Use of Polypropylene Fibers in Concrete Mixtures Produced With Crushed Stone Sand as Fine Aggregate

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Abstract: **Effect of polypropylene fibers on the rheological, mechanical and durability characteristics of concrete mixtures produced with crushed stone aggregate as fine aggregate was experimentally investigated in this project. Slump and density of fresh concrete mixtures and compressive, flexural and split tension strengths of hardened concrete mixtures were investigated. While durability characteristics of these concrete mixtures were tested, using moisture sorption test. Four concrete mixtures were produced using polypropylene fibers of 0.35 in. length with fiber-volume fractions of 0%, 0.25%, 0.50%, and 0.75%. In all mixtures, crushed stone sand was used as fine aggregate. Test results showed that slump values of fresh concrete dropped with increase in dosage of polypropylene fibers, while no appreciable change in fresh concrete density was recorded as a result of incorporation of polypropylene fibers in the concrete mixtures. Compressive and flexural strengths of hardened concrete increased with increase in dosage of polypropylene fibers. On the other hand, concrete mixture with 0.50% fiber-volume fraction showed the highest split tension strength. Moisture sorption characteristics of polypropylene fibers concrete mixtures were comparable to that of control mixture. The use of polypropylene fibers in concrete mixtures produced with crushed stone sand as fine aggregate is thought to be a good practice towards enhancing the compressive, flexural and split tension strengths resulting concrete mixtures without compromising the durability attributes of these admixtures. The use of crushed stone sand replacing normal sand in concrete mixture also proved to be a viable practice.**

Keywords: **Concrete, polypropylene fibers, strength, durability**

I. INTRODUCTION

Concrete is a quasi-brittle material, which has good compressive strength but a limited tensile strength. The tensile strength of concrete is about one-tenth of its compressive strength [1-2]. The lower tensile strength of concrete is an issue in number of its applications in construction of civil infrastructure. It is therefore improved through the use of steel reinforcing bars. These days, however, there has been an increasing use of various types of fibers to improve the tensile strength of concrete [3 - 5]. The use of fibers in concrete has a significant advantage over other materials owing to the very high specific strength of fibers. Capitalizing upon the higher specific strength of fibers, Polypropylene Fiber Reinforced Concrete (PFRC) is a cement-based composite material that has been developed in recent years [4, 6 - 8]. In this type of concrete fibers made of polypropylene are added to normal concrete as an additive material in certain percentage of volume of cement called fiber volume fraction. The resulting concrete has significantly higher flexural and direct tensile strengths, reduced shrinkage, and higher impact resistance characteristics [9 - 12]. Furthermore, PFRC has significantly higher toughness, shock resistance, and lower plastic shrinkage cracking when compared with normal concrete [13 - 15].

In this work, a detailed experimental investigation was carried out to assess the effect of polypropylene fibers on the strength and durability attributes of concrete produced with crushed stone sand as fine aggregate. Concrete mixtures were produced with varying fiber volume fractions. A control concrete mix without the use of polypropylene fibers was also produced for comparison. Compressive, flexural, and split tensile strengths of polypropylene concrete mixtures were tested at 7, 28, and 90 days of concrete age and compared with that of control concrete mix. Effects of polypropylene fibers on the durability of concrete was investigated using the sorption test.

II. MATERIALS & METHODS

Table 1 shows the physical properties of the ingredient materials used in the experimental program. Four concrete mixtures were produced with 0%, 0.25%. 0.50%, and 0.75% volume fraction of polypropylene fibers following the guidelines of ACI 211-09..

Table 1: Physical properties of ingredient of concrete mixtures

Ingredient	Water absorption (%)	Bulk density (lb/ft^3)	Fineness modulus	Length (in.)
Coarse aggregate	0.95	103	6.95	
Crushed stone sand	1.35	106	3.15	
Polypropylene fibers	-	0.056	-	0.75 – 1.50

Table 2 shows the weight-based mix designs for the four concrete mixtures. As can be seen in this table, w/c ratio, water content and aggregate contents were kept constant to have meaningful investigation of the effects of propylene fibers on the strength and durability attributes of the resulting concrete mixtures. Various ASTM specifications as shown in Table 3 were followed for the determination of physical properties of ingredient materials, production of concrete mixtures, and testing of

fresh and hardened concrete properties of the concrete mixtures. Immediately upon completion of mixing process, fresh concrete density and slump test of each concrete mixture was determined.

Table 2: Concrete Mix Designs

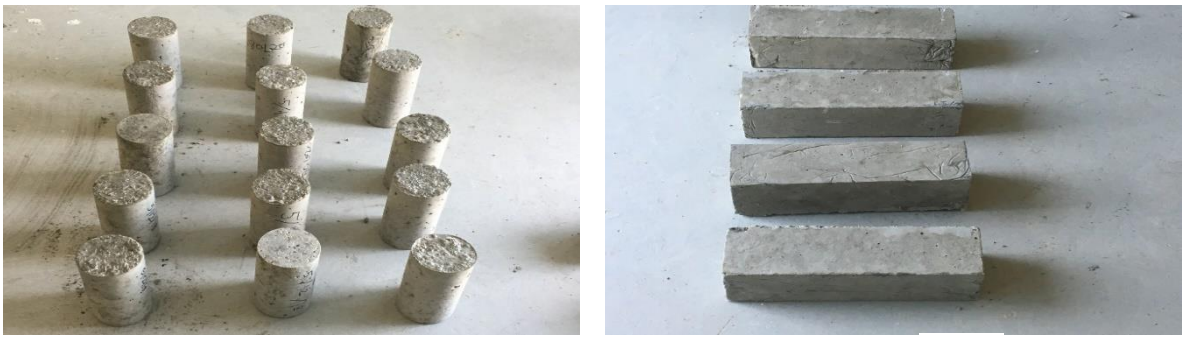
$\%V_f$ = fiber volume fraction; PP = polypropylene

Mix Designation	Coarse Aggregate	Fine Aggregate (lb/ft^3)	Water Content (lb/ft^3)	Cement Content (lb/ft^3)	w/c ratio	PP fibers ($\%V_f$)
CM00PP	45	55.50	13.50	30.25	0.45	0
CM25PP	45	55.50	13.50	30.25	0.45	0.25
CM50PP	45	55.50	13.50	30.25	0.45	0.50
CM75PP	45	55.50	13.50	30.25	0.45	0.75

Table 3: ASTM / ACI Standards followed for testing

Test Name	ASTM / ACI Standards
Sieve analysis of coarse and fine aggregate	ASTM C 136
Slump test	ASTM C 143
Compressive strength	ASTM C 39
Flexural strength	ASTM C 78
Moisture sorption test	ASTM C 1585-04
Concrete mix design	ACI 211-09

Compressive strength of all concrete mixtures at 7, 28, and 90 days of concrete age was tested using concrete cylinder specimens having a diameter of 4 in. (100 mm), and height of 8 in. (200 mm). These specimens were cured in water until the age of testing. For flexural strength tests, concrete prisms having 4 in. (100 mm) width, 4 in. (100 mm) depth and 16 in. (200 mm) length were tested in third-point bending after curing in water until the test age. Split tension strength tests were carried out using the cylinder specimens of same dimensions as used for compressive strength test. Figure 1 shows views of the concrete cylinder and prism specimens used in the experimental program. Concrete discs having 2 in (50 mm) thickness cut from the cylinders were used for moisture sorption test. Theses specimens were prepared according to the guidelines of ASTM C1585 and were sealed with silicone gel on the sides (periphery) to expose them to one-dimensional moisture sorption.



(a) (b)

Fig. 1: Concrete test specimens used in the experimental program *(a)* cylinders *(b)* beams

Sorption test was continued for 15840 minutes (11 days) exposure of specimens to water sorption in a container. At the end of the test-time, moisture sorption of concrete mixtures was calculated as the water absorbed per unit area of the specimen.

III. RESULTS

A. Fresh Concrete Test Results

Table 3 shows the results of fresh concrete density and slump test. It is noticed that while the addition of polypropylene fibers did not cause any appreciable effect on the fresh concrete density, the slump is seen to be significantly decreased with an increase in the fiber volume fraction. The reduction is slump is caused in part by the agglomeration of the tiny fibers inside concrete and partly by the confining effect of the fibers caused to on the aggregate and paste. The significant reduction in the slump value suggests the difficulty caused in the compaction of concrete which at large scale could interfere with the strength and durability of PFRC mixtures. It is therefore recommended to use a suitable water reducing agent in such concrete mixtures.

Table 4: Fresh Concrete Properties

Mix Designation	Slump (in.)	Density (lb/ft^3)
CM00PP	2.50	143
CM25PP	1.75	143
CM50PP	1.25	142
CM75PP	1.00	142

B. *Hardened Concrete Test Results*

Fig. 2 shows the plot of the test results of compressive strength tests of the four mixtures at 7, 28, and 90 days of concrete age. Test results show that the compressive strength of the concrete mixtures increases with an increase in the fiber volume fraction in concrete. Subject figure shows that significant gain in compressive strength is achieved as result of the incorporation of polypropylene fibers in concrete mixtures. The increase in compressive strength because of fiber addition in the mix is thought to be the result of the crack arresting effect of the polypropylene fibers in concrete at the macro level. Furthermore, these fibers tend to delay the propagation of cracks in concrete cylinder specimens and hence result in enhancement of the compressive strength.

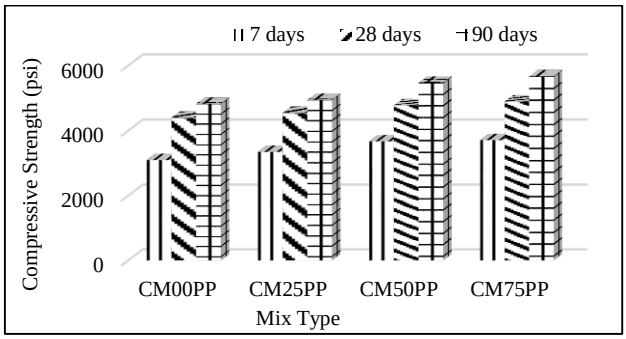


Fig. 2: Compressive strength test results of concrete mixtures at various ages of concrete

Fig. 3 shows the test results of flexural strength test of the four mixtures at 7, 28, and 90 days of concrete age. Flexural strength follows the trend of the compressive strength. That is flexural strength of the concrete increases with an increase in the fiber volume fraction of polypropylene fibers. In this case too, the crack arresting effect of the fibers is thought to be the results of the enhancement in flexural strength of polypropylene containing concrete mixtures. Test results of split-tension strength test are presented in Fig. 4. Significant improvement in split tension strength is caused by the addition of the polypropylene fibers in concrete. Load applied on the concrete cylinder in diametrical position causes the cylinder to expand laterally due the Poisson's ratio effect which is followed by the development of vertical cracking of the specimen. Polypropylene fibers delay the development and subsequent progression of the cracks and hence result into increase of split tension strength of the concrete mixtures containing these fibers. Careful observation of the cracked (failed) specimens suggested that the existence of these fibers also causes confining effect in the concrete cylinders which results not only into ductile failure of these specimens but also in increase in their split tension strength.

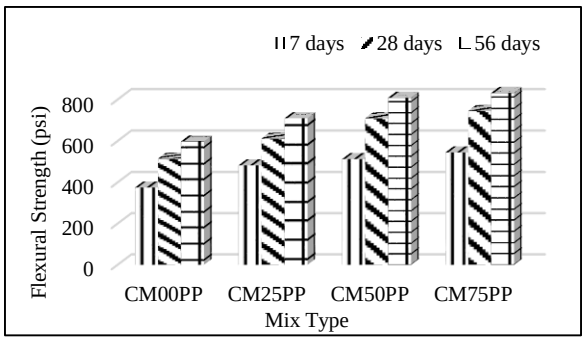


Fig. 3: Flexural strength test results of concrete mixtures at various ages of concrete

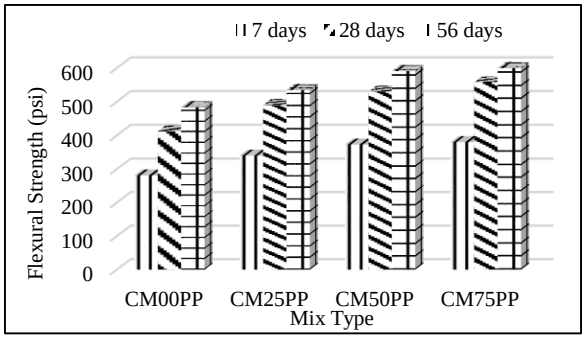


Fig. 4: Split tension strength test results of concrete mixtures at various ages of concrete

Results of the moisture sorption test are shown in Fig. 5. As can be seen the incorporation of polypropylene fibers did not significantly affect the moisture sorption characteristics of the resulting concrete mixtures. Since moisture sorption is an important characteristics of concrete determining its durability and hence long term stability, it is encouraging to note that the

addition of polypropylene fibers caused none to minimal effect on the moisture sorption of characteristic of the resulting mixtures. Significant enhancement in strength without any negative effect on one of the important durability characteristics is viewed as highly positive contribution of polypropylene fibers in PFRC mixtures.

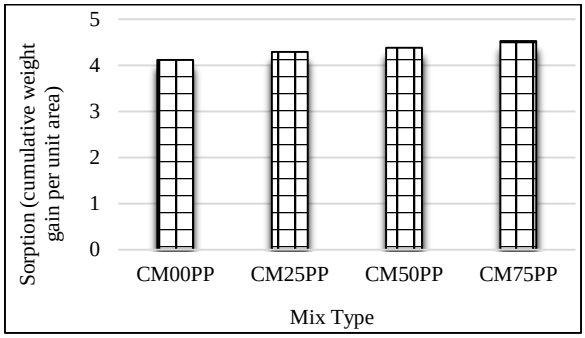


Fig. 5: Sorption test results of concrete mixtures after 11 days of exposure to moisture

IV. CONCLUSIONS

Based on test results in this experimental program, following conclusions are drawn

- The addition of polypropylene fibers results into reduction of slump but no significant effect is noticed on the fresh concrete density.
- It is concluded that considering the significant reduction in slump value due to the addition polypropylene fibers, such concrete mixtures should be produced using water reducing agents to ensure the required workability of these mixtures.
- Significant enhancement in compressive, flexural, and split tension strengths of concrete mixtures produced with incorporation of polypropylene fibers was noticed. This positive impact is thought to be the effect of crack arresting capability of polypropylene fibers.
- No significant effect on the moisture sorption characteristics of concrete mixtures was noticed as a result of the incorporation of the polypropylene fibers.

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