Experimental Study of the Effect of Wire Fiber Addition on the Mechanical Strength of Preplaced Aggregate Concrete

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ABSTRACT

Preplaced Aggregate Concrete (PAC) is a specialized type of concrete, with low tensile strength, making it prone to brittle failure, used in the construction industry. One effective way to enhance durability and minimize cracking is by incorporating fibers into the mix. This study explores the use of wire fibers, produced by cutting wire ropes into pieces approximately 1 mm in diameter and 60 mm in length. Five different concrete mixtures were tested to evaluate the mechanical strength of PAC and Preplaced Aggregate Wire Fiber Concrete (PAWFC). The wire fiber content varied at 0%, 0.25%, 0.5%, 0.75%, and 1% of the total concrete volume, while the proportions of cement, fine and coarse aggregates, water, and Super Plasticizer (SP) remained constant. A mortar mix with a cement-to-sand ratio of 1 and a water-to-cement ratio of 0.45 was used. The mechanical properties, including compressive strength, tensile strength, and modulus of rupture were assessed following the ASTM standards. The results showed that adding wire fiber significantly improved the mechanical strength of PAWFC. Specifically, the optimum 1% wire fiber addition increased compressive strength by 11.23%, tensile strength by 36.85%, and modulus of rupture by 17.23%.

Keywords-preplaced aggregate concrete; wire fiber; compressive strength; tensile strength; modulus of rupture

I. INTRODUCTION

Various types of special concrete are used in the construction industry, with PAC, also called Two-Stage Concrete (TSC), being one of them. PAC is concrete produced by placing coarse aggregate in formwork, and then grouting material or mortar is injected into the void between the coarse aggregate. PAC concrete exhibits a superior modulus of elasticity (E_c), and less shrinkage compared to ordinary concrete [1-5]. The PAC is widely used [6]. Like ordinary concrete, PAC exhibits low tensile strength and is a material subjected to brittle failure. Adding fibers to the concrete mix is one of the most efficient strategies for improving and preventing cracking. Various types of fibers, such as natural (straw, coconut, sisal, etc.) and synthetic (polypropylene, plastic, glass, steel, etc.), have been used for a long time as micro-reinforcement concrete construction material [7-9]. In Indonesia, the use of steel, polypropylene, glass, and carbon fibers in PAC is not yet common, primarily due to their limited availability and high cost. To overcome this challenge, it is important to investigate locally available and cost-effective alternatives, such as wire fibers. The main objective of this study is to enhance PAC with micro-reinforcement by distributing fibers in a random orientation, reducing the risk of premature cracks caused by hydrated heat or applied loads. Wire fiber is produced by cutting reinforcement wire ropes into pieces approximately 1 mm in diameter and 60 mm in length, making it similar to factory-manufactured fibers.

Previous studies have investigated the use of fiber as an additional component in PAC to enhance its mechanical properties. Authors in [10] found that adding steel fibers significantly improved the strength of PAC. Authors in [11] introduced an innovative approach by combining Portland Limestone Cement (PLC) with Preplaced Aggregate Steel Fiber Reinforced Concrete (PASFRC). In this method, steel fibers of varying lengths were incorporated into the mix at concentrations of 1%, 2%, 3%, and 6%. After 90 days, the PASFRC mixture with 6% long steel fibers showed substantial improvements, achieving compressive, tensile, and flexural strengths increases of 188%, 166%, and 290% compared to PAC without fibers. Authors in [12] reported that adding polypropylene fibers to PAC enhances tensile strength, impact resistance, and ductility. However, wire fiber as a reinforcement material in PAC has not been thoroughly studied. This research aims to assess the effects of different wire fiber percentages on the compressive strength (f'c), tensile strength (ft), and Modulus of Rupture (MoR) of PAC.

II. RESEARCH METHODOLOGY

A. Material

For the casting of PAC, Portland Composite Cement (PCC) was used, with a specific gravity of 2.83. River sand was selected as the fine aggregate (specific gravity: 2.55), while crushed stone served as the coarse aggregate (specific gravity: 2.69). Additionally, Sika Viscocrete 3115N SP was used at a dosage of 1%. The wire fibers in this study were straight, measuring 1 mm in diameter and 60 mm in length, resulting in an aspect ratio of 60. A sample of the wire fibers is shown in Figure 1. To fill the voids between the coarse aggregates, a mortar mixture was used as the grouting material, with a cement-to-sand ratio of 1 and a water-to-cement ratio of 0.45.

Fig. 1. Wire fiber sample.

B. Mix Design

Five different concrete mixes were tested to evaluate the mechanical strength of PAC and PAWFC. In all mixtures, the proportions of cement, fine and coarse aggregates, water, and SP remained constant, while the wire fiber content varied. The fiber percentages used in this study were 0%, 0.25%, 0.5%, 0.75%, and 1% of the total concrete volume. The detailed mix design for PAC and PAWFC is presented in Table I.

TABLE I. MIX PROPORTIONS PER 1 m^3

Mix type	Wire fiber (%)	Cement (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Water (kg)	SP (kg)	Wire fiber (kg)
PAC	0%	469.73	469.73	1207.61	211.38	4.70	0
PAWFC -0.25	0.25%	469.73	469.73	1207.61	211.38	4.70	16.70
PAWFC -0.50	0.5%	469.73	469.73	1207.61	211.38	4.70	33.40
PAWFC -0.75	0.75%	469.73	469.73	1207.61	211.38	4.70	50.10
PAWFC -1.0	1.0%	469.73	469.73	1207.61	211.38	4.70	66.80

C. Casting Specimen Process

A total of 30 cylindrical specimens (150 mm × 300 mm) and 15 prism beams (550 mm × 150mm × 150 mm) were produced for each mixture, comprising 6 cylindrical specimens and 3 prism beams per mixture. The specimen manufacturing process begins by arranging the coarse aggregate and wire fiber within the mold and positioning a pipe for the injection process, as shown in Figure 2.

The grouting slurry, composed of cement and sand, underwent a drying mixing process for 2 min with the aid of a mortar mixer machine. Subsequently, the mixing water and SP were incrementally incorporated into the dry mixture for over 4 min, until a uniform consistency was achieved. The mortar mixture was transported into the mold through a plastic pipe utilizing the grouting pumping method until all voids were filled, as illustrated in Figure 3. After casting, the specimens were removed from the mold and placed in a water tank for curing, as shown in Figures 4 and 5.

Fig. 2. Placement of coarse aggregate and wire fibers in cylindrical and prism molds.

Fig. 3. Grouting pumping process.

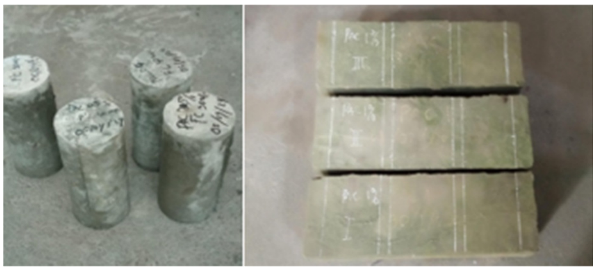

Fig. 4. Cylindrical and prism beam specimens.

Fig. 5. Curing cylindrical and prism beam specimens.

D. Hardening PAC and PAWFC Test

All PAC and PAWFC specimens were tested after 28 days of curing. The compressive strength of cylindrical specimens (150 mm × 300 mm) was assessed following the method outlined in [13]. To determine the modulus of elasticity, as specified in [14], a compression strain gauge was attached to each sample, with two dial gauge indicators positioned on opposite sides, as shown in Figure 6(a). The splitting tensile strength test for cylindrical specimens (150 mm × 300 mm) was conducted according to ASTM C496 [15], as illustrated in Figure 6(b). The modulus of rupture for prism beams (550 mm × 150 mm × 150 mm) was evaluated following the procedure in [16], as shown in Figure 6(c).

(a)

(b)

(c)

Fig. 6. (a) Compressive strength testing, (b) tensile strength testing, (c) modulus of rupture testing.

III. RESULTS AND DISCUSSION

A. Compressive Strength and Modulus of Elasticity

The findings regarding the f'c and Ec of PAC and PAWFC are illustrated in Figures 7 and 8. Figure 7 illustrates that the compressive strength of PAC demonstrates an upward trend with an increase in wire fiber content. This may be attributed to the PAC concrete casting method, where the wire fibers can be evenly distributed directly, enhancing the bonding between the mortar and coarse aggregate in the concrete. The highest compressive strength of PAWFC was observed at 1% wire fiber content, representing an 11.23% increase compared to PAC without wire fiber. Accurately measuring the modulus of elasticity is essential for structures requiring strict control over deformation. This modulus is directly proportional to the compressive strength of concrete—meaning that as compressive strength increases, the modulus of elasticity also rises. Similarly, as the wire fiber content increased, the elastic modulus showed a corresponding increase, as illustrated in Figure 8.

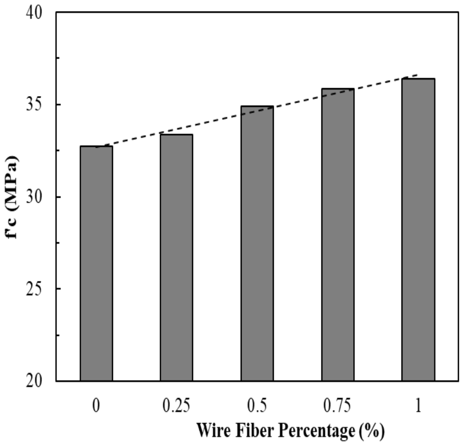

Fig. 7. Compressive strength vs. wire fiber percentage.

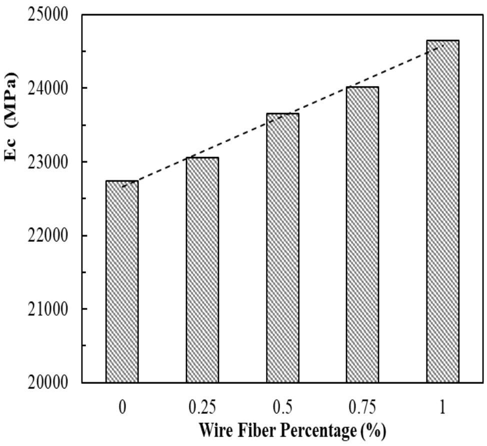

Fig. 8. Modulus of elasticity vs. wire fiber percentage.

B. *Tensile Strength*

Tensile strength (ft) is a critical property of concrete, particularly in its early stages when it is vulnerable to volumetric changes due to moisture and temperature fluctuations. These changes generate stresses that can cause cracking if they exceed the concrete's tensile strength. In concrete testing, splitting tensile strength is commonly used to assess tensile resistance. Figure 9 displays the tensile strength values for PAC and PAWFC, revealing an overall improvement in all cases. The highest increase occurred at 1% wire fiber content, where tensile strength rose by 36.85% compared to PAC without fiber. This improvement is attributed to the enhanced transmission of stress at contact points between aggregate particles, enabling the concrete to better withstand tensile forces [9].

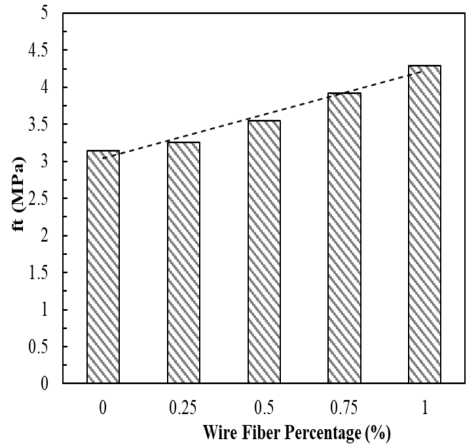

Fig. 9. Tensile strength vs. wire fiber percentage.

C. *Modulus of Rupture*

The MoR, also known as flexural strength, measures a beam's ability to withstand bending before failure. It represents the maximum load a simply supported prism beam can carry when a force is applied perpendicular to its axis. Figure 10 shows the MoR test results for PAC and PAWFC, demonstrating that MoR increases with higher wire fiber content. The highest MoR was observed at 1% wire fiber, showing a 17.23% improvement compared to PAC without fiber. This increase is due to the micro-reinforcement effect of wire fibers, which helps prevent crack formation. Additionally, the fibers contribute to a dowel action effect, further enhancing the concrete's flexural strength.

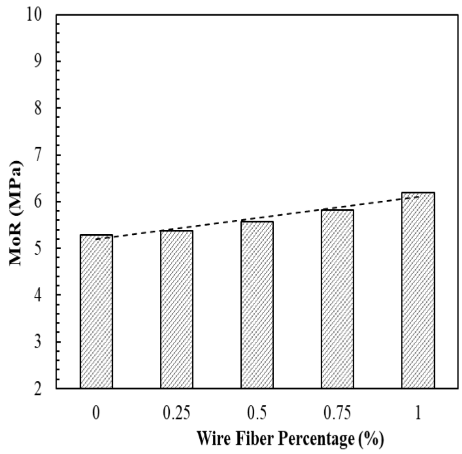

Fig. 10. MoR vs. wire fiber percentage.

IV. CONCLUSION

PAC has a higher modulus of elasticity and lower shrinkage than ordinary concrete but suffers from lower tensile strength and modulus of rupture. To improve these properties, wire fibers were incorporated in this study, creating Preplaced Aggregate Wire Fiber Concrete (PAWFC). The process involves placing dry-mixed coarse aggregate and wire fibers into a mold or formwork, followed by injecting grouting material. This method helps minimize the balling effect commonly observed in fiber-reinforced concrete. In this study, five concrete mixtures were tested to evaluate the mechanical strength of PAC and PAWFC, with wire fiber contents of 0%, 0.25%, 0.5%, 0.75%, and 1% of concrete volume. The proportions of cement, fine and coarse aggregates, water, and SP remained constant across all mixtures. The grouting material consisted of mortar with a cement-to-sand ratio of 1.0 and a water-to-cement ratio of 0.45. The results indicate that adding wire fibers to the grouting material before injection helps prevent fiber clumping. Additionally, incorporating wire fibers significantly improved the compressive strength, tensile strength, and MoR of PAC. Specifically, a 1% wire fiber content increased compressive strength by 11.23%, tensile strength by 36.85%, and MoR by 17.23%. The wire fibers acted as micro-reinforcements, reducing cracks and enhancing the dowel action in PAC.

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