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Research Article

Pull-out Strength of Expansion Anchor Bolt Embedded in Polypropylene Fiber Reinforced Concrete

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ABSTRACT

Concrete is a well-known composite material valued for its high compressive resistance. Its most significant disadvantage is having a deficient tensile strength that causes the development and propagation of cracks—these properties of concrete limit its application with tensile stresses. To improve concrete's tensile strength, durability, and mechanical behavior, uniformly distributing fibers throughout its volume is now widespread and referred to as fiber-reinforced concrete. The study examined how the addition of polypropylene fibers influences the pull-out strength of expansion anchor bolts in concrete. An investigation into the influence of fiber content (0%, 0.1%, 0.2%, and 0.3%) on the material's resistance to splitting, compression, and pull-out was conducted. 56 cylindrical samples were tested for split tensile and compression tests, while 24 rectangular samples were tested for the pullout test. The inclusion of polypropylene fiber reinforcement led to significant enhancements in the splitting strength, compressive strength, and pull-out strength of concrete.

Keywords: Polypropylene Fiber, Split Tensile Strength, Compressive Strength, Anchor Bolt, Pull-Out Strength

INTRODUCTION

Utilizing sustainable construction materials offers numerous environmental advantages, including a reduced carbon footprint, conservation of natural resources, and decreased waste and pollution during production and disposal [1]. These materials often have lower embodied carbon, are sourced from renewable resources, and can be recycled or repurposed, contributing to a more sustainable future [2]. There is a critical necessity of creating sustainable and environmentally friendly alternatives, particularly those made from biodegradable plant-based materials [3]. Bamboo for example is a highly sustainable building material due to its rapid growth, renewability, and strength. Its natural durability, combined with its ability to absorb carbon dioxide, makes it an eco-friendly alternative for construction, promoting both environmental and structural benefits [4][5]. Other eco-friendly materials such as coconut husk ash, rice husk ash, and seawater enhance material performance while promoting sustainability in wall construction [6]. The use of sustainable materials can lead to improved waste management and reduced energy consumption [7]. Both natural and synthetic fibers have roles to play as eco-friendly construction materials. Like for example, utilization of tire waste steel fiber with self-compacting concrete to extend its life resulting in lower carbon emissions produced during the production processes [8]. Polypropylene fiber's integration into concrete mixes offers several eco-friendly benefits as it promotes environmentally beneficial activities and provides sustainable alternatives to traditional additives, reducing the environmental impact of concrete manufacturing processes [9]. Incorporating Polypropylene fiber in concrete can substantially reduce its carbon footprint compared to steel reinforcement, with case studies indicating CO_2 emission reductions of up to 56%. [10]. Ultimately, selecting between natural and synthetic fibers depends on the intended application and the optimal balance of environmental impact, cost, and performance.

Concrete's inherent weakness in tension makes it susceptible to rapid development and growth of micro-cracks under applied stress. Construction professionals often use fiber reinforcement to improve the durability of concrete. A distinguishing characteristic of Fiber Reinforced Concrete (FRC) involves integrating discrete, non-continuous fibers into a hydraulic cement mixture comprising fine and coarse aggregates [11]. To boost the strength and durability of structures, the construction industry is increasingly turning to fiber-reinforced concrete. Fiber reinforcement started 3500 years ago on clay bricks such as horsehair, straw, and natural fibers. Seeking to improve concrete's tensile strength, crack resistance, and overall durability, researchers utilize advanced technologies to discover innovative fiber solutions, including carbon, steel, and a range of synthetic options. Steel fibers provide more satisfying results for structural concrete on all these fibers. Concrete properties vary with time, and strength depends on the duration of loadings [12]. Compared to plain concrete, fiber reinforcement enhances both the strength and flexibility of concrete [13]. Concrete reinforcement goes beyond steel. A diverse range of fibers, including glass, natural, mineral, carbon, polypropylene, and other synthetic varieties, are employed to enhance its performance. How strong and flexible concrete is depends on the type of fibers used to reinforce it. These fibers, in turn, need to be strong enough to handle the concrete's strength [14]. Polypropylene fiber is added to cementitious composites used on airport and road surfaces, concrete floors, and prefabricated elements for aggressive environments like pipes, wells, tank elements, piles, and retaining walls. Moreover, it also finds application in bridge constructions and sprayed concrete [15]. Studies have been made to extend polypropylene fiber application as concrete reinforcement. Research findings indicate that incorporating polypropylene fibers into concrete to enhance its reinforcement results in a reduction of water permeability and an enhancement of flexural strength. This can be attributed mainly to these fibers' elevated modulus of elasticity. Seismic performance of a column reinforced with fibers, noted a high ductile behavior during seismic response [16]. Even the study on carbon fiber as concrete reinforcement demonstrated a notable enhancement in the pull-out strength of anchor bolts [17]. The reinforced concrete's dynamic compressive strength is improved due to the incorporation of polypropylene fibers [18]. It was found out that there is a direct link between the anchor bolt's pull-out length and the underlying concrete's strength [19]. Incorporating both steel and polypropylene fiber resulted in concrete with superior load-carrying capacity and resistance to cracking compared to plain concrete [20]. These researchers found a positive correlation between concrete tensile strength and anchor bolt pull-out force, indicating that stronger concrete leads to stronger bolt anchoring. The research's objective is determining the pull-out strength of expansion anchor bolts in concrete, particularly in cases where polypropylene fibers are used as reinforcement. This study's findings could pave the way for using concrete reinforced with polypropylene fiber as a more viable base material for expansion anchor bolts.

METHODS AND METHODOLOGY

Each material's properties like composition and performance were clearly defined, including fine aggregates, coarse aggregates, cement, anchor bolts, and polypropylene fibers. To ensure quality, the aggregates were put through preliminary tests based on the established benchmarks for concrete aggregates set by ASTM C33 and C136. The aggregates' absorption capacity and specific gravity were known using ASTM C127 and ATSM C128, respectively. Common properties were calculated following procedures outlined in ASTM C29. The study utilized an innovative polypropylene fiber additive that tackles two major concrete issues: plastic shrinkage and settlement cracking. It also enhances the hardened concrete's surface properties and overall durability. The study used Type I Portland Cement, adhering to ASTM C150 standards. Acknowledging that fiber affects workability, a superplasticizer was added.

The expansion anchor bolt used in the study has a diameter of 10 mm of 83 mm length for everyday static loads in uncracked concrete, offering high-performance grip thanks to its carbon steel construction. Fig.1 shows the expansion anchor bolt used in the study.

Figure 1 Expansion Anchor Bolt

This study identified the most cost-effective and readily available material combination for concrete while pursuing the maximum concrete breakout strength achievable under ACI code standards. Engineers opted for a water-cement ratio of 0.45 for wet and exposed structures. ASTM C31 specifications were followed when preparing the concrete mix. A concrete mixer was utilized to avoid inconsistency in concrete. To evaluate how easily each mixture could be handled and placed, a slump test was conducted following ASTM C143 standards. Ensuring the consistency of concrete was essential, as the slump test results informed the potential need for plasticizers. A slump of 25 to 75 millimeters was suggested for various construction types. Superplasticizer is applied to polypropylene fiber to improve their flow and handling characteristics. Samples were casted in cylindrical molds for compression testing, following ASTM C31. Samples were 6 inches in diameter and has 12 inches interior depth. Rectangular forms were constructed for the pull-out strength test specimens. The study employed a high-performance expansion anchor bolt 10mm in diameter and 83mm long. The anchor had an effective embedment depth of 50mm, required a drilling depth of 55mm, and was installed in a 10mm diameter hole. The concrete base needed to be at least 120mm thick. The pull-out test is employed in a concrete block and adheres to ACI 318-08 guidelines. The forms' internal surfaces were cleaned and oiled to facilitate easy removal of the hardened concrete samples without damage. Following a 24-hour setting period, the concrete samples were demolded and transferred to curing tanks for optimal strength development. The concrete specimens required curing to achieve and maintain optimal strength. The materials underwent a curing process as specified by ASTM C31, which involved immersion in a dedicated curing tank. The curing tank gets a water change every week to eliminate impurities and ensure optimal results. After 28 days of water immersion, concrete specimens were extracted. Upon removal from the tank, cylindrical samples were transported to the nearest material testing laboratory for testing.

The anchor bolt was installed after curing, and the specimen's desired compressive strength was attained. The installation of expansion anchor bolts involved embedding them within rectangular samples measuring 350 millimeters in height, width, and depth (150 millimeters). The sample size was based on ACI 318-08, considering the stated critical edge distance to be 1.5hef or more significant for expansion anchors. Figure 2 illustrates the installation of anchor bolts.

Figure 2 Installation of Expansion Anchor Bolt

Upon completion of a 28-day curing process, the samples were evaluated through various tests compressive, splitting strength and pullout tests. Figure 3(a), Figure 3(b) and Figure 3(c) shows the conduct of split tensile strength test, compressive strength test and pull-out strength test respectively.

Figure 3 (a) Split Tensile Strength Test

Figure 3 (b) Compressive Strength Test

Figure 3 (c) Pull-out Strength Test

RESULTS AND DISCUSSION

The study focused on three key factors: split tensile strength, compressive strength, and evaluate the extraction capability of expansion anchors in concrete reinforced with polypropylene fibers. A split tensile examination assessed how polypropylene fibers contribute to improving concrete strength. The mean results are presented in the Figure 4 below. Treatment 3 exhibits the highest value (4.04 MPa), followed by treatments 2 (3.63 MPa) and 1 (3.53 MPa). The control group demonstrates the lowest mean strength (3.23 MPa). To investigate the differences between T1, T2, T3, and the Control, a t-test was conducted. Drawing from the results, it can be inferred that polypropylene fiber content below 0.3% has no statistically significant influence on the split tensile strength.

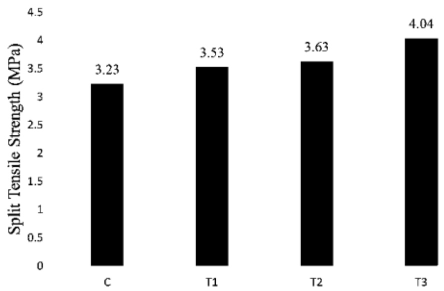

Figure 4 Split Tensile Strength Test Results

This study utilized compressive strength tests to explore the potential of polypropylene fibers for enhancing concrete's compressive capacity. Compressive strength test results show that among the investigated treatments, T3 had the strongest performance with an average value of 37.30 MPa, exceeding T2's 36.40 MPa and T1's 37.17 MPa. Notably, the control group (C) achieved the weakest outcome with an average of 33.09 MPa. The effects of treatments T1, T2, and T3 on compressive strength were evaluated using a t-test, comparing them to the control group. This finding suggests that concrete mixed with polypropylene fibers exhibits improved performance against compressive forces as shown in Figure 5.

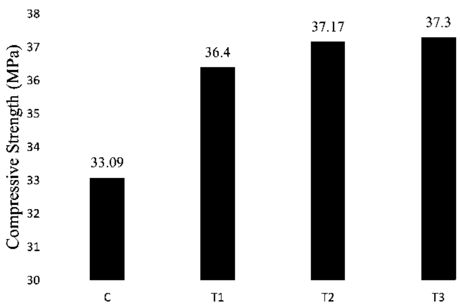

Figure 5 Compressive Strength Test Results

To evaluate the influence of polypropylene fiber on concrete strength, a pull-out test was conducted on an HSA expansion anchor bolt embedded in a 350 mm x 350 mm x 150 mm concrete base. Figure 6 highlights the pull-out strengths of the samples after 28 days of curing. Treatment 3 (T3) stood out with a remarkable mean value of 35.57 KN, exceeding treatments 2 (T2) by 2.35 KN and Treatment 1 (T1) by 3.42 KN. The control (C) demonstrated the lowest strength, at 27.86 KN. Pull-out forces exerted by treatments T1, T2, and T3 were compared to the Control using a t-test. The result implies that adding polypropylene fiber increases the pull-out strength of concrete.

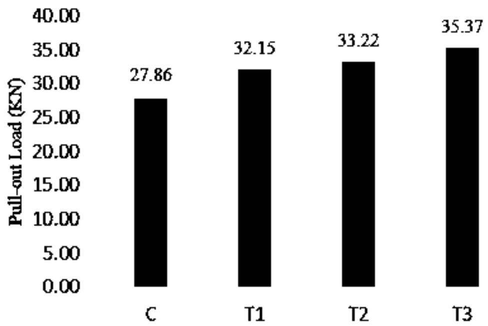

Figure 6 Pull-out Strength Test Results

CONCLUSION

Polypropylene fiber was added to plain concrete in this study to assess its reinforcement effect. The result shows that Treatment 3 with 0.3 % fiber has the highest value of compressive strength followed by Treatment 2 with 0.2 %, third is by Treatment 1 with 0.1 % and lastly with Control. The study found that incorporating polypropylene fibers into concrete resulted in a notable improvement in its ability to withstand splitting and compressive forces. Pull-out test results shows that Treatment 3 with 0.3% fiber attained the highest mean value of 35.37 KN followed by Treatment 2 with 0.2 % fiber having a mean value of 33.22 KN. Treatment 1 with 0.1 % fiber attained a mean value of 32.15 KN and Control with mean value of 27.86 KN. The result implies that adding polypropylene fiber contributed to the increase in pull-out strength.

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DATA AVAILABILITY

The data that support the findings of this study are available from the relevant public repository/datasets link.

CONFLICT OF INTEREST

The author declares that there is **no conflict of interest**.

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