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RESEARCH ARTICLE / ARAŞTIRMA MAKALESI

The Mechanical and Durability Properties of Cement Mortars with Different Types of Fibers and Chemical Admixtures

Farklı Tip Lif ve Kimyasal Katkı İçeren Çimento Harçlarının Mekanik ve Dayanıklılık Özellikleri

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Abstract

Improving the mechanical and durability properties of cement-based materials such as concrete is very important. The use of fibers is a good alternative in cement-based materials production. This study investigated workability, some mechanical and durability properties of cement mortar in cooperation with glass and basalt fiber. Basalt and glass fibers were used instead of the aggregate in the mixture as 0.8 and 1% by weight. The compatibility of the polycarboxylate-based water reducer and the modified phosphonate-based water reducer as chemical admixtures in selected ratios and fibers was tested. Experiments were carried out after 7 and 28 days of water cure and the effect of the curing periods were also determined. Flexural strength values of basalt fiber reinforced samples in all sets were found to be more than glass fiber reinforced samples. However, high compressive strength are obtained in glass fiber reinforced samples. Beside the positive results obtained in the mechanical properties, the effects of the fibers in the abrasion and acid resistance (10% hydrochloric acid solution during 30 days) have given positive results.

Keywords: *Cement mortar, Flexural strength, Durability, Abrasion resistance, Acid resistance*

Öz

Beton gibi çimento esaslı malzemelerin mekanik ve dayanıklılık özelliklerinin iyileştirilmesi çok önemlidir. Çimento esaslı malzeme üretiminde lif kullanımı önemli bir alternatiftir. Bu çalışmada, çimento harcında cam ve bazalt lifi kullanılarak işlenebilirlik, bazı mekanik ve dayanıklılık özellikleri incelenmiştir. Karışımda agrega yerine ağırlıkça %0,8 ve %1 oranında bazalt ve cam lifi kullanılmıştır. Ayrıca, polikarboksilat esaslı hiperakışkanlaştırıcı ve modifiye fosfonat esaslı süper akışkanlaştırıcının çeşitli oranlarda liflerle uyumluluğu test edilmiştir. 7 ve 28 günlük su küründen sonra deneyler yapılmış ve kür sürelerinin etkisi de belirlenmiştir. Bazalt lifi içerikli eğilme dayanımı değerleri, cam lifi içerikli numunelere göre daha fazla bulunmuştur. Ancak cam lifi içerikli numunelerde yüksek basınç dayanımı elde edilmiştir. Mekanik özelliklerde elde edilen olumlu sonuçların yanı sıra, liflerin aşınma ve asit direnci (30 gün boyunca %10 hidroklorik asit çözeltisi) üzerindeki etkileri de olumlu sonuçlar sağlamıştır.

Anahtar Kelimeler: *Çimento harcı, Eğilme dayanımı, Durabilite, Aşınma direnci, Asit direnci*

1. Introduction

Flexural strength and deformation capacity of cement-based materials such as concrete are low. To improve these negative properties, the most important contribution of various fibers, which are added to traditional concrete and especially for repair mortars, prevent crack development [1]. Fibers carry some of the stresses formed in the cement slurry phase together with their geometric and chemical structures depending on their usage amounts and transfer some of them to the solid areas of the matrix. The increase in the strength of the fiber reinforced concrete and the ability of the concrete to absorb energy under load makes it superior to conventional concrete [2]. Many laboratory studies have been conducted on the physical and chemical properties of various reinforced fibers [3–5]. Also, many studies have been conducted on the use of these fibers in cement-based materials. These studies are mostly related to the mechanical properties of the fibers on cement-based materials [4–6]. Besides the importance of the strength of cement-based materials, its durability is also very important [7]. For this reason, studies on durability properties fiber-reinforced concrete are frequently conducted. The number of these studies has been increasing in recent years due to a remarkable improvement in some durability properties of fibers [8–10].

There are many fiber types, such as natural fibers, steel, polymer, basalt, and glass, that can be used in concrete production [11]. The parameters affecting the performance of fiber reinforced concretes are fiber type, length, amount, volume fraction, slenderness ratio and homogeneous distribution of fibers in concrete [12]. There are many studies in the literature that address these parameters [13–15].

In the use of fibers in concrete, it is important to determine what purpose the concrete will serve and what mechanical and durability properties will be required. Therefore, it is important to compare different fiber types or to investigate the usability of these fibers together in the same composite. In a study

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investigating the performance of cement mortars of glass, nylon and carbon fibers of different lengths and quantities, it was stated that each mortar has different mechanical and durability properties [16]. In different types of fibers, when the usage percentages of the fibers are increased at the same rates, although the changes in the mechanical and durability properties at certain rates are parallel, they differ in certain rates. Considering that each fiber has different strength and durability properties, it is the reason that the suitable utilization rate of the fibers is different. This is supported in a study comparing polypropylene and alkali resistant glass fibers [17]. Besides, when different superior properties are preferred in the same composite, the use of various fibers in appropriate rates can be a solution. Many studies show that positive results are obtained by using various fibers simultaneously [18–20].

In this study, mechanical and durability properties of basalt and glass fiber reinforced cement mortars at different fiber lengths and diameters were investigated. Glass [21,22] and basalt [23,24] fibers are among the most widely used fibers in concrete due to their good mechanical and durability properties [25]. Although the production of basalt and glass fibers, both of which are silicate, is similar [26], basalt fibers have a more environmentally friendly production process. In the manufacture of glass fibers, additives such as boron chemicals are used to improve the properties of the fiber. The change of additives used in the production process allows the subtypes of glass fibers to be formed. However, basalt fibers are technically more difficult than glass fiber production [27].

The use of fibers in cement-based materials such as concrete creates a ductile structure and provides a specific improvement in mechanical properties. However, in order to achieve the desired results, the fibers must be distributed homogeneously in the concrete. The use of chemical admixtures reduces the loss of workability caused by the fibers. Chemical admixtures form polymer chains around cement particles. These chains push each other with electrostatic effects, increasing workability [28].

In this study, cement mortars were prepared using glass and basalt fibers which have different lengths in different proportions. Two different chemical admixtures which are different chemical origins (polycarboxylate and modified phosphonate) in the same proportions were used to examine the effect of chemical admixtures on these cement paste. The mechanical properties of these cement mortars, such as flexural and compressive strengths, as well as durability properties such as abrasion and acid resistance, were investigated.

2. Materials and Methods

2.1. Materials

CEM I-42.5 / R type Ordinary Portland Cement (OPC) produced in accordance with EN 197-1 [29] standard was used as hydraulic binder in the preparation of cement mortars. Physical properties and chemical components of cement is given in Table 1. Aggregates obtained from the quarries in Manisa were used in the mixtures. Aggregate granulometry was kept constant in cement mortar mixtures. Sieve analysis test was performed according to ASTM C 136 [30] in order to determine the grain distribution of natural aggregates to be used in cement mortar production. The granulometry curve because of sieve analysis of the aggregates used is given in Figure 1. Two different types of fiber, glass, and basalt were used in Figure 2. The properties of fibers are given in Table 2. C-Glass fiber which made of calcium borosilicate is suitable for acidic corrosive environments. Aggregate in various proportions (0.8%, 1% by weight) was replaced with fibers. Two types of chemical admixtures with different chemical origins, which are modified phosphonate-based water reducer and polycarboxylate-based water reducer, were used 1% by weight of cement. Both water reducers have high water reducing properties.

Table 1. Physical properties and chemical components of cement.

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O
(%)	19.7	4.75	3.5	63.5	2.35	3.44	0.9

Mixed oxides components	%
C_3S	60.2
C_2S	12.7
C_3A	2.9
C_4AF	11.2
Specific weight (gr/cm^3)	3.12
Blaine fineness (cm^2/gr)	3640

Table 2. Properties of glass and basalt fibers.

Fiber type	Length [mm]	Diameter [µm]	Specific weight (gr/cm^3)	Tensile strength [N/mm^2]	Elastic modulus [kN/mm^2]
C-Glass fiber	6	13-15	2.48	3300	70
Basalt fiber	24	13-23	2.60	4840	89

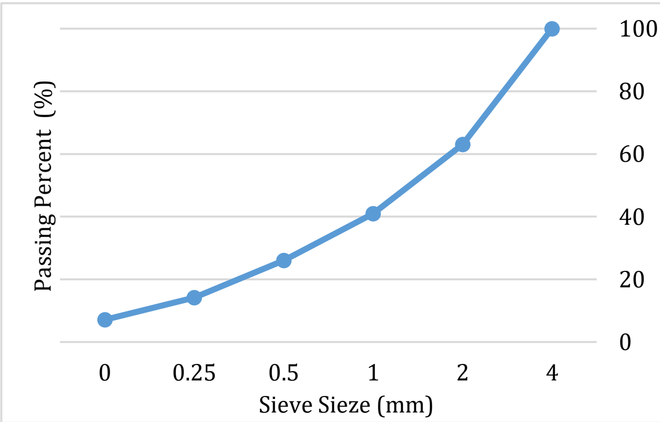

Figure 1. Granulometric curve of the aggregate.


Figure 2. Using glass and basalt fibers.

2.2. Preparation of mixtures

The mixtures were casted in 1:2:6 water-cement-aggregate ratios according to the EN 196-1 [31] standard. Samples using basalt fiber with percentages of use were named BF, samples using glass fiber were named GF. Samples using only polycarboxylate-based water reducer (PK-based water reducer) were named PK, and those using modified phosphonate-based water reducer (MP-based water reducer) were also called MP. Details of the poured samples are given in Table 3. The water-cement ratio (w/c) of 0.5 was selected in all mixtures.

Table 3. Mix proportions of cement mortar specimens.

Sample Codes	Cement (gr)	Aggregate (gr)	Water (gr)	Fiber (gr)	Chemical Admixture (gr)
Reference	2250	6750	1125	0	0
PK	2250	6750	1125	0	23
MP	2250	6750	1125	0	23
GF-0.8-PK	2250	6696	1125	54.0	23
GF-0.8-MP	2250	6696	1125	54.0	23
GF-1-PK	2250	6682.5	1125	67.5	23
GF-1-MP	2250	6682.5	1125	67.5	23
BF-0.8-PK	2250	6696	1125	54.0	23
BF-0.8-MP	2250	6696	1125	54.0	23
BF-1-PK	2250	6682.5	1125	67.5	23
BF-1-MP	2250	6682.5	1125	67.5	23

2.3. Methods

Cement mortars prepared using the ratios in Table 3 were placed in steel molds of 40x40x160 mm dimensions and 50x50x50 mm dimensions. Before the prepared mixes were placed in the molds, spreading tests were performed according to ASTM C1437 [32] to determine the spreading diameters of the mixtures. The spreading diameters of all mixtures were measured in cm. After waiting to set for 24 hours at room temperature, cement mortars removed from the mold hardened were kept in lime saturated water for 7 and 28 days.

After curing, mechanical properties such as flexural strength, post-flexural compressive strength, and compressive strength of the samples were tested. Flexural strength was carried out in prismatic samples with dimensions of 40x40x160 mm according to the flexural test procedure specified in ASTM C 348 [33]. After flexural test, compressive test were performed on the broken samples according to ASTM C349 [34]. The compressive strengths of the samples were found by dividing the breaking loads into the cross-sectional area (40x40 mm) where they were subjected to pressure loading. Direct compressive strength of 50x50x50 mm cube samples for 7 and 28 days was calculated according to ASTM C 109 [35]. Compressive strengths of the samples were found by dividing the breaking loads into the cross-sectional area (50x50 mm).

Some durability properties such as abrasion resistance and acid resistance have been tested. Abrasion tests were carried out in accordance with TS 2824 EN 1338 [36] standards. 50x50x50 mm sized cubic samples were tested by Bohme Device after 7 and 28 days water curing. Before and after the abrasion test, the weight loss of the samples was calculated by measuring the weights on the precision scale. The results are given by calculating in percent weight losses.

To measure the acid resistance of the samples, 10% concentration of hydrochloric acid (100 ml/lt) solutions were prepared to quickly test the acid effect. After soaking in water for 7 and 28 days, samples were exposed to acid attack for 30 days in the solution using HCI, which is classified as strong acid [37]. Reduction in acid concentration of the solution is avoided by replacing the solutions every 5 days. The weights of the samples were measured before putting them in the acid solution. The weight losses of the samples waiting in the solution for 30 days were measured and their compressive strength was tested. Acid resistance of the samples was expressed in terms of weight and compressive strength losses as a percentage. While compressive strength losses were calculated, the first compressive strength values were calculated by using the data obtained directly in the compressive strength test.

3. Results

3.1. Spreading test

As a result of the spreading test, the spreading diameter of the reference mixture was measured as 11.7 cm. Spreading diameters of samples using only PK-based water reducer and MP-based water reducer are 17.9 and 16.2 cm, respectively. Depending on the spreading diameters, the workability of using PK-based water reducer samples is higher than using MP-based water reducer samples. The effect of these water reducers on glass and basalt fiber reinforced samples is shown in Figure 3, clearly. The difference between the spreading diameters of glass and basalt reinforced samples was seen as 6.06% at most when using PK-based water reducer.

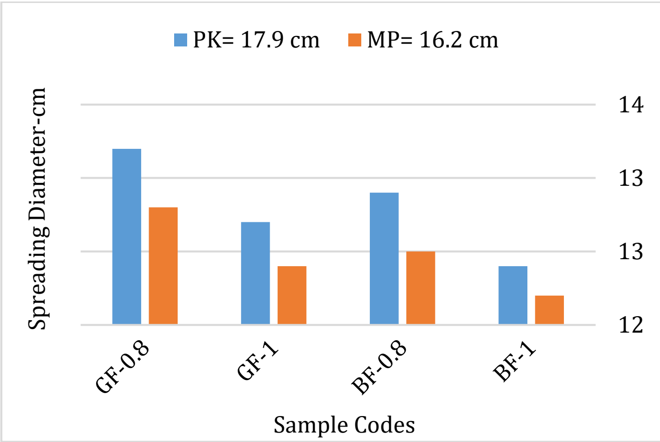

Figure 3. Spreading diameter of samples.

3.2. Flexural strength

Flexural strength of the samples of 7 and 28 days are given in the form of line graphs in Figures 4 and 5, respectively. Flexural strength of basalt fiber reinforced samples is higher than glass fiber reinforced samples. In a study comparing equal length glass and basalt fiber reinforced cement mortars [26], it is concluded that glass fiber reinforced cement mortars have the highest strength. In another study [38], comparing cement mortars prepared using basalt fibers of different lengths, it is observed that the flexural strength increases with increasing fiber length. When these studies are evaluated together, it can be said that the results in this study support other studies.

Compared to the reference sample, the increase in flexural strength with the use of water reducer is up to 17.86%, whereas with the use of fibers, this increase reached up to 30.95%. Flexural strength of basalt fiber reinforced samples using PK-based water reducer and was higher than the others. Increasing the amount of use of fibers has increased the flexural strength of both chemical admixtures. In the use of 1 percent fiber and MP-based water reducer, although the flexural strength of the glass fiber reinforced sample is more than the basalt fiber reinforced sample on the 7th day, the basalt fiber reinforced sample has more flexural strength on the 28th day. Considering the other results, this situation can be evaluated as the 7 days basalt fiber reinforced sample not being well compacted during the molding and having a porous structure.

When the effect of chemical admixture type on flexural strength for basalt fiber reinforced samples is evaluated, the use of PK-based water reducer yields better results compared to MP-based water reducer. However, the use of MP-based water reducer yields better results compared to PK- water reducer in glass fiber reinforced samples. This indicates the importance of the type of chemical admixture used, taking into account the fiber length and type.

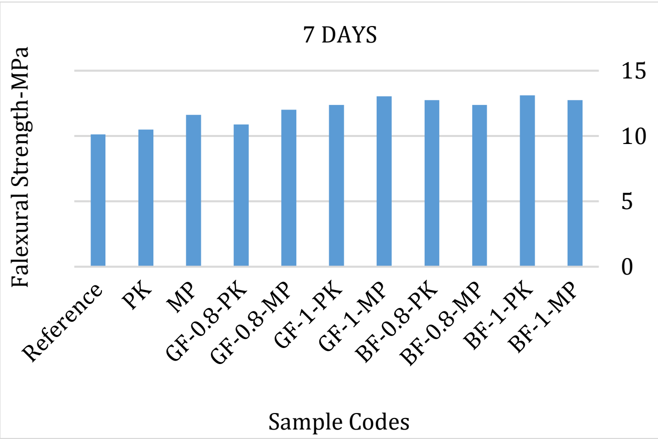

Figure 4 Flexural strength of 7 days samples

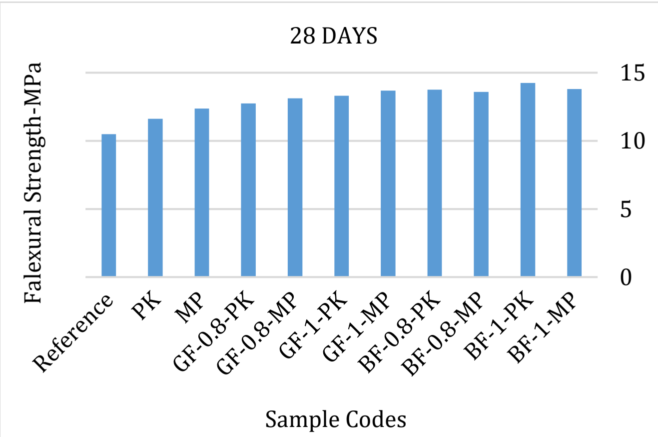

Figure 5. Flexural strength of 28 days samples.

After the flexural test, a compressive test was carried out to determine how much compressive strength they would have with the energy remaining from the samples broken. The results of compressive test after flexural test are given together with their 7 days direct compressive strength values in Figure 6. Looking at the results, the compressive strength values after the flexural test were found to be lower than the direct compressive strength values. The compressive strength is related to how much porous structure the sample forms in the cement mortar after breaking. In this case, it can be said that the samples in this experiment are broken by forming too many cracks in the flexural test until they show maximum strength.

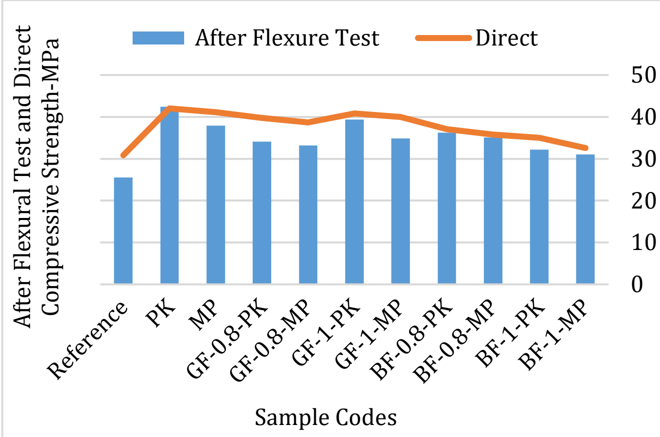

Figure 6. After flexural test and direct compressive strength of 7 days samples.

3.3. Compressive strength

The new generation PK-based water reducer has increased its compressive strength of 7 and 28 days samples more than the MP-based water reducer. In all basalt and glass fiber reinforced samples, despite the increase in compressive strength compared to the reference sample, high compressive strengths were not obtained as much as those using only MP-based water reducer and PK-based water reducer.

Compressive strengths of glass and basalt reinforced samples for 7 and 28 days are given in Figures 7 and 8, respectively. Compressive strength of glass fiber reinforced samples is higher than basalt fiber reinforced samples in every test conditions. This result supports the studies that say that increasing certain fiber length in fiber concretes negatively affects compressive strength. The using fibers more than a certain ratio affects compressive strength, adversely [39]. In this study, the increase in the amount of glass fiber caused an increase in compressive strength, while the increase in the use of basalt fiber caused a decrease in compressive strength.

The increase in the amount of basalt fibers, especially in the use of MP-based water reducer, caused a significant decrease in compressive strength. This is because the MP-based water reducer cannot provide sufficient workability for the cement mortar to increase the use of basalt fiber. The effect expected from the fibers homogeneously distributed under loading is the function of the cracks by transferring the tensions at the end of the cracks to themselves or to the solid areas. However, agglomeration of fibers creates a porous structure and weak bonding surfaces, leading to loss of strength [40].

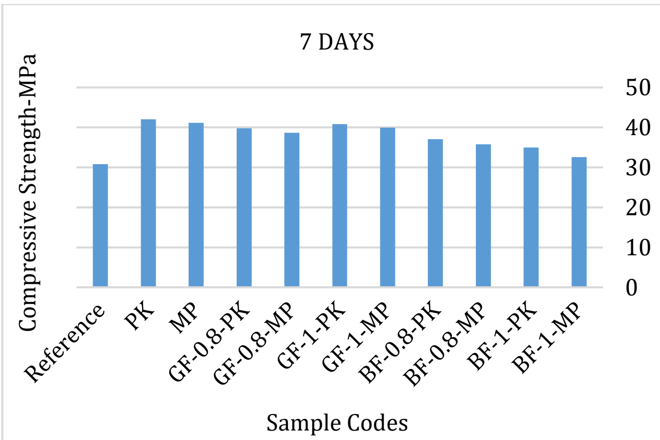

Figure 7. Compressive strength of 7 days samples.

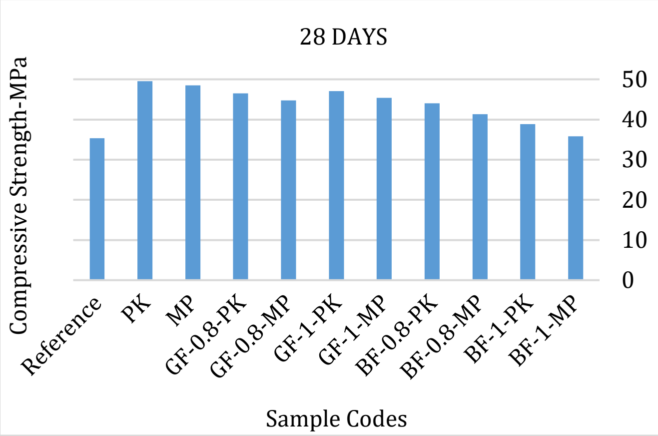

Figure 8. Compressive strength of 28 days samples.

3.4. Abrasion resistance

The abrasion percentages of the samples using PK and MP-based water reducer are lower compared to the reference sample. With the use of fiber, it has increased the abrasion resistance in both types of water reducers. There are studies that say that the basalt fiber has a higher contribution to the abrasion resistance compared to mixtures containing the same size and the same amount of glass and basalt fiber [41]. In this study, it is clearly seen in Figures 9 and 10 that basalt fiber reinforced samples have higher abrasion resistance compared to glass fiber reinforced samples.

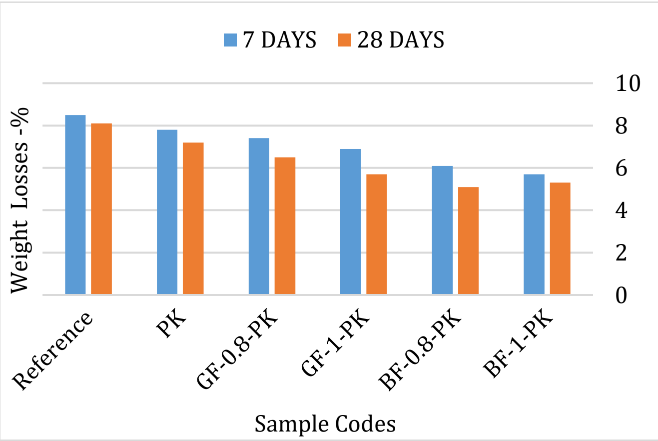

Figure 9. Weight losses of 7 and 28 days samples using PK-based water reducer.

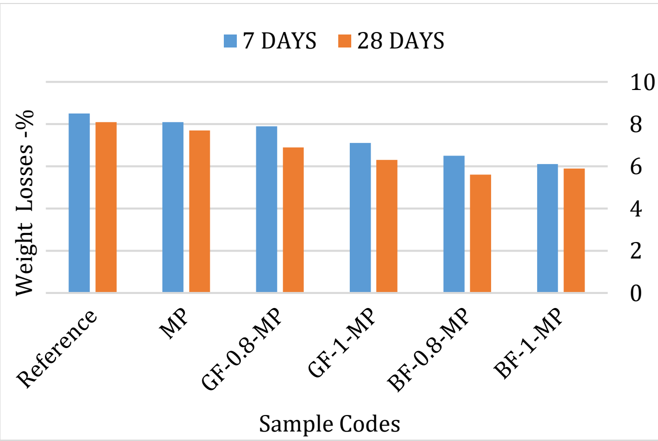

Figure 10. Weight losses of 7 and 28 days samples using MP-based water reducer.

Pores in cement mortars play an important role in the abrasion resistance [42]. PK-based water reducer has provided more homogeneous diffusion of fibers compared to MP-based water reducer and has provided less porous structure. This is a factor that ensures less weight losses in the sample using PK-based water reducer.

3.5. Acid resistance

The weight and compressive strength losses of the 7 and 28 days samples are given together by percent in Figures 11 and 12, respectively. Acid resistance of samples using PK-based water reducer is higher than samples using MP-based water reducer. The best acid resistance has seen in glass fiber reinforced samples with MP-based water reducer. In a study examining the acid resistance of glass and basalt fibers [43], it was concluded that the weight loss of basalt fiber reinforced samples was less than that of glass fiber reinforced samples. This is because C-type glass fiber, which has a higher resistance to acids than ordinary E-glass fibers, is used in this study.

Figure 11. Losses of weight and compressive 7 days samples.

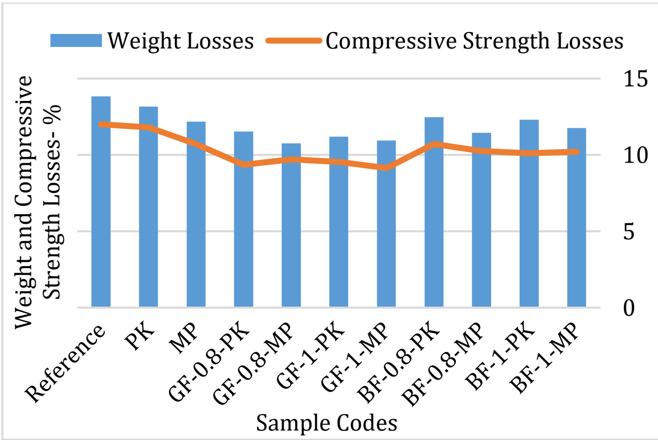

Figure 12. Losses of weight and compressive 28 days samples.

4. Dicussion and Conclusions

The purpose of this study is to evaluate the interaction of fiber types of different lengths and chemical admixture of different origins. The results obtained can be listed as follows.

The types of water reducers used in fiber reinforced cement mortars are very important. Considering the results, the use of fiber caused quite lots of differences compared to only samples with water reducers. Different fiber lengths differ in terms of workability when using fiber and chemical admixture in the same proportions.

The use of 0.8 percent fiber basalt fiber reinforced sample using PK-based water reducer have the most flexure strength. Also, in all fiber reinforced samples there was an increase in flexural strength compared to the reference sample. In addition, the increase in the amount of glass and basalt fibers used both water reducers increased the flexural strength.

While the increase in the amount of use of glass fibers has positive results in compressive strengths, an increase in compressive strength has not been achieved in basalt fibers.

Fiber use in cement mortar represented satisfactory results in terms of abrasion resistance and the results are consistent. However, although the use of fibers gives positive results at acid resistance, acid test results are not consistent as far as abrasion test results. Because of being %10 HCI concentration strong acid environment, acid test results only may not be right to associate with the acid resistance of the fibers. Also, abrasion resistance obtained as a result of the abrasion test applied in this study is a physical durability problem, but acid resistance is a chemical attack. There are many parameters that may cause these changes. Methods such as XRF and FTIR as images from fractured samples are needed to better understand the effect of acids on fiber reinforced cement mortars.

Ethics committee approval and conflict of interest statement

Ethics committee approval is not required for the article.
There is no conflict of interest with any person and institution in this study.

Author Contribution Statement

All writers contributed to the study. Experimental design and execution of experiments were prepared by Dilan Çankal and Ali Uğur Öztürk. Literature review and editing of the article was prepared by Gökhan Kaplan.

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