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Research Article

Effect of Curing Time on Fresh and Physical Properties of Alkaline Activated Fiber Concrete With Quarry Waste, A Natural Pozzolan

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ABSTRACT

Studies on the production of concrete by alkaline activation method continue to increase in today's concrete industry due to the fact that it is more environmentally friendly and sustainable. In this regard, by developing a new building material by activating various natural and/or artificial pozzolanic wastes with the help of an activator as a binder instead of cement, environmental health is protected by preventing the problems of storage and disposal of wastes, and CO2 emission is also prevented as alternative materials to cement are used as binders. In this study, alkali activated concrete (AAC) and fibrous alkali activated concrete (FAAC) were produced using rock dust (RD), which is a waste material of a quarry in operation for various construction productions, and ground blast furnace slag (GBFS), which is also an industrial waste, activated with NaOH and Na2SiO3 and steel and polyester fibers at various ratios by volume (0%, 0.25%, 0.50%, 0.75% and 1.0%). The effects of curing time and fiber ratios were investigated by performing consistency and unit volume weight tests as fresh state properties, compressive strength and physical properties tests at the end of 3,7- and 28-days curing period as hardened concrete properties. It was observed that the use of polyester fibers at the rate of 0.5% by volume contributed more to both the fresh state properties and physical properties of the concretes produced, especially the compressive strength.

Introduction

Cement is undoubtedly the most widely used binding building material since the day it entered the building industry. Considering factors such as the fact that the raw materials used for cement production are mostly easily available from local sources, the relatively low qualified and costly worker profile in the production process, and its practical feature in concrete production, it shows that it is not a building material that can be easily abandoned in the future. However, in addition to these advantages, there are also many disadvantages. The most important of these are high CO_2 emissions and high energy costs. In order to produce only 1 m^3 of concrete, 400 kg of CO_2 is emitted into the atmosphere [1-2]. In addition, the energy used in the cement production industry accounts for 12-15% of the total energy consumed in other industries [3]. Factors such as these have created the need for a more environmentally friendly and sustainable binder other than cement. Studies to produce a new concrete called geopolymer without cement as a result of the reaction of natural and/or artificial materials containing aluminosilicate in its structure with an activator continue to increase day by day [4]. For this reason, it is possible to produce a binder other than cement from amorphous materials containing Al_2O_3, SiO_2 and CaO such as fly ash, bottom ash and blast furnace slag by using alkaline activators. Concretes produced by alkaline activation method offer advantages over conventional concretes such as high mechanical properties, low energy costs, low harmful gas emissions (CO_2, SO_2, NO_x, etc.) and less destruction of the environment. Furthermore, by using largely waste materials, the environmental damage and storage problems of waste are significantly reduced [5-8].

Geopolymer concretes produced by using alkaline activator have lower drying shrinkage values and higher adherence with reinforcement and resistance to environmental conditions compared to conventional concretes [9-11]. The widespread use of amorphous GBFS in concrete will contribute to the economy and the protection of environmental health by recycling an industrial waste material [12-16]. In this study, AAC and FAAC were produced using rock dust (RD), which is a quarry waste, and ground blast furnace slag (GBFS), which is an artificial waste generated as a result of industrial production, as binder. Various physical and mechanical tests were carried out on the produced concretes to examine the effects of fiber type and waste mineral products on FAAC's and to determine the fiber ratio and type contribute the most to concrete properties.

Materials and Methods

Materials

Fibers

Among the fibers used in FAAC production and shown in Figure 1, the long polymer fiber has a twisted structure with a length of 50 mm and a rectangular cross-section with a cross-sectional area of approximately 0.45 mm^2 . The steel fiber with hook is 50 mm long, with a diameter of 0.9 mm and a circular cross section. Technical specifications of the fibers obtained from local producers are given in Table 1.

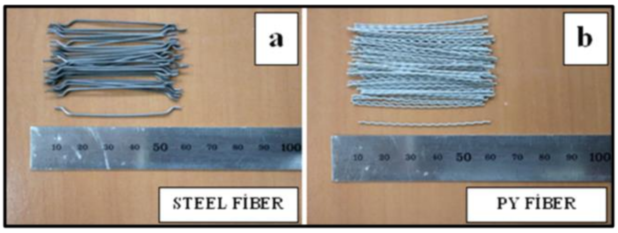


Fig. 1. (a) Steel fiber, (b) Polyester (PY) fiber

Table 1. Technical specifications of the fibers used.

Fiber Properties	**Steel Fiber**	**Polyester Fiber**
Length (mm)	30-60	**25-50**
Width (mm)	-	**0,9**
Thickness (mm)	-	**0,5**
Diameter (mm)	0,9	**-**
Specific mass (g/cm^3)	7,87	**1,36**
Tensile strength (MPa)	~1100	**400-800**
Modulus of elasticity (MPa)	200000	**17237**
Ultimate elongation (%)	**< 2**	**> 8**

Binder

In the production of fibrous concrete, ACI 544.4R and TS 10514 Standards stipulate the use of a certain amount of finely ground material (<0.25 mm) according to the largest aggregate grain diameter used [17,18]. In Turkey, volcanic rocks with high reserves are processed in quarry facilities to be used in various construction applications and a large amount of waste material is generated as a result of the production process (Figure 2). Rock dust obtained as waste from the quarry was used in the production of alkali-activated fibrous concretes together with GBFS as fine material. X-Ray Diffraction (XRF) analysis was carried out to determine the chemical composition of the quarry waste material with GBFS and pozzolanic properties and the data obtained are given in Table-2.

Fig. 2. (a) Volcanic rocks, (b) Processing of rocks, (c) Rock waste, (d) Accumulation of QW in the sedimentation tank.

Table 2. Chemical and physical properties of the binders.

Sample	**$SİO_2$ (%)**	**Al_2O_3 (%)**	**Fe_2O_3 (%)**	**CaO (%)**	**MgO (%)**	**MnO (%)**	**K_2O (%)**	**Na_2O (%)**	**Density (g/cm^3)**	**Blaine (cm^2/g)**
QW	42,90	10,27	18,04	10,57	10,25	0,21	0,74	1,88	2,65	2351
GBFS	41,24	20,64	7,28	25,45	2,93	0,47	0,84	1,15	2,91	5384

Alkaline Solution, Aggregates, Superplasticizer and Water

The preparation of the alkaline solution started by dissolving sodium hydroxide in water. The solution was mixed with water to make 2 liters of solution at a solution concentration of 10 M with 800 grams of solid sodium hydroxide. Crushed sand in the range of 0-4 mm was used as fine aggregate, crushed stone I (NO I) in the range of 4-11.2 mm and crushed stone II (NO II) in the range of 11.2-22.4 mm as coarse aggregate. The plasticizer additive, modified polycarboxylate (PCE), is polymer based and has the appearance of a light brown liquid. Drinking water was used in the production of AAC and FAAC and there are no unusual substances [19; 20].

Mixture Design, Casting and Curing

The fibers used in the study were applied as % of the concrete volume and the actual amounts of material in 1 m^3 concrete are given in Table 3. During the production of alkali-reacted (activated) concrete, the process of producing conventional Portland cement concrete was largely followed. After the mixing was completed, the alkali activated concrete was poured into cube and cylinder molds. Immediately after casting, the molds were covered with plastic covers to prevent alkali volatilization. The concrete specimens thus produced were removed from the molds after 24 hours. Laboratory conditions were defined by a temperature of 23±2 ºC and a relative humidity of 60±5% and the extracted samples were placed in a water pool. The specimens were kept in the curing pool for 3, 7 and 28 days respectively and were ready for the experiments.

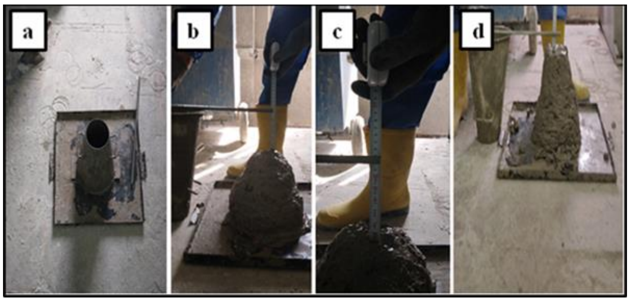
Table 3. Mix proportion details of AAC and FAAC (1 m^3)

Concrete Type	Binder (GBFS) (kg)	Na_2SiO_3 /NaOH	Fiber content (kg)		SP (kg)	QW (kg)	Aggregate (kg)			Water (kg)
			ÇL	PYL		0-0,25 (mm)	0,25-4 (mm)	4 -11,2 (mm)	11,2-22,4 (mm)	
Reference	350	117/58	-	-	6	400	384,8	523,2	436,1	106
SAAC/0,25	350	117/58	19,6	-	6	400	384,8	523,2	436,1	106
SAAC/0,50	350	117/58	39,2	-	6	400	384,8	523,2	436,1	106
SAAC /0,75	350	117/58	58,8	-	6	400	384,8	523,2	436,1	106
SAAC /1,00	350	117/58	78,4	-	6	400	384,8	523,2	436,1	106
PYAAC/0,25	350	117/58	-	3,4	6	400	384,8	523,2	436,1	106
PYAAC /0,50	350	117/58	-	6,8	6	400	384,8	523,2	436,1	106
PYAAC /0,75	350	117/58	-	10,2	6	400	384,8	523,2	436,1	106
PYAAC /1,00	350	117/58	-	13,6	6	400	384,8	523,2	436,1	106

Methods

Fresh Concrete Consistency and Unit Volume Mass

In this study, the consistencies of witness concrete, alkali-reacted (activated) fresh concretes produced with different fiber ratios were determined according to TS EN 12350-2 using the free slump test (slump, Abrams funnel) method [21]. The free slump height of the concretes was determined with a cone called abrams funnel with a top diameter of 100 mm, a base diameter of 200 mm and a height of 300 mm as shown in Figure 3. The unit masses of fresh concrete specimens were performed in accordance with the principles specified in TS EN 12350-6 [22].



Şekil 3. Determination of AAC and FAAC consistencies (a) Abrams cone, (b) Reference (c) and (d) Fiber concrete.

Compressive Strength Test and Physical Properties of Hardened Concrete

Uniaxial compressive strength of the hardened AAC and FAAC specimens at the end of 3, 7 and 28 days curing periods was performed on standard cube specimens according to TS EN 12390-3 [23]. Physical properties were determined according to TS EN 12390-7 by taking 3 samples from each concrete group produced with different fiber rations and witness AAC samples produced without fibers [24]. Standard cylinder specimens (100x200 mm) that completed 28 days of curing time were used in the tests and hardened unit masses, saturated and dry unit volume masses, water absorption and porosity values of the specimens were determined.

Results and Discussion.

Fresh Concrete Results

In order to determine the workability among the concrete groups produced, the slump value of the witness (fiber-free) concrete was measured as 14 cm and the unit volume mass was measured as 2290.1 kg/m^3 (Table 4). The slump and unit mass values of other concretes with different mix ratio vary depending on this ratio. Previous studies show that the FAAC slump height varies depending on the type and proportion of fiber used [25].

Table 4. Fresh concrete properties

Concrete Type	Fiber content (%)	Unit mass (kg/m³)	Slump value (cm)
REFERENCE	% 0	2290,1	14
SAAC	% 0,25	2293,5	12
SAAC	% 0,50	2339,3	11
SAAC	% 0,75	2353,2	9
SAAC	% 1,00	2378,9	8
PYAAC	% 0,25	2293,5	10
PYAAC	% 0,50	2303,2	8
PYAAC	% 0,75	2316,4	7
PYAAC	% 1,00	2325,7	5

Hardened Concrete Results

Compressive Strength Tests

When the 3, 7 and 28-day compressive strengths (Figure 4) of macro synthetic and steel fiber concretes and witness (unadmixed) concretes are examined, it is seen that there is an improvement of 13.7% compared to the witness concrete, especially in the 28-day compressive strength results, up to the use of 0.5% of steel fiber, whereas there is a decrease of 9.4% when 1% fiber is used. In the use of 0.5% polyester fiber, there is an increase of 27.7% in strength. However, it was determined that the increase in strength decreased in samples with a polyester fiber ratio exceeding 0.75%. It was also observed that both fiber types did not have much effect on the compressive strength of 3 and 7 days concrete specimens. In fiber concrete studies, compressive strength does not show a systematic decrease or increase depending on the fiber ratio. On the other hand, in some of the studies on this subject, it increases depending on the fiber type, size and participation rate, while in others it decreases [26-28].

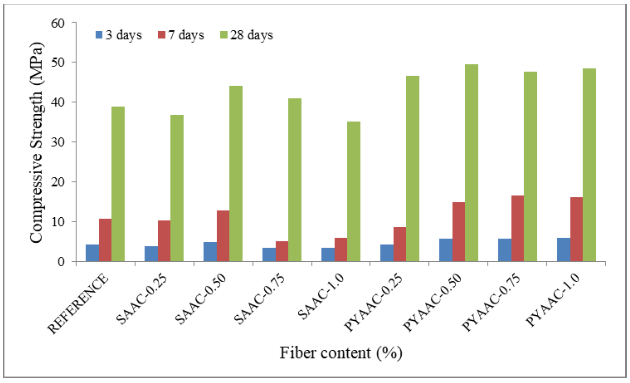


Figure 4. Compressive strengths of concretes produced with different fiber ratios depending on the curing time

Physical Properties

Different types of pozzolanic materials, alkali activators and plasticizing admixtures used in the production of AAC and FAAC affect the durability properties of concrete. Water absorption and porosity are directly related to the durability of concrete as they are interrelated. The water absorption rate and porosity values of the witness concrete produced without fibers were obtained as 8.09% and 16.87%, respectively. As the amount of fiber increases, water absorption and porosity values decrease within each fiber type (Figures 5 and 6).

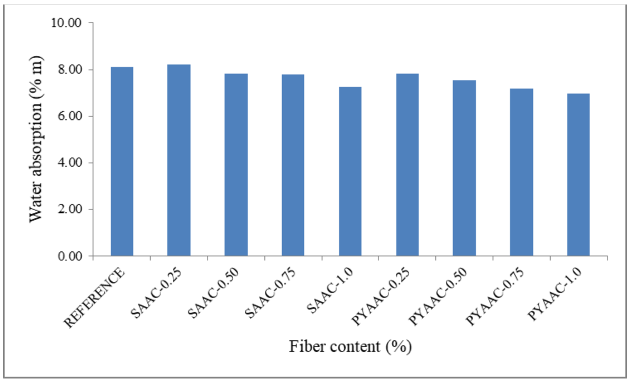


Figure 5. Water absorption of reference and fiber concretes

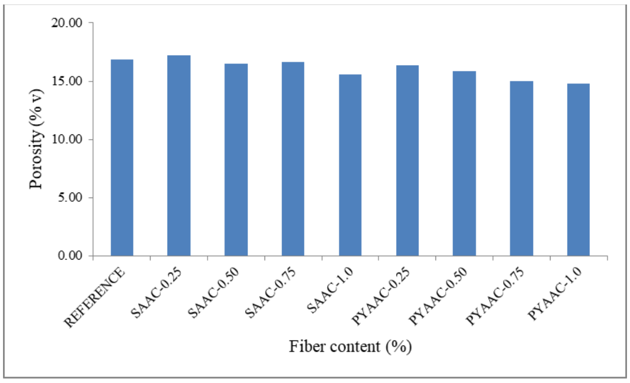


Figure 6. Porosity of reference and fiber concretes

Conclusion

AAC and FAAC were produced by using rock dust (RD), which is the waste of an industrial quarry, and GBFS, which is also an artificial waste generated as a result of industrial production, as binders, and the application of steel and polyester fibers separately as a result of their reaction (activation) with various activators, in 4 different mixture ratios (0.25%; 0.25%, 0.50%, 0.75% and 1.0%), fresh and hardened concrete tests were performed and the effect of curing time on hardened concrete properties, especially compressive strength, was investigated:

- It was observed that as the fiber ratio increased within the concrete groups, slump values decreased compared to the witness (fiber-free) concrete. While a decrease of 42.86% was observed in steel fiber samples depending on the fiber ratio, this rate was 64.29% in polyester fiber samples. It is thought that there is a greater decrease in collapse values due to the water-repellent properties of polyester fibers.

- The use of polyester (PY) fiber did not seem to cause a significant change in the unit mass of concrete. However, in steel fiber specimens, the unit mass increases depending on the fiber ratio. The maximum increase in steel fiber use was 3.9% depending on the unit mass fiber ratio, while this rate was 1.6% for polyester fiber use. This is thought to be due to the high density of steel fiber and its higher amount per unit volume in concrete specimens.

- In general, saturated and dry unit volume masses of both steel fiber and polyester fiber specimens increase as the fiber ratio increases, while water absorption and porosity values decrease. This is thought to be related to the fact that RD, which has pozzolanic properties and high alimunosilicate content, used with GBFS as a binder, causes the N-A-S-H gel formed as a result of alkali activation to develop more intensively and the three-dimensional filling behavior of the fibers.

- In the compressive strengths, it was observed that there was an improvement of 13.7% in the compressive strength up to the limit of 0.5% application of steel fiber, whereas a higher increase of 27.7% was recorded in polyester fiber application. The improvement provided by polyester fibers in the compressive strength of concrete is due to the fact that polyester fibers do not retain water in terms of workability and do not need extra water, so that there is no increase in the w/c ratio, which positively affects the compressive strength.

According to this study, early curing time has a very weak effect on alkali-activated concrete specimens, and sufficient strength and microstructural properties of alkali-activated concretes do not develop in early curing times. It was observed that the use of polyester fibers at a rate of 0.5% by volume contributed more to the compressive strength of concrete and showed superior properties compared to the witness concrete produced without fibers.

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