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INVESTIGATION OF THE EFFECT OF SEWAGE SLUDGE ASH ON THE MECHANICAL PROPERTIES OF MORTAR SPECIMENS

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Keywords
Sewage Sludge Ash, Additive Cement, Sustainability.

Abstract

In recent years, the rising awareness of environmental protection and the rapid depletion of natural resources have increased the strategic importance of sustainable building materials, especially in the construction sector. Increasing construction trends lead to a noticeable increase in the use of materials. In this context, the environmental impacts of cement production come to the forefront with the amount of energy used in clinker production and the resulting CO_2 emissions. Recycling of waste materials can solve the problem of waste storage and reuse of waste materials can form the basis of sustainable construction approaches to reduce energy consumption. This research focuses on the incineration of dewatered sewage sludge into ash and its usability as a building material. In this context, the incinerated sewage sludge ash was ground and used as an additive material at different ratios instead of cement to produce mortar specimens. Flexural and compressive strength tests were carried out to determine the mechanical properties of the sewage sludge ash admixed specimens by comparing them with mortar specimens produced with Class F fly ash on the 7th, 28th and 90th days.

ARITMA ÇAMURU KÜLÜNÜN HARÇ NUMUNELERİNİN MEKANİK ÖZELLİKLERİ ÜZERİNDEKİ ETKİSİNİN ARAŞTIRILMASI

Anahtar Kelimeler
Arıtma Çamuru Külü, Katkılı Çimento, Sürdürülebilirlik.

Öz

Son yıllarda çevre koruma bilincinin yükselmesi ve doğal kaynakların hızla tükenmesi, özellikle inşaat sektöründe sürdürülebilir yapı malzemelerinin stratejik önemini artırmıştır. Artan yapılaşma eğilimleri, malzeme kullanımında gözle görülür bir artışa neden olmaktadır. Bu bağlamda, çimento üretiminin çevresel etkileri, klinker üretiminde kullanılan enerji miktarı ve bunun sonucunda ortaya çıkan CO_2 emisyonlarıyla ön plana çıkmaktadır. Atık malzemelerin geri kazanılması atığın depolanma sorununa, yeniden kullanılması ise tüketilen enerjinin azaltılması yönünde sürdürülebilir inşaat yaklaşımlarının temelini oluşturabilir. Bu araştırma, suyu alınmış arıtma çamurunun yakılarak kül haline getirilmesi ve yapı malzemesi olarak kullanılabilirliğini incelemeye odaklanmaktadır. Bu kapsamda, yakılarak elde edilen arıtma çamuru külü öğütüldükten sonra çimento yerine farklı oranlarda katkı malzemesi olarak kullanılarak harç numuneleri üretilmiştir. Arıtma çamuru külü katkılı numunelerin mekanik özelliklerinin belirlenmesinde; 7., 28. ve 90. günlerde F sınıfı uçucu kül ile üretilen harç numuneleriyle karşılaştırma yapılarak eğilme ve basınç dayanımı deneyleri gerçekleştirilmiştir.

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Highlights

- The feasibility of using sewage sludge ash as a cement substitute was investigated.
- Flexural and compressive tests were performed to determine the mechanical properties.
- The storage problem of sewage sludge and the environmental impact of energy consumption in clinker production were emphasized.

Graphical Abstract

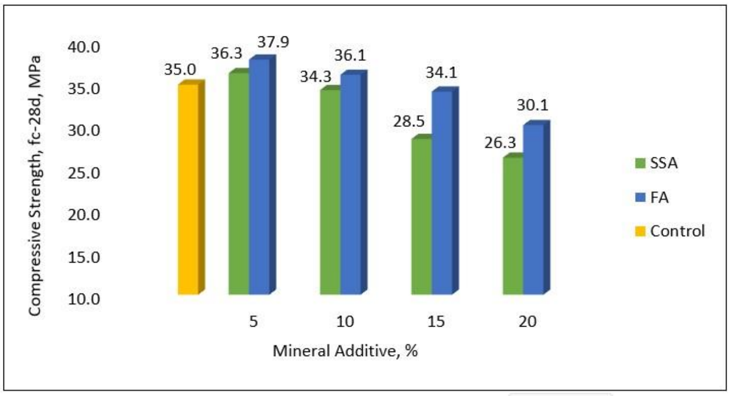

Figure. Compressive strength test results of mortar specimens on the 28th day

Purpose and Scope

This study aims to demonstrate the feasibility of using sewage sludge ash as a substitute for cement.

Design/methodology/approach

The cement substitutability of sewage sludge ash was determined by flexural strength and compressive strength tests.

Findings

According to the results of flexural and compressive strength tests, it was revealed that sewage sludge ash can be used as a substitute for cement at 5% and 10%.

Originality

This study proposes a sustainable approach to the field of building materials investigating the replacement of sewage sludge ash with cement.

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1. Introduction

Along with population growth, the construction sector plays an important role in terms of environmental impacts. Most of the waste generated as a result of the use of natural resources and production processes originates from the construction sector (Kahraman, 2019). The construction and use of buildings has a significant impact on the environment, accounting for 36% of global energy and nearly 40% of carbon dioxide emissions (Nwoda and Anumba, 2019).

Worldwide, there are currently more than 4 billion people living in urban areas. According to the United Nations, two-thirds of the world's population will live in urban areas by 2050. According to 2021 data, the urbanization rate in the world is approximately 56%. People living in rural areas migrate to cities for reasons such as health, education, social opportunities and job opportunities. These migration movements bring more energy needs and environmental pollution (Uzun et al., 2019). This situation has led to negative impacts such as global warming and climate change, and it has become inevitable for governments around the world to take the necessary measures (Ivanova, 2019; Tuğaç., 2022).

With the increase in urban population, the sludge generated in wastewater treatment plants causes storage difficulties (Rorat et al., 2019). However, this waste material is partially recovered by using it as fertilizer in agricultural areas and as fuel in industrial areas and cement factories (Chakraborty et al., 2017; HaiBing et al., 2015). Environmental problems caused by waste will continue as long as mankind exists. However, the use of waste in cement production in combination with its recovery can significantly reduce environmental impacts by reducing the amount of clinker.

Previous studies (Hu et al, 2019; Vouk et al., 2018; Nakic, et a.l, 2018; Baeza-Brotons et al., 2014) have shown that sewage sludge ash (SSA) derived from sewage sludge provides pozzolanic activity and is suitable for use as a substitute for cement. As a result, the amount of carbon dioxide released into the atmosphere during cement production can also be reduced. With this method, carbon dioxide emissions in cement production can be effectively reduced as well as waste control (Filibeli et al., 2022).

In addition, the use of cement-based composites has the potential to reduce carbon dioxide (CO_2) emissions and offers advantages in terms of environmental sustainability due to the pozzolanic properties of these composites. Pozzolans react with the calcium hydroxide ($CaOH_2$) produced during cement hydration to form additional C-S-H (calcium silicate hydrate) gel (Atabey et al., 2023). This process improves the mechanical properties of cement-based composites, while at the same time reducing cement consumption and lowering CO_2 emissions. In particular, materials such as fly ash, silica fume, marble powder, limestone and rice husk ash are widely used in cementitious composites (Davraz et al., 2018). The use of such materials both encourages the recycling of waste materials and reduces energy consumption and thus the carbon footprint. Therefore, developing more sustainable and environmentally friendly construction materials by utilizing the pozzolanic properties of cementitious composites offers both industrial and environmental benefits (Çelikten et al., 2022).

The research was conducted to investigate the effects of using incinerated sewage sludge ash as cement admixture. Experimental studies were carried out to investigate the mechanical effects of different proportions of sewage sludge ash on mortar specimens.

2. Material and Method

According to the partial substitution method; 5%, 10%, 15% and 20% SSA (Sewage Sludge Ash) and FA (Fly Ash) were added to the mortar mixtures. Three samples were prepared for each age and series. 7 th, 28 th and 90 th days flexural strength and compressive strength tests on specimens were performed. The results obtained were compared with the control samples produced.

CEM I 42.5 R type cement, F class fly ash and CEN standard sand were used in the production of mortar samples. Mortar samples were prepared according to TS EN 196-1 (TSE, 2016) standard with 450±2g cement, 1350±5g standard sand and 225±1g standard sand. The amount of water was revised according to the consistency test. K value (Efficiency Factor) was taken as 0.4 according to TS 206 (TSE, 2021) in determining the amount of material. Material quantities were redetermined. Mechanical tests were performed on mortar specimens at 7th, 28 th and 90 th days.

CEM I 42.5 R type cement obtained from Isparta Göltaş Cement Company was used in the study (Göltaş, 2023). The chemical composition of CEM I 42.5 R type cement was given in Table 1.

Table 1. Chemical composition of cement

Compounds	Content (%)	Physical and Mechanical Properties	
SiO_2	19.70	Fineness (45 μ)	0.50
Al_2O_3	4.52	Fineness (90 μ)	3.50
Fe_2O_3	3.07	Blaine (cm^2/g)	4100
CaO	63.10	Specific Gravity (g/cm^3)	3.14
MgO	2.01	Le Chatelier (mm)	0.46
SO_3	3.01	Setting Time Initial (min.)	156.0
K_2O	0.55	Setting Time Final (min.)	265.0
Na_2O	0.29	2 Days (MPa)	24.30
Other	3.75	28 Days (MPa)	50.10

Class F fly ash obtained from Iskenderun - Sugözü thermal power plant was used in the study. According to ASTM C618 standard, Sugözü fly ash was classified as Class F (low calcareous) fly ash since the SiO_2+Al_2O_3+Fe_2O_3 value was above 70% and the CaO content was less than 10% (ASTM, 2017). The density of fly ash was 2.3 g/cm^3, the amount of grains larger than 45μm was 18.5% and the specific surface area (blaine) was 3000 cm^2/g. The chemical composition of fly ash was shown in Table 2.

Table 2. Chemical composition of fly ash

Compounds	Content %
SiO_2	58.25
Al_2O_3	22.95
Fe_2O_3	7.25
CaO	2.58
MgO	2.42
SO_3	0.27
K_2O	0.99
Na_2O	2.06
KK	3.23

Sewage sludge obtained from Isparta wastewater treatment plant in dry form was used by incineration. The treatment sludge obtained in dry form from the wastewater treatment plant was incinerated at 800°C for 3 hours and turned into ash.

When the data obtained as a result of the grain size distribution analysis of sewage sludge ash were analyzed; it was determined that 47.5% of the grains finer than 45μm. The average surface area (Blaine fineness) value of sewage sludge ash is 6600 cm^2/g. The specific mass value was found to be 2.6 g/cm^3 on average using a helium pycnometer. The chemical composition of sewage sludge ash was given in Table 3.

Table 3. Chemical composition of sewage sludge ash

Compounds	Content %
SiO_2	48.09
Al_2O_3	19.19
Fe_2O_3	2.72
CaO	6.50
MgO	1.22
K_2O	8.41
Na_2O	3.19
CO	10.68

Material quantities used in mortar samples were given in Table 4. Water requirement was organized according to the consistency.

Table 4. Material quantities used in the production of mortar sample

Sample	Mineral Additive (g)	Cement (g)	Water (g)	Water/Binder Ratio	Standard Sand (g)
PC	0.00	450.00	243.00	0.54	1350.00
SSA5	52.33	397.67	254.25	0.57	
SSA10	97.83	352.17	255.15	0.57	
SSA15	137.75	312.25	267.75	0.60	
SSA20	173.08	276.92	270.00	0.60	
FA5	52.33	397.67	243.00	0.54	
FA10	97.83	352.17	245.25	0.55	
FA15	137.75	312.25	246.15	0.55	
FA20	173.08	276.92	247.50	0.55	

The prepared mortars were placed in three-cavity mortar molds with dimensions of 40×40×160mm. Three prismatic specimens for each batch were stored in lime-saturated water at 20±1°C until the test date. Before the measurement, the samples removed from the water were dried and made ready for the experiment. According to the findings obtained from the tests, the flexural strength of the specimens was calculated using Equation 1 according to TS EN 196-1 standard.

$$f_{cf} = \frac{P\ x\ L}{b\ x\ h^2} \qquad (1)$$

Where;
f_{cf} , flexural strength, N/mm²; P, axial load, N; L, distance between bearings, mm; b, cross-section width, mm; h, section height, mm.
The specimens obtained by breaking as a result of flexural strength were used for compressive strength determination in accordance with TS EN 196-1 standard (TSE, 2016). The compressive strength values of 6 specimens for each series were averaged. The compressive strength of the specimens was calculated using Equation 2.

$$f_{cc}= \frac{P}{A} \qquad (2)$$

f_{cc} , compressive strength, N/mm²; P, Axial pressure force, N; A, cross-sectional area of the specimen, mm².

The mortar specimens was shown in Figure 1, the flexural and compressive strengths test were shown in Figure 2.

Figure 1. Mortar specimens

Figure 2. Flexural and compressive strength test

3. Experimental Results

When the compressive strength values of the sewage sludge ash-amended mortar samples determined on the 7th day were examined; it was observed that the closest to the strength value of the control sample, which was 30.9 MPa, and the highest strength among the mortar samples with sewage sludge ash additives was 32.2 MPa with 5% added. These values were followed by the other series as 31.9 MPa at 10%, 28 MPa at 15%, and 23.2 MPa at 20%.

When the compressive strength values of the fly ash-added mortar specimens determined on the 7th day were examined; it was seen that the strength value of the control specimen, which was 30.9 MPa, was the closest to the strength value of the control specimen and the highest strength among the fly ash-added mortar specimens was 27.7 MPa, which was provided by the 5% added mortar specimens. These values were followed by the other series as 24.8 MPa at 10%, 20.9 MPa at 15%, and 20.8 MPa at 20%.

When the flexural strength values of the sewage sludge ash-amended mortar samples determined on the 7th day were analyzed; it was determined that the control sample provided a strength of 6.0 MPa. Among the mortar samples with sewage sludge ash additives, the highest strength was 6.6 MPa at 5%, followed by 6.3 MPa at 10%, 5.9 MPa at 15%, and 5.0 MPa at 20%.

When the flexural strength values of the mortar specimens with fly ash additives determined on the 7th day were analyzed; it was determined that the control specimen provided 6.0 MPa strength. Among the mortar specimens with fly ash admixture, the highest strength was 6.0 MPa at 5%, followed by 5.7 MPa at 10%, 4.8 MPa at 15%, and 4.7 MPa at 20%. Compressive strength test results of the mortar specimens on the 7th day was shown in Figure 3 and flexural strength test results of the mortar specimens on the 7th day was shown in Figure 4.

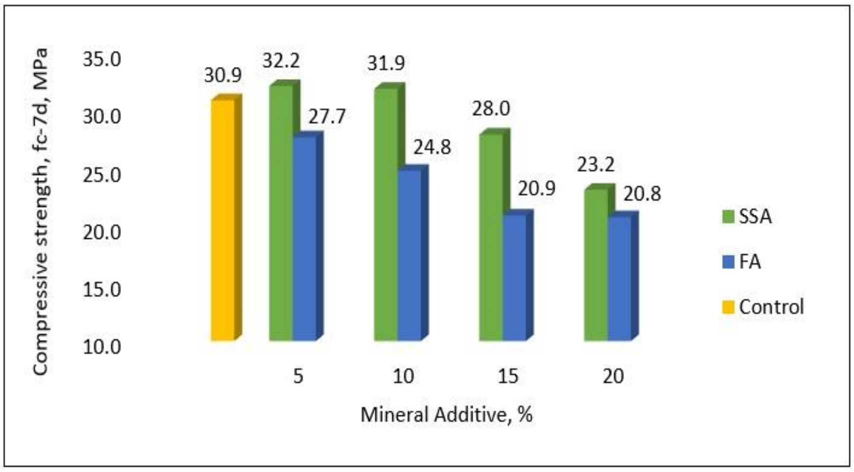

Figure 3. Compressive strength test results of mortar specimens on the 7th day

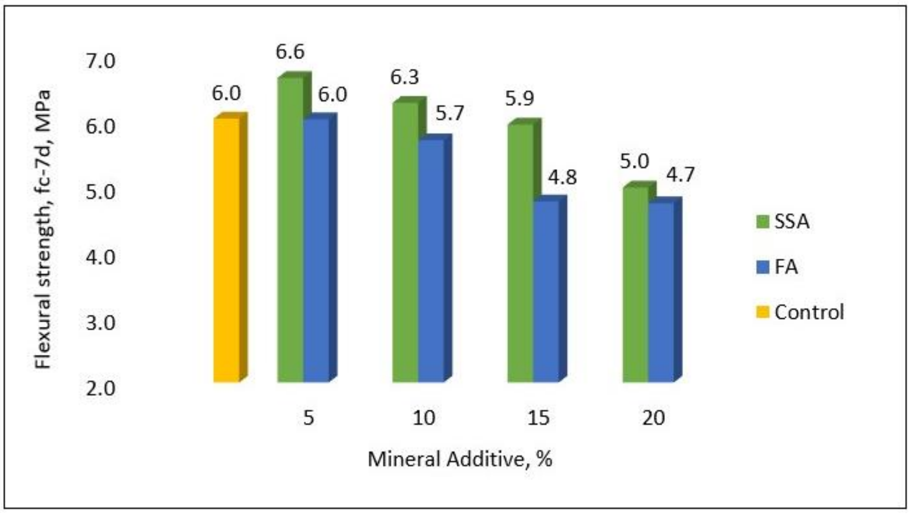

Figure 4. Flexural strength test results of mortar specimens on the 7th day

When the compressive strength values of the mortar samples with sewage sludge ash additives determined on the 28th day were analyzed; it was determined that the control sample provided a strength of 35.0 MPa. Among the mortar specimens with sewage sludge ash admixture, the highest strength was 36.3 MPa for the specimens with 5% admixture. These values were followed by the other series as 34.3 MPa at 10%, 28.5 MPa at 15%, and 26.3 MPa at 20%.

When the compressive strength values of the mortar specimens with fly ash additives determined on the 28th day were analyzed; it was determined that the control specimen provided a strength of 35.0 MPa. Among the mortar specimens with fly ash admixture, the highest strength was 37.9 MPa for the specimens with 5% admixture. These values were followed by the other series as 36.1 MPa at 10%, 34.1 MPa at 15%, and 30.1 MPa at 20%.

When the flexural strength values of the sewage sludge ash-amended mortar specimens determined on the 28th day were analyzed; it was determined that the control specimen provided a strength of 6.3 MPa. Among the mortar specimens with sewage sludge ash admixture, the highest strength was 7.4 MPa with 5% admixture, followed by 7.1 MPa at 10%, 6.2 MPa at 15%, and 5.1 MPa at 20%.

When the flexural strength values of the mortar specimens with fly ash additives determined on the 28th day were analyzed; it was determined that the control specimen provided a strength of 6.3 MPa. Among the mortar specimens with fly ash admixture, the highest strength was 7.5 MPa with 5% admixture, followed by 7.4 MPa at 10%, 7.3 MPa at 15%, and 6.9 MPa at 20%. The compressive strength test results of the mortar specimens on the 28th day was shown in Figure 5 and flexural strength test results of the mortar specimens on the 28th day was shown in Figure 6.

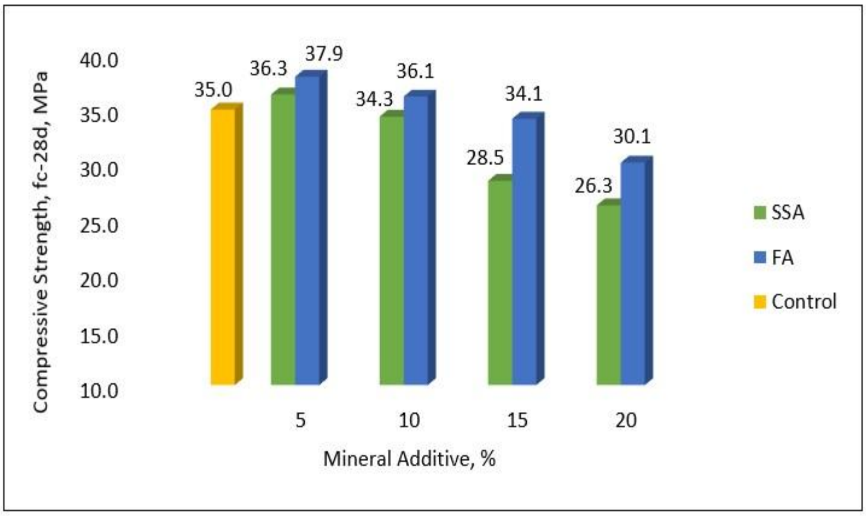

Figure 5. Compressive strength test results of mortar specimens on the 28th day

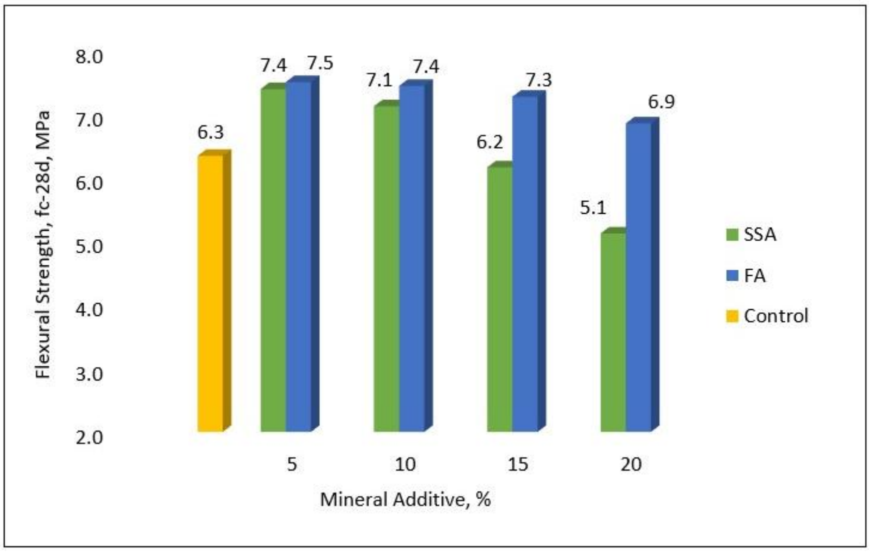

Figure 6. Flexural strength test results of mortar specimens on the 28th day

When the compressive strength values of the SSA-added mortar specimens determined on the 90th day were analyzed; the control specimen provided a strength value of 40.2 MPa. Among the mortar specimens with SSA admixture, the highest strength was 42.6 MPa for the specimens with 5% SSA admixture. This values; 40.5 MPa at 10%, 34.0 MPa at 15%, 30.0 MPa at 20%, followed by the other series.

When the compressive strength values of the FA-added mortar specimens determined on the 90th day were examined; the control specimen provided a strength value of 40.2 MPa. The highest compressive strength among the FA admixed mortar specimens was 42.8 MPa for the specimens with 5% admixture. These values were 38.1 MPa at 10%, 37.9 MPa at 15%, 36.9 MPa at 20%, followed by the other series.

Flexural strength values of SSA admixed mortar specimens on the 90th day when analyzed; the control sample provided 10.1 MPa strength. Among the mortar specimens with SSA additives, the highest strength was 10.6 MPa at 5%, followed by 10.1 MPa at 10%, 8.3 MPa at 15%, and 7.9 MPa at 20%.

Flexural strength values of FA admixed mortar specimens on the 90th day when examined; the control sample provided a strength of 10.1 MPa. Among the mortar specimens with FA additives, the highest strength was 9.7 MPa at 5% added additive, while 10% provided 9.6 MPa, 15% provided 9.5 MPa, 20% provided 9.4 MPa strength values. Compressive strength test results of the mortar specimens on the 90th day was shown in Figure 7 and flexural strength test results of the mortar specimens on the 90th day was shown in Figure 8.

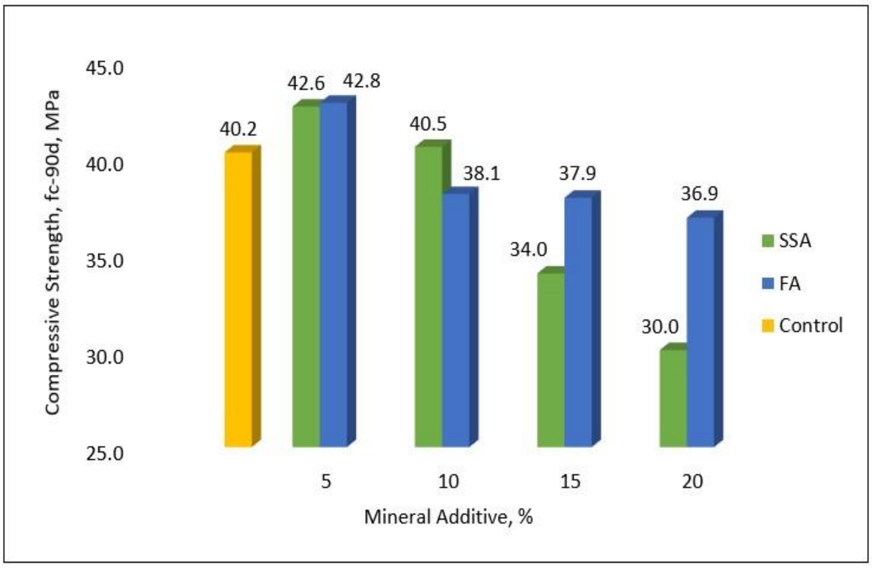

Figure 7. Compressive strength test results of mortar specimens on the 90th day

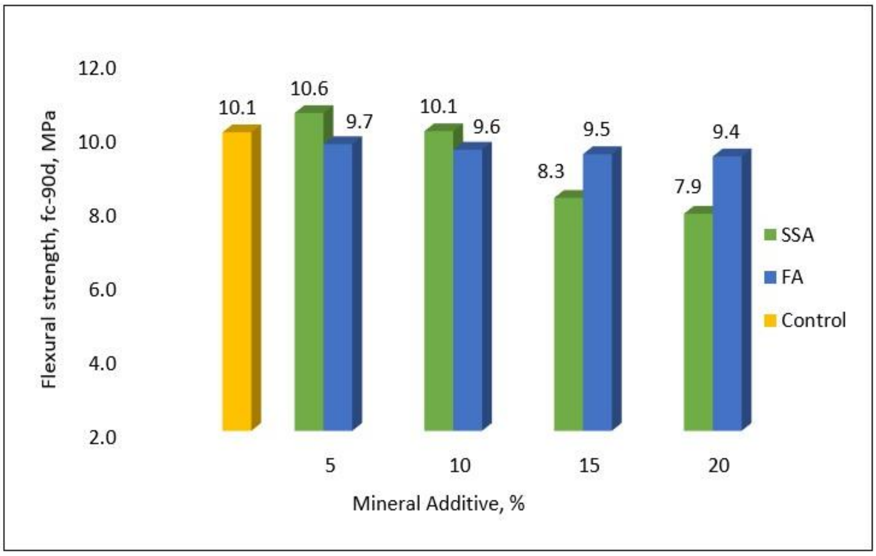

Figure 8. Flexural strength test results of mortar specimens on the 90th day

4. Result and Discussion

The treatment sludge obtained in dry form from the wastewater treatment plant was burned at high temperatures and turned into ash. After determining the pozzolanic properties of the ash, its usability as a mineral additive was investigated. When the chemical structure of the SSA obtained after incineration was analyzed, the amount of SiO_2, Al_2O_3 and Fe_2O_3 in it met the standard requirement of 70% (ASTM C618-17a, 2017). This shows that SSA gives results close to the literature and fulfills the requirement specified in the standard (Pan et al. 2003; Lynn et al, 2015). The water requirement increased in SSA admixed mortar specimens in accordance with the fineness compared to FA. It was noted that the different water/binder ratios in the mixtures varied with the fineness of the SSA and the amount used. As the fineness increased, the water requirement also increased.

Flexural and compressive strength tests were performed on the mixtures containing 5%, 10%, 15% and 20% sewage sludge ash and fly ash added by partial substitution method instead of cement on the 7th, 28th and 90th days. The results obtained were compared with the control specimens.

When the compressive strength values of the mortar specimens determined on the 7th day were analyzed; it was observed that the 5% SSA added specimens with a strength value of 32.2 MPa gave 4% higher strength value compared to the control specimen. 10% SSA doped specimens was showed a 3.2% strength increase compared to the control specimen, while the other series showed a strength loss.. FA doped specimens in all series showed a compressive strength below that of the control specimen and SSA doped specimens. When the flexural strength values were analyzed, it was observed that 5% SSA doped samples with a strength value of 6.6 MPa gave a 10.0% higher strength value compared to the control sample. The 10% SSA doped specimens showed a strength increase of 5% compared to the control specimen, while the other series showed a strength loss. The FA doped specimens in all series gave a flexural strength below the control specimen and SSA doped specimens. The early strengths of mortar specimens with 5% and 10% SSA additives increased in accordance with the literature (Chang et al., 2010). The strength of the mortar specimens with fly ash additives decreased depending on the fineness (Yazici et al., 2012).

When the compressive strength values of the mortar specimens on the 28th day were analyzed, it was observed that the 5% FA doped specimens had a compressive strength value of 37.9 MPa, which was 8.0% higher than the control specimen. The highest compressive strength value was obtained in 5% FA doped specimens. 5% SSA doped specimens had the closest value to FA with a strength of 36.3 MPa. In flexural strength, it was observed that 5% FA doped specimens had a strength value of 7.5 MPa, 19.0% higher than the control specimen. The highest flexural strength value was obtained in 5% FA doped specimens. 5% SSA doped specimens had the closest value with a strength of 7.4 MPa.

When the compressive strength values of the mortar specimens determined on the 90th day were analyzed, it was observed that the specimens with 5% FA admixture obtained a strength value of 42.8 MPa, which was 6.5% higher than the control specimen. 5% SSA admixture specimens had the closest value with a strength of 42.6 MPa. In flexural strength, it was observed that 5% SSA doped specimens had a strength value of 10.6 MPa, which was 5.0% higher than the control specimen. The specimens with 5% FA additives were closest to this value with a strength of 9.7 MPa. When all the series whose strength results changed with time were analyzed, it was determined that the use of 5% mineral additives was generally more effective in the use of different mineral additive ratios. The strength increase values of fly ash and SSA doped specimens as a function of fineness were close to the literature (Yazici et al., 2012).

When the results were analyzed; it was determinated that the use of SSA as 5% mineral additive was appropriate. When the results obtained were analyzed; it was seen that the use of SSA as 5% mineral admixture in advanced age strengths gave similar results with the literature. (Chin et al., 2016). The amount of sewage sludge is continuously increasing with population growth worldwide and disposal is becoming a major problem. Therefore, environmentally friendly disposal development and use of methods is of great importance. Incorporating waste into concrete production contributes positively to the environment and increases the unit volume of concrete. The amount of cement used per cement production process is reduced. This results in less energy consumption and carbon dioxide emissions in the clinker production stage of the cement production process through the use of substitute materials. This is a significant contribution to the sustainable environment and provides support.

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Conflict of Interest

No conflict of interest was declared by the authors.

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