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Tam Faktöriyel Tasarım Kullanılarak Çimento Harçlarında Cam Atıklarının Kullanımının İncelenmesi

An Investigation of the Usage of Glass Wastes in Cement Mortars Using Full Factorial Design

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Öz

Dünyada atık yönetimi son yıllarda ön plana çıkmaktadır. Alternatif hammadde olarak kullanılan birçok malzeme gibi cam atıkları da giderek daha önemli bir durum haline gelmektedir. Bu atıkların çeşitli endüstriler için yeni malzeme üretiminde alternatif hammadde olarak kullanılması sürdürülebilirlik açısından oldukça önemlidir. Geniş bir yelpazede üretilen ve tüketilen camın geri dönüşümü birçok farklı sektöre katkı sağlamaktadır. Bu amaçla atık camdan üretilen toz ve elyaf olmak üzere iki farklı formda elde edilen malzemelerin çimento harçlarında kullanımı bu çalışmada araştırılmıştır. 0, 45, 90 ve 135 g olarak dört farklı cam tozu (GP) miktarı, 0 ve 13.37 g olmak üzere iki farklı cam elyaf (GF) miktarı ve 7, 28 ve 56 gün olmak üzere üç farklı kür süresi (CP) harçlara uygulanmıştır. Çimento harcı numunelerinin basınç, eğilme dayanımları ve aşınma dayanımları belirlenmiştir. Ayrıca çoklu regresyon analizi kullanılarak kabul edilebilir regresyon modelleri türetilmiştir. Varyans analizi (ANOVA), çimento harçlarının mekanik özellikler üzerindeki her üç faktörün ve GP ve CP faktörlerinin aşınma direnci üzerindeki etkilerinin önemli olduğunu göstermiştir. Uygun oranlarda üretilen cam elyaf ve cam tozu katkılı çimento harçlarının kullanımında mekanik dayanım ve aşınma direncinde iyileşmeler gözlemlenmiştir. Çalışma, beton gibi aşınmaya maruz kalan çimento esaslı malzemelerin üretiminde cam elyafı ve cam tozunun ayrı ayrı veya birlikte kullanılmasının faydalı olduğunu göstermektedir. Sonuç olarak üretilen betondan beklenen özellikler karşılanacaktır. Cam atıklarının kullanılması, ekonomik ve çevre dostu bir beton üretiminin gerçekleştirilmesine katkı sağlayacaktır.

Anahtar Kelimeler: *Çimento Harcı, Cam Atıkları, Cam Tozu, Cam Elyaf, Aşınma Dayanımı, Mekanik Mukavemet*

Abstract

Waste management in the world has come to the fore in recent years. Like many materials used as alternative raw materials, glass waste has become an increasingly important situation. It is very important in terms of sustainability that these wastes are used as alternative raw materials in the production of new materials for various industries. Recycling of glass, which is produced and consumed in a wide range, contributes to many different sectors. For this purpose, the use of materials obtained in two different forms, namely powder and fiber produced from waste glass, in cement mortars was investigated. There are three factors, including glass powder (GP) amount with four levels of 0, 45, 90 and 135 g, glass fiber (GF) amount with two levels of 0 and 13.37 g, and curing period (CP) with three levels of 7, 28 and 56 days. Compressive, flexural strengths and abrasion resistance of cement mortar samples were determined. In addition, acceptable regression models were derived by using multiple regression analysis. Analysis of variance (ANOVA) showed that the effects of all three factors on the mechanical properties and, GP and CP factors on abrasion resistance of cement mortars are significant. Improvements in mechanical strength and abrasion resistance were observed in the use of glass fiber and glass powder added cement mortars produced at appropriate rates. The study shows that the use of glass fiber and glass powder separately or together in the production of cement-based materials such as concrete, which is exposed to abrasion, is beneficial. As a result, the properties expected from the produced concrete will be met. The use of glass waste will contribute to the realization of an economical and environmentally friendly concrete production.

Keywords: *Cement Mortar, Glass Wastes, Glass Powder, Glass Fiber, Abrasion Resistance, Mechanical Strength*

1. Introduction

With the increasing population, technological developments and industrial activities, a lot of domestic and industrial waste is generated. In recent years, the management and disposal of these wastes has become an important issue. A large part of these are construction industry wastes. However, these wastes are used in the production of building materials. There are many studies on the use of industrial wastes in the production of concrete, which is a cement-based material. It is a very good approach to include another industrial waste in concrete, which is a building material that is very harmful to the environment and has uneconomical production processes [1]. Considering that concrete is the most used building material in the construction sector, it is very important to evaluate these wastes as alternative raw materials in concrete.

The glass sector is one of the industrial fields that provides input to many sectors such as construction, white goods, automotive, pharmaceuticals, cosmetics, and food. Waste glass generated after being used in these sectors can be used in concrete production by substituting aggregate [2] or cement [3]. Waste glass is purified from possible undesirable substances and brought to the desired grain sizes. Coarse-grained waste glass is used as aggregate in cement mortar and concrete, and finer-grained ones are used as binders instead of cement, or it can be used as mineral additive in cementitious products [4,5]. Aliabdo et al. [4] investigated cement mortars produced by using waste glass powder, and that stated that the amount of calcium hydroxide ($Ca(OH)_2$) decreased and the increase in compressive strength was associated with the detection of C-S-H formation.

When glass powder is used in appropriate proportions, it can improve the ultimate mechanical properties of concrete [6–8]. Also, Islam et al. [6] stated that glass powder particles have a positive effect on workability by reducing friction due to its glassy surface structure. However, in the literature, it is seen that different evaluations have been made on the effect of glass powder on the compressive strength of cement mortars and concretes. The fact that the recycled glass has different chemical components, the change in grain size during the grinding of the glass, the change in the amount of glass powder use can cause an increase or decrease in the compressive strength at different curing times [9]. Waste glass powder generally has pozzolanic activity with its relatively high SiO_2 content and amorphous structure [10]. This pozzolanic property, which directly affects the compressive strength, is related to components such as silica oxide (SiO_2), alumina oxide (Al_2O_3), iron oxide (Fe_2O_3), calcium oxide (CaO) in the material and the particle size of the ground glass.

Waste from the glass industry can also be included in the glass fiber production. These glass fibers produced by various methods are also widely used in concrete production. Glass fiber is a type of fiber with relatively low production cost and high tensile strength. As with all other fiber types, the distribution of fibers in the mortar is provided uniformly with the help of suitable plasticizers, and if optimum use is provided, the properties expected from fibers are obtained. When used in the appropriate ratio, the fibers carry some stresses that occur in the cement matrix under the effect of load and help transfer these stresses. They take these stresses, which cause the spread of the crack in the matrix and transmit them to the non-cracked areas.

Due to the chemical composition of glass and its components, many studies have been conducted on the resistance of cement mortars and concretes obtained using waste glass against chemical attacks [11–13]. There are few studies on the mechanical and durability properties of concretes where glass powder and glass fiber are used together [14,15]. Also, the number of studies on abrasion resistance is few. To increase the abrasion resistance of concretes, it is possible to use alternative additives and various fibers to cement. At the same time, studies in which glass powder and glass fiber are used together are very limited.

In this study, it is thought to contribute to the literature by examining the effect of glass powder and glass fiber obtained from waste glass on the abrasion resistance, compressive strength and flexural strength of cement mortars. It is well known that Portland cement production is an energy-intensive industry. Also, cement production is responsible for approximately 5% of global anthropogenic carbon dioxide emissions worldwide. An important contribution to the sustainability of construction and building materials is usage of pozzolanic additives, especially if they are obtained from wastes such as waste glass. Therefore, glass powder was used in this study. In addition, glass fiber was used to tolerate the loss of strength due to the reduction of cement. Within the scope of this study, the compressive strength, flexural strength and abrasion resistance of cement mortars cured for 7, 28 and 56 days, obtained by using glass powder and glass fiber, were tested. In addition, these three curing periods were preferred in order to see the contribution of glass powder to strength in the medium term. Furthermore, full factorial design technique is adopted considering factors such as GP amount (g), GF amount (g) and CP (days) to analyze these factors' effects on compressive strength, flexural strength and abrasion resistance of cement mortars. Also, ANOVA analyses were carried out for each dependent variable (compressive strength, flexural strength and abrasion resistance) to determine the significance of each factor on the dependent variables, and to predict appropriate regression models. In addition, optimal values of all factors for each three properties of cement mortars were tried to detect.

2. Materials and Methods

2.1. Materials used and mix proportions

Cement mortars consisting of cement, water, aggregate, chemical additives, glass sand and glass fiber were produced. CEM I 42.5 N with a density of 3.14 g/cm^3 was used as the main binder, and the chemical analysis of the cement are given in Table 1.

Table 1. Chemical analysis of cement and glass powder used

Tablo 1. Kullanılan çimento ve cam tozunun kimyasal analizi

Compounds (%)	Cement	Glass Powder
CaO	63.72	8.25
SiO_2	19.65	69.40
Al_2O_3	5.70	1.10
Fe_2O_3	2.99	0.49
MgO	0.90	4.26
Na_2O	0.22	12.30

The granulometric curve obtained as a result of the sieve analysis of the aggregates with grain sizes ranging from 0-4 mm obtained from the river according to TS EN 933-1 [16] is shown in Figure 1.

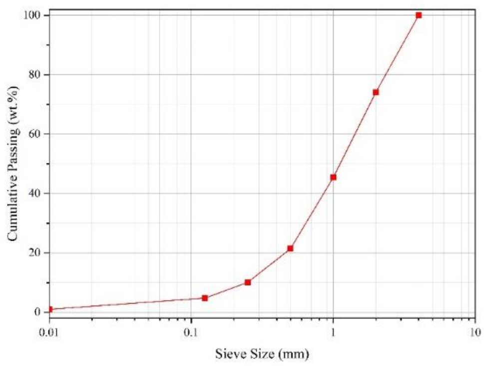

Figure 1. The granulometric curve of the aggregate used

Şekil 1. Kullanılan agreganın granülometri eğrisi

Glass powder is produced by pulverizing recycled glass in grinding mills. Glass fiber was produced by melting the waste glass and hardening it by pouring it through small-sized holes. Both products were obtained from Akcihan, which are sold as commercial products and are shown in Figure 2. The chemical composition of the glass powder is given in Table 1 by cement analysis. The particle size of the glass powder is below 50 μm and its density is 2.55 g/cm³. Glass fiber has a length of about 12 mm and a diameter of 0.3 mm. To reduce the workability loss with the use of glass fiber, 0.6 % of the weight of the Nanoment HP 1045 superplasticizer cement supplied from Lyksor Company was used.

Figure 2. Waste glass powder and glass fiber

Şekil 2. Atık cam tozu ve cam elyafı

The ratios of water:binder:aggregate in all prepared mixtures were determined as 1:2:6 in accordance with TS EN 196-1 [17]. The water/binder and binder/aggregate ratios of all mixtures are fixed. The amounts of the materials used in the mixtures and the naming of the samples are shown in Table 2.

Table 2. Amounts of components in cement mortars

Tablo 2. Çimento harçlarındaki bileşen miktarları

Sample Name	Water (g)	Cement (g)	Glass Powder (g)	Sand (g)	Glass Fiber (g)
GP0GF0	225	450	0	1350	0
GP10GF0	225	405	45	1350	0
GP20GF0	225	360	90	1350	0
GP30GF0	225	315	135	1350	0
GP0GF1	225	450	0	1350	13.37
GP10GF1	225	405	45	1350	13.37
GP20GF1	225	360	90	1350	13.37
GP30GF1	225	315	135	1350	13.37

The sample named GP0GF0 represents the sample that does not contain any glass powder and glass fiber, and only consists of water, cement, and aggregate. While GP10GF0, GP20GF0, GP30GF0 refer to samples using 10%, 20% and 30% glass powder replacement with cement, GP10GF1, GP20GF1, GP30GF1 refer to samples using 1% glass fiber addition by weight and using 10%, 20% and 30% glass powder replacement with cement. A total of 24 mixtures were tested; 8 different mixture designs in the table, were subjected to mechanical tests on days 7, 28 and 56, and the results are discussed in the following sections.

2.2. Methods

First, dry materials were mixed in the ratios indicated in Table 2, and then water and additive were added together to ensure that the liquid mixture and the dry mixture were blended. Before the prepared cement mortars were placed in the molds, the workability of each set was determined by the spreading table while the mortar of each set was fresh. The flow diameters of the mortars were calculated by measuring the distances between the two furthest points and taking the average. Then the mixtures were placed in molds with the help of shaking table. 50*50*50 mm cubic molds used for compressive strength and abrasion resistance tests, and 40*40*160 mm prismatic steel molds were used for bending strength. After 24 hours, the hardened cement mortar samples were removed from the molds and water cured for 7, 28 and 56 days.

The compressive strengths of the samples were tested in accordance with ASTM C 109 [18] and flexural strengths in accordance with ASTM C 348 [19]. Compressive strength values were calculated by dividing the ultimate loads read from the devices by the cross-sectional area (50*50 mm). The abrasion resistance test was carried out on the cube samples with the Bohme device shown in Figure 3 according to TS 2824 EN 1338 [20]. Weight measurements of the pre-wear samples were made to determine their wear resistance. Afterwards, the samples were exposed to abrasion with corundum powder in a total of 352 full turns on 4 selected surfaces. Abrasion resistance was calculated as a percentage by measuring the weight of the samples after wear.

Figure 3. Bohme Device used for abrasion resistance

Şekil 3. Aşınma direnci için kullanılan Bohme Cihazı

In this research, full factorial design was adopted to develop the design of the experiments. The independent variables, namely GP (g), GF (g) and CP (days), were considered at four (0, 45, 90, 135), two (0, 13.37) and three (7, 28, 56) levels, respectively (Table 3). For each level, three replicates were carried out. The 8 different mortar combinations were analyzed by Minitab statistical software.

Table 3. Factors and levels adopted for full factorial design.

Tablo 3. Tam faktöriyel tasarım için kullanılan faktörler ve seviyeleri.

Factor	Level 1	Level 2	Level 3	Level 4
GP: Glass Powder (g)	0	45	90	135
GF: Glass Fiber (g)	0	13.37	-	-
CP: Curing Period (day)	7	28	56	-

3. Test Results

3.1. Flow test

In Figure 4, it is clearly seen that the flow diameter of the mortars increased with the addition of glass powder when compared to the reference sample. It is thought that the increase in flow diameters is due to both the particle size distribution of the glass powder and the surface structure of the glass powder particles. Glass powder particles have a positive effect on workability by reducing friction due to its glassy surface structure, and this increase is further supported by the addition of superplasticizer admixture. Islam et al. [6] obtained similar results in their study.

Also, filling effect of the glass powder increased the flowability of the cement mortar samples. Moosberg-Bustnes et al. [21] and Subaşı et al. [22] using filler materials finer than 0.125 mm is quite effective on the fresh state properties of concrete due to improving and maintaining the cohesion and segregation resistance of concrete and filling the intergranular voids between cement particles and improving the compactness of the concrete. However, excessive use can also cause loss of workability.

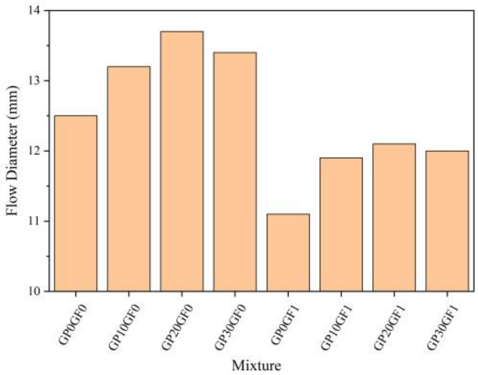

Figure 4. Flow diameters of cement mortars

Şekil 4. Çimento harçlarının yayılma çapları

The flow diameter of cement mortars decreased with the addition of glass fiber to the samples with glass powder. The workability of each fresh mortar with fiber additives is less than the reference cement mortar sample. However, when glass fiber is used, better workability was obtained in the use of glass powder and superplasticizer compared to the without glass powder sample (GP0GF1). It is seen that the effect of glass powder addition to cement mortars on the flow diameters, although the amount of glass powder is different in the addition of glass fiber additive, closer flow diameter values are obtained. The reason for this is the appearance of agglomerating with the fiber additive and the loss of consistency by restricting the mobility of the components in the mortar. The difficulty experienced in placing the fiber-added mortars into the mold compared to other tools during the experiment is an indicator of this.

3.2. Compressive strength

The compressive strengths of all samples at days 7, 28 and 56 are given in Figure 5. When 10% and 20% glass powder was added as cement substitute, an increase in compressive strength was observed at all curing times. Aliabdo et al. [4] investigated cement mortars produced by using waste glass powder, and that stated that the amount of calcium hydroxide ($Ca(OH)_2$) decreased and the increase in compressive strength was associated with the detection of C-S-H formation.

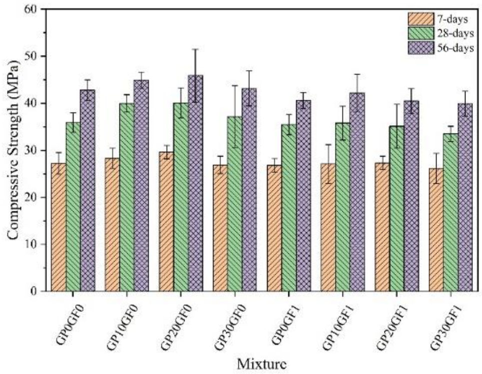

Figure 5. Compressive strengths of cement mortars

Şekil 5. Çimento harçlarının basınç dayanımları

With the addition of 30% glass powder, there was a decrease in compressive strength. Islam et al. [6] found that the use of more than 30% glass powder for $Ca(OH)_2$ for pozzolanic activity may be insufficient.

Especially for glass powder addition in the early period, longer curing is required so that the effect of the pozzolanic reaction on the compressive strength can be evident. While the compressive strength increase on the 7th day is 4.04% and 8.82% for 10% and 20% GP usage level without using GF compared to the reference sample, it is 11.37% and 11.65% on the 28th and 4.96% and 7.20% on the 56th days. This is a positive property that pozzolanic materials such as glass powder form in concrete at advanced ages. According to test results, 20% glass powder usage ration can be considered as the optimum usage level for both waste consumption and compressive strength increase in mortars.

A decrease in compressive strength was observed when glass fiber was added to mortars containing glass powder. Adding more than a certain amount of fiber to cement mortars can cause a decrease in compressive strength. However, despite the decrease in compressive strength, the toughness and energy absorption capacity of mortars may increase with more ductile fracture. For this reason, it may not be a correct approach to evaluate the effect of fibers on this issue by only considering at the fracture loads of fiber-reinforced cement-based materials. On the other hand, the compressive strength value of the test samples produced using 10% GP and 1% GF (GP10GF1) was determined to be very close to the compressive strength value of the reference (GP0GF0) mixture. The compressive strength of the GP0GF0 mixture at 7, 28 and 56 days was determined as 27.2, 35.87 and 42.78 MPa, respectively. The compressive strength values of the GP10GF1 mixture determined at the same curing times are 27.1, 35.8 and 42.2 MPa. It has been determined that glass powder and glass fiber are suitable for use together in these usage levels without a significant loss in compressive strength.

According to the test results, the analysis of variance (ANOVA) for compressive strength of cement mortars was performed and the ANOVA results are presented in Table 4. Table 4 indicates that since the p-values are less than 0.05, all three factors (GP, GF, CP) are significant factors on compressive strength of cement mortars. Furthermore, considering the p-values, it is observed that the interaction between GP and GF factors and between GF and CP factors are also significant on compressive strength. Figure 6 represents the main effects plot for compressive strength of cement mortars considering the factors GP (g), GF (g) and CP (days). It can be concluded from the figure that the compressive strength increases up to 20% GP usage ratio. This is due to both filling effect of glass powder and pozzolanic characteristic of the GP. On the contrary, GF usage decreases the compressive strength. This can be attributed to the agglomeration of glass fiber and making porous zones in the mortar samples. As expected, it is also seen that the compressive strength of the mortars improves with the increase in the curing period.

A model is developed by using multiple regression analysis for the compressive strength based on the significant parameters in the ANOVA results in Table 4. The compressive strength regression equation is given in Equation 1.

Table 4. Analysis of variance for compressive strength of mortar

Tablo 4. Harçların basınç dayanımı için varyans analizi

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
GP	3	19.14	1.91%	19.137	6.379	17.54	0.002
GF	1	40.96	4.09%	40.964	40.964	112.61	0.000
CP	2	923.68	92.23%	923.679	461.840	1269.60	0.000
GP*GF	3	7.69	0.77%	7.690	2.563	7.05	0.022
GP*CP	6	1.65	0.16%	1.646	0.274	0.75	0.630
GF*CP	2	6.21	0.62%	6.209	3.105	8.53	0.018
Error	6	2.18	0.22%	2.183	0.364		
Total	23	1001.51	100.00%				

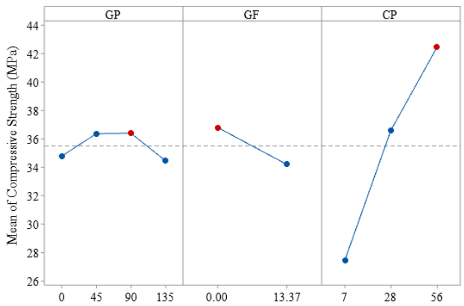

Figure 6. Main effect plots for compressive strength

Şekil 6. Basınç dayanımı için ana etki grafikleri

$$\text{Compressive Strength (MPa)} = 26.67 + 0.0048\,GP - 0.029\,GF + 0.3236\,CP - 0.00104\,GP{*}GF - 0.00318\,GF{*}CP \quad (1)$$

$R^2 = 93.10\ \%$ $\quad$ $R^2\ (adj) = 91.18\ \%$

3.3. Flexural strength

The increase in flexural strength of all mortars with glass fiber added is clearly seen in Figure 7.

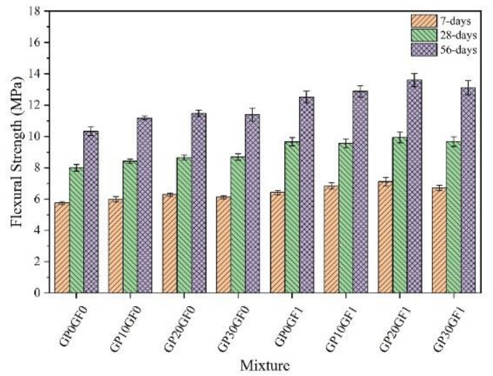

Figure 7. Flexural strengths of cement mortars

Şekil 7. Çimento harçlarının eğilme dayanımları

While the flexural strength of non-fibrous mortar was 7.99 MPa at 28-days of curing, the flexural strength values of fibrous mortars were measured between 9.55-9.93 MPa at 28-days of curing. As the curing period increased, a noticeable increase was detected in the flexural strength of the fiber reinforced mortars. Considering the 56-day curing periods, the addition of 1% fiber without the use of glass powder increased the flexural strength of the cement mortar by 21.22% compared to the reference mortar. Moreover, with the addition of waste glass powder to 1% fiber reinforced mortars (GP10GF1, GP20GF1, GP30GF1) the flexural strength of cement mortars was further improved. With the addition of 10%, 20% and 30% glass powder to 1% fiber reinforced cement mortar, the flexural strength of the mortar increased by 24.59%, 31.59% and 26.91%, respectively. In the later curing ages, it is thought that the pozzolanic property of the glass powder around the fibers fills the gaps between the fiber and the matrix and increases the adherence, thereby increasing the flexural strength. It has been observed that the fibers exhibit a more homogeneous distribution in the mortar and are more effective in preventing the microcracks that occur due to tensile stresses in the lower parts of the mortar during the flexural strength test, and accordingly, the flexural strength increases with the increase of the fiber amount [23].

According to the test results, the analysis of variance (ANOVA) for compressive strength of cement mortars was performed and the ANOVA results are presented in Table 4. Table 4 indicates that since the p-values are less than 0.05, all three factors (GP, GF, CP) are significant factors on flexural strength of cement mortars. Furthermore, considering the p-values, it is observed that the interaction between GF and CP factors is also significant on flexural strength. Figure 8 represents the main effects plot for compressive strength of cement mortars considering the factors GP (g), GF (g) and CP (days). It can be concluded from the figure that the flexural strength increases up to 20% GP usage ratio (i.e., 90 g). This is due to both filling effect of glass powder and pozzolanic characteristic of the GP. When Figure 7 and Figure 8 are evaluated together, it is observed that glass fiber reinforcement is an important factor in increasing the flexural strength of cement mortars. This can be attributed to the crack bridging effect of glass fibers. As expected, it is also seen that the flexural strength of the mortars improves with the increase in the curing period.

A model is developed by using multiple regression analysis for the flexural strength based on the significant parameters in the ANOVA results in Table 5. The compressive strength regression equation is given in Equation 2.

Table 5. Analysis of variance for flexural strength of mortar.

Tablo 5. Harcın eğilme dayanımı için varyans analizi.

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
GP	3	1.691	1.19%	1.691	0.5637	31.28	0.000
GF	1	10.323	7.26%	10.323	10.3228	572.78	0.000
CP	2	128.164	90.17%	128.164	64.0818	3555.71	0.000
GP*GF	3	0.154	0.11%	0.154	0.0514	2.85	0.127
GP*CP	6	0.277	0.20%	0.277	0.0462	2.57	0.138
GF*CP	2	1.423	1.00%	1.423	0.7113	39.47	0.000
Error	6	0.108	0.08%	0.108	0.0180		
Total	23	142.140	100.00%				

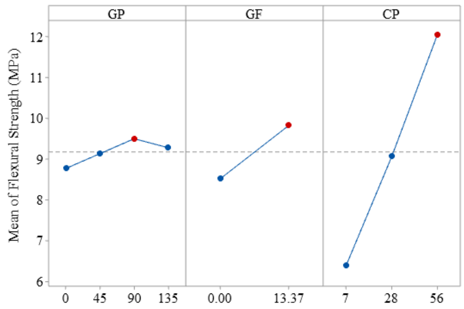

Figure 8. Main effect plots for flexural strength

Şekil 8. Eğilme mukavemeti için ana etki grafikleri

$$\text{Flexural Strength (MPa)} = 5.116 + 0.00420\,GP + 0.0431\,GF + 0.10286\,CP + 0.001814\,GF*CP \quad (2)$$

R^2 = 98.96 % R^2 (adj) = 98.74 %

3.4. Abrasion resistance

Abrasion resistance of all mixtures was evaluated as weight loss. In Figure 9, these weight losses of cement mortars are represented as a percentage.

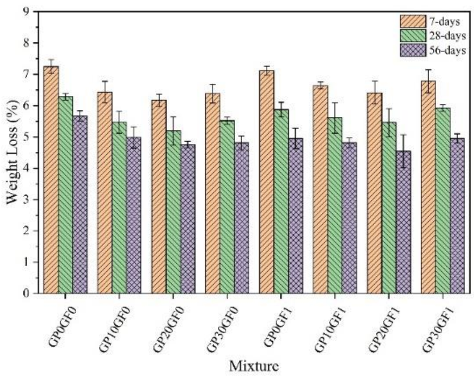

Figure 9. Weight losses of cement mortars due to abrasion

Şekil 9. Çimento harçlarının aşınmaya bağlı ağırlık kayıpları

It was observed that the abrasion resistance of the mortars increased as the curing time increased in all cement mortar series.

An increase was observed in the abrasion resistance of the mortars with only glass powder added to the reference mortars at all curing times. Considering the samples cured for 28 days, the weight loss of reference mortar on abrasion was determined as 6.28%. In the mortar samples produced without fiber, the weight loss on abrasion of the mortars using 10% and 20% glass powder is 5.47% and 5.19%, respectively. Glass powder strengthens the cement matrix structure and provides a more compact structure of the mortar by filling effect. Thus, up to 20% usage rate, glass powder considerably increases the abrasion resistance of cement mortar. Thus, there is a rapid increase in abrasion resistance up to 20% use of glass powder. With the addition of 30% glass powder, this increase in abrasion resistance decreased. The abrasion resistance of the mortars using 30% glass powder on the 7th day is less than the samples using 10% glass powder. However, after 28 days of curing, this difference was greatly reduced. Even after 56 days of curing, the weight loss of the mortars with 10%, 20% and 30% glass powder added is 4.81%, 4.54% and 4.95%, respectively. With the increase of the curing time, the improvement in the abrasion resistance of the samples using 30% glass powder is evident. However, longer curing times should also be examined in order to more clearly interpret the difference between the abrasion resistance in the use of 30% glass powder and the use of 10% glass powder.

With the addition of glass fiber to the glass powder added mortars, an increase was observed in the weight losses of the mortars on the 7th and 28th days. However, this weight loss difference significantly decreased at the end of 56 days. The abrasion resistance of all glass powder and glass fiber added mortars is higher than the reference samples. Abrasion resistance in fiber usage varies depending on many factors such as the amount of fiber near the surface, the distribution of fibers, the abrasion resistance of the fiber, the adherence between the matrix and the fiber and the amount of space. In particular, an increase in abrasion resistance can be achieved by using fiber without creating voids. In this study, the best abrasion resistance was observed on the 56th day in the samples in which 20% glass powder and glass fiber were used, which is GP20GF1 coded sample with 4.54 % weight loss on abrasion.

Analyses of variance for the abrasion resistance property in study is given in Table 5. According to the analysis of variance (ANOVA) for abrasion resistance of cement mortars, since the p-values are less than 0.05, glass powder (GP) amount and curing period (CP) are significant factors on abrasion resistance of cement mortars since the p-values of these factors are less than 0.05. Furthermore, considering the p-values, it is observed that the interaction between GP and GF factors and between GF and CP factors are also significant on abrasion resistance of cement mortars. The main effects of each factor are represented in Figure 10. It can be concluded from the figure that the abrasion increases up to 20% GP usage ratio (i.e., 90 g). It is observed that the effect of using 1% glass fiber on the abrasion resistance of cement mortar remains at a very minimal level. It is also seen that the abrasion resistance of the mortars improves with the increase in the curing period.

A model is developed by using multiple regression analysis for the flexural strength based on the significant parameters in the ANOVA results in Table 6. The compressive strength regression equation is given in Equation 3.

Table 6. Analysis of variance for weight loss of mortar on abrasion.

Tablo 6. Aşınma sırasında harcın ağırlık kaybı için varyans analizi.

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
GP	3	1.8547	12.89%	1.8547	0.61823	159.20	0.000
GF	1	0.0009	0.01%	0.0009	0.00094	0.24	0.641
CP	2	11.8123	82.08%	11.8123	5.90615	1520.90	0.000
GP*GF	3	0.4377	3.04%	0.4377	0.14590	37.57	0.000
GP*CP	6	0.0612	0.43%	0.0612	0.01021	2.63	0.132
GF*CP	2	0.2007	1.39%	0.2007	0.10035	25.84	0.001
Error	6	0.0233	0.16%	0.0233	0.00388		
Total	23	14.3909	100.00%				

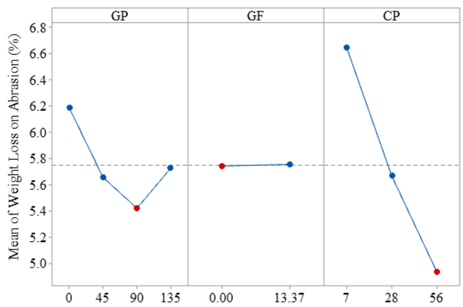

Figure 10. Main effect plots for weight loss on abrasion

Şekil 10. Aşınma sebebiyle ağırlık kaybı için ana etki grafikleri

$$\text{Abrasion Resistance (\%)} = 5.404 + 0.00346\,GP + 0.09740\,CP + 0.000111\,GP*GF + 0.002630\,GF*CP \quad (3)$$

$R^2 = 98.57$ % R^2 (adj) = 97.45 %

4. Discussion and Conclusion

In this study, some mechanical and physical properties of cement-based mortars with glass powder and glass fiber additives at different rates were investigated and the following results were obtained:

1. The flow diameters and thus the workability properties of the mortars produced with glass powder additive without using glass fiber are improved up to 9.6 %.

2. The flow diameters decreased with the use of 1% fiber in mortars, but the flowability was slightly improved with the use of glass fiber and glass powder together.

3. When the flexural strength test was performed on glass fiber reinforced mortars, it was observed that the fiber addition increased the flexural strength, that is, the tensile strength of the mortars.

4. It has been determined that the addition of glass powder can increase the compressive strength of the cement mortar up to 7.20%.

5. 1% glass fiber reinforcement without using glass powder increased the flexural strength of the mortar by 21.22% compared to the reference mortar, while adding 20% glass powder to the fibrous mortar increased the flexural strength by 31.59% compared to the reference mortar.

6. Up to 20% usage rate, glass powder considerably increases the abrasion resistance of cement mortar. In this study, the highest abrasion resistance was observed on the 56th day in the samples in which 20% glass powder and glass fiber were used, which is GP20GF1 coded sample with 4.54 % weight loss on abrasion.

7. In addition, in this study, the effects of each factor separately and in combination with each other on the compressive, flexural and abrasion resistance of mortars were analyzed by ANOVA test. Moreover, regression analyzes were performed and mathematical equations of compressive, flexural and abrasion strengths based on the factors determined in the study were produced. The significance levels of the obtained equations are quite high. (R^2(adj.) from 91.18 to 98.74 %)

According to the results of the study, it was determined that the use of glass powder and glass fiber together is appropriate.

5. Tartışma ve Sonuç

Bu çalışmada, farklı oranlarda cam tozu ve cam elyaf katkılı çimento esaslı harçların bazı mekanik ve fiziksel özellikleri incelenmiş ve aşağıdaki sonuçlar elde edilmiştir:

1. Cam elyaf kullanılmadan cam tozu katkı maddesi ile üretilen harçların akış çapları ve dolayısıyla işlenebilirlik özellikleri %9,6'ya kadar iyileştirilmiştir.

2. Harçlarda %1 elyaf kullanımı ile akış çapları azalırken, cam elyafı ve cam tozu birlikte kullanımı ile akışkanlık bir miktar iyileştirilmiştir.

3. Cam elyaf takviyeli harçlar üzerinde eğilme mukavemeti testi yapıldığında, cam elyaf ilavesinin harçların eğilme mukavemetini yani çekme mukavemetini arttırdığı görülmüştür.

4. Cam tozu ilavesinin çimento harcının basınç dayanımını %7,20'ye kadar artırabildiği belirlenmiştir.

5. Cam tozu kullanılmadan %1 oranında cam elyaf takviyesi, harcın eğilme mukavemetini referans harca göre %21,22, elyaflı harca %20 cam tozu ilavesi ise referans harca göre eğilme mukavemetini %31,59 oranında artırmıştır.

6. %20'ye varan kullanım oranı ile cam tozu, çimento harcının aşınma direncini önemli ölçüde artırmıştır. Bu çalışmada aşınmada %4,54 ağırlık kaybı ile GP20GF1 kodlu numune olan %20 cam tozu ve cam elyafı kullanılan numunelerde en yüksek aşınma direnci 56. günde gözlenmiştir.

7. Ayrıca bu çalışmada, her bir faktörün ayrı ayrı ve birbiriyle etkileşimi halinde harçların basınç, eğilme ve aşınma direnci üzerindeki etkileri ANOVA testi ile incelenmiştir. Ayrıca regresyon analizleri yapılarak çalışmada belirlenen faktörlere bağlı olarak basınç, eğilme ve aşınma dayanımlarının matematiksel denklemleri üretilmiştir. Elde edilen denklemlerin anlamlılık düzeyleri oldukça yüksektir. (R2(adj.) %91,18'den %98,74'e kadar)

Çalışma sonuçlarına göre cam tozu ve cam elyafının birlikte kullanımının uygun olduğu belirlenmiştir.

6. Etik kurul onayı ve çıkar çatışması beyanı

<u>"Hazırlanan makalede etik kurul izni alınmasına gerek yoktur"</u>

<u>"Hazırlanan makalede herhangi bir kişi/kurum ile çıkar çatışması bulunmamaktadır"</u>

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