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Research Article

Investigation of Alkali Activated Ferrochromium Slag Composites Including Waste Marble Powder

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ABSTRACT

This study investigates the potential of alkali-activated ferrochrome slag (AAFS) as a sustainable building material in combination with waste marble powder. Na_2SiO_3 and various molarity levels of NaOH, were evaluated to create AAFS. The study encompasses a comprehensive analysis, including SEM, XRD, and XRF, to understand the microstructure and chemical composition of the resulting composites. Consistency tests showed that an increase in molarity of the alkali activator decreased setting times, indicating that higher NaOH concentrations led to the earlier setting of the samples. XRD analysis revealed the presence of forsterite, spinel, and other crystal phases in the alkali-activated dough samples, suggesting incomplete activation of the ferrochrome slag. Higher molarity values improved compressive strength, while the inclusion of more waste marble powder reduced due to increased porosity. Additional tests, such as density measurements, capillarity experiments, and ultrasonic pulse velocity tests, provided valuable insights into the material's physical and mechanical properties. The results showed that temperature, molarity, and presence of waste marble influenced these properties. The compressive strength achievement of approximately 15 MPa at a modest temperature of 60°C during alkaline activation expresses the exceptional performance of the mixture, with marble powder utilized at the highest proportion (30%). This not only represents an energy-efficient solution but also showcases a sustainable approach that efficiently repurposes waste materials. As a result, this study demonstrates that AAFS, when properly activated and blended with waste marble powder, can yield alkali-activated composites with promising compressive strength and potential as a sustainable building material.

1. Introduction

Blast furnace slag is produced as a by-product during the manufacture of iron in a blast furnace. It results from the fusion of a limestone flux with ash from coke and the siliceous and aluminous residue remaining after the reduction and separation of the iron from the ore [1]. Blast furnace slag is a waste product that basically contains silica, calcium aluminates silica, and some of the basic compounds obtained during the production of iron [2]. The crystal structure of the slag is as important as its chemical compounds consisting of $CaO\text{-}SiO_2\text{-}Al_2O_3$ [3]. Conversely, slag typically has specific surface properties similar to ordinary Portland cement; their variability and more comprehensive composition range make their reactivity less intense, particularly at early ages [4].

Ferro-alloys are commonly used as master alloys in the iron and steel industry because they are the most economical way to introduce an alloying element into the steel melt. Ferrochromium is a master alloy of iron and chromium, containing 45–80% Cr and various amounts of Fe, C, and

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other elements. The ferrochromium slag consists mainly of SiO_2, Al_2O_3, and MgO in different phases such as spinel, $MgO{\cdot}Al_2O_3$, and forsterite, $MgO{\cdot}SiO_2$, but also smaller amounts of CaO, chromium and iron oxides and metal fragments. This slag is chemically very stable and has better mechanical properties than many rock types used in road building, paving, landfills, etc. Especially in areas where suitable rocks for these purposes are in short supply, ferrochrome slag is in great demand. Comprehensive studies have been carried out on recycling Elazig ferrochromium slag in a certain period, either as aggregate in concrete or asphalt pavement or by replacing it with cement as supplementary cementitious materials. Some recent studies have paid attention to the potential use of ferrochromium slag as puzzolans in cement clinker and as an aggregate in concrete or asphalt mixes [5].

Zelic (2004) investigated the properties of the ferrochromium slag and the standard physical and mechanical properties of Portland cement concrete pavements made with the slag as aggregate. Zelic indicates that better concrete pavement having higher compressive strength, wear resistance, and specific weight than those from natural (limestone) aggregate in commercial Portland cement, type CEM II/B-S 42.5 (EN 197) can be made with a proper selection of slag as an artificial aggregate [5]. Yazıcıoğlu et al. (2005) investigated the effects of ferrochromium slag on compressive strength and impact energy of the concrete. They demonstrate that ferrochromium slug can be used as a cementitious material for up to 5 % to decrease the cost of concrete [6]. Yılmaz and Sütaş (2008) have investigated the usage of ferrochromium slag in the base layer material of road pavements, and they indicated that using the ferrochromium slag is a good alternative for stabilization of base layers of pavements with high traffic volume highways in terms of its satisfying strength [7].

One of the prerequisites for ensuring sustainable industrial production is the contribution of science to environmental material technologies. Although concrete is the most widely used building material today, its processes that consume the most natural resources and energy and cause environmental pollution in building technology during cement and concrete production are not environmentally friendly [8]. During cement production, an average of 125 liters of fossil fuel and 118 kWh of electricity are consumed. Thus, it is a building material that releases greenhouse gases at a high rate [9]. For this reason, many studies have been carried out to obtain environmentally friendly alternative products for cement and concrete production. These are mainly the preference of pozzolans in concrete production, evaluation of geopolymer, and alkali-activated composites. Although these materials are generally more environmentally friendly than conventional concrete, it is known that they have disadvantages compared to concrete in terms of physical and mechanical properties [8-13]. Researchers have studied composites containing alkali-activated slag (AAC) since the 1940s. Intensive studies have been conducted on these composites' production, tests, and standardization in the last two decades. AAC stands out with its many positive features as a clinker-free composite that can be an alternative to conventional concrete production [13].

Waste marble dust, another environmental problem of industrial production, comes out after cutting and surface treatments of marble production. This waste, which has a high limestone content, has been evaluated as a filling material in cement composites in recent years, and positive results have been reported [14-17]. Alyamaç and İnce (2007) evaluated the marble sludge as a powder material in self-compacting concrete. As a result, they stated that waste marble dust could be used as a powder material to produce self-compacting concrete [18]. Demirel (2010) evaluated waste marble dust as fine aggregate in concrete production [19].

Kelestemur et al. (2014) investigated the possibility of producing fiber reinforced concrete with waste marble dust and determined the freeze-thaw resistance of the composites [20]. Alyamaç and Aydın (2015) evaluated marble dust as fine aggregate in the concretes produced with waste marble dust [21]. When the studies on ferrochrome slag are examined, it is observed that most of the studies carried out to date have focused on replacing this waste with cement by volume or weight or evaluating it as aggregate in

conventional concrete or asphalt concrete [16, 22-26]. Studies involving the evaluation of Elazig ferrochrome slag and its use in the production of alkali-activated concrete/mortar can be listed as follows. Kantarcı (2013) and Türkmen et al. (2013) investigated the behavior of the alkali-activated composite produced with Elazig ferrochrome slag under the influence of fire [27, 28]. Maraş (2013) examined the performance of the composite obtained with Elazig ferrochrome slag under the influence of sulfate [29]. Mahmut and Emiroğlu (2016) investigated composites' physical and mechanical properties produced with Elazig ferrochrome slag [30]. Elibol and Şengül (2016) investigated the possibility of using slag to produce alkali-activated mortar in their study [31]. When the studies are examined, evaluating both wastes as building materials makes it possible to produce new composites, and the environmental effects of these wastes are reduced.

When examining studies on alkali-activated slag composites and geopolymers, it becomes evident that researchers usually concentrate on critical issues such as curing conditions [32-34], strength (primarily compressive strength) [35, 36] durability [37], and hydration [38, 39]. Moreover, researchers conduct extensive studies on how to reuse various natural and artificial waste materials [40-42] in these composites.

The primary goal of this study is to explore the potential of activated composites incorporating two industrial wastes, namely Ferrochromium slag and waste marble dust, both of which are local issues. Sustainable production methods such as alkali activation have gained significant attention in both practical applications and academic research. The study aims to develop novel composites with sufficient strength and durability for diverse applications, promoting energy efficiency and effective waste management practices.

2. Materials and Method

2.1. Determination of concrete mixture ratios

In this study, slag stored in the stocks of Etikrom A.Ş.'s Elazığ Ferrochrome plant, marble powder, sodium silicate, sodium hydroxide, and fine and coarse aggregates were used as raw materials in the production of alkaline-activated ferrochrome slag (AAFC). The specific gravity of ferrochrome slag and marble dust is 2.62. Ferrochrome slag contains 30.95% SiO_2, 20.13% Al_2O_3, and 34.83% MgO. Marble dust primarily comprises a high percentage (98.49%) of CaO. The ferrochrome slag was obtained and ground using a Los Angeles device and subsequently sieved through a 125-micron sieve. After grinding, marble powder was sieved through a 2 mm sieve and utilized in the ACC. The maximum grain diameter of the aggregate used is 12 mm. Na_2SiO_3 aqueous and NaOH solutions were used as alkaline activators in the mixtures prepared at 16, 18, and 20 mole ratios. When adding these aqueous solutions to the mixture, the ratio of NaOH to Na_2SiO_3 by weight was maintained at 1:1.50. In the study, the alkali activator ($NaOH+Na_2SiO_3$) to binder (slag+marble powder) ratio, as detailed in Table 1, was kept constant at 0.40. In Table 1, the ratios of EFC (Elazığ Ferrochrome Slag) to other materials were separately calculated for each molarity value.

Table 1. Geopolymer mortar mixture ratios

Alkaline Activator ($NaOH+Na_2SiO_3$) / binder (slag+marble powder)	NaOH molarity	The rate of Waste Marble Powder (%)	EFC (g)	EFC/ Waste Marble Powder (g)	EFC/ Fine Aggregate (g)	EFC/ Coarse Aggregate (g)	EFC/NaOH (g)	EFC/Na_2SiO_3 (g)
0.40	16	10	253.6	0.112	0.889	1.333	0.178	0.267
	18	20	225.4	0.250	1.000	1.500	0.200	0.300
	20	30	197.23	0.429	1.143	1.714	0.229	0.343

In addition to fine aggregate, coarse aggregate, blast furnace slag ground to a size smaller than 0.125 mm, and waste marble, sodium hydroxide, and sodium silicate were added as activators. The prepared specimens were created by mixing fine aggregate, coarse aggregate, blast furnace slag,

and waste marble powder according to the specified mixing ratios. The alkaline activators were mixed and quickly added to the binder mixture. Each prepared specimen was placed into lubricated molds in three layers, each tamped 25 times. As a final step, the sample surfaces were leveled with the assistance of a trowel, completing the casting process.

Samples with molarity values of 16, 18, and 20 were placed in an oven for 24 hours each at activation temperatures of 25°C, 60°C, and 90°C. Once removed from the oven, the samples were kept in the molds under laboratory conditions for three days. To determine the consistency, tests were conducted on freshly prepared samples following TS EN 196-3/2017 guidelines. A spreading table test was also performed for consistency determination, following TS EN 1015-3 (2000). The samples' initial and final setting times were determined per TS EN 196-3/2017. The fresh mortar specimens samples were then subjected to SEM and XRD analysis following the relevant temperature curing. Finally, three 70x70x70 mm cube specimens were produced for each temperature and molarity value. Compressive strength tests were conducted on these cube specimens in accordance with TS EN 12390-3/2010. Additionally, ultrasound transmission rate tests, following TS EN 12504-4/2004, capillarity tests, following TS EN 3526, and unit weight tests, following TS 706 EN 12620 standard, were performed on cube samples of the same size.

2.2. Experiments on geopolymer paste

2.2.1. Consistency

The required amounts of Elazığ ferrochrome slag and waste marble powder for a 500-gram sample were accurately calculated and weighed using a precision scale with a 1-gram precision. The alkaline activator content to be added to the mixture was determined to be 25%, 30%, 35%, and 40% of the total weight and measured in graduated containers. Furthermore, a flow table experiment was performed to evaluate the consistency.

2.2.2. Determination of the setting times of samples

The sample was prepared by weighing 500 grams of Elazığ ferrochrome slag and waste marble powder. A mixture was created by measuring approximately 35% of the powder material, which amounted to 175 grams. The initial setting time, also known as the socket start time, was recorded in minutes when the socket reached an insertion depth of 3-5 mm. The specimens placed in the Vicat ring were inverted to determine the final setting time, and a needle was inserted into the instrument. The final setting time was recorded in minutes when the needle reached an insertion depth of 0.05 mm.

2.2.3. SEM analysis

Electron microscopes use data obtained from the interaction of electrons emitted from an electron source with the sample to generate images. SEM analysis, commonly used to evaluate the surface morphology of various products, including concrete, ceramics, and alkali-activated composites, was also employed to examine the microstructure of the composites produced in this study. Specifically, scanning electron microscope (SEM) analyses, a type of electron microscope, were conducted at the Inonu University Scientific and Technological Research Centre. The schematic is shown in Figure 1.

Figure 1. SEM working principle and samples prepared for analysis

2.2.4. XRD analysis

The X-ray diffraction method (XRD) is grounded on the principle that X-rays are characteristically refracted by each crystalline phase, depending on

its distinctive atomic arrangement. These diffraction profiles serve as a unique "fingerprint" for each crystal. The alkali-activated slag composites underwent XRD analyses in this study at the Central Research Laboratory of Eskisehir Osmangazi University. The shape is shown in Figure 2.

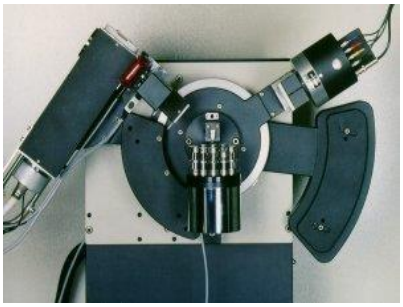


Figure 2. XRD device and samples prepared for analysis

2.2.5. XRF analysis

X-ray fluorescence (XRF) analysis can be used to analyze the composition of many materials. The fact that this method can be done quickly and a large number of elements can be analyzed non-destructively in a few minutes is one of the reasons why it is mainly preferred [43]. The chemical compositions of Elazığ ferrochrome slag and waste marble dust used in the study were analyzed by Elazığ Seza Cement with an XRF device.

2.2.6. Unit weight test

The unit weight test was conducted on 70x70x70 mm cubic samples for each temperature and molar condition in accordance with TS EN 12390-7 standards. Subsequently, calculations were performed based on the obtained measurements (Figure 3).

2.2.7. Capillarity

The capillarity test determines the capillarity coefficients (k) of concrete specimens [44]. Cubic specimens measuring 70x70x70 mm are prepared and exposed to temperatures of 60 °C and 90 °C in an oven for 24 hours. Before the experiment, the dry weights of the specimens were measured.

Figure 3. Unit weight measurements of the specimens

These specimens are then placed in a container to contact the water's surface, and weight measurements are taken at specific intervals between the first and last measurements. The amount of water absorbed through capillary action is recorded during these intervals. Capillarity coefficients are calculated using the Eq.1.

$$q^2 = \left(\frac{Q}{A}\right)^2 = k \times t \quad (1)$$

Where Q represents the absorbed water amount (g), A is the surface area (cm²), q is the water absorbed per unit area (g/cm²), and k is the capillarity coefficient (cm/sec$^{0.5}$). This method provides valuable information about the capillary water absorption properties of concrete [45], which is essential for assessing its durability and performance in different environmental conditions.

2.2.8. Ultrasonic pulse velocity test

The Ultrasonic Pulse Velocity (UPV), a non-destructive test, is conducted to measure the ultrasonic wave propagation velocity in the specimens, and it is performed per TS EN 12504-4 standards. 70x70x70 mm cubic samples were used, and three samples were prepared for each temperature and molar condition. Measurements are taken from the smooth surfaces of these cubic samples. During measurements, the sensors are positioned opposite each other to ensure accurate readings and a rigid platform countertop is used to facilitate sensor alignment. The UPV testing apparatus transmits ultrasound waves into the specimen, and the time it takes to pass through the specimen between its two surfaces is measured. This allows the calculation of the wave velocity within the composite. This method

provides essential data for assessing composite specimens' structural integrity and quality under varying conditions [30].

$$UPV = \frac{l}{V}(\text{km/sec}) \quad (2)$$

In this context, the variables used to calculate the speed of sound waves (V) in alkali-activated slag composite are V (speed in km/s), S (L) (distance in meters), and t (transit time in µs). The resulting UPV values estimate the composite's quality, allowing for quick assessments of its structural characteristics and suitability for various applications [30].

2.2.9. Compressive strength

The compressive strength test involved 70x70x70 mm cubic samples for various temperatures and molar conditions, following TS EN 12390-3 standards. A constant loading rate of 0.4 MPa/s was applied until the maximum load was reached. The results were obtained by averaging data from three samples for each condition. The shape is shown in Figure 4.

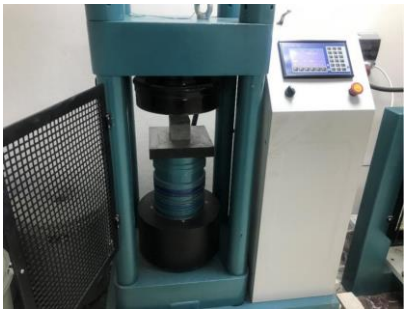


Figure 4. Picture of compressive strength test

3. Findings and Discussion

3.1. Consistency determination and setting time results

Flow diameter test and setting time determination tests were performed on the prepared blast furnace slag alkali-activated composite mortar, and the results are presented in Figure 5 and Figure 6.

The flow diameter values of the specimens decreased with an increase in MP content in all series. These results suggest that the consistency of the composites decreases as the percentage of marble powder increases, regardless of the molarity of the alkaline activator (NaOH).

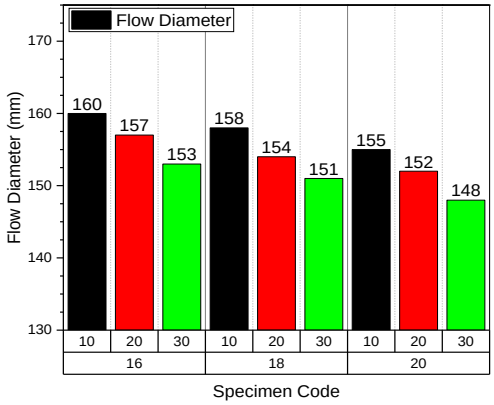


Figure 5. Flow table test result

Based on the results obtained from the setting time experiments, it is evident that an increase in the molarity of the NaOH solution leads to a decrease in the initial setting time of the samples (Figure 5). In other words, using a higher concentration of NaOH allows the samples to be set earlier. The experimental results indicate that AAFC composites typically initiated the setting process within an average time of 60 minutes.

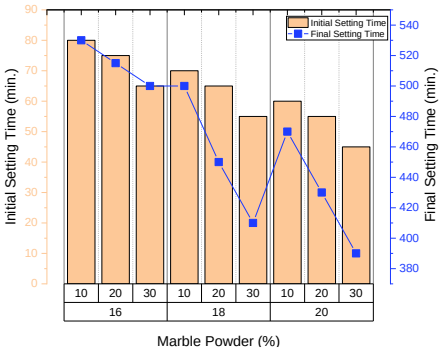
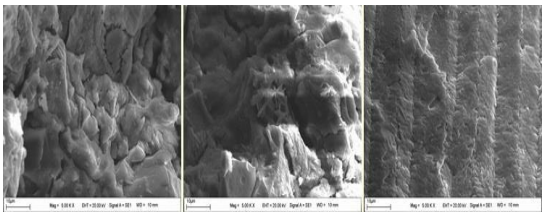


Figure 6. Setting time test result

Moving on to Figure 6, a similar relationship is observed between NaOH molarity and the setting times, specifically regarding the final setting time. It was observed that the samples' final setting times ranged between 390 minutes and 530 minutes (approximately 6-9 hours). Notably, the inclusion of marble powder instead of ferrochrome slag resulted in a reduction in both the initial and final setting times of the samples. Including marble powder instead of ferrochrome slag resulted in an earlier setting of the samples, indicating a decrease in the setting time as the molarity value of the mixture increased.

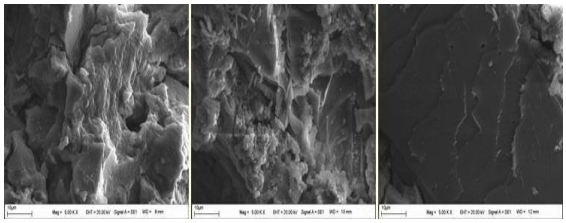
3.2. Results of SEM analysis

Specimens were prepared by incorporating 10%, 20%, and 30% waste marble dust in the alkali-activated composites, followed by curing at an activation temperature of 60˚C. SEM images of these specimens are presented in Figure 7., Figure8., Figure 9. Upon examining the figures, it is evident that the specimens exhibit a dense and smooth structure of sodium alumino-silicate hydrate (NASH) gels. The cracks in the samples observed in the SEM images are likely attributed to two factors. Firstly, it is believed to result from incomplete NASH (sodium aluminate silicate hydrate) gelation, which can lead to structural weaknesses and crack formation. Secondly, the crumbling of the samples during the preparation for analysis may have contributed to the appearance of cracks.



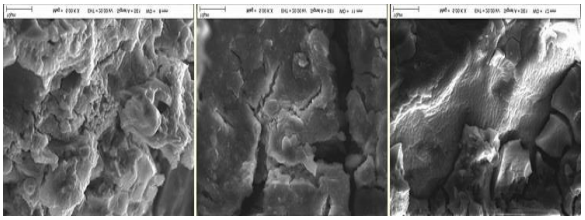
a) %10 AMT, b) %20 AMT, c) %30 AMT

Figure 7. SEM images of samples containing 16 mol NaOH cured at 60˚C activation temperature



a) %10 AMT, b) %20 AMT, c) %30 AMT

Figure 8. SEM images of samples containing 18 mol NaOH cured at 60˚C activation temperature

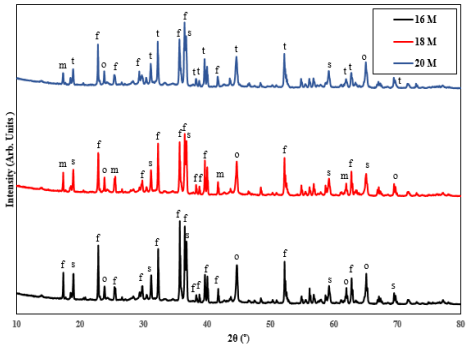


a) %10 AMT, b) %20 AMT, c) %30 AMT

Figure 9. SEM images of samples containing 20 mol NaOH cured at 60˚C activation temperature

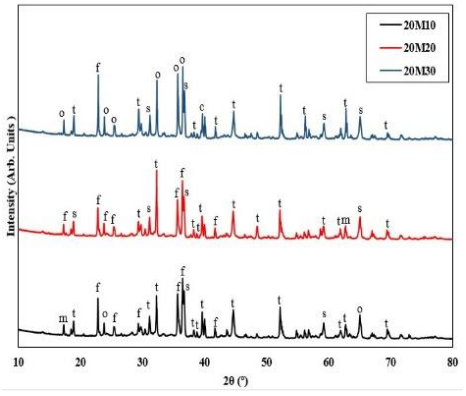
3.3.Results of XRD analysis

XRD experiments were conducted on alkali-activated dough samples, which were subsequently ground into powder for analysis. The XRD diffractograms of the samples are depicted in Figure 10. and Figure 11. Upon examining the diffractograms, distinct peaks corresponding to crystal phases of forsterite (Mg_2SiO_4), spinel ($MgAl_2O_4$), olivine (MgFe)2SiO_4, and magnesium iron silicate ($Fe_{0.2}Mg_{1.8}SiO_4$) were observed in relation to the alkali-activated dough samples.



f: forsterite, s: spinel, o: olivine,
m: magnesium iron silicate, t: tobermorite

Figure 10. XRD diffractograms of samples containing 16M, 18M, and 20M NaOH



f: forsterite, s: spinel, o: olivine,
m: magnesium iron silicate, t: tobermorite

Figure 11. XRD diffractograms of samples containing 20M NaOH

In their study, Yazıcı and Kaya (2003) examined the XRD analyses of samples taken from ferrochrome slag. Since the elemental analysis results in the fractions were closely matched, the phases containing chromium elements could not be observed in the diffractograms. Instead, forsterite (Mg_2SiO_4) and spinel ($MgAl_2O_4$) crystal phases were prominently detected [46]. This suggests that ferrochrome slag did not

undergo sufficient reaction, especially at 16 and 18 mol NaOH molarities. However, at 20 mol NaOH molarity, the presence of CSH peaks in the XRD analysis indicates that the slag requires a higher NaOH molarity for activation. In another study by Türkmen et al. (2019), they reported the presence of spinel and forsterite crystals in the XRD analysis of ferrochrome slag-based geopolymer samples. These peaks were attributed to the ferrochrome slag, suggesting incomplete activation [28].

Additionally, in the samples prepared with a 20 mol activator, formations of tobermorite (C-S-H) were also observed. This observation suggests that at higher molarity values, such as 20 mol, the hydration of CaO in the marble powder occurs. As a result, CSH (calcium silicate hydrate) gels are formed in a manner similar to those found in cement-based samples.

3.4. XRF analysis results

XRF analysis results on ferrochrome slag and marble powder used in the study are depicted in Table 2.

Table 2. shows that the chemical composition of Elazig ferrochrome slag is dominated by MgO (34.83%), SiO_2 (30.95%), Al_2O_3 (20.13%), and Cr_2O_3 (6.22%). It is understood that these results agree with the information presented by Vapur et al. (2013) and Yazıcıoğlu et al. (2003) [47, 48]. Yılmaz and Sütaş (2008) observed that silicon, magnesium, aluminum, and calcium elements dominate in the chemical content of ferrochrome slag. It was stated that the elements in oxides constitute 95% of the slag on average. Small amounts of iron and chromium were also observed [7]. In light of the XRF results of the waste marble powder, it is understood that the waste marble dust used in the study consists of a high proportion (98.49%) of CaO when the loss of superheat is not considered. The chemical composition results obtained in this study were analyzed and are consistent with the data [49].

Table 2. XRF results of ferrochromium slag and marble powder used in the study

Materials/Oxides (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Cr_2O_3	L.O.I.
Slag	30.95	20.13	2.72	2.58	34.83	6.22	1.61
Marble Powder	0.18	0.32	0.01	56.05	0.47	--	43.09

3.5. Tests applied to hardened concrete specimens

3.5.1. Density test

Based on the experimental results, the density values were generally found to be 2.49 g/cm³. In the 18-mole samples, the highest density value of 2.49 g/cm³ was obtained in the samples containing 10% waste marble powder and cured at 25°C. A decrease in unit weight values was observed with increasing temperature.

Density measurements for AAFC specimens were performed after a 28-day curing period at 60°C and 90°C. It is observed that the density values of specimens cured at both 60°C and 90°C are positively affected as the molarity of the NaOH alkali solution increases.

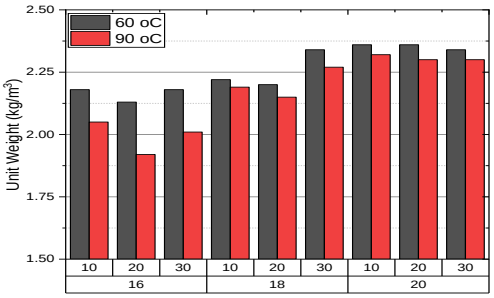


Figure 12. Unit weight of the specimens

Figure 12 shows how density values change when marble powder is used in the mixtures. It is believed that the lower density values in some samples, despite the filling effect of marble powder, may be attributed to insufficient chemical reactions during activation when marble powder is substituted.

3.5.2. The results of the capillarity experiment

When the results of the capillarity experiments were observed, the capillarity coefficients decreased with the increase in molarity. In contrast to this situation, it was observed that capillarity increased with the rise in marble dust. The highest capillarity coefficient value was obtained from the samples at 16 molarity, while the lowest capillarity coefficient results were obtained from the samples at 20 molarity. The shape is shown in figure 13.

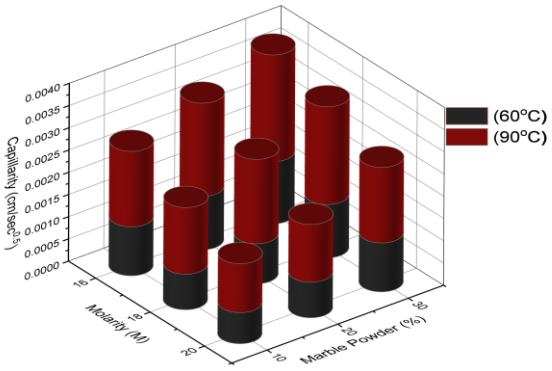


Figure 13. Capillarity test result

3.5.3. The results of the ultrasonic pulse velocity test

As a result of the experimental findings, the ultrasonic pulse velocity values of the samples decreased with the increase in the amount of waste marble dust; the increase in the molarity ratio increased the ultrasonic pulse velocity of the samples (Figure 14).

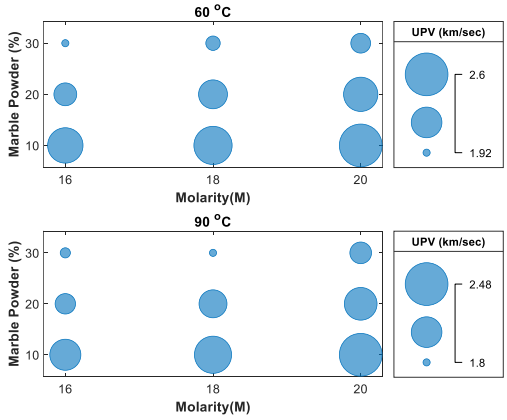
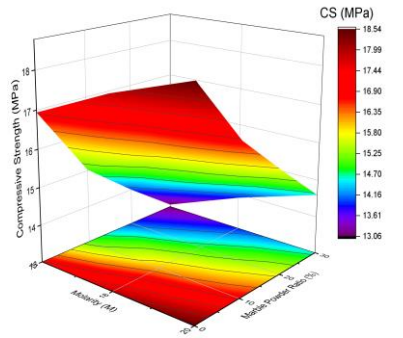


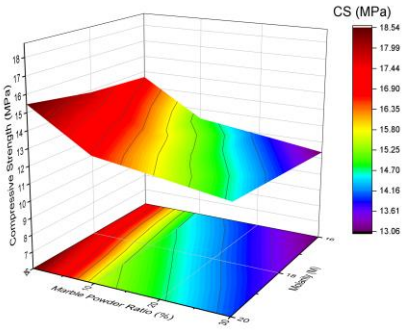
Figure 14 Ultrasonic pulse velocity (UPV) values of the specimens

3.5.4. Compressive strength

Compression tests were performed on the specimens in accordance with TS EN 12390-3/2010 with a constant loading rate of 0.4 MPa/s. The results obtained were calculated by taking the average of these three samples.



a) 60°



b) 90°

Figure 15. Compressive strength (CS) of the specimens (under 60° and 90° degrees)

When the test results obtained from the specimens, cast in groups of three for each mixture ratio (10%, 20%, 30%), and cured separately at 25°C, 60°C, and 90°C, were analyzed, the highest strengths were achieved in the specimens cured at 60°C activation temperature. According to the data obtained, the highest strength of 16.85 MPa was recorded for the mixture prepared with a 20 mol activator and 10% marble powder. With an increase in activation temperature, some decrease in strength was observed, especially in the samples cured at 90°C.

The increase in compressive strengths was observed to have a strong positive correlation with the rise in molarity values, indicating a high linear relationship. However, when considering the specimens containing 100% ferrochrome slag used for control purposes, a decrease in

compressive strength was observed as the amount of waste marble dust substitution increased. The ratios of marble dust substitution inversely affected the compressive values. The shape is shown in figure 15.

4. Conclusion

In conclusion, the critical findings of this study can be summarized as follows:

- Sodium silicate and sodium hydroxide as alkaline activators contribute to forming alkali-activated concrete, demonstrating binding properties.

- SEM analyses revealed a dense and smooth structure in the samples, but crack formations were observed, potentially occurring during sample reduction for analysis.

- Diffractograms showed the presence of crystal phases such as forsterite, spinel, olivine, magnesium iron silicate, and tobermorite in the alkali-activated dough samples.

- The molarity value of alkaline activators and the ratio of waste marble powder influenced the spreading diameters and receptacle durations of the samples.

- Compressive strength increased with higher molarity values, while the inclusion of more waste marble powder led to a decrease in compressive strength due to an increased clearance rate in the internal structure.

- Temperature had an impact on unit weight values, with an increase resulting in a decrease, and water absorption decreased with increasing molarity.

- Ultrasound passage rates were influenced by the molarity ratio and the presence of waste marble powder, with higher ratios and less marble powder resulting in increased passage rates.

- During capillarity experiments, stains were observed on sample surfaces due to sodium hydroxide accumulation.

- Alkaline-activated mixtures containing Elazığ ferrochrome slag and waste marble powder demonstrated compressive strengths above 16 MPa, increasing with higher molarity values.

- Elazig ferrochrome slag used in the study was observed to be finer-grained than waste marble dust. The specific surface area of ferrochrome slag was 2375.1 cm^2/g, while the specific surface area of waste marble dust was 1187.8 cm^2/g. The chemical composition of Elazığ ferrochrome slag was mainly composed of MgO, SiO_2, Al_2O_3, and Cr_2O_3, while the composition of waste marble dust was 98.49% CaO.

- Based on the analysis of strength and durability, it was observed that the mixtures containing 20M NaOH and reference (0%) activated at 60°C, combined with 10% waste marble powder, exhibited the best results. In terms of sustainability, it can be concluded that the series with 20M NaOH molarity and 30% waste marble dust activated at 60°C is the most suitable option, as it has the necessary strength and durability properties.

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No conflict of interest or common interest has been declared by the author.

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