Konya Mühendislik Bilimleri Dergisi, c. 9, s. 2, 416-427, 2021
Konya Journal of Engineering Sciences, v. 9, n. 2, 416-427, 2021
ISSN: 2667-8055 (Elektronik)
DOI: 10.36306/konjes.825996

PROPERTIES OF MORTARS PRODUCED WITH CLASSLESS AFSIN-ELBISTAN FLY ASH AND WASTE GROUND GLASS

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(Geliş/Received: 14.11.2020; Kabul/Accepted in Revised Form: 02.02.2021)

ABSTRACT: The aims of the present study to investigate classless Afsin-Elbistan fly. For this purpose, classless Afsin-Elbistan fly ash and waste granulated glass have been mixed at certain rates. After several experiments, obtained mixture according to standard were determined. The mortar samples produced by these mixtures with different percentages replaced of cement. Setting time, volume expansion, flexural and compressive strengths of samples were determined at 3-7-28 days. Moreover, alkali-silica reaction (ASR) of samples was tested according to using mortar bar experiments. The results of this study, Afsin-Elbistan fly ash can be used as C and F class ash in accordance. The bending and compressive strengths of the samples that added ten percent glass powder to the fly ash were found to be the highest. The expansion rates of the samples were found in accordance with the standard. The results obtained from experimental studies have shown that many properties of mortars produced with class ash are better than the Reference sample. The results of this study showed that by adding different amounts of glass powder to the Afsin-Elbistan fly ash, it could be used in cement production as the ash was classified into class.

Keywords: *ASR; Fly ash; Strength; Ground Glass.*

Sınıfsız Afsin-Elbistan Uçucu Külü ve Atık Cam Tozundan Yapılan Harçların Özellikleri

ÖZ: Bu çalışmanın amacı, sınıfsız Afsin-Elbistan uçucu külünün çimentoda katkı maddesi olarak kullanımı incelemektir. Bu amaçla, sınıfsız Afşin-Elbistan uçucu kül ve atık granül cam belirli oranlarda karıştırılarak deneysel çalışmalar yapılmıştır. Birkaç denemeden sonra, söz konusu karışım sınıflı kül haline getirilmiştir. Elde edilen sınıflı kül farklı oranlarda kullanılarak standart harç numuneleri yapılmıştır. Numunelerin priz süresi, hacim genişlemesi, 3, 7 ve 28 günlük eğilme ve basınç dayanımları belirlenmiştir. Ayrıca numunelerin alkali-silika reaksiyonu (ASR) harç çubuğu deneylerine göre test edilmiştir. Uçucu küle yüzde on cam tozu katılan numunelerin eğilme ve basınç dayanımların en yüksek bulunmuştur. Numunelerin genleşme oranları standarda uygun bulunmuştur. Numunelerin genleşme oranları standarda uygun bulunmuştur. Deneysel çalışmalardan elde edilen sonuçlar sınıflı külle üretilen harçların birçok özelliğinin Referans örnekten daha iyi olduğunu göstermiştir. Bu çalışmanın sonuçları, Afsin-Elbistan uçucu külüne değişik oranlarda cam tozu katılarak söz konusu kül sınıflı hale getirildiğinden çimento üretiminde kullanılabileceğini göstermiştir.

Anahtar Kelimeler: *ASR; Uçucu kül, Dayanım; Cam tozu.*

1. INTRODUCTION

Pozzolana is defined as a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties. Natural and artificial pozzolanas have been used to obtain hydraulic binders for over a thousand years. Hardening of pozzolanic cement pastes can result from the reaction between pozzolana and the lime that is added to the mix as hydrated lime or is produced following hydration of Portland cement silicates. The pozzolanic reaction does not alter cement clinker hydration; it complements and integrates the hydration process because it results in a lower portlandite content and an increase in calcium silicate hydrates (Massaza, 1993; Turkmenoglu et al. 2000).

Besides reviewing the most recent investigations on pozzolana-containing cements, this paper shows that the behaviour of different types of pozzolana can be quite similar when they are blended and become hydrated along with Portland cement clinker. Portland cement properties may undergo several qualitative modifications the extent of which substantially depends on the pozzolana/clinker ratio. So, a maximum is reached in pozzolanic cements (Kaplan and Binici, 1996). The use of pozzolana has expanded because it has various advantages over other cementitious materials. They have a relatively constant chemical composition compared to pure Portland cement. Moreover, it has advantages like low heat of hydration, high sulphate and acid resistance better workability, higher ultimate strength, etc. These properties are beneficial to special applications such as hydroelectric dams, large bridges, power stations, metro systems, motorways, and harbours (Binici and Aksogan, 1996).

A number of artificial pozzolanas were investigated including Ground Granulated Blast furnace Slag, Fly Ash, Calcined Clay, Microsilica, Rice Husk Ash, Red Brick Dust, and Tile and Yellow Brick Dust etc. Fly ash is a very fine material produced by burning of pulverized coal in a thermal power plant. Fly ash is a general name used for the residual products of combustion that rise with flue gases. Fly ash, also known as flue ash, is one of the residues generated in combustion, and comprises the fine particles that rise with the flue gases. In an industrial context, fly ash usually refers to ash produced during combustion of coal. It is carried by the flue gas and is collected by the electrostatic precipitators or cyclones. Chemically and physically, fly ash can have many forms like C-fly ash and F-fly ash depending on the type of fuel burned and handling methods. A typical fly ash contains a significant amount of silicon dioxide and calcium oxide, which make it frictional and abrasive. Usually, fly ash has a fine particle size distribution less than 100 microns. Given the fine particle size, frictional nature and high temperature, fly ash can be a difficult material to handle reliably. Quantity does pose challenging problems, in the form of land usage, health hazards, and environmental dangers (Ghazali and Kaushal, 2015). A small portion of these amounts is used in the cement production and dam injections and brick production. However, fly ashes that are an industrial waste have many different and common usage areas in many countries (Kılınckale, 1995). The fly ashes whose production amounts have reached large measures in parallel with the energy needs have many potential usage areas such as in agriculture, in chemical industry, soil stabilization and in the production of various structural materials (Tokyay, 1994).

According to chemical test results, for $SiO_2 + Al_2O_3 + Fe_2O_3$ (S + A + F) in ash A, S + F + A> 50% specified in ASTM C 618 class C and S + F + A> 70% in TS 639 could not meet the specified quality standards. Furthermore, the condition of maximum 1.0% for free lime in the TS EN 450 standard could not be achieved as it contained high volume of lime fly ash. The glow loss, MgO and Cl- contents remained within the limit values given in the standards. As a result, it has been observed that the Afşin-Elbistan Thermal Power Plant fly ash does not fully comply with the requirements of the relevant standards (Turker et al. 2009).

Exponentially increasing effects of industrial facilities, population growth, and technological developments cause environmental problems along with the necessity of disposal of accumulating industrial wastes like waste glasses. The annual amount of waste glass in our country is approximately 120,000 tons, which indicates the importance of utilizing this material in appropriate areas (Topcu and Canbaz, 2004; Turgut, 2007). Waste glasses in the industrial waste material group have an important share in the classification due to the high silica value it contains. The amount of silica in waste glass powders reduces the amount of $Ca(OH)_2$, which is harmful and known as the undesired phase, and enables the formation of CSH gels known as useful phases that contribute to strength (Omran and Tagnit, 2016; Shao et al. 2000; Shi et al. 2005; Turgut, 2018). In addition, studies have shown that pozzolanic mineral additives reduce the void structure, improve permeability and reduce ASR expansions (Omran and Tangit, 2016; Park et al. 2004). In this study, Afsin-Elbistan ash, known as classless ash, is classified with waste glass powder additive and it is seen that the ASR expansion of the samples meet the boundary conditions specified in TS EN 196-3.

According to ASTM C 618, fly ashes are divided into two classes, namely F and C. The F class fly ashes are obtained as a result of burning anthracite coal and they are entitled as low ash lime since they include CaO less than 10 %. Since free lime has not been found in these ashes, they don't have self-hardening property. However, they gain hardening by reacting with lime in aqueous media. Pozzolanic reactions are very slow in normal conditions (Atis et al. 2002; Bentli et al. 2005; Sevim, 2003; Kockal and Ozturan, 2010). C class fly ashes are obtained as result of burning lignite coal. They are defined as high-lime fly ash because they keep more than 10% CaO in them. In accordance with ASTM C618'c, since the fly ash of Afsin-Elbistan Thermal Power Station is classless, it cannot be used in cement and concrete production. In the present study, this ash has been classified by using granulated glass at certain rates. Then, the cement produced by (AEFA-GG) with the class ash obtained, has been studied to find out if it could be used in the concrete production or not.

There are academic studies on the purpose of utilizing pozzolan and industrial wastes in cement production. Afsin - Elbistan thermal power plant is one of the power plants that has the highest energy generation capacity and the most fly ash in terms of ash amount in production. However, since the ashes produced do not have the limit values specified in ASTM C 618 and TS 639 standards, they are called non-class ash. Therefore, it is stated that these ashes cause environmental pollution and health threats by mixing with groundwater due to storage problems. This paper tries to explore the use of Afsin-Elbistan classless fly ash in cement and mortar production as C and F class ash with the addition of glass powder.

2. MATERIAL AND METHOD

2.1. Material

The materials used in this study are Afsin-Elbistan Fly Ash (AEFA), CEM 1, Standard Rilem Sand and Tekirdag glass (GG). CEM 1, which was used as control cement, has been supplied from Kahramanmaras Cement Industry and Classless Fly Ash has been supplied from Afsin Elbistan Thermal Power Stations. The standard sand used had the size specified in TS 819.

2.2. Method

Fly ashes are classified differently according to their chemical content as specified in ASTM C618. Ashes that meet the requirement of $SiO_2 + Al_2O_3 + Fe_2O_3 > 70\%$ in their chemical composition are called F class, and ashes that meet the condition of $SiO_2 + Al_2O_3 + Fe_2O_3 > 50\%$ are called C class ashes. Afsin-Elbistan Thermal Power Plant is one of the power plants in Turkey operating with a high capacity in terms of energy and fly ash production. When the chemical analysis of the ash samples taken from that plant were made, it was observed that the amount of lime in it was high. The amount of CaO and SO_3, not meeting the requirements of the standards specified in ASTM C 618 it was considered to be classless ash. Since this waste material causes a storage and waste problem, it will be beneficial to evaluate it properly.

Turkey is one of the dependant countries on glass industry. As a result of increasing consumption together with the production, the problem of waste glass has increased to a great extent. Leaving glass, which is a fragile and sharp material, in the nature as a waste is very dangerous and harmful to health. The damage to be caused in the environment cannot be eliminated for long years. We have tried to combine the Afsin Elbistan fly ash (AEFA) and granulated glass (GG) in various ratios to make them SILclassed material. Glass is made of soil that has much silicium material (SiO_2). Its SiO rate being high, putting it in classless Afsin Elbistan Fly Ash at various rates, has made the latter class fly ash. The purpose of this study is to investigate the effect of mixing waste granulated glass at various proportions with fly ash, which is an artificial pozzolana, to make it classed. All the experiments applied in the research have been made based on the standards of certain developed countries and Turkish Standards. In these experiments normal consistency water rates were applied to the cement paste. Start and ending durations of the setting and volume expansion were determined in accordance with TS (TS EN 196-3, 2002) and the flexural and compressive strengths in accordance with TS (TS EN 196-1, 2002). The experimental studies have been carried out in Gaziantep University, Faculty of Engineering and Architecture concrete laboratory and Kahramanmaras Cement Industry, Physics and Concrete Laboratory. AEFA and GG combination percentages applied in this work are given in Table 1. The chemical, mineralogical and physical features of the materials used in the work are given in Table 2.

Table 1. Mix proportion

Sample number	Additives	
	AEFA	Granulated glass (GG)
Reference (R)	-	-
S_1	95	5
S_2	90	10
S_3	85	15
S_4	80	20
S_5	70	30
S_6	60	40
S_7	50	50

Table 2. Chemical content of AEFA and AEFA-GG mixes

Samples	Componenet								Flay ash class	
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	Loss ignigation	S+A+F	Class
AEFA	18.27	9.16	3.26	53.44	1.75	11.4	0.19	2.12	30.69	classless
S_1	44.7	15.9	7.8	17.6	2.8	4.2	1.48		68.4	C
S_2	46.6	15.2	7.3	16.5	2.9	4.3	2.26		69.1	C
S_3	49.7	13.8	6.7	15.6	3.1	3.9	3.69		70.2	F
S_4	52.2	13	6	15.2	3.3	3.6	4.70		71.2	F
S_5	54.4	12.8	6.8	15.8	3.4	3.6	5.32		74.0	F
S_6	55.7	10.8	5.2	14.5	3.4	2.9	6.58		71.7	F
S_7	58.0	9.2	4.5	14.1	3.6	2.5	7.81		71.7	F
TS 639	F				<5	<5		<10	>70	
ASTM C 618	F					<5		<6	>70	
	C					<5		<6	>50	

2.2.1. Fineness

The kind of cement and features are one of the most important features affecting the concrete strength. The effect of cement features on the strength can be explained well by the speed of the process of hydration. If hydration develops very quickly, the strength of cement gets high values in a short time. The increase of the cement fineness causes increase of the specific area. The strength of binding agent increases when fineness increases and tendency to increase are seen in the 3, 7, 28, 90 and 180 day strengths of cement. The substituting rates instead of cement of the additives obtained by the mixtures of AEFA and GG are given in Table 3. Mortar samples have been produced by the new cement produced. Afsin-Elbistan fly ash and granulated glass mixture (AEFA –GG) have been mixed for 30 minutes in ball mill and the homogeneity of the cement has been provided.

Table 3. Mix proportion and Blaine values

Samples	Addition system and its ratio	Blaine (cm^2/g)
R	%100 CEM-I + 0 % AEFA-GG	4101
S_1	%95 CEM-I + 5 % AEFA-GG	4490
S_2	%90 CEM-I + 10 % AEFA-GG	4760
S_3	%85 CEM-I + 15 % AEFA-GG	4764
S_4	%80 CEM-I + 20 % AEFA-GG	4966
S_5	%70 CEM-I + 30 % AEFA-GG	5144
S_6	%60 CEM-I + 40 % AEFA-GG	5135
S_7	%50 CEM-I + 50 % AEFA-GG	5057

2.2.2. Setting time and volume expansions

The setting time of the produced pastes and mortars has been determined in accordance with the standards. Le Chatelier **(TS EN 196-3, 450-1, 459-2; TS EN ISO 9597)** has been used for determining volume expansion.

2.2.3. The Production of mortar samples

Standard size prismatic moulds (40x40x160 mm) have been used. For mortar samples, classes Afsin-Elbistan fly ash and granulated glass (AEFA-GG), cement, sand and water ratios of mixtures are given in Table 4.

Table 4. Mortars mixtures (g)

Samples	Cement	AEFA-GG		Rilem sand	Water
R	450	0		1350	225
S_1	427	22		1350	225
S_2	405	45		1350	225
S_3	382	67		1350	225
S_4	360	90		1350	225
S_5	315	135		1350	225
S_6	270	180		1350	225
S_7	225	225		1350	225

2.2.4. Alkali silica reaction test (ASR)

This test was applied according to ASTM C 1293. The ASR expansion was determined by accelerated mortar bar tests as per ASTM C 1260. For each mix, three 25 mm 25 mm 285 mm mortar bars were prepared. They were demolded 24 h after casting and placed in water at 800 C for the next 24 h. The initial lengths of the mortar bars were then recorded before they were immersed into 1 N 80 C NaOH solution for curing. The expanded lengths were subsequently measured after 14 days. The average values found for the three mortar bar specimens were reported as the ASR expansion. According to ASTM C 1260, expansion larger than 0.2% at 14 days is considered potentially deleterious while less than 0.1% is innocuous.

2.2.5. Flexural and compressive strength

Flexural and compressive strengths of the mortars at 3-7-28 days were tested according to TS EN 196-1.

3. **RESULTS** AND DISCUSSION

3.1. Fineness

As it can be seen from Table 3, as long as the rate of AEFA-GG increases up to 30 %, the fineness value of the cement increased. This situation can be explained by particle size of granulated glass.

3.2. Setting Time

The setting durations of the mortar are given in Figure 1. Experimental results were found between limit values in the TS10156 standard. As the additive ratio increases, setting duration decreases. However, both the starting and ending period of the reference sample has been found lower than that of the others. Delaying of the starting and ending times of Afsin-Elbistan fly ash and glass powder mortar is the general character of pozzolans.

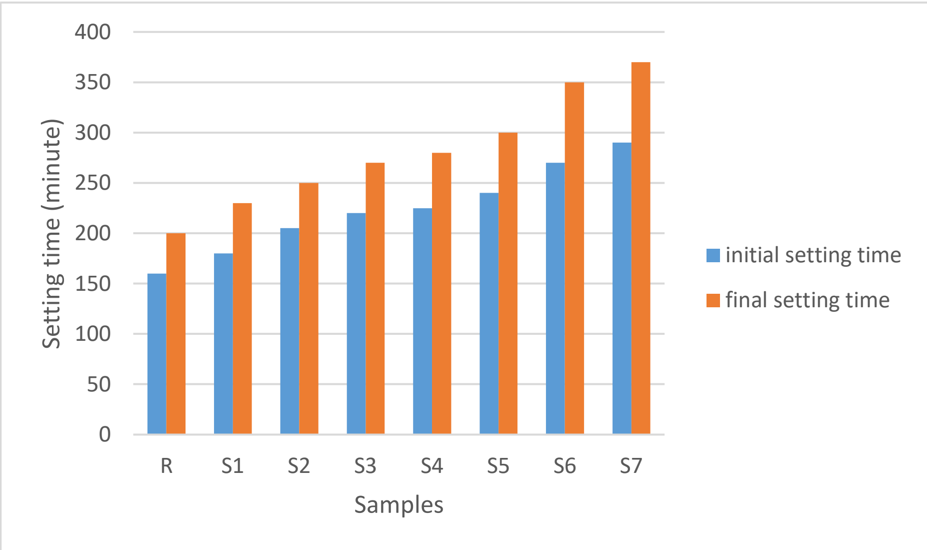

Figure 1. Setting time of samples.

3.3. Volume Expansions

The volume expansion of the pastes produced by AEFA–GG is given in Figure 2. None of the samples including the reference has shown any expansion above the limit value specified by the standards. This value is average around 1 mm. Crystal MgO and calcium sulphate are the main factors affecting the excessive expansion of the cement pastes. In this context, it has been seen that fly ashes used in the research have decreased the amounts of expansion of the cement pastes slightly. These results have shown that the mortars with Afsin-Elbistan fly ash and granulated glass will not bring about an expansion over the value by the standard requirements. Moreover, the volume expansion almost close to zero has been determined in S1 and S2 samples. It has been revealed that the values obtained fulfilled the requirements of TS EN 196-3.

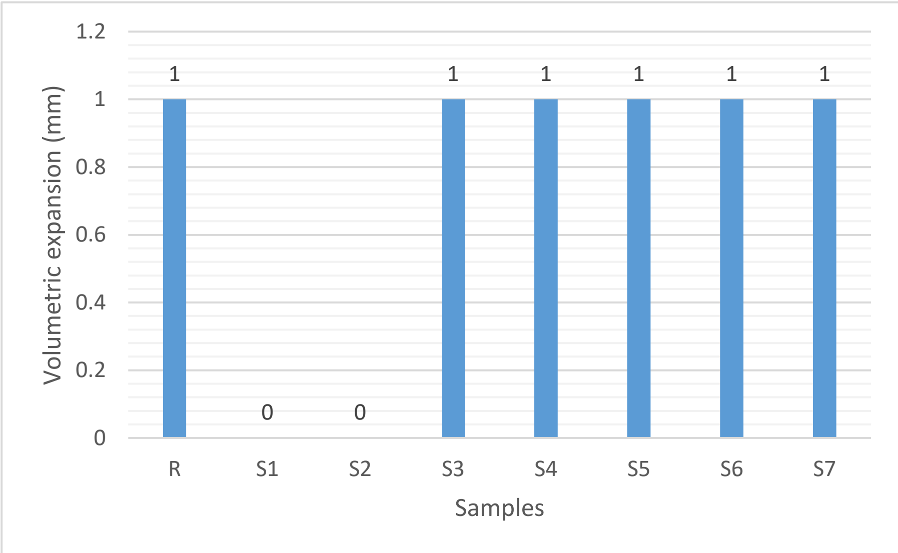

Figure 2. Volumetric expansion of samples.

3.4. Alkali Silica Reaction Test Results

Alkali-silica reaction (ASR) is one of the challenging problems related to the durability of concrete. During the process of ASR, various metastable forms of silicate phases in the reactive aggregates are dissolved by the alkaline pore solution of concrete and form the ASR gel. The alkali silica reaction test result of samples is given in Figure 2. Compared to the control sample, there was a reduction in the expansion of the mortars prepared with 5% -30% GG.

The reduction level of the mortars prepared with 5% GG was the highest, followed by that prepared with a 10% GG, and the least reduction level of 20% was found for the mortars prepared with 5% GG. The relative ineffectiveness of GG was consistent with the previous findings reported by Mukhopadhyay (Mukhopadhyay and Liu, 2015) and Zeidan (Zeidan and Said, 2016) who found that 0.5% and 3% GG were not effective to reduce the ASR expansion.

Test results showed that the ASR expansion increased with higher glass content, but this increase is within acceptable limits. Moreover, S1, S2, S3, S4 and S5 samples have shown lower ASR expansion than the reference, S6 and S7 samples. These results showed that 30% additive was the optimum amount. The mechanical values of all additive samples up to thirty percent were higher than the reference sample. Glass additive more than optimum ratio can cause alkaline silica reaction due to active silica. Hence, both the improvement of the mechanical properties and the contribution rate against the negative effects caused by the alkali aggregate reaction should be limited. Standard cement can be produced equally classless fly ash and ground glass (optimum ratio 30%). The effect of replacing more than 40% cement by ground glass and classless fly ash on ASR expansion are also shown in Figure 3. The suppressing effect of ground glass and classless fly ash (5% - 30%) was relatively more prominent than others.

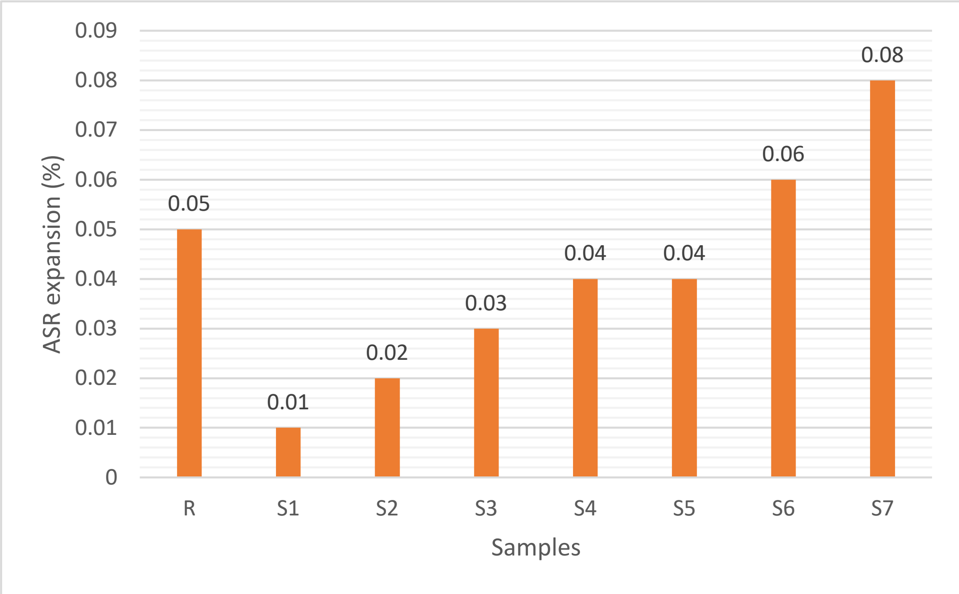

Figure 3. Alkali silica reaction test result of samples

The use of any supplementary cementitious material will depend on its performance, namely its strength, durability, and volumetric stability over time. In the case of waste glass, this performance is further challenged by the tendency for ASR to occur. The controlling process between a beneficial pozzolanic reaction, which would improve the performance of glass as an SCM, and a damaging ASR is the production of either a stable or swelling product. Depending on several factors, including calcium content, particle size, and alkalinity, the dissolved silica will repolymerize into expansive gel, hydrate into C–S–H, or a combination of both (Buchwad et al. 2003; Federico and Chidiac, 2009). The similarity between the ASR and pozzolanic reactions observed for waste glass in concrete suggests that they are closely related and may be simply various stages of one another subject to several controlling factors, including particle size, pore solution, and chemical composition. Furthermore, as the rate of waste glass additives in ash increased, the SO3 ratio decreased. This was effective in all experimental results, especially ASR. However, at a replacement of more than 30 percent of GG, it primarily has a negative impact on ASR.

On the other hand, according to the TS EN 196, the total alkali oxides ($Na_2O + K_2O$) of the mixture to be used in cement production must be below 5.0%. In this study, the total alkali oxides ($Na_2O + K_2O$) in S5, S6 and S7 samples were found to be above 5.0%. As a result of the reaction of Silica + Alkali + Water, Alkali-Silica Gel is formed. The expansion caused by the gels emerging as a result of this reaction causes cracks in the concrete. In this respect, the ratio of GG should be limited to 30 percent.

3.5. Flexural Strengths of Samples

Flexural strengths of the mortars at 3, 7, and 28-days in accordance with the TS EN 196-1 are given in Figure 4, respectively. While the 3-day flexural strengths of the samples have increased up to the level of 15 %, then they have fallen substantially. The flexural strength of **S3** sample has been found higher than the reference sample. On the other hand, the flexural strength of sample **S7** has been found about 2,2 times higher than the reference sample.

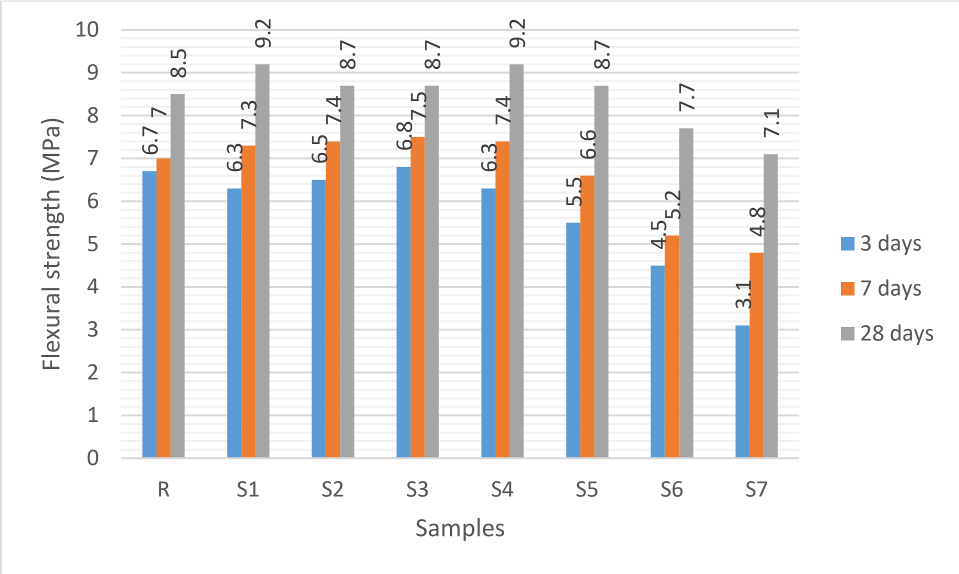

Figure 4. 3, 7 and 28-days flexural strength of the samples

While the 7 day-flexural strengths of the samples increase up to 20 % level of the mixture, then it has decreased. The flexural strengths of the samples with additives 5%, 10%, 15% and 20% AEFA–GG have been found higher than the reference sample. The flexural strength of **S3** has been found 9,3 % higher than the flexural strength of the reference sample. On the other hand, flexural strength of samples dropped with more than 20% by weight of AEFA–GG. The flexural strength of **S3** sample has been found 35 % higher than the flexural strength of the sample S7. The flexural strengths of the samples made with 5%, 10 %, 15%, and 20% and 30 % AEFA-GG have been found higher than the reference sample. The flexural strength of the samples made with AEFA-GG had the highest flexural strength in this group and had been found 9% higher than the reference sample. However, even the flexural strength of the sample made with 50% AEFA-GG has been found higher than the limit value of the standards. The optimum additive ratio from these results has been seen as 30%. Above this rate, decreasing of the flexural strengths somewhat can be explained by the micro structure of the glass. In case of adding more than the optimum additive rate, glass' bending strength has been found to be low since it is a brittle material.

3.6. Compressive Strengths of Samples

The compressive strengths of the samples at 3, 7 and 28-days are given in Figures 5, respectively. The 3-day flexural strengths of the samples made with 5 % AEFA-GG have been found higher than the reference sample. With higher ratio than this, compressive strength of the sample reduces significantly. 7-day compressive strength of the samples increased up to 20 % dope level, and then they have reduced. The compressive strengths of the samples made with 5%, 10%, 15% and 20% AEFA-GG have been found higher than the reference sample. The compressive strength of S1 sample has been found 9 % higher than that of the reference sample. On the other hand, the compressive strength of this sample has been found 1,83 times higher than those of S7 sample.

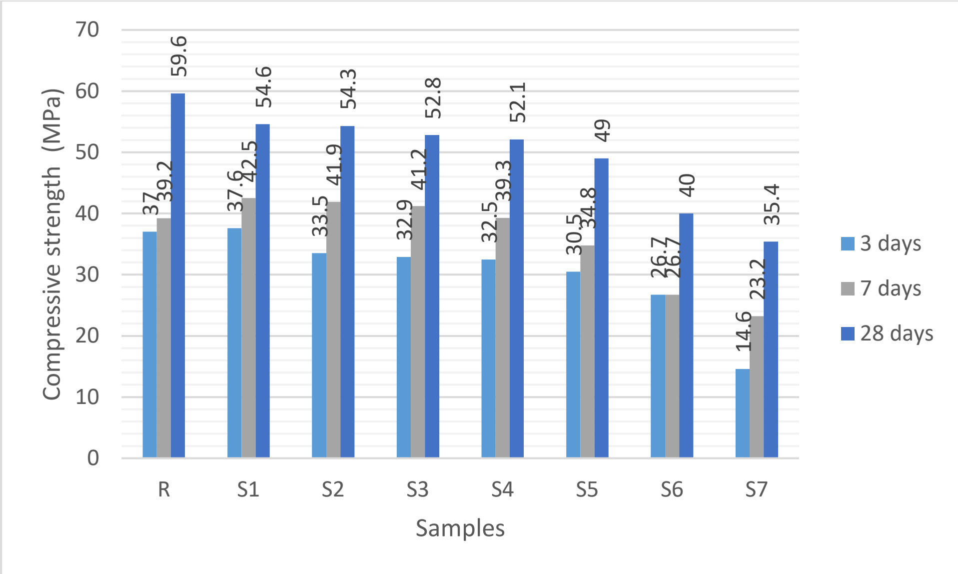

Figure 5. 3, 7 and 28-days Compressive strength of the samples

The compressive strengths obtained up to 30% made with AEFA-GG have been found higher than the requirements in the standards. From these results, the optimum additive rate has been seen as 30%. It is generally known to cause a reduction in the compressive strengths of the samples when over a certain contribution level of pozzolans is used. When flexure and compressive strengths with the optimal contribution of fly ash is roughly around 20%. The high values obtained as a result of the determined optimum mechanical effects can be explained by the fine-grained glass powder used to classify the fly ash. As a result of the addition of fine-grained glass powder to cement with fly ash, it has a high reactivity feature and provides a positive effect on the mechanical properties and a delaying effect on the progress of the cracks.

4. CONCLUSION

Overall results obtained in the study are listed below.

1. Flexural strength of samples made with 15% AEUA- GG at 3 and 7-day were found to be highest.
2. 28-day flexural strengths of the samples containing 20% AUFA-GG have been found the highest. This can be explained by the high pozzolanic feature of the additives.
3. 28-day compressive strengths of the samples containing 5%, 10%, 15%, 20%, 30%, 40%, 50% AEFA–GG have been found higher than compressive strengths of reference samples. The 28-day compressive strengths of some samples have exceeded the 42,5 MPA values.
4. With an increase of additives, the starting and expiration setting time of mortars have increased.
5. Volume expansion has been found zero mm in the mixtures containing 5 % and 10% AEFA-GG, other samples have been found 1 mm.
6. By using AEFA-GG as supplementary cementitious materials, ASR expansion of mortars could be reduced to below acceptable limits, i.e., 0.1% at 14 days.
7. The incorporation of 5% GG and 10% GG in fly ash glass mortars can reduce the ASR expansion by different degrees. The mitigation effectiveness of 5% GG was lower than 10% GG.

Finally, the use of fly ashes providing both required strength, economic and environmental benefits together with granulated glass are an issue worth investigating. When classless Afsin-Elbistan fly ash is used at certain proportions with granulated glass, it can be brought back to economy as class fly ash.

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