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EFFECTS OF POLYPROPYLENE FIBERS ON PHYSICAL AND MECHANICAL PROPERTIES OF CONCRETES

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ABSTRACT

In this present study, the effects of adding polypropylene fibers on physical and mechanical properties of concretes are investigated. To this end, three concrete mixtures consists of 6 mm, 12 mm and 19 mm polypropylene fibers are made and their physical/ mechanical aspects are studied and compared with control concrete. The results manifest that adding polypropylene fibers increases the flexural strength slightly and decreases the cracks width. Besides, the compressive strength decreases slightly. These properties are improved with increase of fibers length.

Keywords: concrete, polypropylene fibers, crack bridge, flexural strength, impact resistance

1. INTRODUCTION

Nowadays concrete is one of the most applicable materials in construction of structures such as buildings, dams, bridges, tunnels, highway pavements, offshore structures, towers and so on. This material has received great attention because of its desirable performance in compression.

Concrete is considered to be a relatively brittle material, so it is prone to cracking. Many investigations have been carried out in order to overcome this problem. The inclusion of adequate fibers improves tensile strength and provides ductility [1-3]. There are more investigations on the effects of different fibers on concrete properties [4-9].

Some of the important effects of fibers in concrete are: increasing the tensile strength, preventing the crack development and increasing the toughness of concrete. The fundamental advantage of adding fibers to concrete is known as crack bridging [9-14].

In recent years, concrete containing different fibers has been applied in large structures such as highway pavements and airports, huge foundations with large deformations and concrete cover of tunnels. Recently in order to prevent cracking in the covers of the pre-cast tunnels, un-reinforced concrete with the fibers has been used. On the other hand the investigations have shown the compressive strength reduction in fiber concretes. This reduction occurs because of the collection of Calcium-Hydroxide in the interface of hydrated cement and various types of fibers (such as Steel, Carbon, Dacron, Polypropylene fibers, and …) [15].

In recent decades the polypropylene fibers have been widely used in industries. Polypropylene fibers are relatively inexpensive, easy to split into finer sizes, durable in the environment of cement matrix and they don't rust. They have a relatively low modulus of elasticity, relatively poor bond and it is difficult to obtain uniform dispersion with Polypropylene fibers when a sufficiently large volume of fibers is used. In the present study, the effects of adding polypropylene fibers on physical and mechanical properties of concretes are investigated.

2. EXPERIMENTAL PROGRAM

2.1. Materials

2.1.1. Aggregates

Crushed coarse aggregates with maximum nominal size of 19mm and natural fine aggregates were selected. The Physical properties of coarse and fine aggregates are presented in Table 1. The aggregates grading curve is shown in Figures 1, 2.

Table 1: Physical properties of aggregates

Aggregates	Type	SSD Density* (gr/cm^3)	Water absorption (%)	Passing from sieve #200 (%)
Coarse	Crushed	2.53	1.61	0.5
Fine	Natural	2.56	2.46	1.1

SSD: Saturated Surface Dry

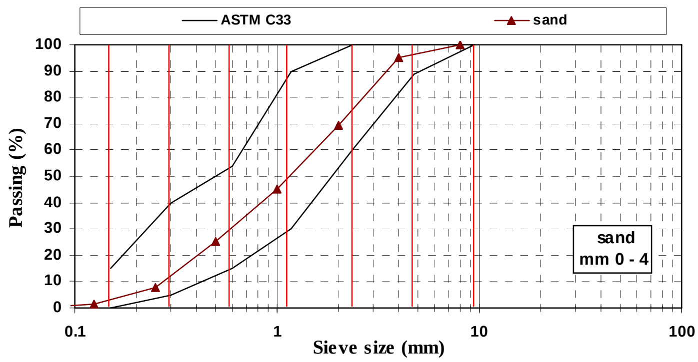

Figure 1. Particle size distribution of fine aggregates

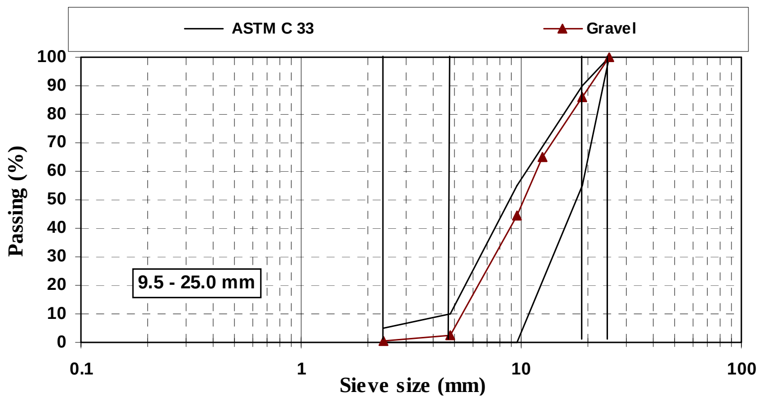

Figure 2. Particle size distribution of coarse aggregates

2.1.2. Cement

Type II Portland cement (according to ASTM C595) produced by Tehran Cement manufactory, was used in this investigation. The chemical and physical properties of this cement are presented in Table 2.

2.1.3. Polypropylene Fibers

The polypropylene fibers in three sizes of 6, 12 and 19 mm were used. A sample of the fibers is shown in Figure 3.

Table 2: Chemical and physical properties of cement

Chemical analysis, %	
Calcium oxide (CaO)	61.9
Silica (SiO_2)	21.1
Alumina (Al_2O_3)	4.2
Iron oxide (Fe_2O_3)	4.6
Magnesia (MgO)	3.4
Sodium oxide (Na_2O)	0.6
Potassium oxide (K_2O)	0.5
Sulfur trioxide (SO_3)	1.79
Bogue potential compound composition, %	
Tri-calcium silicate (C_3S)	52.74
Di-calcium silicate (C_2S)	20.31
Tri-calcium aluminate (C_3A)	3.35
Other properties	
3 days compressive strength, kg/cm^2	223
7 days compressive strength, kg/cm^2	306
28 days compressive strength, kg/cm^2	414
Initial setting time, min	150
Final setting time, min	190
Specific surface, cm^2/gr	3296

Figure 3. Sample of polypropylene fibers (6, 12 and 19 mm)

2.2. Mix Design

The mixtures were made on the basis of a series of experimental mix parameters

such as suitable slump, lack of segregation and bleeding. The mixture proportions are shown in Table 3.
To prevent breaking the fibers, first concrete materials were mixed, and then the fibers were poured in the mixture by hand rapidly in a 1-2 minute period [16].

3. RESULTS AND DISCUSSIONS

3.1. Fresh Concrete

The fresh concrete specifications for each kind of the mixtures are shown in Table 4. The concretes containing polypropylene fibers had lower slump than the control concrete.

Table 3: Mixture proportions (per m^3)

Mixture identification	W/C	Water (kg)	Cement (kg)	Coarse (kg)	Fine (kg)	Polypropylene fibers (kg) 6 mm	12 mm	19 mm
Control mix	0.5	175	350	860	980	--	--	--
Mix 1	0.5	175	350	860	980	2	--	--
Mix 2	0.5	175	350	860	980	--	2	--
Mix 3	0.5	175	350	860	980	--	--	2

Table 4: Fresh concrete specifications

Mixture identification	Density (Kg/m^3)	Slump (cm)	Air percentage	Observations
Control mix	2400	7	4.5	No bleeding- No segregation
Mix 1	2385	3.5	4	
Mix 2	2380	3	4	
Mix 3	2380	3	4	

3.2. Hardened Concrete

In order to determine the physical/ mechanical properties of mixtures, tests of compressive strength, flexural strength, modulus of elasticity, abrasion resistance, impact resistance and shrinkage were performed.

3.2.1. Compressive Strength

The compressive strength of cube specimens was obtained according to the BS 1881 at the ages of 7, 28 and 56 days. The results are presented in Figure 4.
It can be observed that the compressive strength of fiber concretes is less than the control concrete. This strength reduction can be induced by collection of Calcium-Hydroxide in the interface of fibers and hydrated cement. Besides, the compressive strength increased with increase of fibers length. The compressive strength of 19 mm fibers concretes is almost equal to the control concrete.

3.2.2 Flexural Strength

The flexural strength of the specimens was measured according to ASTM C293 at the ages of 7, 28 and 56 days. The results are shown in Figure 5.

As can be seen, the use of fibers increases the flexural strength of the concrete. This increasing trend may have occurred due to crack bridging of the fibers. Besides, the flexural strength increased with an increase in the length of the fibers. It can be concluded that longer fibers (with higher aspect ratio) can bridge the cracks better than other fibers.

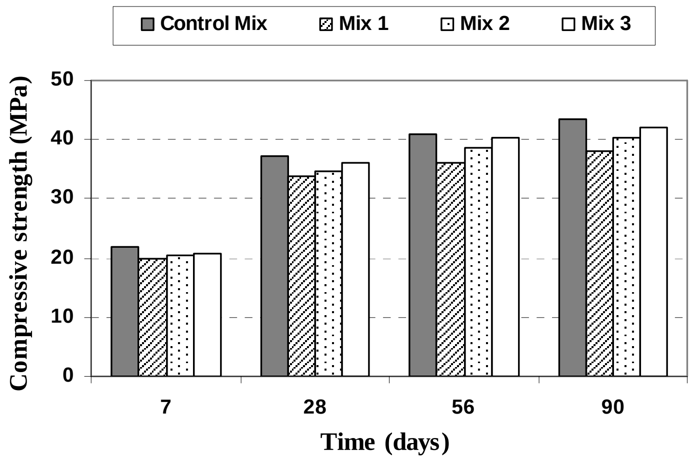

Figure 4. Compressive strength versus age

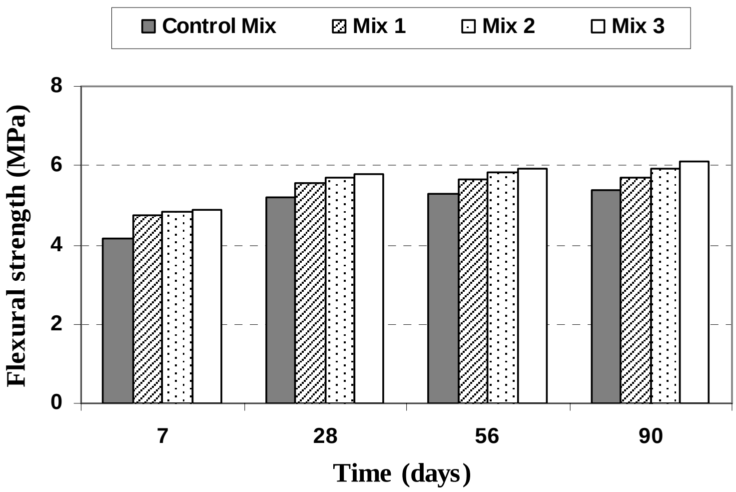

Figure 5. Flexural strength versus age

3.2.3 Modulus Of Elasticity

The modulus of elasticity of the specimens was determined at the ages of 7, 28 and 56 days according to ASTM C469 and the results are shown in Figure 6.

The use of fibers decreases the static modulus of elasticity of the concrete slightly. Besides, the increase in the length of the fibers causes a slight increase in the static modulus of elasticity. This increase may have occurred because of increase in the aspect ratio.

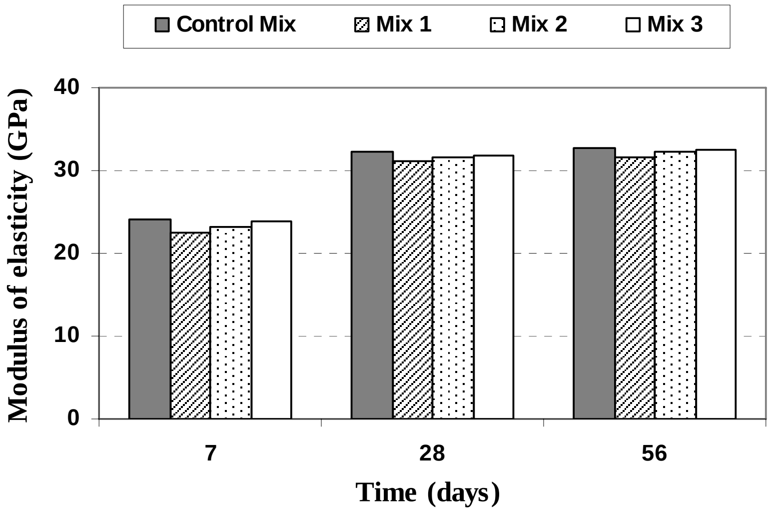

Figure 6. Modulus of elasticity versus age

3.2.4. Abrasion Resistance

The abrasion resistance of the specimens was measured at age of 28 days according to standards ASTM C779 and EN 1338. The results are shown in Table 5.

It can be observed that abrasion resistance of the fiber concretes is better than the control concrete. Besides, the abrasion resistance of the concrete slightly increases with increase in the length of the fibers.

Table 5: Abrasion resistance

Mixture Identification	Abrasion depth according to ASTM C779-89a			Abrasion according to EN 1338	
	After 30 min (mm)	After 60 min (mm)	Variation (%)*	Abrasion (cm)	Variation (%)
Control mix	0.94	1.68	--	2.2	--
Mix 1	0.54	1.09	0.351	2.1	0.045
Mix 2	0.56	1.05	0.375	2.05	0.068
Mix 3	0.52	0.98	0.417	1.85	0.159

*** Variation has been calculated with respect to after 60 min results**

3.2.5. Impact Resistance

One of the important properties of the fiber concretes is the resistance against impact. The test of impact repeat with load drop is one of the valid tests for evaluation of impact resistance of concrete which has been suggested by ACI 544- part 2.

In this test, the number of required impacts which causes to crack and rupture in concrete specimen, is determined and this number implies the qualitative estimation of the absorbed energy by the concrete specimen. In this test the standard hammer (with the weight of 4.5 kg and drop height of 457 mm) drops on the steel sphere of 63.5 mm diameter which has been fixed on the surface of the

concrete, and transfers the impact to the concrete specimen. The specimen shape is cylindrical with 152 mm diameter and 63.5 mm height. The results are shown in Table 6 at the age of 28 days.
Adding fibers to concrete decreases the required number of impacts due to first crack, while it increases the required number of the impacts due to complete rupture. The number of impacts until complete rupture is also increased with the increase of the length of the fibers.

Table 6: Impact resistance in 28 days

Mixture Identification	Required number of impacts due to first crack			Required number of the impacts due to complete rupture		
	Minimum impacts	Maximum impacts	Average	Minimum impacts	Maximum impacts	Average
Control mix	21	25	23	27	27	27
Mix 1	19	21	20	27	28	28
Mix 2	16	18	17	28	29	29
Mix 3	16	18	17	29	31	30

3.2.6. Restrained Shrinkage Test

If the shrinkage of concrete occurs freely, the concrete section doesn't crack, but if it is restrained, the tensile stresses will appear and the concrete becomes more prone to cracking. One of the effective methods of controlling restrained shrinkage cracking is the use of fibers in the concrete mixture. In this research, in order to evaluate the cracking potential caused by restrained shrinkage, the method of cracking in circular specimens which is suggested by ACI 544- part 2 is used. In this test, concrete is molded into a ring formwork with the thickness of approximately 30mm and of 300mm outer diameter. The specimen is subjected to wind blowing and low relative humidity and the procedure of crack development is monitored. A sample of this test is shown in Figure 7. In this test, width of the cracks and the pattern of cracks from the time of cracking were studied up to 90 days. The results of restrained shrinkage up to 90 days are shown in Table 7.
As can be observed, fiber concrete mixtures have less crack width in comparison with control concrete. The time of the first cracking in the fiber concrete has also increased. These results confirm results of the flexural strength test about fiber's crack bridging.

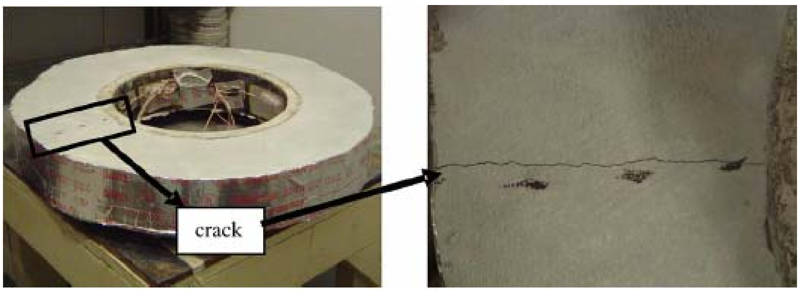

Figure 7. Crack in restrained ring specimen drying from the top and bottom [14]

Table 7: Observed results of restrained shrinkage cracks up to 90 days

Mixture identification	Time of the first cracking after 7 days curing (days)	Maximum crack number	Maximum crack width	Average crack width
Control mix	3	3	0.3	0.27
Mix 1	4	3	0.26	0.21
Mix 2	6	2	0.2	0.18
Mix 3	6	2	0.2	0.17

4. CONCLUSION

From the results of this investigation, the following conclusions can be drawn:

- Adding polypropylene fibers to the concrete has led to a slight decrease in the compressive strength and modulus of elasticity of the specimens. The strength was decreased slightly (up to 10 percent for specimens made of 6 mm length fibers). Besides, the compressive strength has been increased with the increase in the length of the polypropylene fibers. The compressive strength of 19 mm fibers concrete is almost equal to the control concrete.
- According to obtained results of the flexural strength test, adding fibers to concrete has led to increase of flexural strength with respect to the control concrete. Flexural strength also increases with the increase in the length of the fibers. The concrete mixture with 19 mm fibers showed 10 percent higher flexural strength than the control concrete.
- The specimens which contained polypropylene fibers had better abrasion resistance than control concrete. Generally the fibers with different lengths showed equal abrasion resistance.
- Adding fibers to concrete decreased the required number of impacts for the first cracking, but increased it for complete rupture. The number of impacts for complete rupture increases with the increase of the length of the fibers. It can be concluded that adding fibers to concrete has an effective role in reduction of the crack width.
- According to obtained results, polypropylene fibers concretes are useful in control of shrinkage and fine cracks. It is recommended to apply these materials in construction of the concrete floors such as airports and industrial floors.

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