DURABILITY PERFORMANCE AND DIMENSIONAL STABILITY OF POLYPROPYLENE FIBER REINFORCED CONCRETE

Ali Mardani-Aghabaglou,[1*] Süleyman Özen[1] and Muhammet Gökhan Altun[1]

ABSTRACT

In this study, the durability performance and dimensional stability of polypropylene fiber reinforced concrete mixture were investigated. For this purpose, two series of concrete mixtures, including a 0.45 water/cement ratio was prepared both in the absence and presence of fiber. A CEMI 42.5 R type portland cement and crushed limestone aggregate with a maximum particle size of 25 mm were used. In addition to the control mixture without fiber, three different concrete mixtures were prepared by adding polypropylene fiber as 0.4%, 0.8% and 1% of total volume into the mixture. The time-dependent fresh state properties, strength, ultrasonic pulse velocity, transport properties, drying shrinkage and freeze-thaw resistance of concrete mixtures, sodium sulfate attack and abrasion were investigated comparatively. Test results demonstrated that utilization of fiber affected the fresh properties of the concrete mixtures negatively. However, the 0.8% fiber-bearing mixture showed the highest performance in terms of durability and dimensional stability. Beyond this utilization ratio, the durability performance of the concrete mixture was negatively affected. The risk of nonhomogeneous dispersion of the fiber in the mixture was relatively high in the excess fiber-bearing mixture. Consequently, with the formation of flocculation in the mixture the void ratio of concrete mixture increased.

KEYWORDS

fresh properties, durability performance, dimensional stability, polypropylene fiber reinforced concrete

1. INTRODUCTION

High-performance concrete is widely used for building construction due to its advanced mechanical properties and durability performance. The term, high-performance concrete, describes concrete mixtures with high workability, strength, and durability, as well as low shrinkage and creep [1–3]. As expected, the brittleness of concrete increases with the increase of its strength

1. Department of Civil Engineering, Uludag University, Nilufer-Bursa, Turkey (*corresponding author: ali.mardani@gmail.com).

[4]. Consequently, tensile and flexural strengths of concrete members and their energy absorption capacity decrease [5–7]. Several methods are introduced in order to improve the ductility of the concrete [4]. Utilization of discontinuous fibers is known as one of the most efficient methods to improve the ductility of concrete members [8, 9]. Addition of fibers modifies the nonlinear behavior of structural concrete, especially its tensile strength, prevents the formation and propagation of cracks, and increases its ductility [10–14].

Fibers with various shapes and sizes produced from steel, glass, plastic or polypropylene can be employed in structures successfully [7]. Polypropylene fibers show a tendency to more likely exist in the concrete area compared to other polymer fibers [15–19].

Polypropylene, used as a synthetic textile material, is a by-product of the petroleum industry. It is produced at a lower cost compared to polyester. Moreover, it can be used as an alternative to plastic and it is also a material that dissolves in water and has a very low water absorption capacity. However, the dissolution of polypropylene in the soil causes environmental pollution [20].

Mardani-Aghabaglou et al. [6] reported that the use of fiber up to a certain ratio in concrete mixtures positively affected their permeability properties and the dimensional stability. Consequently, the performance and service life (durability) of concrete mixtures are also positively affected. The utilization of different types and lengths of polypropylene fibers in concrete mixtures has increased recently. Therefore, polypropylene fibers, which can cause problems in terms of environmental pollution, are used as a performance-enhancing material in concrete mixtures. Various waste materials that are harmful to the environment occur when the service-life of a completed concrete structure is demolished. In addition to the decrease in the amount of waste materials resulting from the demolition of cement-based structures due to their long service-life, the consumption of cement can also be considerably reduced. The cement dosage can also be reduced considerably without compromising the concrete strength when a water-reducing admixture compatible with cement is selected [21].

Recall that for 1 ton of cement production roughly 1.2 tons of raw materials and about 130 kWh of energy are needed. Furthermore, roughly 1-ton CO_2 will also be emitted [22]. Therefore, potential environmental problems will be reduced due to the decrease in consumption of cement.

Some related studies are summarized below:

The fire resistances of concrete mixtures containing polypropylene or steel fibers were analyzed by Serrano R. et al. [23]. Test results demonstrated that the use of both fibers increased the strength and fire resistance of concrete. Plastic shrinkage and permeability of polypropylene fiber reinforced concrete were investigated by Islam G.S. and Gupta S.D. in another study [5]. According to their test results, the shrinkage behavior of the concrete mixture was improved by using fiber. However, the authors claimed that addition of the polypropylene fiber increased both the water and gas permeability coefficients.

In the other study, the effects of polypropylene fiber utilization on the mechanical and transport properties of recycled aggregate-containing concrete mixture was investigated by Akça et al. [24]. For this purpose, different concrete mixtures were prepared by using fiber at 0%, 1% and 1.5% by volume. Test results showed that the flexural properties of concrete mixtures were increased with the addition of fiber up to 1%. Beyond this ratio, no significant effect was observed in the mentioned properties.

In a similar study, Mohammadhosseini et al. [25] investigated the impact resistance and mechanical properties of concrete reinforced with waste polypropylene carpet fibers. With this aim, six volume fractions varying from 0 to 1.25% of 20-mm-long carpet fires were used. In addition to the control mixture containing ordinary portland cement as binder, a mixture was prepared by replacing 20% cement with palm oil fuel ash. According to the test results, the workability of the concrete mixture was negatively affected by the presence of fiber and increase of fiber content. Fiber use showed no significant effect on the compressive strength of the concrete mixture. However, tensile and flexural strengths, as well as the impact resistance of the concrete mixture, increased with the addition of fiber into the mixtures. Compared to the control mixture, the mixture with palm oil, fuel ash showed better performance in terms of ultimate compressive strength.

The research literature reveal various studies on the mechanical properties and shrinkage behavior of polypropylene fiber containing mixtures [26–31]. However, the literature does not have adequate studies about the durability performance of concrete mixtures with polypropylene fibers.

In this study, the fresh properties involving strength, ultrasonic pulse velocity, transport properties, sulfate attack, drying shrinkage, abrasion and freeze-thaw resistance of a concrete mixture containing 0–1% of polypropylene fiber by volume were investigated.

2. MATERIALS, MIX PREPARATION AND TEST PROCEDURES

2.1 Materials

In this study, an ordinary portland (a CEM I 42.5 type) cement with a specific gravity of 3.11, conforming to EN 197-1 standard was used as a binder. The chemical composition, physical and mechanical properties of the cement provided from its manufacturer are given in Table 1 and Table 2, respectively.

TABLE 1. Chemical composition of cement.

Item	(%)
SiO_2	20.06
Al_2O_3	5.68
Fe_2O_3	2.23
CaO	64.09
MgO	1.45
K_2O	0.93
Na_2O	0.29
SO_3	3.09
Cl^-	0.0064
Loss on ignition	1.74

TABLE 2. Physical and Mechanical Properties of cement.

Physical properties		
Specific gravity		3.11
Blaine specific surface (cm^2/g)		3362
Residual on 0.090 mm sieve (%)		0.7
Residual on 0.032 mm sieve (%)		—
Mechanical properties		
Compressive strength (MPa)	2-day	25.4
	7-day	37.2
	28-day	44.6

The physical properties of crushed limestone aggregates used for preparing the concrete mixtures are presented in Table 3. The specific gravity and water absorption capacity of the aggregates were determined according to the EN 1097-6 standard. As seen in Table 3, the water absorption capacity of the aggregates ranged from 0.27% to 0.33%.

Sieve analysis of aggregates was performed in accordance with the EN 206+A1 standard. The gradation curve of aggregates is shown in Figure 1. The gradation of combined aggregate was obtained by mixing 60% 0–5 mm, 20% 5–15 mm and 20% 15–25 mm aggregate size fractions (by mass) and were confirmed with EN 206+A1 standard gradation limits.

A 0.5x1.15x5 mm prismatic polypropylene fiber was used in the mixtures with fiber. The density and tensile strength of the fiber were determined by the manufacturer as 0.92 g/cm^3 and 400–600 N/mm^2, respectively.

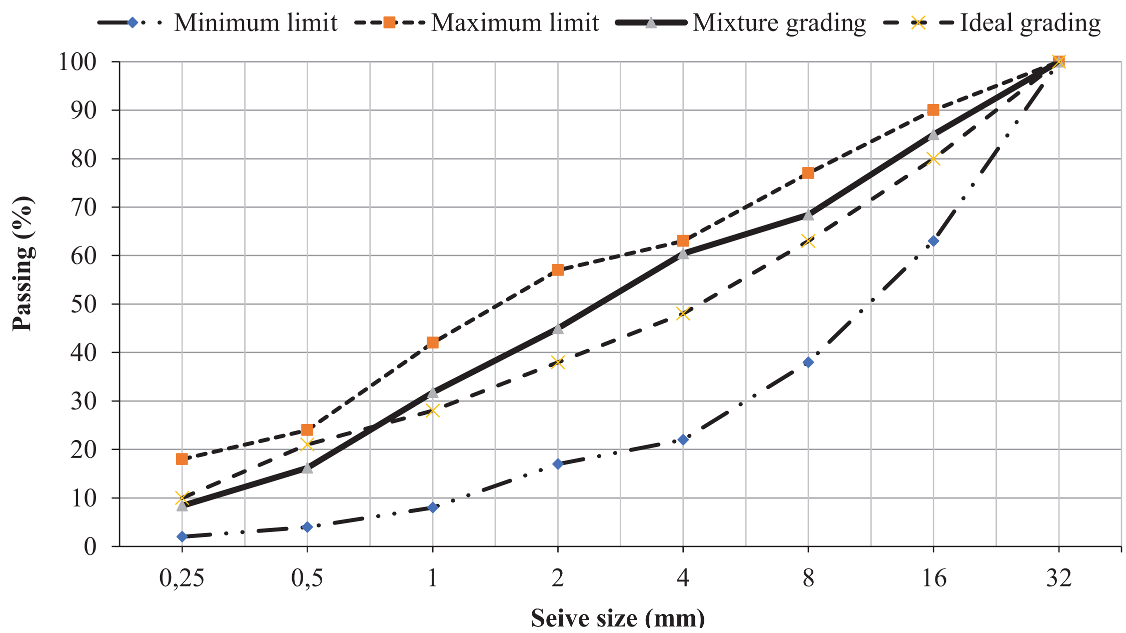
2.2 Mixture preparation

In addition to the control mixture, three different concrete mixtures were prepared by using polypropylene fiber at 0.4%, 0.8% and 1% by volume. The water/cement ratio, cement content, and slump values were kept constant in all concrete mixtures as 0.45, 350 kg/m^3 and 130±10 mm, respectively. A polycarboxylate-ether based high range water reducing (HRWR) admixture was used to provide the desired slump values of concrete mixtures. All theoretical and corrected

TABLE 3. Physical properties of aggregates.

Aggregate		Bulk SSD specific gravity	Absorption capacity (%)	Loose bulk density (kg/m^3)
Type	Size (mm)			
Limestone	0–5	2.72	0.27	1694
	5–15	2.68	0.33	1486
	15–25	2.68	0.32	1391

FIGURE 1. Gradation curve of combined limestone aggregate and EN 206+A1 [32] standard limits.



concrete mix proportions for 1 m^3 are given in Table 4-a and Table 4-b. As seen from Table 4, the HRWR admixture requirement to provide the desired slump values of the concrete mixtures increased by using polypropylene fiber. For example, compared to the control mixture without fiber, a two times higher amount of HRWR admixture was used in the 1% fiber-bearing concrete mixture in order to ensure the desired slump value. Compared to the control mixture, the unit weights of the polypropylene fiber-bearing mixtures decreased due to the lower density of the fiber than those of the other concrete components.

TABLE 4-A. Mix proportions of the concrete mixtures.

Mix	Cement (kg)	Water (kg)	Aggregate (mm) 0–5 (kg)	Aggregate (mm) 5–15 (kg)	Aggregate (mm) 15–25 (kg)	Fiber (kg)	HRWRA* (kg)	Slump (mm)	Unit Weight (kg/m^3) Theoretical	Unit Weight (kg/m^3) Measured
Control	350	158	1161	382	382	0	4	135	2437	2418
C-0.4%Fb	350	158	1154	379	379	3.7	4.6	130	2428.3	2401
C-0.8%Fb	350	158	1143	376	376	7.4	6	135	2416.4	2382
C-1%Fb	350	158	1138	374	374	9.2	8	125	2411.2	2364

* High range water-reducing admixture

TABLE 4-B. Corrected mix proportions of the concrete mixtures.

Mix	Cement (kg)	Water (kg)	Aggregate (mm)			Fiber (kg)	HRWRA* (kg)
			0–5 (kg)	5–15 (kg)	15–25 (kg)		
Control	347	157	1152	379	379	0	4.0
C-0.4%Fb	346	156	1141	375	375	3.7	4.5
C-0.8%Fb	345	156	1127	371	371	7.3	5.9
C-1%Fb	343	155	1116	367	367	9.0	7.8

* High range water-reducing admixture

2.2 Test procedures

Within the scope of the study, 192 concrete samples were prepared in the absence and presence of fiber. The samples were cured in water at standard conditions until the testing day.

Strength and ultrasonic pulse velocity (UPV)

The compressive strength, splitting tensile strength and ultrasonic pulse velocity (UPV) of 150 mm cube specimens, as well as the center-point flexural strength of 100x100x600 mm prism specimens, were determined in accordance with EN 12390-3, EN 12390-6, ASTM C597 and EN 12390-5 standards, respectively.

Transport properties

The 28-day water absorption capacity, permeable void content and the water penetration depth under the pressure of 150 mm cube specimens were determined in accordance with the TS 3624 and EN 12390-8 standards. Absorption after immersion (m_1), absorption after immersion and boiling (m_2) and permeable void contents (B_o) of hardened concrete specimens were calculated according to Equations 1 and 3,

$$m_1 = \frac{b-a}{a} \times 100 \qquad [1]$$

$$m_2 = \frac{c-a}{a} \times 100 \qquad [2]$$

$$B_o = \frac{c-a}{c-d} \times 100 \qquad [3]$$

where (a) is the oven dry weight of the sample, (b) is the saturated dry surface weight of the sample, (c) is the saturated dry surface weight after boiling the sample and (d) is the weight of the sample in the water.

Sulfate attack

The sulfate resistances of the concrete mixtures were calculated according to the ASTM C1012 standard on the 75x75x285 mm prism specimen. For this purpose, the concrete samples were immersed into 5% sodium sulfate solution after a 28-day standard water curing. The length changes of the concrete mixtures were calculated every 30 days up to 180 days as shown in Eq. 4,

$$\Delta L = \frac{L_1 - L}{250} \times 100 \qquad [4]$$

where ΔL is the percentage of expansion of the specimen, L_1 is the initial length of the specimen after the curing and L represents the length of the specimen in the following days.

Drying-shrinkage

Three 25x25x285 mm prism specimens were produced for each series in order to investigate the drying shrinkage behavior of concrete mixtures. The specimens were stored at 20°C for approximately 24h and then were cured in lime-saturated water at 20°C for about 48h. Afterwards, the specimens were kept in the room, where the temperature and relative humidity were 20°C and 55%, respectively, until the testing day. The length change of the concrete samples was recorded every 5 days up to 60 days in accordance with the ASTM C596 by using Eq. 5,

$$S = \frac{L_1 - L}{L_0} \times 100 \qquad [5]$$

where S is the percentage for shrinkage of the sample, L_1 is the initial length of the sample after the curing, L is the length of the specimen in the following days and L_0 is the effective length (250 mm).

Abrasion resistance

The 28-day abrasion resistance of the concrete mixtures was measured on 71 mm cube specimens by using a Bohme test apparatus. The specimens were dried in an oven at 50°C until the stabilization of their weights. The initial weights of the specimens were recorded. The Bohme test apparatus consists of a 750-mm diameter steel disc, rotating at a speed of 30 ± 1 rpm, a counter and a lever, which can apply a load level of 300 N on the specimens. At the beginning of the test, 20 ± 0.5 g of abrasion dust was spread on the disc, the specimens were placed, the load was applied to the specimen and the disc was rotated for 90 cycles. Then the surfaces of the disc and the specimen were cleaned. The same procedure was repeated for 4 periods up to 360 cycles. The total mass changes were measured in the end.

Freeze-thaw resistance

The applied method in this study was the fast freeze-thaw method. The samples were frozen in air and thawed in water. The freezing and thawing temperatures of samples were adjusted at 18°C ± 2°C and 15°C ± 2°C temperatures, respectively, according to the ASTM C666 standard. The freezing time (the time from maximum temperature to minimum temperature) was set as 180 minutes, and the thawing time (the time from minimum temperature to maximum temperature) was set as 60 minutes. Hence, each freeze-thaw cycle was set as 240 minutes in total.

The specimens were exposed to 300 freeze-thaw cycles. A mass change of concrete mixtures for every 30 cycles was recorded in accordance with the TS 3699 standard.

3. TEST RESULTS AND DISCUSSION

Strength

The compressive, splitting tensile and flexural strength of concrete mixtures are shown in Tables 5 and 6. Each value was determined by calculating the average of 3 different specimens. According to the test results, the use of polypropylene fiber in the concrete mixture affected the 1-day compressive strength of mixtures negatively. This negative effect became more obvious with the increase in fiber utilization rate. It can be seen from Table 4 that the workability of concrete mixtures was affected negatively from the use of polypropylene fiber. In these mixtures, more water-reducing admixture was used than that of the control mixture in order to provide the desired slump value. The apparent reduction in 1-day strengths of concrete mixtures is believed to be occurring due to the late setting of mixtures containing more water-reducing admixture. This proves that the C-1% Fb mixture was not set in one day after the casting. This mixture contains water-reducing admixture up to 2.3% of the cement weight and polypropylene fiber as 1% of the total volume. The 1-day compressive strengths were not affected negatively from the use of 0.4% and 0.8% fiber by volume. According to the 28-day compressive strength values, the mixtures of C-0.4% Fb and C-0.8% Fb showed higher strengths as 3.61% and 6.73%, respectively, compared to the control mixture. However, the use of 1% fiber of the

TABLE 5. Compressive strength of concrete mixtures (MPa).

Mix	1-day	3-day	7-day	28-day
Control	12.2	20.4	34.2	41.6
C-0.4%Fb	11.3	20.2	33.4	43.1
C-0.8%Fb	6.1	18.6	32.5	44.4
C-1%Fb	—	14.8	30.5	38.9

TABLE 6. Splitting tensile and flexural strength of the concrete mixtures (MPa).

Mix	Splitting Tensile Strength (MPa)		Flexural Strength (MPa)	
	7-day	28-day	7-day	28-day
Control	3.15	4.06	3.82	4.95
C-0.4%Fb	3.92	4.12	3.99	5.12
C-0.8%Fb	4.64	5.72	4.96	6.21
C-1%Fb	2.88	4.04	3.80	4.92

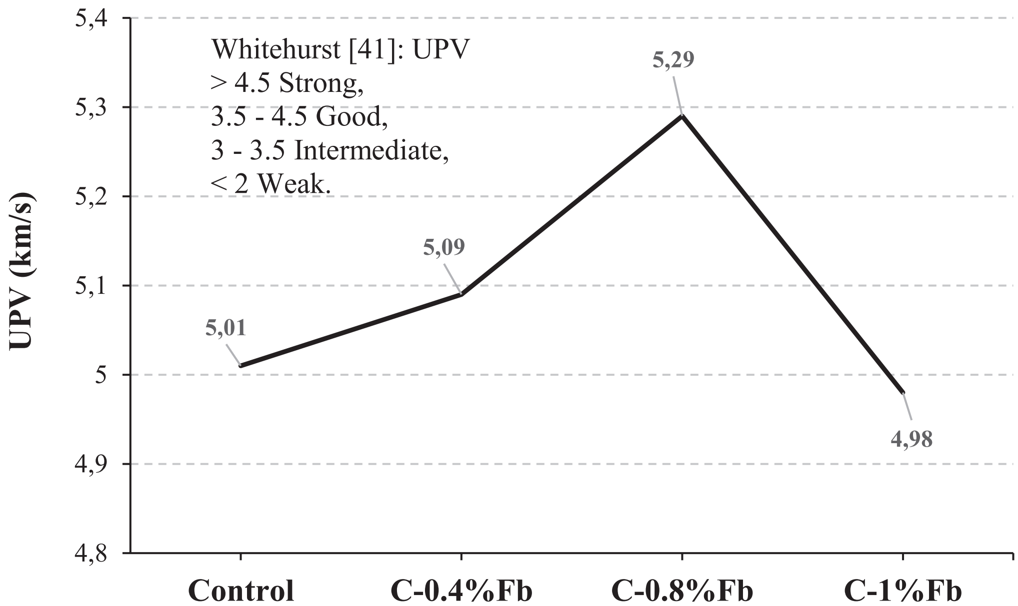
total volume affected compressive strengths for all ages negatively. The 3-day, 7-day and 28-day compressive strengths of the C-1% Fb mixture were lower in comparison with the control mixture as 27.45%, 10.81% and 6.49%, respectively. These results are thought to be due to the reduction in differences among the strength values caused by the late setting of mixtures and the disappearance of this effect in the course of time. Researchers emphasized that using fiber in concrete mixtures affects the compressive strength of concrete mixtures both positively [32–35] and negatively [5, 36]. In this study, the use of fiber up to a certain ratio affected compressive strength of mixtures positively. The fiber usage is thought to be preventing the lateral deformation of the specimen under a pressure load and consequently restraining the development of cracks, reducing stress concentration at the tip of cracks, changing the crack direction, and retarding the crack opening [37, 38]. Beyond 0.8% the fiber utilization compression of concrete mixtures is reduced. Islam and Gupta [5] claimed that the utilization of fiber beyond a certain content in the concrete mixtures creates more of an Interfacial Transition Zone that might affect the compressive strength negatively. Besides, the agglomeration and pore formation resulting from excessive fiber in the mixture is believed to cause reduction in the compressive strength of mixtures [39].

As shown in Table 6, the use of polypropylene fiber, in general, contributed to the splitting-tensile strength of the concrete mixtures. While the 7-day splitting-tensile strength of C-1% Fb concrete mixture was 8.57% lower than that of the control mixture, no significant decrease in the 28-day splitting tensile strength of this mixture was observed. The mixture containing 0.8% fiber by volume gave the best result in terms of splitting tensile strength. The 7-day and 28-day splitting tensile strengths of the C-0.8% Fb mixture were 47.30% and 40.89% higher than that of the control mixture, respectively. The 7-day and 28-day flexural strengths of mixtures containing polypropylene fiber as 0.4% and 0.8% by volume are higher in comparison with the control mixture. Although there was no increase in the 7-day and 28-day flexural strengths of the C-1% Fb mixture containing 1% of fiber by volume, no significant reduction occurred for these strengths. C-0.8% Fb concrete mixture showed the highest flexural strength as well as splitting-tensile strength. The 7-day and 28-day flexural strengths of the C-0.8% Fb mixture were higher than that of the control mixture at 29.84% and 25.45%, respectively. It is known that the flexural strengths, tensile strengths and energy absorption capacities of concrete mixtures increase with respect to different mechanisms depending on the fiber length. The use of micro-sized fiber improves the flexural and tensile strength of the concrete by preventing the development of cracks caused by loading. Yazici et al., [31] stated that control samples containing no fiber were fractured according to brittle behavior, whereas fibrous sample were fractured according to ductile behavior. They also noted that polypropylene fiber dispersed within the matrix in three dimensions, thereby limiting the development of cracks by transferring tension, although to a lesser extent than steel fibers. However, the use of macro-sized fiber increases energy absorption capacity by debonding from the concrete specimen during crack formation [40].

Ultrasonic pulse velocity (UPV)

The 28-day ultrasonic pulse velocity test results are shown in Figure 2. Each value was determined by calculating the average of 3 different specimens. As shown in Figure 2, the addition of polypropylene fiber up to 0.8% by volume increased the UPV values of concrete mixtures. The UPV values of C-0.4% Fb and C-0.8% Fb mixtures are 1.60% and 5.59% higher than that of the control mixture. Figure 2 reveals that the use of polypropylene fiber as 1% of the total

FIGURE 2. UPV values of concrete mixtures.



volume in concrete mixture showed no negative effect on the UPV values of this mixture compared to the control mixture. As explained in the test results, the use of excessive fiber increases the risk of agglomeration in the mixture. Besides, according to the classification proposed by Whitehurst [41], the UPV values of all concrete mixtures produced within the scope of this study are higher than 4.5 km/h, which is the limit for strong concrete.

Transport properties

The water absorption and void ratios of the concrete mixtures are given in Figures 3 and 4. It is shown in Figure 3 that the water absorption ratio of all concrete mixtures is less than 3%. Therefore, all concrete mixtures belong to a good concrete class according to the recommended classification by CEB-FIP [42] for the water absorption of concrete mixtures. As expected, the water absorption values obtained by boiling concrete mixtures are above the normal water absorption values of mixtures. The water absorption and void ratios of the concrete mixtures with polypropylene fiber were reduced compared to those of the control mixture. The maximum reduction was observed in the concrete mixture containing 0.8% fiber by volume. An increase in the water absorption and void ratios of the mixtures was noticed with the use of 1% fiber in the concrete mixture. Void ratios of C-0.4% Fb, C-0.8% Fb and C-1% Fb mixtures were less by comparison with the control mixture of 4.86%, 20.36% and 0.61%, respectively.

Penetration depth values of water under the pressure of concrete mixtures are shown in Figure 5. Each value was determined by calculating the average of 3 different specimens. As seen from the results, the penetration depth of the water under pressure of the mixtures decreased by nearly 50% with the addition of polypropylene fiber at 0.8% of the total volume in the mixture. It is thought that the decrease in penetration depth of water results from two different factors. These factors can be explained as the prevention of crack development caused by shrinkage in concrete mixture containing fiber during drying and as the improvement of the

FIGURE 3. Water absorption values of concrete mixtures after immersion (m_1) and after immersion & boiling (m_2).

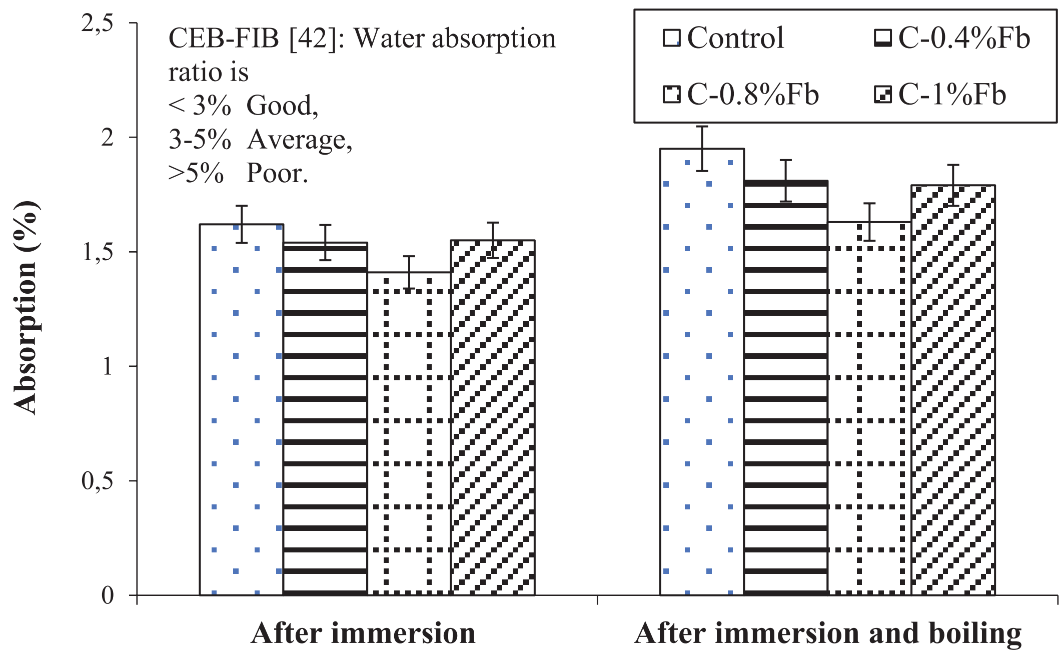
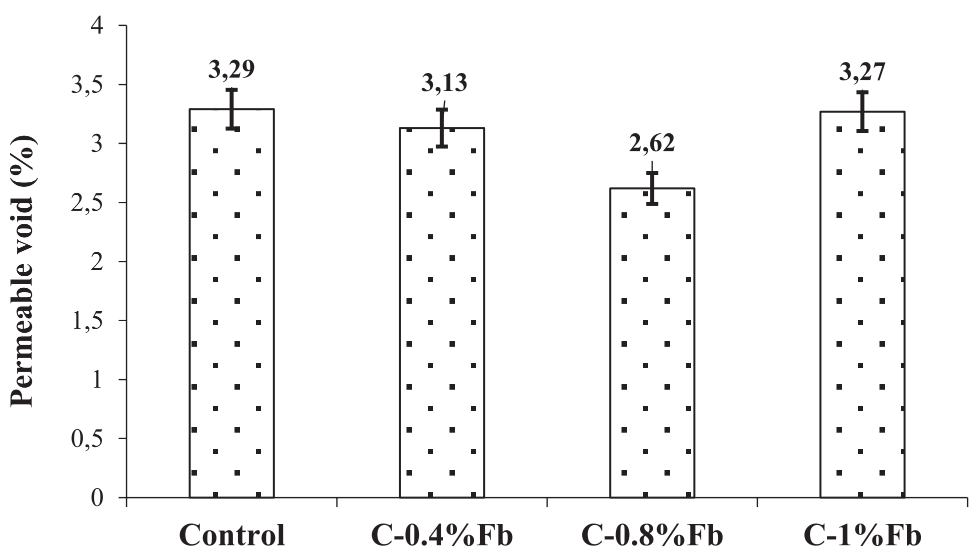


FIGURE 4. Permeable void contents of concrete mixtures (B_o)



paste phase adherence with the use of fiber. On the other hand, when fiber was used as 1% of the total volume, the penetration depth of the water under pressure in mixtures increased. It is known that the risk of nonhomogeneous dispersion of the fiber in the mixture is relatively high in excess fiber-containing mixtures. This situation may cause flocculation in the mixtures. Thus, the void ratio of the mixtures may increase. Besides, Afroughsabet and Ozbakkaloglu

[32] emphasized that the addition of high amounts of polypropylene fiber in a mixture results in an increase in transition zone thickness and porosity. As a result, the water absorption rates also increase. The decrease in the strength values of this mixture might be the evidence of this claim. Figure 6 shows that there is a strong polynomial relationship between penetration depth of the water under pressure and the void ratio of the mixtures. The fiber added into the mixtures caused a change in the void ratio of the mixtures. Increasing the amount of fiber up

FIGURE 5. Depth of penetration of water under pressure of concrete mixtures.

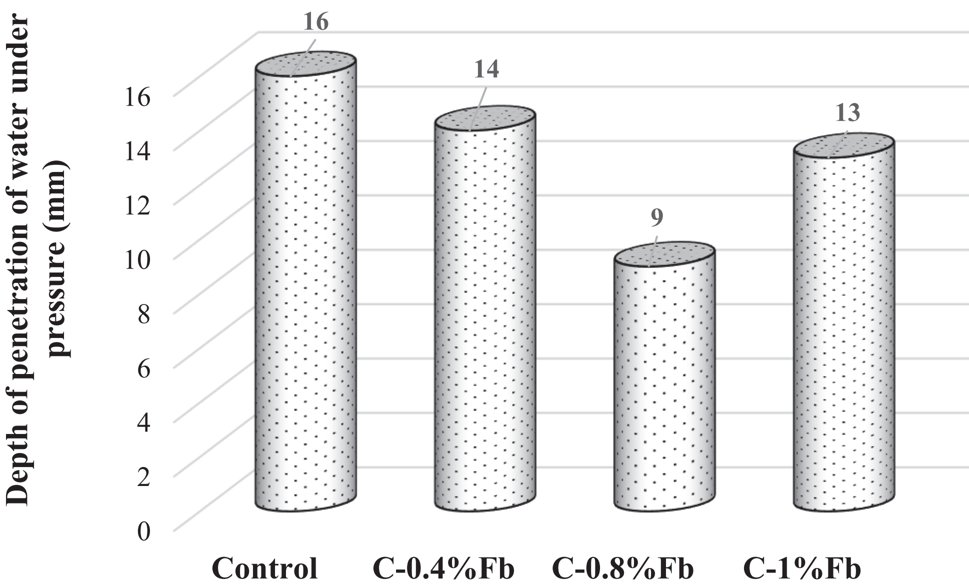
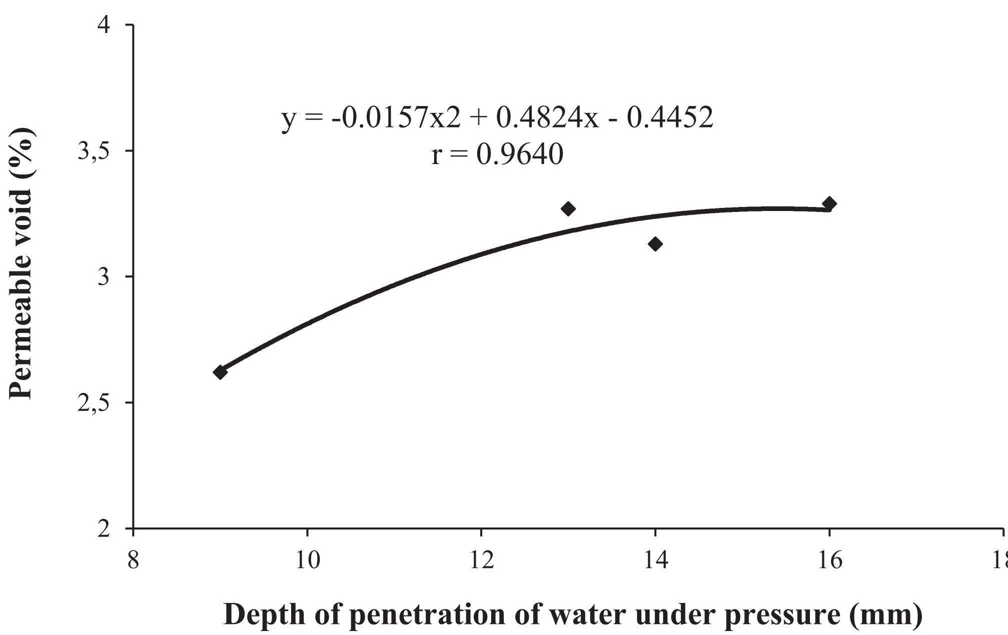


FIGURE 6. Relationship between permeable void and depth of penetration of water under pressure of concrete mixtures.



to 0.8% reduced the permeable voids. Thus, a reduction in the penetration depth of the water was noticed. However, the permeable void ratio of the C-1% Fb mixture was determined to be higher than that of the C-0.8% Fb mixture. In this regard, the C-0.8% Fb mixture with the lowest void ratio held the lowest penetration depth of water under pressure compared to those of the other mixtures.

Sulfate attack

The expansion and relative expansion values of the concrete mixtures are shown in Figures 7 and 8. Each value was determined by calculating the average of 3 different specimens. As shown in Figure 7, the use of polypropylene fiber up to 0.8% by volume in the mixtures caused a decrease in the expansion values. However, it was stated that the increasing fiber ratio in the mixtures to 1% showed no significant effect on the expansion amount of the concrete mixture. Within the first 30 days after production, the expansion values of all mixtures were close to each other. Significant differences in expansion between mixtures occurred especially after 60 days. The C-0.8% Fb mixture was the most resistant mixture in terms of the performance against sulfate attack. Figure 8 shows that the expansion value of this mixture was determined to be approximately 25% lower than that of the control mixture. These reductions in expansion are thought to be arise from the improvement in the permeability performance of the mixtures and increase in adherence of the paste phase with the use of fiber.

Drying-shrinkage

Drying shrinkage and relative shrinkage values of concrete mixtures after 60-days exposure to drying-shrinkage are shown in Figures 9 and Figure 10. A major change in terms of length was observed in all of the mixtures during the first 10 and 20 days after production. A significant length change was not clearly seen in the mixtures after 20 days. Drying shrinkage of the mixtures were reduced by using fiber and increasing the ratio of fiber in mixtures. The C-0.8%

FIGURE 7. Expansion values of the concrete mixtures immersed in Na_2SO_4 solution.

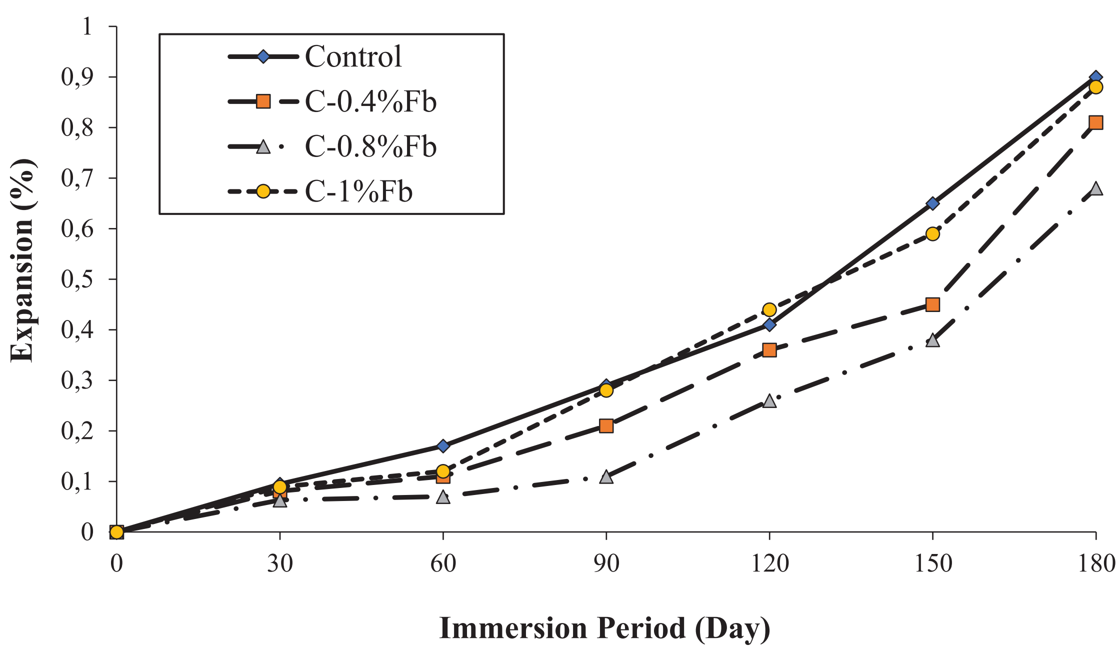
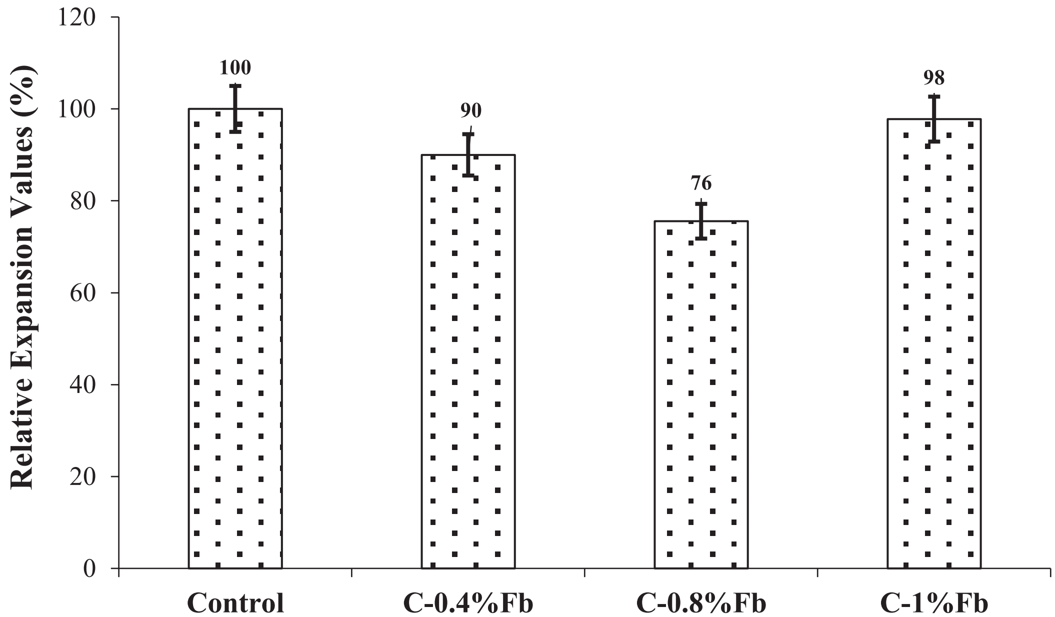
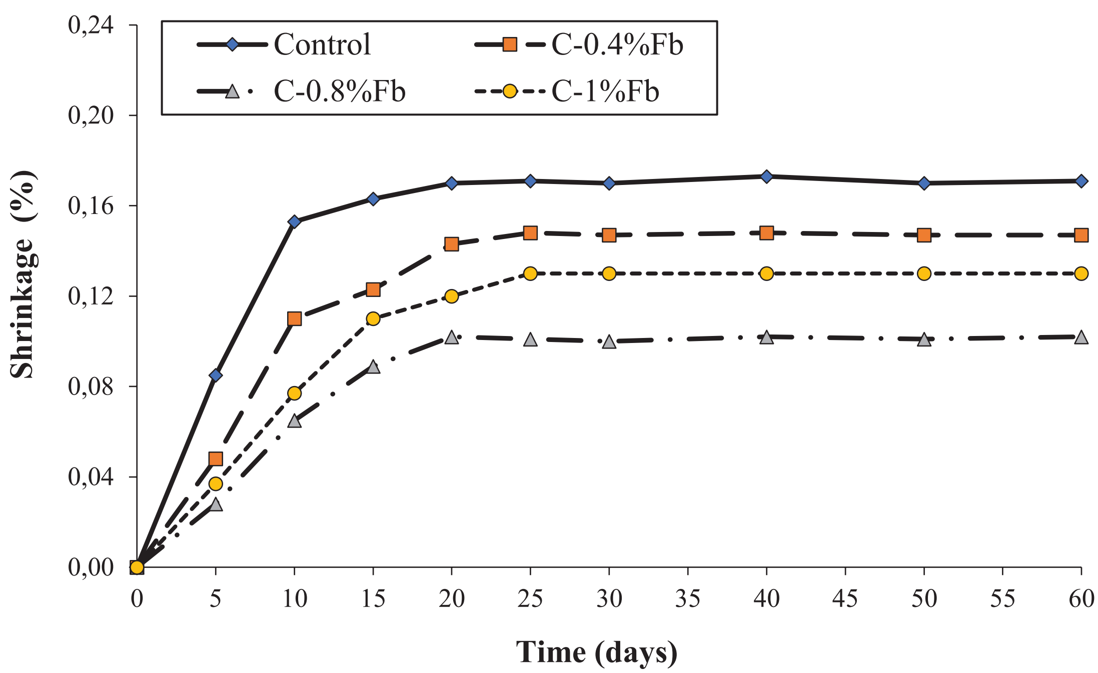


FIGURE 8. Relative expansion values of the concrete mixtures at the end of 180-day immersion.



Fb mixture shows the best performance in terms of shrinkage behavior. The shrinkage of this mixture is recorded as 40% lower than that of the control mixture. The shrinkage values of the C-0.4% Fb and C-1% Fb mixtures are lower by comparison with the control mixture as 14% and 24%, respectively. It is known that shrinkage occurs in the paste phase in concrete mixtures. If the stresses occurring in the concrete due to the shrinkage exceed the tensile

FIGURE 9. Drying-shrinkage of concrete mixtures.

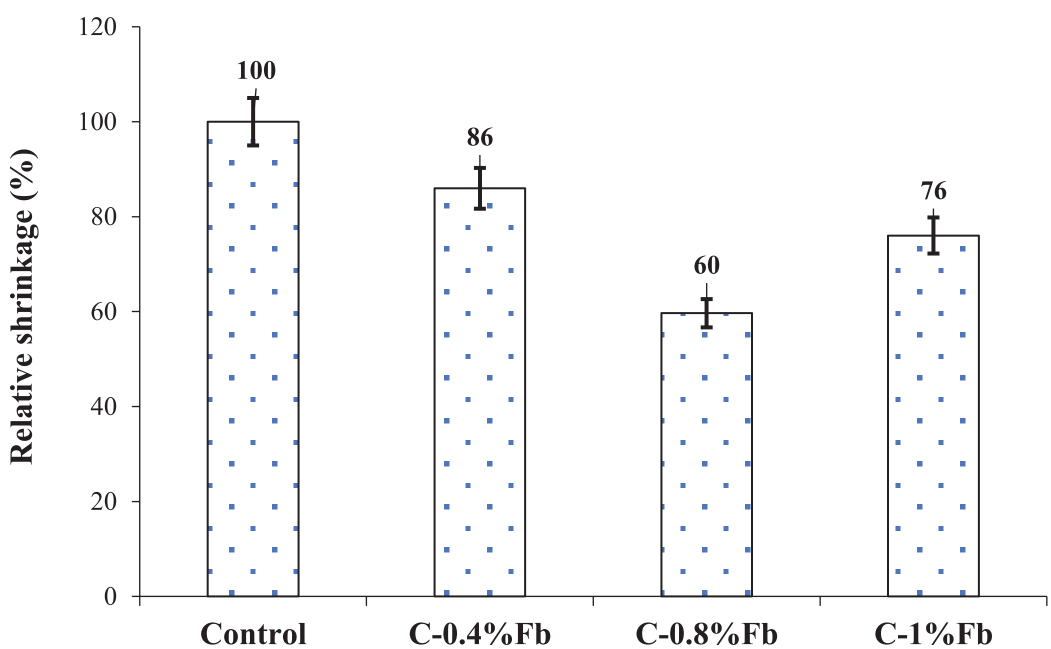


strength of concrete, then shrinkage cracks will probably be formed in the concrete [7]. If the interfacial transition zone (ITZ) of aggregate-paste is strong, then crack formation is prevented. Adherence in cement paste increases with the use of fiber in mixtures [26]. Accordingly, the shrinkage of the mixture reduces with the use of fiber. Thus, the development of cracks resulting from shrinkage can be prevented. Besides, the permeability properties of concrete mixtures are affected adversely owing to the increase in shrinkage cracks [43]. Shrinkage in concrete mixtures is known to result from water movement in the concrete, which is from micro-pores into the macro-pores, and hence the water loss in the concrete. It was previously emphasized that the use of fiber in concrete mixtures produced within the scope of this study showed a positive effect on the permeability properties of concrete mixtures. The drying shrinkage value of the C-1% Fb mixture containing polypropylene fiber as 1% by volume was nearly 20% higher than that of the C-0.8% Fb mixture. Similar results were also obtained in the permeability properties.

Abrasion resistance

The mass loss values resulting from the abrasion of concrete mixtures within 90, 180, 270 and 360 cycles are shown in Figure 11. As expected, the mass loss of concrete mixtures increased with the increase in the number of abrasion cycles. This mass loss was more obvious after 90 abrasion cycles. The mass loss due to the abrasion of concrete mixtures was decreased with the use of fiber and the increase in the fiber ratio. As shown in Figure 12 at the end of 360 cycles, the abrasion resistance of the mixtures containing fiber increased to 12–22% compared with the control mixture. This can also be observed in other experiments that the C-0.8% Fb mixture shows the best performance in terms of abrasion resistance. The increase of abrasion resistance of the concrete with fiber is thought to arise from the improvement of ITZ and the increase of compressive strength of the concrete mixtures. Figure 13 shows that there is a relationship between the compressive strength and the abrasion resistance of concrete mixtures.

FIGURE 10. Relative drying shrinkage of concrete mixtures after 60 days exposure to drying-shrinkage.



Similar results were also expressed by other researchers [44–49]. However, up to a 1% of fiber content increase affected the abrasion resistance negatively compared to the C-0.8% Fb mixture. It is believed that the excessive amount of fiber prevents the homogeneous distribution of the fibers in the mixtures. Therefore, the number of pores in the mixture increases and the ITZ weakens.

FIGURE 11. Mass loss (%) of concrete mixtures during exposed to 360 abrasion cycles.

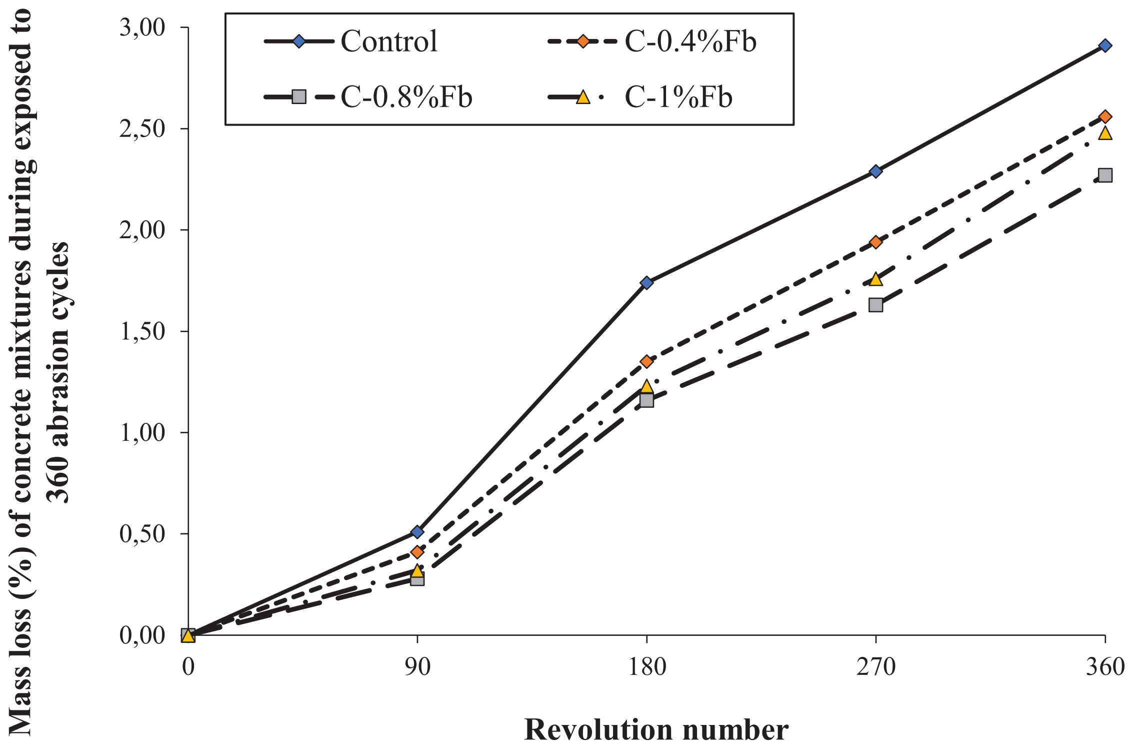


FIGURE 12. Relative mass loss of concrete mixtures at the end of 360 abrasion cycles.

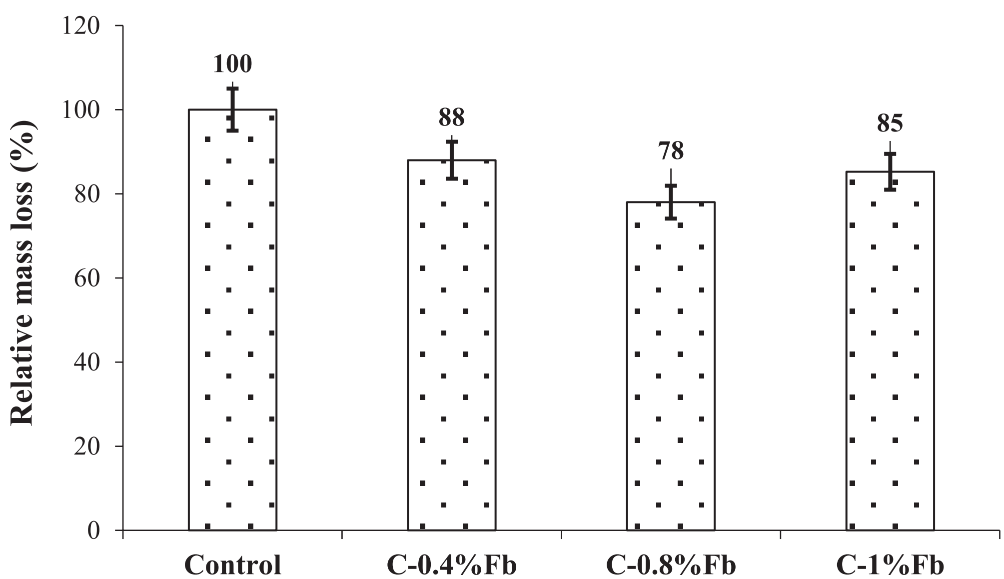
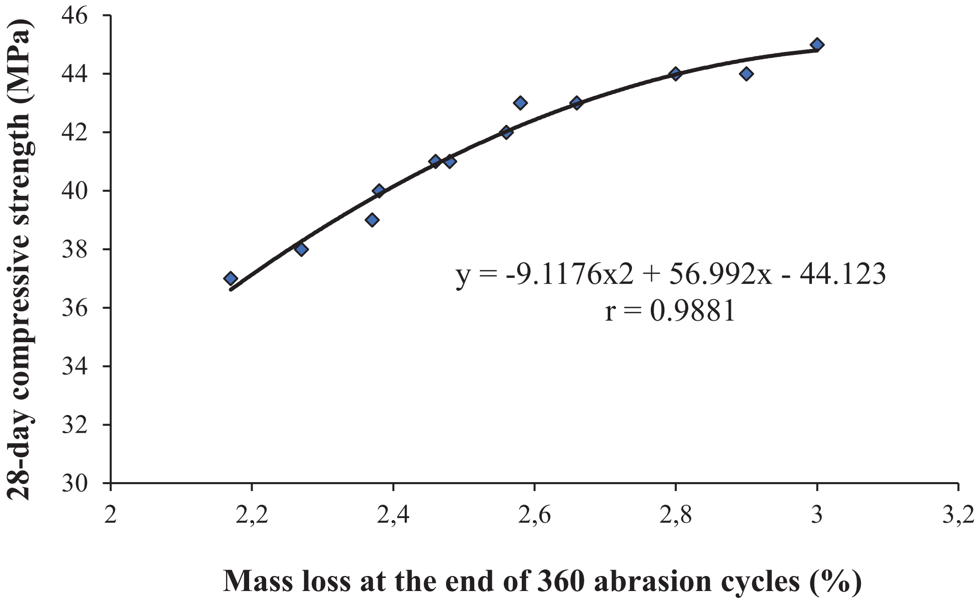


FIGURE 13. Relationship between 28-day compressive strength and mass loss of concrete mixtures after exposed to abrasion cycles.



Freeze-thaw resistance

The mass losses resulting from freeze-thaw of the concrete mixtures are shown in Figure 14. As expected, the mass loss of the concrete mixtures increased when the number of freeze-thaw cycles increased. At the end of the 300 freeze-thaw cycles, the maximum mass loss was observed in the control mixture without fiber. The mass loss of the mixtures containing fiber was less than that of the control mixture. As observed in Figure 15, at the end of 300 freeze-thaw cycles, the C-0.8% Fb mixture containing 0.8% fiber by volume showed the best performance in terms of freeze-thaw resistance with 24% less weight loss than the control mixture. Compared to the control mixture, mass losses of the C-0.4% Fb and C-1% Fb mixtures were determined as 12% and 18%, respectively.

One of the most important factors affecting the freeze-thaw resistance of concrete is the permeability of concrete [7]. This can be understood from Figure 16 that there is a strong relationship between water absorption and freeze-thaw resistance of concrete mixtures. The water in the capillary pores of the concrete has an impact on the freezing resistance of the concrete mixtures. If the stresses occurring in the cement paste due to freezing exceed the tensile strength of concrete, cracks might be formed in the concrete structure. As a consequence of freezing and thawing cycles in the concrete structure, mass losses occur due to the increase of micro cracks and the spallings in the mixtures [50]. Furthermore, the most important factor in the freeze-thaw behavior is the saturation degree of the material. In this context, the permeability properties of mixtures are important measurements of the freeze-thaw resistance. Permeability properties of the mixtures prove that the use of fiber up to a certain ratio reduced permeability. However, the permeability of the mixture increases when the fiber ratio of the mixture exceeds 0.8%. Thus, the water entering into the capillary pores damages the concrete structure with internal expansion during freezing.

FIGURE 14. Weight change percentage of concrete mixtures during 300 freeze-thaw cycles.

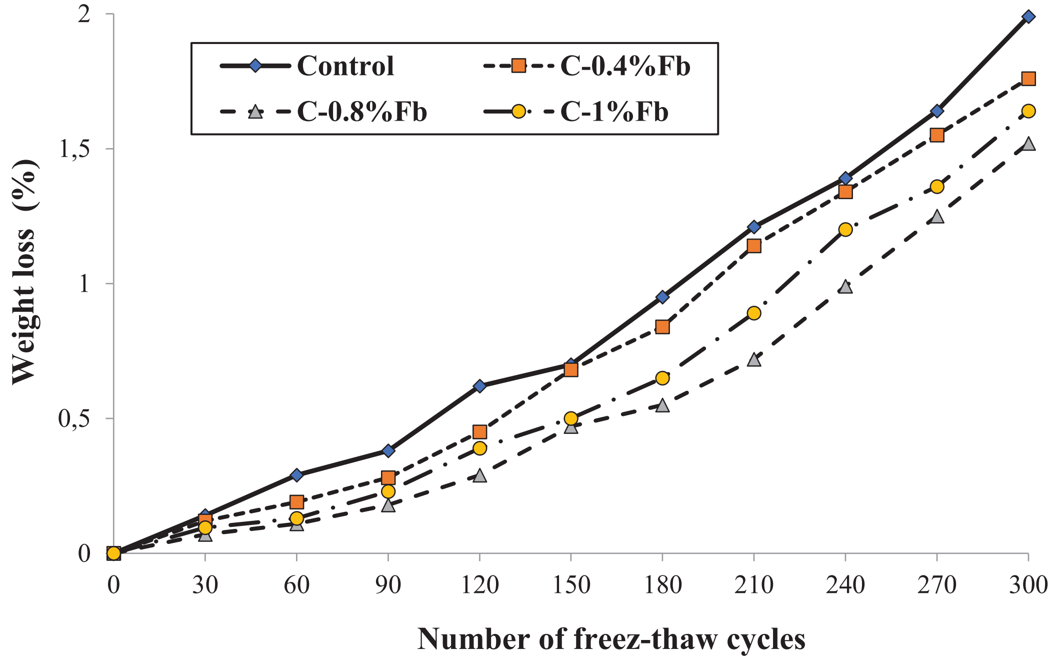


FIGURE 15. Relative weight loss of concrete mixtures after 300 freeze-thaw cycles.

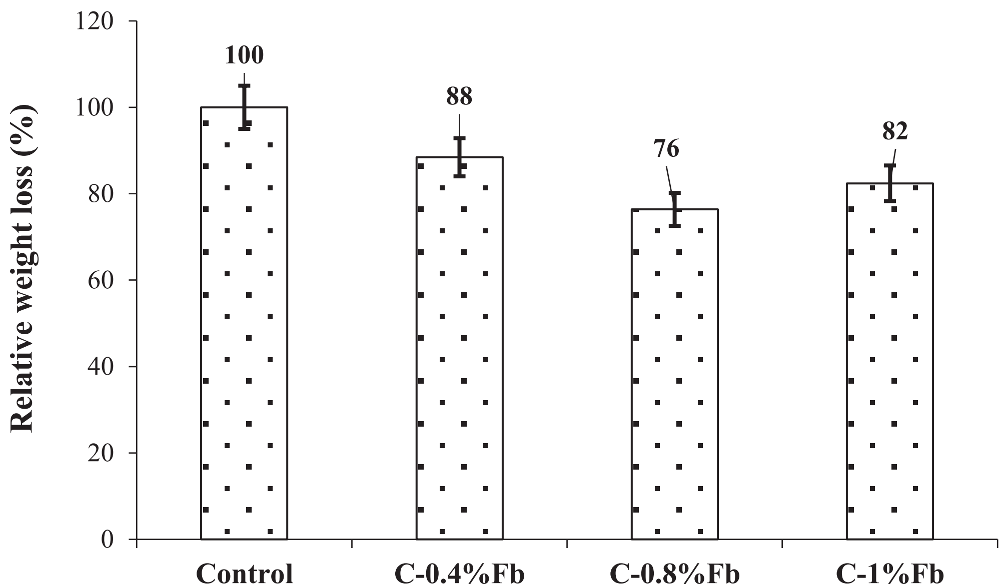
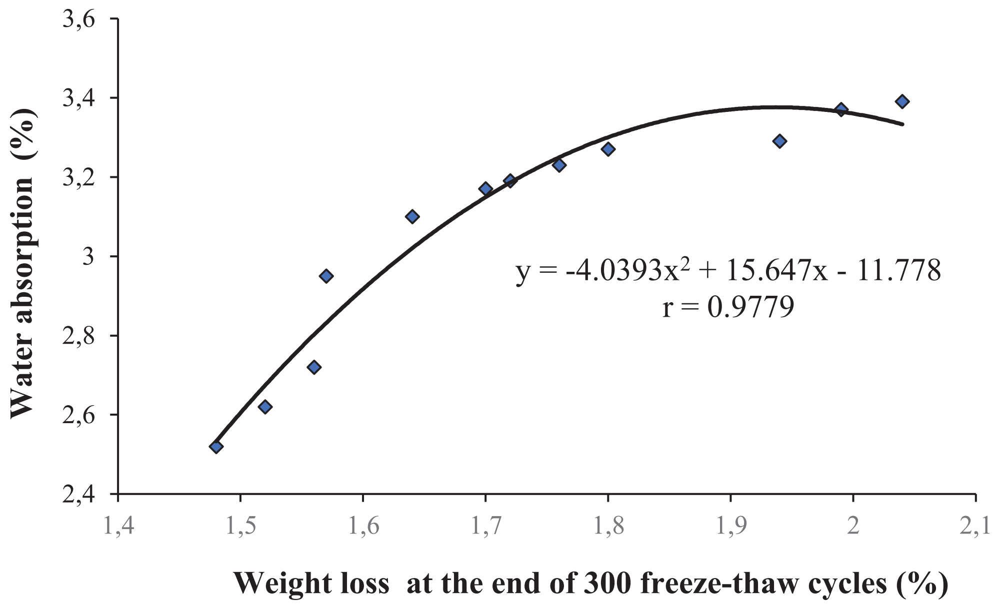


FIGURE 16. Relationship between water absorption and weight loss arising from exposure to 300 freeze-thaw cycles.



CONCLUSIONS

The utilization of polypropylene fiber in the concrete mixtures up to a certain ratio positively affected the dimensional stability, mechanical properties and durability performance of the mixtures. Depending on these positive effects, it is thought that cement consumption will decrease due to extending the service life of reinforced concrete structures. Decreasing cement consumption reduces both CO_2 emission and the amount of raw materials used in construction, as well as the energy consumed for cement production. In addition, the amount of waste materials from the demolition of buildings will be reduced.

The requirement for a water reducer admixture increased to keep the flow value of concrete mixtures constant as a result of the use of polypropylene fiber and the increase in its usage amount in mixtures. The fiber usage affected the early age compressive strength of concrete mixtures negatively. However, the use of fiber up to 0.8% by volume affected the 28-day compressive strengths of the mixtures positively. Similar behaviors were observed in the splitting-tensile strength, flexural strength and ultrasonic pulse velocity of the mixtures. The 1% fiber use by volume for all ages affected these properties in concrete mixtures negatively. An increase in the water absorption and void ratio of the mixtures was observed by increasing the fiber ratio in the mixture to 1%. The permeability properties of the concrete mixtures showed positive results by adding fiber into the mixtures. Concrete mixtures containing 0.8% of fiber by volume showed the best performance in terms of permeability properties. Sodium sulfate, abrasion, freeze-thaw resistances and drying-shrinkage behavior of the mixtures were affected positively from the fiber usage up to 0.8% by volume. On the other hand, using fiber above this ratio affected the relevant properties of concrete mixtures with fiber adversely. However, it was concluded that all properties of the fiber containing mixtures were superior to the control mixture.

ACKNOWLEDGEMENT

The authors would like to thank Izmir Çimentaş Cement Plant and Polisan Construction Chemicals Company authorities for their kind assistance in providing the cement, superplasticizer admixture and polypropylene fiber as well as determining the chemical composition, physical and mechanical properties of these products. The authors gratefully acknowledge support provided by Uludag University Scientific Research Projects Centre (BAP) under grant numbers KUAP(MH)-2017/11.

REFERENCES

[1] Maluk, C., Bisby, L., & Terrasi, G. P. (2017). Effects of polypropylene fibre type and dose on the propensity for heat-induced concrete spalling. Engineering Structures, 141, 584–595.
[2] Bilow, D. N., Kamara, M. E. (2008). Fire and Concrete Structures. In: Proceedings of the ASCE Structures Congress 2008: Crossing Borders, 24–26 April, Vancouver, Canada, 10 pp.
[3] Mehta, P. K., & Aïtcin, P. C. (1990). Principles underlying production of high-performance concrete. Cement, concrete and aggregates, 12(2), 70–78.
[4] Yoo, D. Y., Park, J. J., & Kim, S. W. (2017). Fiber pullout behavior of HPFRCC: Effects of matrix strength and fiber type. Composite Structures, 174, 263–276.
[5] Islam, G. S., & Gupta, S. D. (2016). Evaluating plastic shrinkage and permeability of polypropylene fiber reinforced concrete. International Journal of Sustainable Built Environment, 5(2), 345–354.
[6] Mardani-Aghabaglou, A., Yüksel, C., Hosseinnezhad, H., & Ramyar, K. (2016). Performance of steel micro fiber reinforced mortar mixtures containing plain, binary and ternary cementitious systems. Journal of Green Building, 11(4), 109–130.
[7] Mehta, P. K., & Monteiro, P. J. M. (2006). Concrete: microstructure, properties, and materials (3th ed.). NJ: McGraw-Hill.
[8] Banthia, N., & Gupta, R. (2004). Hybrid fiber reinforced concrete (HyFRC): fiber synergy in high strength matrices. Materials and Structures, 37(10), 707–716.
[9] Yoo, D. Y., Yoon, Y. S., & Banthia, N. (2015). Flexural response of steel-fiber-reinforced concrete beams: effects of strength, fiber content, and strain-rate. Cement and Concrete Composites, 64, 84–92.
[10] AENOR, UNE-EN 14889-1:2008, Fibras para hormigón. Parte 1: Fibras de acero. Definiciones, especificaciones y conformidad, AEN/CTN 83, Hormigón, España, 2008.
[11] Haselwander, B., Jonas, W., & Riech, H. (1995). Material equations for steel fibre reinforced concrete members. Nuclear engineering and design, 156(1–2), 235–248.
[12] Tailhan, J. L., Rossi, P., & Daviau-Desnoyers, D. (2015). Probabilistic numerical modelling of cracking in steel fibre reinforced concretes (SFRC) structures. Cement and Concrete Composites, 55, 315–321.
[13] Nguyen, D. L., Ryu, G. S., Koh, K. T., & Kim, D. J. (2014). Size and geometry dependent tensile behavior of ultra-high-performance fiber-reinforced concrete. Composites Part B: Engineering, 58, 279–292.
[14] Abrishambaf, A., Barros, J. A., & Cunha, V. M. (2015). Tensile stress–crack width law for steel fibre reinforced self-compacting concrete obtained from indirect (splitting) tensile tests. Cement and Concrete Composites, 57, 153–165.
[15] Wang, K., Shah, S. P., & Phuaksuk, P. (2001). Plastic shrinkage cracking in concrete materials-influence of fly ash and fibers. ACI Materials Journal, 98(6), 458–464.
[16] Bayasi, Z., & Al Dhaheri, M. (2002a). Effect of exposure to elevated temperature on polypropylene fiber-reinforced concrete. Materials Journal, 99(1), 22–26.
[17] Mu, B., Meyer, C., & Shimanovich, S. (2002). Improving the interface bond between fiber mesh and cementitious matrix. Cement and Concrete Research, 32(5), 783–787.
[18] Bayasi, Z., & McIntyre, M. (2002b). Application of fibrillated polypropylene fibers for restraint of plastic shrinkage cracking in silica fume concrete. Materials Journal, 99(4), 337–344.
[19] Song, P. S., Hwang, S., & Sheu, B. C. (2005). Strength properties of nylon-and polypropylene-fiber-reinforced concretes. Cement and Concrete Research, 35(8), 1546–1550.
[20] Broda, J. 2016. High Performance Concrete Technology and Applications. Chapter 8. ISBN 978-953-51-2651-5, 212 pages, Publisher: In Tech, DOI: 10.5772/61562.

[21] Mardani-Aghabaglou, A., Son, A. E., Felekoglu, B., & Ramyar, K. (2017). Effect of Cement Fineness on Properties of Cementitious Materials Containing High Range Water Reducing Admixture. Journal of Green Building, 12(1), 142–167.
[22] Mardani-Aghabaglou, A., Investigation of cement-superplasticizer admixture compatibility, PhD Thesis. Turkey, Izmir, Ege University, Engineering Faculty, Civil Engineering Department, NO. 10103689, 290 pp, 2016.
[23] Serrano, R., Cobo, A., Prieto, M. I., & de las Nieves González, M. (2016). Analysis of fire resistance of concrete with polypropylene or steel fibers. Construction and building materials, 122, 302–309.
[24] Akça, K. R., Çakır, Ö., & Ipek, M. (2015). Properties of polypropylene fiber reinforced concrete using recycled aggregates. Construction and Building Materials, 98, 620–630.
[25] Mohammadhosseini, H., Awal, A. A., & Yatim, J. B. M. (2017). The impact resistance and mechanical properties of concrete reinforced with waste polypropylene carpet fibres. Construction and Building Materials, 143, 147–157.
[26] Yousefieh, N., Joshaghani, A., Hajibandeh, E., & Shekarchi, M. (2017). Influence of fibers on drying shrinkage in restrained concrete. Construction and Building Materials, 148, 833–845.
[27] Ahmadi, M., Farzin, S., Hassani, A., & Motamedi, M. (2017). Mechanical properties of the concrete containing recycled fibers and aggregates. Construction and Building Materials, 144, 392–398.
[28] Conforti, A., Minelli, F., & Plizzari, G. A. (2017). Shear behaviour of prestressed double tees in self-compacting polypropylene fibre reinforced concrete. Engineering Structures, 146, 93–104.
[29] Li, J. J., Niu, J. G., Wan, C. J., Jin, B., Yin, Y. L. (2016). Investigation on mechanical properties and microstructure of high performance polypropylene fiber reinforced lightweight aggregate concrete. Construction and Building Materials, 118, 27–35.
[30] Rahmani, T., Kiani, B., Sami, F., Fard, B., Farnam, Y., & Shekarchizadeh, M. (2011). Durability of glass, polypropylene and steel fiber reinforced concrete. XII DBMC-International Conference on Durability of Building Materials and Components, 12th-15th April, Porto, Portugal.
[31] Yazici, Ş., Mardani-Aghabaglou, A., Tuyan, M., & Üte, A. A. (2015). Mechanical properties and impact resistance of roller-compacted concrete containing polypropylene fibre. Magazine of Concrete Research, 67(16), 867–875.
[32] Afroughsabet, V., & Ozbakkaloglu, T. (2015). Mechanical and durability properties of high-strength concrete containing steel and polypropylene fibers. Construction and building materials, 94, 73–82.
[33] Kakooei, S., Akil, H. M., Jamshidi, M., & Rouhi, J. (2012). The effects of polypropylene fibers on the properties of reinforced concrete structures. Construction and Building Materials, 27(1), 73–77.
[34] Topcu, I. B., & Canbaz, M. (2007). Effect of different fibers on the mechanical properties of concrete containing fly ash. Construction and Building Materials, 21(7), 1486–1491.
[35] Hsie, M., Tu, C., & Song, P. S. (2008). Mechanical properties of polypropylene hybrid fiber-reinforced concrete. Materials Science and Engineering: A, 494(1), 153–157.
[36] Fallah, S., & Nematzadeh, M. (2017). Mechanical properties and durability of high-strength concrete containing macro-polymeric and polypropylene fibers with nano-silica and silica fume. Construction and Building Materials, 132, 170–187.
[37] Mardani-Aghabaglou, A., Tuyan, M., Yılmaz, G., Ramyar, K., (2013). Farklı Liflerin Kendiliğinden Yerleşen Betonun Taze Hal ve Mekanik Özelliklerine Etkisi. Hazır Beton Kongresi, 21-23 Şubat, İstanbul, 52–62.
[38] Yan, H., Sun, W., & Chen, H. (1999). The effect of silica fume and steel fiber on the dynamic mechanical performance of high-strength concrete. Cement and Concrete Research, 29(3), 423–426.
[39] Karahan, O., & Atiş, C. D. (2011). The durability properties of polypropylene fiber reinforced fly ash concrete. Materials & Design, 32(2), 1044–1049.
[40] Söylev, T. A., & Özturan, T. (2014). Durability, physical and mechanical properties of fiber-reinforced concretes at low-volume fraction. Construction and Building Materials, 73, 67–75.
[41] Whitehurst, E. A. (1951). Soniscope tests concrete structures. American Concrete Institute, 47(2), 433–444.
[42] CEB-FIB. Diagnosis and assessment of concrete structures—state of art report. CEB Bull 1989;192:83–85.
[43] Hu, X., Shi, Z., Shi, C., Wu, Z., Tong, B., Ou, Z., & de Schutter, G. (2017). Drying shrinkage and cracking resistance of concrete made with ternary cementitious components. Construction and Building Materials, 149, 406–415.
[44] Siddique, R., Kapoor, K., Kadri, E. H., & Bennacer, R. (2012). Effect of polyester fibres on the compressive strength and abrasion resistance of HVFA concrete. Construction and Building Materials, 29, 270–278.

[45] Naik, T. R., Singh, S. S., & Hossain, M. M. (1995). Abrasion resistance of high-strength concrete made with class C fly ash. ACI Materials Journal, 92(6), 649–659.
[46] Laplante, P., Aitcin, P. C., & Vezina, D. (1991). Abrasion resistance of concrete. Journal of Materials in Civil Engineering, 3(1), 19–28.
[47] Atiş, C. D. (2003). Abrasion-porosity-strength model for fly ash concrete. Journal of materials in civil engineering, 15(4), 408–410.
[48] Gjorv, O. E., Baerland, T., & Ronning, H. R. (1990). Abrasion resistance of high strength concrete pavements. Concrete International, 12(1), 45–48.
[49] Mardani-Aghabaglou, A., Hosseinnezhad, H., Boyacı, O. C., Arıöz, Ö., Yaman, İ. Ö., & Ramyar, K. (2014). Abrasion resistance and transport properties of road concrete. 12th International Symposium on Concrete Roads, 23–26 September, Prague, Czech Republic.
[50] Tuyan, M., Mardani-Aghabaglou, A., & Ramyar, K. (2014). Freeze–thaw resistance, mechanical and transport properties of self-consolidating concrete incorporating coarse recycled concrete aggregate. Materials & Design, 53, 983–991.