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Effect of different fibers on the mechanical properties of concrete containing fly ash

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Abstract

The results of an experimental investigation to study the effects of replacement of cement (by weight) with three percentages of fly ash and effects of addition of steel and polypropylene fibers are presented. Current day knowledge of concrete technology focuses attention primarily on the use of different materials in the production of concrete, industrial wastes in particular. The use of fly ash in concrete today is an important subject and is growing in importance day by day. Using fly ash in concrete may both provide economical advantages and better properties in the production of concrete. Besides, concretes produced with three different replacement ratios of fly ash and three different types of steel and polypropylene fibers were compared to those without fibers used in concrete with FA. According to the results of the study, addition of fibers provide better performance for the concrete, while fly ash in the mixture may adjust the workability and strength losses caused by fibers, and improve strength gain.
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Keywords: Concrete; Fibers; Fly Ash; Workability; Strength

1. Introduction

The usage of industrial waste materials in concrete, both in regard to environmental pollution and the positive effect on a country's economy are beyond dispute. Utilization of fly ash (FA) in concrete technology is more common. FA causes environmental pollution and the cost of storage of FA is very high [1,2]. When some types of FA replaces with cement in concrete mixture, fresh concrete workability is increased, early strength and shrinkage of hardened concrete are decreased [3], and permeability is decreased [4] due to filling the micropores of concrete [5–7]. All these variations on concrete properties, caused by FA, depend on the mineralogical composition and fines of FA. In addition, FA positively affected durability of concrete and mortar like freeze-thaw resistance [8], sulphate resistance [9], alkali–silica reaction, and abrasion resistance [10–12]. Fibers used in concrete are produced from a wide variety of materials, those being composed of glass, ceramic, steel, organic and some polymer materials [13]. Experimental studies showed that fibers improve the mechanical properties of concrete such as flexural strength, compressive strength, tensile strength, creep behaviour, impact resistance and toughness [14–16]. There is not enough study carried out on fiber reinforced concrete produced with FA.

2. Experimental

Several experimental studies are carried out on concrete specimens according to Turkish and European codes. The properties of materials used in concrete mixtures are given below.

2.1. Materials

2.1.1. Aggregates

In this study, natural river sand (S) 0–4 mm and 4–8 mm and 8–16 mm calcareous crushed stones (CS) were used as

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Table 1
The results of aggregates tests

Grain size (mm)	Sieve size (mm)							Fineness modulus	Specific gravity	Loose unit weight (kg/m^3)	Unit weight (kg/m^3)	Water abs. ratio 24 h (%)
	16	8	4	2	1	0.5	0.25					
0–4	100	100	97	71	46	18	1	2.66	2590	1566	1712	2.19
4–8	99	95	11	2	0	0	0	4.87	2700	1454	1610	0.47
8–16	99	5	2	2	0	0	0	5.9	2710	1435	1603	0.32

aggregates. Crushed stones were brought from Zemzemiye and sand was taken from Sakarya river. The properties of aggregates used in this study are given in Table 1 and Fig. 1.

2.1.2. Cement

The cement used in this study was a commercial grade ASTM Type I Portland cement (C), which produced as CEM I cement in Turkey. The chemical composition and physical properties of the cement are given in Table 2.

2.1.3. Fly ash

Class F type fly ashes used in this study belong to the thermal power plant in Tunçbilek. These ashes were separated and are appropriate for the Turkish Code [17]. The properties of fly ash are given in Table 3.

2.1.4. Fibers

Steel fibers (SF) used in the study are wires, with their two ends having been twisted, and belong to C Type of Turkish Code [18]. Such fibers are manufactured from low carbon steel with the method of cold drawn process. Plastic propylene fibers are mostly used for reinforcing mortar and concrete composites. These fibers are used as fibrillated film, varying from 50 to 100 μm in diameter. Physical and mechanical properties of fibers are given in Table 4.

2.2. Experimental method

Twelve series of concretes were prepared. Fly Ash was used as replacement of cement, at the levels of 0, 10, 15 and 20% by weight. Steel fiber (SF) and two different plastic polypropylene (PPI and PPII) fibers were used in this study. The mix designs of concretes are given in Table 5. Cylindrical, cubic and prismatic specimens were produced

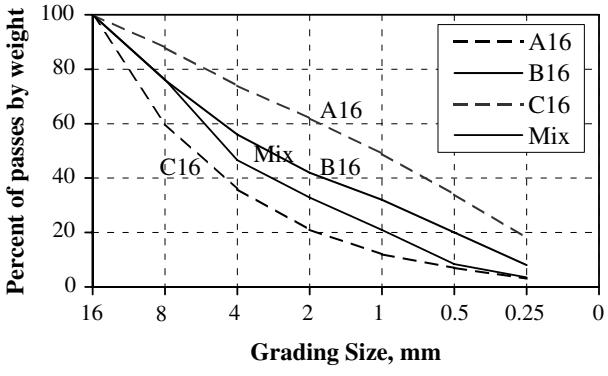


Fig. 1. Grading curve of aggregates.

Table 2
Characteristics of cement

Physical test results	
Initial setting time	03:15
Final setting time	04:15
Total volume expansion (mm)	4
Specific surface (cm^2/gr)	3130
Specific gravity	3120
Residue on 200 (μm %)	1.0
Residue on 90 (μm %)	1.2
Chemical test results	%
CaO	63.39
SiO_2	19.96
Al_2O_3	5.17
Fe_2O_3	3.41
MgO	1.61
SO_3	1.92
Cl_2	0.004
Other materials	3.03
LOI	1.10
Mechanical properties	
Compressive strength, MPa	
7 days	23
28 days	34
Bending strength, MPa	
7 days	4.4
28 days	5.7
Composition of cement	%
C_3S	61.19
C_2S	11.09
C_3A	7.92
C_4AF	10.39

Table 3
Chemical properties of Tunçbilek FA

Properties	%	TS EN 450 limits [17]
SiO_2	58.59	–
Al_2O_3	21.89	–
Fe_2O_3	9.31	–
S + F + A	89.79	–
CaO	4.43	–
MgO	1.41	–
SO_3	0.41	<3.00
K_2O	1.81	–
Na_2O	0.28	–
LOI	0.59	<5.00
Radium activity	501.07	200–750
Binder activity	89.40	> = 70.00

Table 4
Physical and mechanical properties of fibres

Fibre type	Thickness of fibre (μm)	Length (cm)	Relative density	Tensile strength (MPa)	Elastic modulus (GPa)	Ultimate elongation (%)	Ignition temperature (°C)	Melt temperature (°C)
PPI	50	2.3	0.91	350	4.2	15	600	165
PPII	36	1.2	0.90	325	4	20	600	165
SF	55	3.5	7.8	400	200	18	–	–

Table 5
Specialties and mixtures belonging to concrete groups

Series	FA (%)	Fiber type	Fiber (%)	W/(C + FA)(%)	C (kg/m^3)	FA (kg/m^3)	F (kg/m^3)	W (kg/m^3)	S (kg/m^3)	CS I (kg/m^3)	CS II (kg/m^3)
A1	10	NF	0.00	45	315.0	35.0	–	203	613.2	547.9	641.6
A2	10	PPI	0.08	45	315.0	35.0	1.8	203	611.4	546.3	639.7
A3	10	PPII	0.05	45	315.0	35.0	1.2	203	612.0	546.8	640.4
A4	10	SF	0.65	45	315.0	35.0	15	203	611.5	546.4	639.8
B1	15	NF	0.00	45	297.5	52.5	–	203	611.7	546.6	640.0
B2	15	PPI	0.08	45	297.5	52.5	1.8	203	609.9	544.9	638.1
B3	15	PPII	0.05	45	297.5	52.5	1.2	203	610.5	545.5	638.8
B4	15	SF	0.65	45	297.5	52.5	15	203	609.9	545.0	638.2
C1	20	NF	0.00	45	280.0	70.0	–	203	610.2	545.2	638.4
C2	20	PPI	0.08	45	280.0	70.0	1.8	203	608.3	543.6	636.5
C3	20	PPII	0.05	45	280.0	70.0	1.2	203	608.9	544.1	637.2
C4	20	SF	0.65	45	280.0	70.0	15	203	608.4	543.6	636.6

for each series of concrete. All specimens were cured in water at 20 ± 2 °C until the time of testing. At the end of this curing period destructive and non-destructive tests were applied on concrete specimens to determine the mechanical properties of fiber concrete with FA. The FA concretes without fibers are presented as NF in Table 5. In codifying concretes produced, concrete specimens were named as A, B and C, in which 0%, 10%, 15% and 20% of FA was used by replacing cement, respectively. A1, B1 and C1 were described as non-fiber (NF) with FA concrete. A2, B2 and C2 were described as concrete containing PPI fiber with FA. A3, B3 and C3 were described as concrete containing PPII fiber with FA. A4, B4 and C4 were described as concrete containing steel fiber (SF) with FA.

3. Results and discussion

3.1. Workability

Slump tests were carried out to determine the consistency of fresh concrete. Ultrasonic pulse velocity, rebound hummer, resonance frequency, compressive strength, splitting-tensile strength and bending strength tests applied on hardened concrete specimens. Tests results are examined presented and discussed below. The results of slump tests belonging to twelve series of concrete are given in Table 6. It can be seen that slump values of fresh concretes were decreased related to fiber addition of concrete. Therefore, it could be concluded that addition of fibers into the concrete may cause a decrease in workability of concretes. Fibers hindered the flowability of fresh concrete and this caused the decrease in workability of concrete. Studies have reported the decrease in workability of fiber reinforced concrete and suggested that the alternative workability test method for fiber reinforced concrete [19].

3.2. Compressive strength

The results of compressive strength tests of concrete specimens are given in Figs. 2 and 3. The compressive strength of concrete specimens is given on Table 7. It can be seen that compressive strength of concrete produced with fibers were increased compared to concrete produced without fibers. However, there was a decrease of 6% at 28 day compressive strength of cylinder concrete specimen produced with PPII fiber. The compressive strengths of

Table 6
Results of slump test

Series	Slump (mm)	Decrease %	Series	Slump (mm)	Decrease (%)	Series	Slump (mm)	Decrease (%)
A1	70	–	B1	69	–	C1	68.5	–
A2	67	4.28	B2	66	4.34	C2	65	5.11
A3	65	7.14	B3	64	7.24	C3	66	3.65
A4	68	2.85	B4	66	4.34	C4	67	2.19

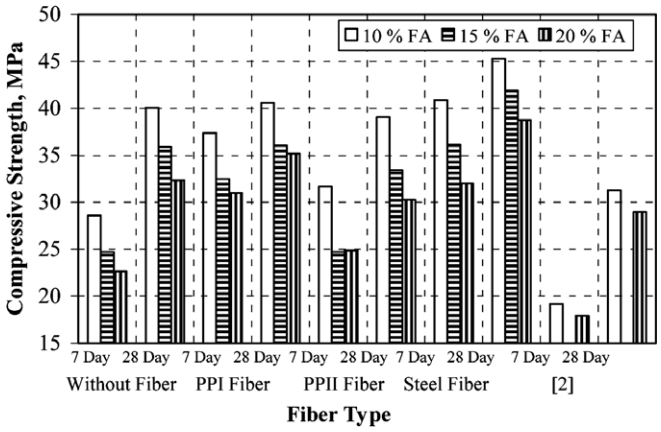


Fig. 2. Cylindrical compressive strength versus fiber type.

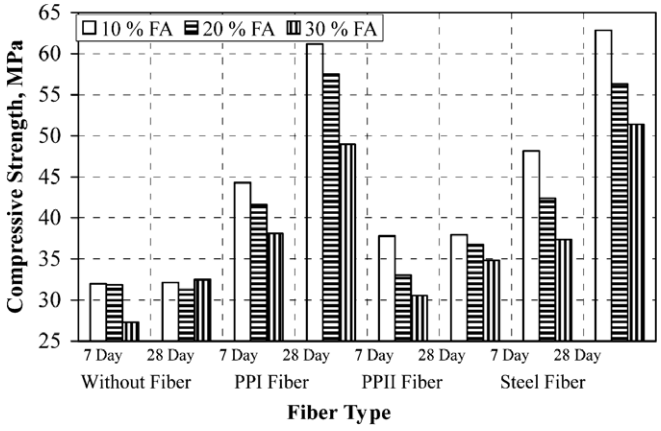


Fig. 3. Cubic compressive strength versus fiber type.

concrete specimens were decreased related to FA content in concrete mixture. On the other hand, compressive strength of non-fiber concrete with different amounts of FA was determined to be higher than that of reference concrete [2]. Under axial loads, cracks occur in microstructure of concrete and fibers reduce the crack formation and development. Thus, compressive strength of concrete increased. Tensile strength of PPII fiber is lower then PPI and steel fibers. For this reason, the adherence and the compressive strength of concrete made with PPII decrease compared to PPI containing concrete. FA retards the strength development of concrete when replace with cements. Therefore, compressive strength of 7 and 28 days concrete specimens were decreased related to FA ratio.

3.3. Bending and splitting tensile strength

The results of bending strength tests of concrete specimens are given in Fig. 4. Relative bending strength of concrete specimens is given on Table 7. It can be seen that bending strength of concrete produced with fibers increased compared to concrete produced without fibers. Table 7 shows that this increase can be 100%. Fig. 4 reveals that bending strength decreases as the amount of FA increases. Under bending loads, tensile stresses occur in microstructure of concrete and fibers withstand this tensile stress, thus, bending strength of concrete increased. Since the FA's binding properties are lower than cement, the

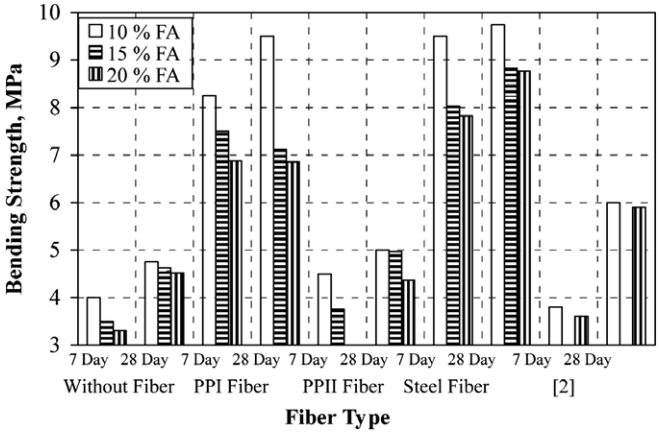


Fig. 4. The change of bending strength versus fiber type.

Table 7
Relative strength of concrete

Series	Relative compressive strength (%)				Relative bending strength (%)		Relative splitting tensile strength (%)
	7 Day cyl.	28 Day cyl.	7 Day cube	28 Day cube	7 Day	28 Day	28 Day
A1	100	100	100	100	100	100	100
A2	131	101	138	190	206	200	130
A3	111	97	118	118	113	105	122
A4	143	113	151	195	238	205	154
B1	86	89	100	97	88	97	99
B2	114	90	130	179	188	150	116
B3	87	83	103	114	94	105	109
B4	126	105	132	175	201	186	139
C1	79	81	85	101	83	95	87
C2	108	88	119	152	172	144	104
C3	87	76	95	108	72	92	96
C4	112	97	117	160	196	185	130

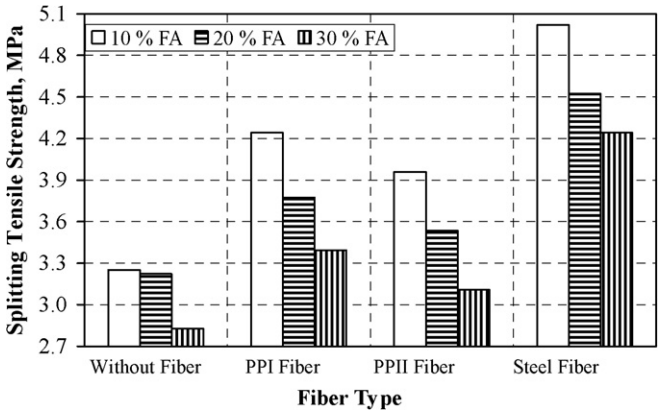


Fig. 5. The change of splitting-tensile strength versus fiber type.

bending strength of concrete produced with FA decreased. The splitting-tensile strength of concrete specimens is given in Fig. 5. Relative splitting-tensile strength of concrete specimens is given on Table 7. A significant increase was determined for the splitting-tensile strength of concrete specimens containing SF fibers. Fig. 5 shows that this increase can range between 10% and 50%. Fibers especially SF fibers make the concrete less brittle and more ductile. Tensile strength of ductile materials is higher than brittle materials.

Results related to resonance frequency test are given in Table 8. There was no significant variation in the resonance frequency of concrete specimens containing fibers. An ultrasonic pulse velocity test is applied to the cylindrical specimens on 28 day after their production. Related values are given in Table 9 and Fig. 6. There was an increase in the ultrasonic pulse velocity of concrete specimens containing PPI and SF fibers. However, as the amounts of FA increases, ultrasonic pulse velocity values decrease. Fibers affected the ultrasonic pulse velocity of concrete positively. There was an average decrease of 3.91% in ultrasonic pulse velocity values in concretes with PPII-fibers. Causes of this decrease in concrete with PPII-fiber are pores inside concrete. Cubic specimens were placed in an axial compression test machine and for each specimen ten Scmidth hammer rebounds were achieved, the results of which are given in Table 10. As shown in Table 10, as the amount of FA increases, compressive strength, determined from rebound number, decreases. Since the pozzolanic reaction of FA occurs and develops later, concrete produced with FA has lower early strength and surface hardness. The increase in compressive strength was about 7.46% for the addition of PPI fibers, while a decrease of 1.18% was detected for the addition of PPII fibers. By the addition of SF fibers,

Table 9
The results of ultrasonic pulse velocity test

Series	Ultrasonic pulse velocity (km/s)	Variation (%)
A1	4.00	–
A2	4.80	20.00
A3	2.99	−5.00
A4	3.09	22.50
B1	3.80	–
B2	4.50	18.42
B3	3.70	−2.63
B4	4.60	21.05
C1	3.65	–
C2	3.90	6.85
C3	3.50	−4.11
C4	4.00	9.59

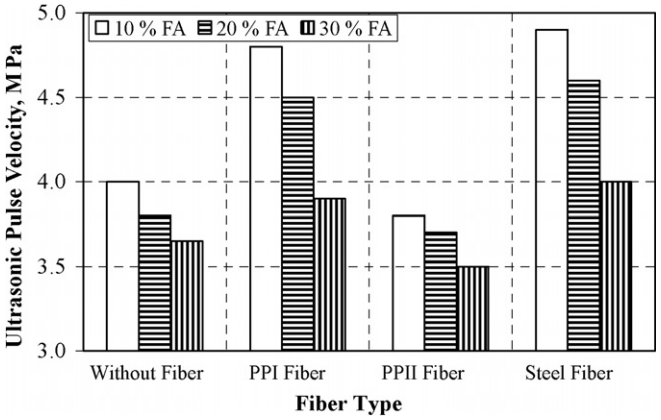


Fig. 6. Ultrasonic pulse velocity versus fiber type.

Table 10
Compressive strength results of determined from Schmidt rebound hammer test

Series	Compressive strength (MPa)	Variation (%)
A1	32	–
A2	36	12.50
A3	33	3.12
A4	37	15.62
B1	31	–
B2	33	6.45
B3	30	−3.22
B4	33	6.45
C1	29	–
C2	30	3.44
C3	28	−3.44
C4	31	6.89

Table 8
Results of resonance frequency test

Series	A1	A2	A3	A4	B1	B2	B3	B4	C1	C2	C3	C4
Resonance frequency (kHz)	3.07	3.08	2.99	3.09	3.04	3.05	3.00	3.10	3.02	3.10	3.01	3.11
Variation, %	–	0.32	−3.70	0.65	–	0.32	−2.40	1.97	–	2.65	−0.33	2.98

there was an increase of 9.65% in the compressive strength. Fibers withstood the stress which is occurred when the impact were achieved on concrete. Therefore, fibers increased compressive strength, determined from rebound number.

4. Conclusions

In this paper, the influence of fly ash and fibers (steel fiber and plastic polypropylene) were experimentally investigated. Fibers are causing a 2–8% decrease in the workability of concrete. Conversely, the workability is kept in constant for the addition of FA. The maximum amount of FA in concretes is limited to 25%. In studies 15% is advisable. When costs are considered for the usage of 15% FA replacing cement, up to 7% savings are gained. The decrease in the compressive strength is observed due to the FA replacement. However, increment in compressive strength of concrete is observed up to 90%, 18% and 95% for PPI, PPII and steel fibers respectively. In bending strength, decrements are seen for FA replacement ratio at about the level of 12%. However, increases in compressive strength of concrete were observed up to 114%, 1% and 130% for PPI, PPII and steel fibers respectively. In splitting-tensile strength, decrements are also seen for FA concrete; but fiber addition provides increments. Especially, increments in steel fiber reinforced concretes are noticeable as 54%. A decrease was determined in ultrasonic pulse velocity and resonance frequency values for addition of fibers. It can be suggested that fiber reinforced FA concrete can be used in precast infrastructure components due to both of its improving the mechanical properties by fibers and beneficial effect of fly ash on other properties of concrete.

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