	6.90
Compression resistance	14.0	16.0	14.0

The data obtained from the flexural tensile and axial compression strength tests highlighted the significant benefits of Kevlar fiber reinforcement in improving the mechanical performance of concrete. Flexural tensile strength increased from 0.29 MPa to 0.31 MPa, representing an improvement of approximately 6.90%. This increase demonstrates Kevlar's ability to distribute stresses more uniformly, reducing crack propagation in the concrete matrix, particularly in areas subjected to tensile stresses.

Similarly, axial compression strength showed a substantial increase, from 14 MPa to 16 MPa, equivalent to a 14% improvement. This result reflects Kevlar's effectiveness in enhancing the structural integrity of concrete, reducing the formation of typical failures such as conical or sheared fractures observed in unreinforced specimens. This improvement also reinforces Kevlar's role as an effective reinforcement material in high-load contexts, where durability and structural preservation are essential.

These gains in mechanical strength not only confirm Kevlar's potential for practical applications but also emphasize its contribution to mitigating common pathologies, such as the formation and expansion of cracks. By controlling these pathological manifestations, Kevlar reinforcement not only increases structural durability but also reduces maintenance costs over the lifetime of constructions. These findings corroborate previous studies that identified similar benefits in the use of aramid fibers in concrete, aligning with theories on the effectiveness of high-strength reinforcements in advanced civil construction contexts.

Conclusions

This study demonstrates that Kevlar aramid fiber significantly enhances the mechanical performance and durability of concrete structures. The research objectives were addressed by showing a 6.90% increase in flexural tensile strength, from 0.29 MPa to 0.31 MPa, and a 14% improvement in axial compression strength, from 14 MPa to 16 MPa, along with a significant reduction in pathological manifestations such as crack propagation and structural deformities in Kevlar-reinforced samples. These findings confirm the potential of Kevlar as a high-performance material for sustainable and reliable civil construction applications. Future studies could explore the long-term performance of Kevlar reinforcement under varying environmental conditions.

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