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Evaluation of strength parameters of plain and reinforced concrete with the addition of polypropylene fibers

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KEYWORDS

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ABSTRACT

This research investigates the influence of incorporating small-diameter polypropylene fibers on the mechanical properties of concrete. The studied concrete properties include compressive strength, tensile strength, flexural strength (both plain and reinforced), shear strength, and the mitigation of shrinkage cracks. A total of 92 specimens were meticulously fabricated in the laboratory, comprising cylinders (12 inches in length and 6 inches in diameter), beams (20 x 4 x 4 inches), larger beams (60 x 9 x 9 inches), and slab panels (48 x 48 x 4 inches). During the specimen casting process, a consistent mix with a ratio of 1:2:4 and a water-cement ratio of 0.60 was consistently applied. The polypropylene fiber content varied at 0%, 0.2%, 0.4%, and 0.6% for each property examination. Results indicate a positive impact on all concrete properties studied upon the addition of polypropylene fibers. However, the optimal percentage of polypropylene fibers exhibited variability for each variable and property under investigation. This research contributes insights into the nuanced effects of polypropylene fibers on concrete properties, providing a basis for further exploration and practical application in optimizing concrete performance and durability.

1. Introduction

Concrete is a very useful building material with respect to its properties such as stiffness, low thermal & electrical conductivity, compressive strength and its ability to transform into desirable designs [1] Two characteristics however have limited its use i.e. it is brittle and weak in tension [2]. Concrete takes time to harden and most of the times, cracks start to appear even before its final setting time because of shrinkage [3]. These small cracks on their own don’t cause much damage but when considered as a whole, they can become a major cause of reduced strength and durability over time. Fiber can be the answer to deal with shrinkage problem and reduce these cracks which would then make the tensile and flexural properties of concrete elements more reliable [4]. Fibers may be of steel, glass, synthetic, carbon or natural. Polypropylene is the most common synthetic fibre mostly used in precast industry and available in two varieties. Bayasi [5] conducted research on the plastic shrinkage cracking mechanism as well as the effects of fibrillated polypropylene fibres and came to the conclusion that fibres restrain cracks by encouraging water retention, increasing tensile strain capacity, setting acceleration, and limiting the growth of cracks in new concrete. Study done by Berke et al [6] included the effects of low addition rates of polypropylene fibers on mechanical properties of concrete and plastic shrinkage cracking by different addition rates and fiber lengths. Relatively low addition rates were shown to significantly reduce plastic shrinkage cracking. Also, addition of fibers in concrete increase ductility and reduce spalling which result in an increase in the fire-resistant property of concrete.[7]. Malisch [8] studied the effectiveness of crack control with polypropylene fibers and concluded that under the same stress, polypropylene stretches mush more than steel and it has a lower tensile strength. The purpose of this study was to evaluate the effect of different mixing volumes of polypropylene fibers on plain and reinforced concrete. Commonly used polypropylene fibers were used in different amounts. The outcomes of this study will provide a chance to compare laboratory results in the enhancement of the concrete properties. Soroushian [9] took into consideration concrete slabs and studied the effect of addition of polypropylene fibers. Fiber fractions reduced the number of cracks, crack widths and restrained plastic shrinkage considerably. Tavakoli [10] performed experimental program to determine the tensile and compressive strength of concrete by using polypropylene fibers having modulus of elasticity 2.55 x 105 kgf/cm2 (3,642,857 psi) by varying the fiber ratios of 0.5, 1.0, 1.5, 2.0 and 2.5 percent by volume and concluded that there a considerable increase in tensile strength of concrete which was 80 percent but it did not have any effect on compressive strength. Reliable findings on the mechanical characteristics of polypropylene fibre reinforced concrete and the interactions between the fibres and pozzolanic admixtures in determining these qualities were established by statistical analysis of the results. Although flexural toughness and impact resistance increased when polypropylene fibres were present, it was found that polypropylene fibres had no major impact on the flexural or compressive strength of concrete. To understand how polypropylene fibres affect concrete's plastic shrinkage, Banthia [11] created a test programme. At dose rates ranging from 0.1% to 0.3%, four polypropylene fibres that are readily accessible on the market were examined. Although polypropylene fibres generally work well to prevent plastic shrinkage cracking in concrete, the results showed that finer fibres perform better than coarser ones and longer fibres perform better than shorter ones. Based on testing guidelines provided by ACI committee 544, Alavi Nia [12] examined the impact loading results of fiber-reinforced concrete (FRC) and plain concrete (PC) and found that the impact resistance increase was greater for normal-strength concrete than it was for high-strength concrete. Additionally, it was shown by the outcomes that steel fibres outperformed polypropylene fibres in terms of enhancing impact resistance. When improving the mechanical characteristics of concrete reinforced with oil palm shell fibre, Soon Poh Yap [13] examined the effects of polypropylene (PP) and nylon fibres (OPSFRC). It was claimed that mixtures reinforced with this fibre had a post-failure compressive toughness improvement of up to 14%. Okan Karahan [14] examined the durability characteristics of concrete containing both fly ash and polypropylene fibre and discovered that while fly ash enhances durability, polypropylene fibre makes concrete harder to work with. The elastic modulus or compressive strength of concrete prepared with fly ash or Portland cement did not increase when polypropylene fibre was added. In the study by Zoran J. Grdic [15], the abrasion resistance of regular concrete and micro-reinforced concrete was investigated. The research found that there is an inverse relationship between the water/cement factor and the abrasive resistance of concrete, and that micro-reinforced concrete has stronger compressive and bending strengths and better abrasive resistance compared to regular concrete. This was achieved by using two different types of polypropylene fibers. The influence of the innovative non-metallic fibre Polypropylene Twisted Bundle (PPTB) on the mechanical properties and slump of concrete made from oil palm shells was examined in a study by Ming Kun Yew [16]. The findings demonstrated that PPTB fibres may be utilised as a substitute material to improve the qualities of concrete made from oil palm shells. Peng Zhang investigated the effect of polypropylene fibre on the resilience and workability of a concrete composite containing fly ash and silica fume [17]. The results demonstrate that the workability of a composite concrete containing fly ash and silica fume is somewhat decreased by the addition of polypropylene fibre. Both the slump and slump flow eventually lessen as the fraction of fibre volume increases. Priti A. Patel [18] evaluated the performance of polypropylene FRC. The qualities of polypropylene fibre reinforced concrete were investigated experimentally, including split tensile, flexural, shear and compressive strength. When compared to ordinary concrete, the split tensile test, tensile test and shear strength show a substantial improvement. Compressive strength does not change considerably, though. The qualities of light weight self-compacting concrete (LSCC), both in its fresh and hardened forms, were studied in Mazaheripour's [19] study in relation to the impact of polypropylene fibres. The findings demonstrated that the inclusion of polypropylene fibres increased tensile strength and split tensile strength by 14.4% and flexural strength by 10.7%. Elastic modulus and compressive strength of LSCC, however, remained unaltered.

2. Experimental Design

2.1 Materials

2.1.1 Cement

ASTM Type 1 (Ordinary Portland Cement) was used.

2.1.2 Aggregate

Margalla crush was used as coarse aggregate with a maximum size of ¾" and Lawrencepur sand was used because of its high fineness modulus. Both aggregates are available locally easily. The grading of both aggregates was done according to ASTM C 33-93 [20].

2.1.3 Polypropylene Fibers

The utilized fibers were fibrillated polypropylene fibers with a specific gravity of 0.9 and zero water absorption. These fibers had an aspect ratio of 475 and measured approximately 0.748 inches in length and 0.00157 inches in diameter. The fibers had a melting temperature between 160 and 170 °C and an igniting value of 590 °C. According to the producer (Fibermesh®), the fibers exhibited excellent resistance to acids and salts, as well as low thermal and electrical conductivities. The Young's modulus of elasticity of the fibers was determined to be approximately 3.5 GPa. The specimens used in the study are listed in Table 1.

Table 1

List of Specimens

Sr. No	Test	Specimen	No's	Type
1	Crushing Strength	Cylinder	9	A (Control)
2	Crushing Strength	Cylinder	9	B (0.2%)
3	Crushing Strength	Cylinder	9	C (0.4%)
4	Crushing Strength	Cylinder	9	D (0.6%)
5	Tensile Strength	Cylinder	3	A (Control)
6	Tensile Strength	Cylinder	3	B (0.2%)
7	Tensile Strength	Cylinder	3	C (0.4%)
8	Tensile Strength	Cylinder	3	D (0.6%)
9	Flexural (Plain)	Beam Dimension (20"x 4"x4")	4	A (Control)
10	Flexural (Plain)	Beam Dimension (20"x 4"x4")	4	B (0.2%)
11	Flexural (Plain)	Beam Dimension (20"x 4"x4")	4	C (0.4%)
12	Flexural (Plain)	Beam Dimension (20"x 4"x4")	4	D (0.6%)
13	Flexural (Reinforced)	Beam Dimension (20"x 4"x4")	4	A (Control)
14	Flexural (Reinforced)	Beam Dimension (20"x 4"x4")	4	B (0.2%)
15	Flexural (Reinforced)	Beam Dimension (20"x 4"x4")	4	C (0.4%)
16	Flexural (Reinforced)	Beam Dimension (20"x 4"x4")	4	D (0.6%)
17	Shrinkage-Cracks	Slab-panel	1	A (Control)
18	Shrinkage-Cracks	Slab-panel	1	B (0.2%)
19	Shrinkage-Cracks	Slab-panel	1	C (0.4%)
20	Shrinkage-Cracks	Slab-panel	1	D (0.6%)
21	Shear-Strength	Beam (5' x 9" x 9")	2	A (Control)
22	Shear-Strength	Beam (5' x 9" x 9")	2	B (0.2%)
23	Shear-Strength	Beam (5' x 9" x 9")	2	C (0.4%)
24	Shear-Strength	Beam (5' x 9" x 9")	2	D (0.6%)
		Totals	92	

3. Experimental Program

A hardened concrete specimen was tested for plastic shrinkage cracking, flexural strength, compressive strength, shear behaviour and tensile strength and as part of the experimental programme. With a water cement ratio of 0.6 and mix ratio of 1:2:4, all of the concrete samples were prepared. Fibers were added as the last ingredient with varying amount i.e., 0, 0.2%, 0.4% and 0.6% respectively. All concrete specimens were cured and prepared in accordance with ASTM C192 and tested in the laboratory in compliance with ASTM C39, ASTM C496, ASTM C78, ASTM C1018 [20-26].

3.1 Casting Schedule

1. To assess compressive strength, three groups of three cylindrical specimens, each with a length of approximately 1.42 inches and a diameter of approximately 5.91 inches, were evaluated for their compressive strength at 3, 7, and 28 days of age for each of the nine specimens created for each fiber proportion.
2. For tensile strength, twelve cylindrical specimens (approximately 11.81 inches length & 5.91 inches diameter), three specimens for each fiber ratio were prepared. Splitting tension tests were carried out on three cylinders for each fiber ratio at the age of 3, 7, and 28 days, respectively.
3. For flexural strength, sixteen plain cement concrete (P.C.C.) beam specimens (19.69 x 3.94 x 3.94 inches), four specimens for each ratio were prepared. Also, sixteen reinforced cement concrete (R.C.C.) beam specimens (19.69 x 3.94 x 3.94 inches), four specimens for each fiber ratio were prepared. In both cases, a two-point flexural test was carried out on four cylinders for each ratio at the age of 7 and 28 days, respectively.
4. For shear strength and toughness, eight R.C.C beam specimens (59.06 x 8.86 x 8.86 inches), having the same dimensions but different fiber ratios i.e., two specimens for each ratio, were prepared and tested for bending at the age of 7 and 28 days each.
5. For shrinkage crack observations, four slab panels (47.24 x 47.24 x 3.94 inches), one panel for each fiber ratio, were prepared, and plastic shrinkage cracks developed were observed by visual inspection and compared.

4. Results and Discussion

4.1 Compressive Strength

From the results presented in figure 1, it can be seen that the addition of polypropylene fibers did increase the compressive strength by 5% when small doses i.e. 0.20% to 0.40% are added to concrete but when addition is increased beyond 0.2% which is very similar to what Alsadey found in his research [27], However, an additional aspect that was found out in this research was that the strength goes down and decreases 3 to 5% from the original value. It can be said that the optimum value for addition of polypropylene for increasing the compressive strength of concrete is 0.40%. But when the amount of dose is increased than 0.4%, it starts to interfere with the cohesiveness of concrete matrix and strength starts to go down.

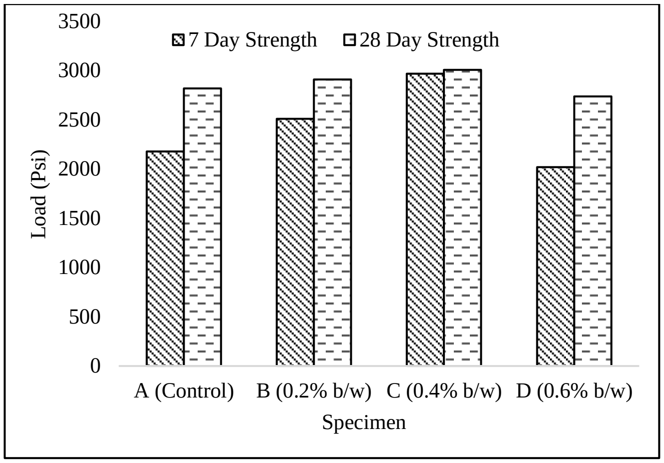

Fig. 1. Average Compressive Strength

4.2 Tensile Strength

Figure 2 from the research show that the normal tensile strength of concrete is just 10% of its compressive strength. When polypropylene fibers are added to the concrete, the tensile and compressive strength become more similar. The tensile strength of the concrete increases by around 65% to 70% with the addition of 0.40% polypropylene fibers, but decreases beyond this point. This increase in tensile strength with the addition of up to 0.40% polypropylene fibers is attributed to the bridging mechanism they create. However, when more fibers are added, the bond strength of the concrete decreases, leading to a drop in strength and an early failure point. The trend scene in this research is comparabale to what Zhang found out when he did an experimental study on the axial tensile properties of polypropylene fiber concrete [28].

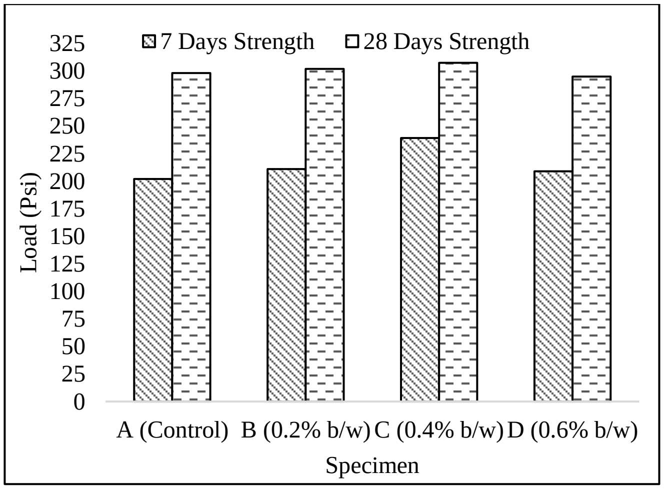

Fig. 2. Average Tensile Strength

4.3 Flexural Strength P.C.C

In case of flexural strength, a similar sort of behaviour was seen. An increase in tensile strength was noticed for smaller dosage that is up to 0.2%. Instead of increase in strength as it happened in case of compressive strength up to 0.4% of dosage, the strength started to go down after 0.2%. Also, it was noticed that the increase in 7-day strength was much more as compared to increase in 28 days strength because use of polypropylene reduced the initial cracking. The results can be seen in figure 3 which are very similar to findings of Zhang [28].

4.4 Flexural Strength R.C.C

With the addition of polypropylene fibers in reinforced beams no change was seen in flexural strength. This was because under flexural loading, reinforcing steel came in to equation. Figure 4 show the results obtained from tests.

4.5 Shear Strength R.C.C

When reinforced beams were subjected to shear loading it was seen that shear capacity of beams does increase with the addition of polypropylene fibers similar to what Hoessein et al. observed [29]. In case of lower dosage, the shear strength tends to reduce but increases when the dosage goes above 0.4% and a slight increase failure load was seen when the dosage was increased to 0.6% as compared to control beams (with no fibers). Figures 5 and 6 demonstrates the results.

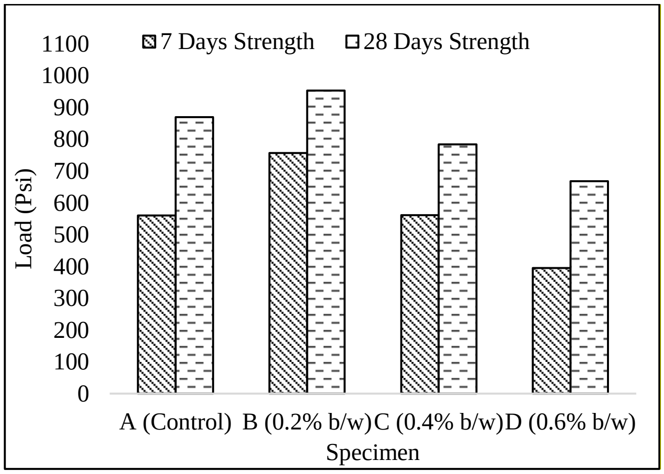

Fig. 3. Average Flexural Strength P.C.C

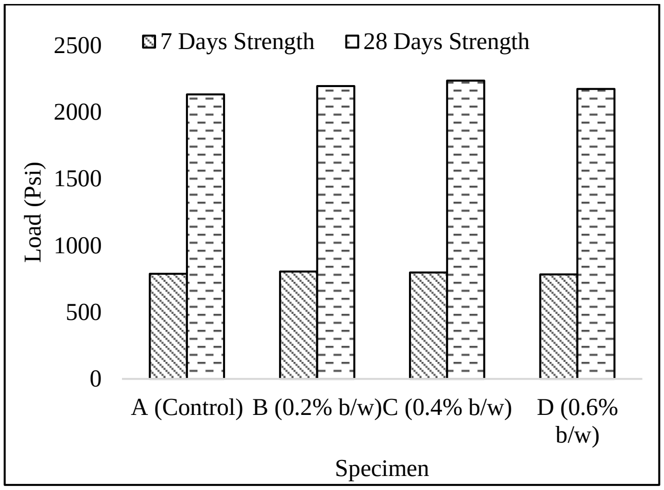

Fig. 4. Average Flexural Strength R.C.C

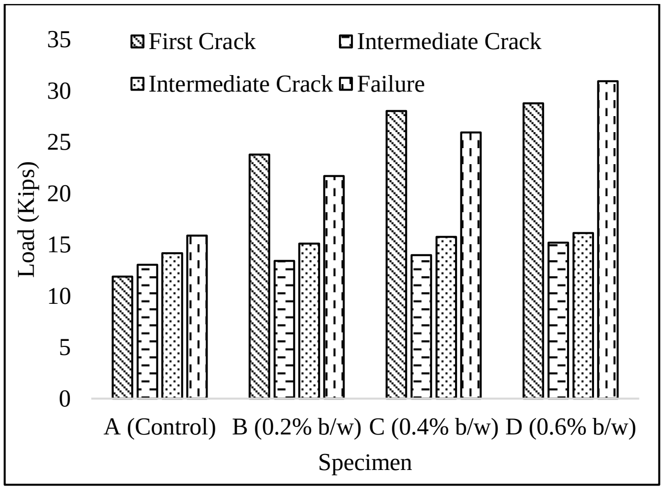

Fig. 5. Shear Strength (Set 1)

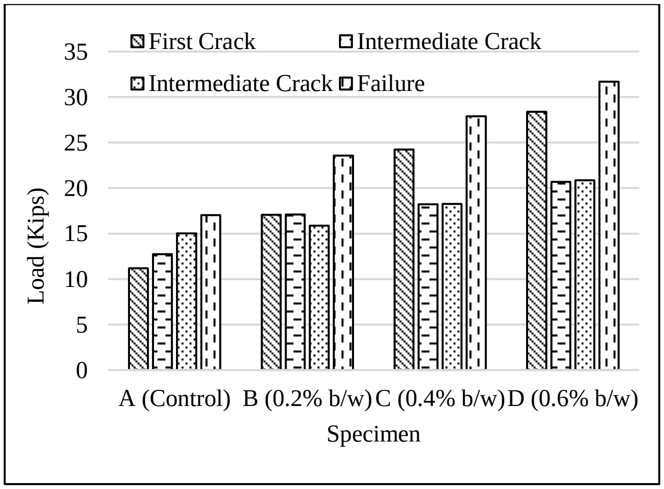

Fig. 6. Shear Strength (Set 2)

4.6 Plastic Shrinkage Cracking

Previous researches have shown that addition of fibers can reduce plastic shrinkage cracking [30-32]. This Study also shows that polypropylene fibers can be used to reduce plastic shrinkage cracking. It is reduced 83 to 85% after an addition of fiber content from 0.40% to 0.60 % by volume. Lower dosages of polypropylene fibers reduce the initial cracking up to 70% because of crack bridging mechanism created. Figure 7 shows the results obtained.

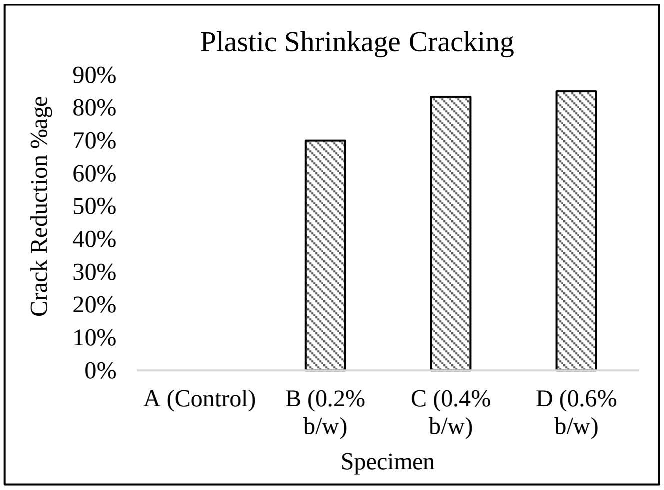

Fig. 7. Plastic Shrinkage Cracking

5. Conclusions and Recommendations

As far as compressive, tensile and flexural strengths are concerned, there is no noticeable increase or decrease in these strengths. At some ratios of polypropylene fibers, there is an increase while at some ratios it shows a decrease in strength with compared to the strength of normal concrete without fibers. The actual beauty of using polypropylene fibers lies in crack controlling. Plastic shrinkage cracks are reduced more than 70 % by using a fiber ratio of 0.20 % or more. As far as shear cracks are concerned, the load at which the first crack appeared increased considerably. The load at which failure occurred also increases at higher percentages of fibers used i.e. 0.6 % or more. As addition of fibers plays an important role in crack controlling, spalling decreases and the behavior of concrete becomes more ductile. As a result, the structural performance of concrete under large fires or high temperatures is improved. This research can further be improved by increasing the range of percentages addition and types and length of polypropylene fibers.

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