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Article

A comprehensive performance evaluation of the cement mortar and sulfur mortar

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ABSTRACT

Concrete, one of the most important construction materials used in the building industry in Türkiye, is not a sustainable material because it relies on non-renewable natural resources. However, by replacing a certain percentage of the cement in the concrete mixture with industrial by-products and binders, the material's sustainability-related properties can be improved, resulting in more durable materials. Sulfur mortar is a type of waterless mortar obtained by melting sulfur and mixing it with aggregate, it is known to have a different structure than traditional cement-bound mortars and concrete. Studies have shown that sulfur concrete demonstrates superior durability in aggressive environments, maintaining its structural integrity while Portland cement concrete undergoes significant deterioration. It has a similar feature to polymer concrete, and since it does not contain cement, it does not have the hydration products of cement-bound mortars. The reason why sulfur concrete does not absorb water is that it is produced by melting and therefore has no voids.

As part of the study, a literature review was conducted to examine the sustainability of sulfur and evaluate previous studies on sulfur-modified concrete and mortar. Following this, three different types of mortar samples were produced in the laboratory based on the literature: Sulfur mortar, standard cement mortar, and a cement mortar with the same mix proportions as the sulfur mortar. When determining the mix proportions, the EN 196-1 standard was used as a reference for the standard cement mortar. Since there is no specific standard for sulfur mortar production, literature data were used during the preparation of both the sulfur mortar and the cement mortar with the same mix proportions. After all samples were subjected to curing under standard conditions, they were tested on the 28th day for flexural strength and compressive strength to determine their mechanical properties. In addition, ultrasound pulse velocity was taken to compare the void content of different mortars, providing insights into material strength and void structure. In addition to mechanical tests, the dry weights of the produced mortars were measured before being saturated in water. Physical parameters such as unit weight, water absorption by weight, and water absorption by volume were determined through measurements in air and water. Capillary water absorption tests were also conducted to compare the capillarity coefficients of the mortars. The results of the study showed that sulfur mortar had lower mechanical strength than cement mortars, but it exhibited significantly higher permeability compared to cement mortars.

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INTRODUCTION

Concrete is one of the most important construction materials used in the building industry in Türkiye. It is a brittle material created by mixing cement, aggregate, and water (and chemical additives if necessary), which gains its required properties through the hydration of cement (Ararat, 2015). Concrete is not a sustainable material because it relies on non-renewable natural resources. However, by partially replacing the cement in its composition with secondary binders (mineral additives) such as ground granulated blast furnace slag or fly ash, which are industrial by-products, the material can be made more sustainable (or less unsustainable) (Justnes & Martius-Hammer, 2016). Studies on the sustainability of cement-based mortars have demonstrated that optimizing their performance is possible through the incorporation of different binders and aggregates (Yi et al., 2023). In this regard, research on the use of expanded perlite and other lightweight aggregates has yielded significant findings in terms of water permeability and durability.

The aim of this study is to observe the contribution of naturally occurring organic structures to the permeability of concrete, based on key characteristics of good concrete, such as being dense, hard, impermeable, wear-resistant, and durable against external effects. Additionally, it aims to provide insight into the performance of additives to be used in concrete or mortar production under the fundamental principles of sustainability. The research question of this study is whether such materials can be produced solely through the use of local resources and whether they can be manufactured in a laboratory setting. In this context, a literature review was conducted to determine whether substances found in ant nests could contribute to the permeability of concrete products. It was found that ant nests have a consistent effect on the chemical properties of soil, with higher levels of carbon, nitrogen, sulfur, phosphorus, and electrical conductivity compared to the surrounding soil. Studies in this field show that the elements found in ant nests alter the macroporosity of the soil and, consequently, its water conductivity (James et.al., 2008). The water absorption and permeability of concrete depend on the total number of voids within the hardened concrete and whether these voids are interconnected. The durability of concrete is also affected by its water absorption properties (Ilıca, 2008). As a result of the literature review, it was determined that the factor responsible for the water permeability in ant nests is the high sulfur content in their chemical composition.

Sulfur differs from other minerals in terms of mining issues and supply concerns. Due to the depletion of sulfur resources, sulfur mining has come to a near halt; however, sufficient sulfur can still be obtained as a by-product in oil refineries and natural gas processing plants. Today, the amount of sulfur produced far exceeds global demand for sulfur.

Various studies have been conducted to date on the contribution of sulfur, which is found in higher concentrations in ant nests compared to other soil products, to concrete impermeability. Research that began in the 1930s showed that products obtained by combining sulfur and aggregate gained strength quickly and were more resistant to acid and chemical effects. During these years, improvements were made to sulfur-based cement formulations by adding various components to cement formulations. In the late 1960s, Dale & Ludwig (1968) pioneered studies on sulfur and emphasized the importance of aggregate ratios in achieving the best durability (Dale & Ludwig, 1968). This study was followed by the research of Crow & Bates (1970) on the development of high-strength sulfur-basalt concretes (Crow & Bates, 1970). In the early 1970s, various projects were undertaken where sulfur concrete was used as a construction material. In 1971, the U.S. Department of the Interior's Bureau of Mines and the Sulphur Institute (Washington, D.C.) established a cooperative program to research and develop new uses for sulfur. At the same time, the Canada Centre for Mineral and Energy Technology (CANMET) and the National Research Council of Canada (NRC) launched a research program to develop sulfur concrete (Malhotra, 1974). In 1973, the Canada Sulfur Development Institute (SUDIC) was jointly established by the Canadian federal government, the Alberta provincial government, and Canadian sulfur producers to develop new markets for the increasing sulfur stock in Canada. In 1978, CANMET and SUDIC organized an international conference on sulfur in construction, where many researchers published papers and presentations exploring various aspects of sulfur concrete. Mc Bee and other researchers have published a series of articles and reports on various aspects of sulfur and sulfur concrete. All these activities have raised awareness regarding the potential use of sulfur as a construction material. Recent studies aim to develop a new technology that enhances the performance of sulfur concrete products by adding bitumen as an additive to sulfur concrete (Mohamed & El Gamal, 2010).

Sulfur concretes have many positive properties from various perspectives:

- They can be used as a construction material in industrial facilities exposed to highly corrosive acids or in other structures where acid and salt environments cause early deterioration.
- They achieve high mechanical strength rapidly during setting (approximately 80% of the ultimate strength is achieved within just a few hours, and full strength is reached within one day).
- Their low permeability and porosity contribute to the water impermeability of the material.

- Mechanical properties, including flextural, compressive, and flexural strengths, as well as fatigue life, can be enhanced with additives used in sulfur concrete.
- They have comparable density and radiation protection properties to hydrated Portland cement.
- They can be protected throughout the year at temperatures below freezing.
- The materials in the mixture are recyclable and reusable.
- Impurities in the materials used do not affect the final strength properties.
- No water is needed for production.

It has been observed that sulfur, which provides the water impermeability characteristic of ant nests and is one of its chemical components, has also been used in studies related to the production of waterless concrete on Mars. The abrasion resistance of sulfur concrete, its rapid setting and strength gain, and its lack of water requirement during production make it a suitable construction material for creating habitable environments for permanent human settlement on Mars. Furthermore, with NASA's renewed interest in manned missions to the Moon and the idea of establishing a permanent base in the lunar environment, research on waterless concrete has gained importance. In this context, the experimental studies conducted by Toutanji and colleagues in 2010 demonstrated that sulfur concrete could be used as an alternative construction material in lunar applications (Toutanji & Grugel, (2009)).

EXPERIMENTAL STUDIES

Since the concrete of the load-bearing system is permeable, it is affected by water. These effects can be physical, such as swelling and shrinkage, or they can be corrosive with salts and harmful chemicals in the water. Damages and defects that may occur in the carrier system will affect the durability of the structure. Making concrete less permeable. It is known that the presence of sulphur in ant hills provides impermeability to protect the nest from the effects of water. With the research, some impermeability can be provided with the addition of sulphur to be used in concrete mortar. In this study, the aim was to determine the effects of sulfur found in the chemical composition of ant nests, which provides water impermeability to the nest on concrete, with the goal of contributing to the production of new building products by increasing concrete's water impermeability and durability against chemical effects.

Materials

In the experimental part of the study aggregate, cement and sulphur were used as materials. The aggregates used in the mortar are granular materials of mineral origin and constitute the dispersed phase of the mortar. The most important factors in the workability and strength of the mortar are the particle size, shape, and distribution. In mortars, silica or limestone-based sand or fired clay aggregates are used, with the maximum particle size being 2-4 mm. (Ekşi & Yüzer, 2013; Gökyiğit, 2016). In this study, silica-based CEN Standard Sand conforming to EN 196-1 was used in all types of mortars produced.The particle size distribution of the CEN Standard Sand described in EN 196-1 is presented in Table 1.

In the cement mortars produced in this study, PC 42.5 Portland cement was used. The physical properties of PC 42.5 Portland cement according to EN 197-1 are provided in Table 2 (BSI, 2011).

The physical properties of the sulfur (sulphur) element used in the produced sulfur mortar were created in accordance with the data from the General Directorate of Mineral Research and Exploration (MTA) and are presented in Table 3. During the literature review, it was noted that the impurities in the sulfur element do not affect the final strength of the material; therefore, impurities were not sought in the sulfur obtained during the experimental study.

Table 1. Particle Size Distribution of CEN Standard Sand (BSI, 2016)

Square Mesh Opening (mm)	2.00	1.60	1.00	0.50	0.16	0.08
Retained on Sieve (%)	0	7±5	33±5	67±5	87±5	99±1

Table 2. Physical properties of PC 42.5 Portland cement

Physical Properties	Desired Values
Fineness - Blaine (cm^2/g)	Min. 2800 cm^2/g
2-Day Compressive Strength (N/mm^2)	Min. 20 N/mm^2
7-Day Compressive Strength (N/mm^2)	Min. 31.5 N/mm^2
28-Day Compressive Strength (N/mm^2)	Min. 42.5 N/mm^2
Initial Setting Time (hour-minute)	Min. 1 hour
Final Setting Time (hour-minute)	Max. 10 hours
Volume Expansion (mm)	Max. 10 mm

Table 3. Physical properties of the sulfur element

Physical Properties	Values
Color	Yellow
Melting Temperature	119°C
Ignition Temperature	270°C
Boiling Temperature	444°C
Hardness	1.5 - 2.5
Density	2.03 - 2.06 g/cm^3
Thermal Conductivity	Low
Electrical Conductivity	None
Solubility in Water	None

Table 4. Codes assigned to the produced samples

SAMPLE CODE	SAMPLE CONTENT	AGGREGATE (CEN standard SAND)	CEMENT	SULFUR	WATER
A	Standard Cement Mortar	3 (1350g)	1 (450g)	-	0,5 (225g)
B	Cement Mortar with Same Mix Ratio as Sulfur Mortar	4,6 (1855g)	1(400g)	-	0,5 (200g)
C	Sulfur Mortar	3.1 (1855g)	-	1 (600g)	-

In this study, three different types of samples were produced: Standard cement mortar (EN 196-1), cement mortar with the same mix ratio as sulfur mortar, and sulfur mortar. This approach allowed for the comparison of all mortar types with each other. The produced samples were designated as A, B, and C codes, respectively (Table 4).

The production methods and curing conditions of all the types of mortars produced and compared in this study are explained in detail. Experimental studies on the water resistance and durability of mortars have shown that no-cure mortars can exhibit comparable performance to conventional counterparts (Gul et al., 2024). However, for non-water-based binders such as sulfur mortar, specific considerations regarding high-temperature requirements and different hardening mechanisms must be taken into account.

Production and Curing Conditions of Standard Cement Mortar (A):

According to the EN 196-1 the standard cement mortar with sample code "A" consists of 1 part cement, 3 parts aggregate (sand), and 0.5 parts water were used; specifically, 450g of cement, 1350g of CEN standard sand, and 225g of water (Figure 1).

The prepared mortar was filled into previously oiled triple prismatic molds with dimensions 40×40×160 mm. Following the EN 196-1 standard, the molds were first filled halfway and then completely, followed by compaction on a vibration table. The molded samples were kept covered in an environment of 20±2 °C temperature and 90% relative humidity for 24 hours. After this period, the samples were removed from the molds and stored in lime-saturated water at a temperature of 20±2 °C until the testing day (28th day).

Production and Curing Conditions of Cement Mortar with the Same Mixture Ratio as Sulfur Mortar (B):

In this study, since there is no standard to produce cement mortar with the same mixture ratio as sulfur mortar, the ratios specified in the literature for sulfur mortar have been utilized. Accordingly, the produced mortar consists of 400g of cement, 1855g of CEN standard sand, and 200g of water, with a mixture ratio of 1 part cement, 4.6 parts aggregate (sand), and 0.5 parts water by weight.

To apply the same mixing procedure as for sulfur mortar, a mechanical mixer was not used; instead, mixing was carried out manually with a trowel (Figure 2). Initially, water and cement were added to the mixing container and mixed for 30 seconds, followed by the addition of sand during the next 30 seconds. Afterward, all materials were mixed with a trowel at a higher speed for an additional 90 seconds.

The cast samples were kept covered in an environment with a temperature of 20±2°C and relative humidity of 90% for 24 hours. After this period, the samples were removed from the molds and stored in lime-saturated water at a temperature of 20±2°C until the testing day (28^{th} day).

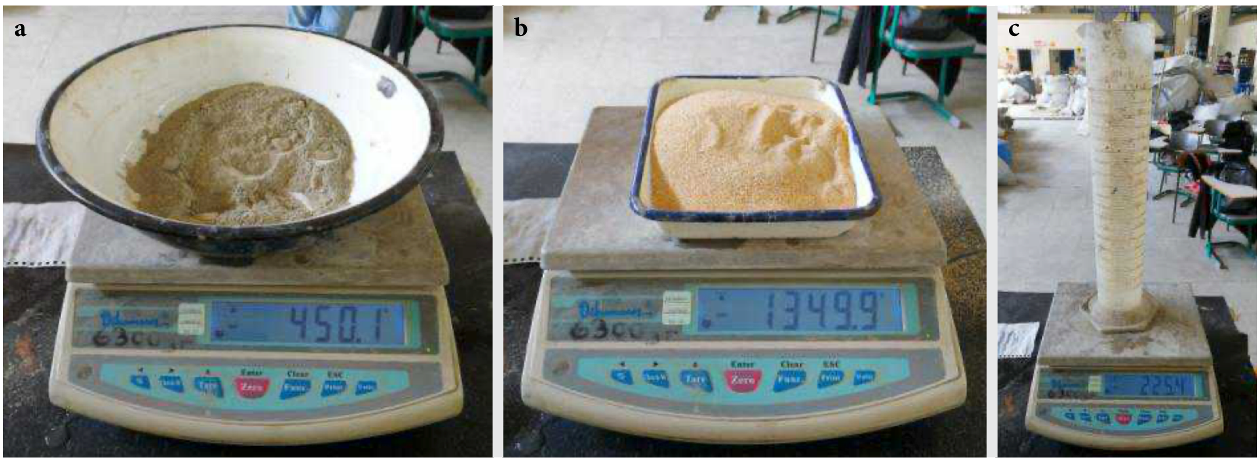

Figure 1. Materials and their weights used during the production of standard cement mortar: **(a)** PC 42.5 Portland cement **(b)** CEN standard sand **(c)** Water.

Figure 2. **(a)** Mixing with a trowel **(b)** Compacting mortar B.

Production and Curing Conditions of Sulfur Mortar (C): According to literature research (Vroom, 1977) the sulfur mortar with sample code "C" consists of 1 part sulfur and 3.1 parts aggregate (sand) by weight. To investigate the effect of the sulfur element, the cement mortar with sample code "B," which has the same mixing ratio as the sulfur mortar which consists of 1 part cement, 4.6 parts aggregate (sand), and 0.5 parts water by weight; 600g of sulfur and 1855g of CEN standard sand were used. The production of the standard cement mortar was carried out using a mechanical mixer in accordance with the standard.

Methods

However, due to the high temperature required for producing sulfur mortar (ranging from 132°C to 141°C), an electric stove was used during the mixing process, and the mixing was done with the help of a trowel. The mixing procedure for the cement mortar with the same mixing ratio as the sulfur mortar was determined based on the mixing procedure of the sulfur mortar.

Sulfur mortar is a type of mortar produced without the use of water, which is crucial for its binding properties, as can be inferred from its composition. Therefore, it is also referred to as dry mortar. In this type of mortar, the binding properties that arise from the combination of cement and water are provided by the sulfur element. However, unlike cement mortars, the production of sulfur mortar involves a thermal process. Sulfur melts at 119°C and rapidly loses its viscosity above 149°C. For this reason, many literature sources indicate that the suitable working range for transporting, placing, and finishing the mixture is between 132°C and 141°C (ACI, 1998).

The temperature required for the production of sulfur mortar was achieved using an electric stove during the mixing process (Figure 3). The mixing was done with the help of a trowel. The mixing container and trowel, along with the sulfur and aggregates to be included in the mixture, were kept in an oven heated to 140°C for 1 hour. The melted sulfur poured into the mixing container was then mixed with the CEN standard sand, which had been heated to 140°C, for 30 seconds. After that, the mixture continued to be stirred with the trowel on the electric stove for an additional 90 seconds.

Figure 3. Electric stove used during the production of sulfur mortar.

The 40×40×160 mm tripartite prismatic molds were greased with mold oil and kept in a 140°C heated oven until the time of production. Then, they were filled and compacted with the prepared sulfur mortar (Figure 4). The molded samples were kept covered in an environment of 20±2°C temperature and 90% relative humidity for 24 hours. After this period, the samples were removed from the molds and placed in lime-saturated water at 20±2°C until the testing day (28^{th} day).

The high temperature requirement for the production of sulfur mortar made the process difficult. Due to the material's rapid heat loss, vibration could not be performed on the vibration table; instead, the vibration process was carried out by striking the mold against the workbench. After production, crystalline shimmering was observed on the dark, yellow-colored sample produced, and it was noted that the material began to set rapidly due to heat loss.

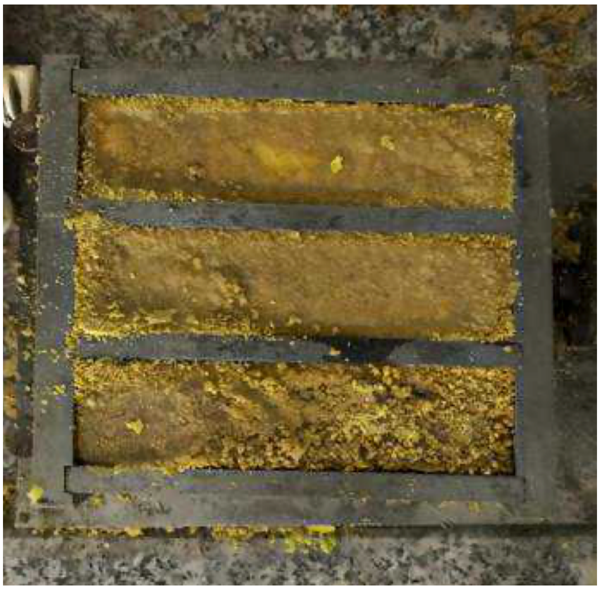

Figure 4. Molded sulfur mortar.

Experimental Studies

In order to determine the physical and mechanical properties of sulfur mortar, the experimental study conducted in this work was limited to density, water absorption by weight and volume, capillary water absorption, compressive and flexural strength, and ultrasound pulse velocity.

Physical Tests

Physical tests provide information about the material's pore structure, such as water and gas permeability, freeze-thaw resistance, and pore size. In this study, the samples prepared for physical tests were weighed in air and water, and capillary water absorption tests were conducted. From the test results, density, weight-based water absorption (as, %), volume-based water absorption (hs, %), and capillarity coefficients (Kk, cm^2/s) were determined.

Density, Weight and Volume Water Absorption:

According to EN 1015-10, the samples were kept in an oven at 60±5°C for 24 hours to allow the evaporation of free water (BSI, 1999). To calculate the density, the dry weights of all samples were first recorded. In this study, the samples were placed in a deep container and initially filled with water to a height equal to one-fourth of their height. After waiting for 1 hour, water was added until it reached half the height of the samples. After another hour, the same procedure was repeated until the water level reached three-fourths of the sample height, and finally, the samples were completely submerged. After 24 hours, the samples were removed from the water and weighed in both air and water.

Capillary Water Absorption:

In the study, mortar samples prepared in accordance with the standard (EN 1015-18) were kept in a drying oven at a temperature of (60±2)°C until they reached a constant weight (BSI, 2002). Measurements were taken at 64 seconds, 144 seconds, 256 seconds, 576 seconds, 1024 seconds, and 1600 seconds (t_i, s), and their weights (W_i, g) were determined. All measurements were performed at an ambient temperature of 20±2°C and a relative humidity of 40±5%. (Figure 5).

Capillary water absorption tests were conducted on three test samples from each of the three different mortars. To determine the capillary coefficient, the averages of the measurements taken during the first 26 minutes were used to plot the graph of Qi/A - √t nd the slope of the line was utilized (Figure 6). The capillary water absorption coefficient (K, cm^2/s); has been determined as specified in Equation 2.

$$K= \frac{m^2}{60} = \frac{Q^2}{A^2.t.60} \ cm^2/s \qquad (2)$$

The capillarity coefficient of A mortar (Standard Cement Mortar) has been found to be 1,5.10-7 cm^2/s, and the capillarity coefficient of B mortar (Cement Mortar with the Same Mixture Ratio as Sulfur Mortar) has also been found to be 1,5.10-7 cm^2/s. However, the capillarity coefficient of C mortar (Sulfur Mortar) has been found to be 0 cm^2/s due to the linear appearance of the value in the graph and the fact that the mortar absorbs almost no water.

Figure 5. The capillary water absorption test.

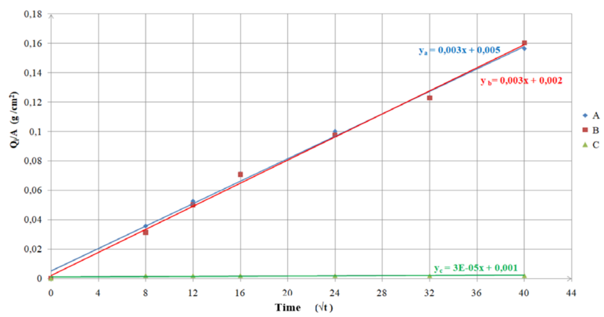

Figure 6. Qi/A - √t Graph of three different mortar samples.

Mechanical Tests

Mechanical tests provide information about the material's strength under vertical loads (fracture strength) and indirectly about its flexural strength. The compressive strength (fb, MPa) and flexural strength (fe, MPa) of the samples prepared for mechanical tests are tested in a laboratory environment. In this study, the ultrasound pulse velocity, which is considered a non-destructive in-situ test, is also examined within the scope of mechanical tests, as it helps determine the voids within the material and indirectly provides information about the material's strength.

Flexural Strength

Within the scope of the study, the flexural test was performed on 40x40x160 mm specimens on the 28th day, according to EN 1015-11 (BSI, 2019). The aim is to determine the flexural strength of hardened mortars on the 28th day. The flexural test was applied to three prismatic samples of each of the three different types of mortar (Figure 7).

Compressive Strength:

In this study, compressive tests were conducted according to EN 1015-11 (BSI, 2019) on the 28th day using steel plates measuring 40x40 mm placed above and below the two separated pieces from the flexural test results. The compressive strengths were determined by dividing the maximum load identified after the sample broke by the area over which the load was applied (Figure 8). The compressive test was applied to three prismatic samples of each of the three different types of mortar.

Ultrasonic Measurement:

It is known that there is a direct proportional relationship between the speed of sound transmission and strength. Knowing the speed of sound in a porous material provides information about the number of voids contained in the material. The voids present within the material negatively affect its strength. If the density of the object is low and/or if there are cracks within it, the propagation of sound waves and, consequently, the speed of ultrasound pulse velocity will be low. Conversely, if the object has few voids and high strength, the speed of ultrasound pulse velocity will be high. However, while this test provides information about the strength of the object, it is not sufficient on its own to determine strength; a comprehensive assessment should be made in conjunction with other measurements (Aköz et al., 2005; Ekşi, 2006; Gökyiğit, 2016).

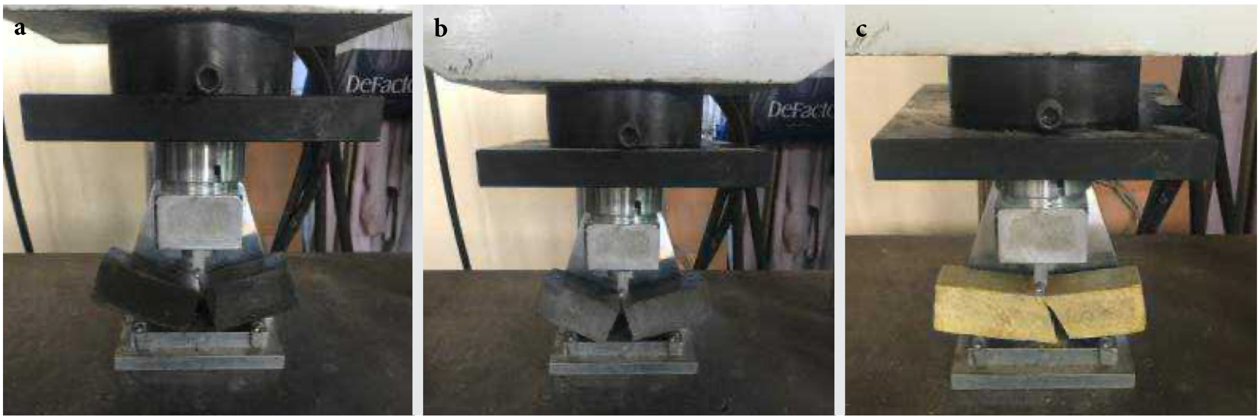

Figure 7. Flexural test of three different mortar samples **(a)** A mortar **(b)** B mortar **(c)** C mortar.

Figure 8. Compressive test of three different mortar samples **(a)** A mortar **(b)** B mortar **(c)** C mortar.

To obtain information about the number of voids in the samples produced during the study, an ultrasound pulse velocity was performed as specified in the EN 12504-4 standard (European Committee for Standardization, 2021). During ultrasonic pulse velocity tests, signal processing techniques based on frequency-modulated waveforms can be utilized to detect voids within the material structure. Particularly, phase noise compensation techniques have been shown to enhance the accuracy of experimental data analysis (Vardarlı & Aldoğan, 2018) (Figure 9).

Using the ultrasonic measurement device, as shown in Figure 9, the ultrasound pulse velocity time and the measurement distance were measured directly, and the ultrasound pulse velocity speed was calculated using equation 3.

$$V_{sound} = L/t \text{ (mm/µs)} \quad (3)$$

L (mm) = The measurement distance

t (µs) = The ultrasound pulse velocity time

V_{sound} (mm/µs) = The ultrasound pulse velocity speed

RESULTS AND EVALUATION/DISCUSSION

In this study, the aim was to evaluate the physical and mechanical properties of sulfur mortar to contribute to the production of building materials that can be used in the future. In this context, three different types of mortar samples were produced: Sulfur mortar, standard cement mortar, and cement mortar with the same mixing ratio as sulfur mortar. Density of all types of mortars were determined, and water absorption tests by weight and volume, as well as capillary water absorption tests, were conducted. Additionally, the mechanical performances were evaluated through flexural and compressive strength tests. Finally, an ultrasound pulse velocity was performed to obtain information about the void structure of the material (Table 5).

After determining the density parameter for all mortars, it was observed that the density of standard cement mortar was 1.97±0.01 g/cm³, the density of the cement mortar with the same mixing ratio as sulfur mortar was 1.96±0.01 g/

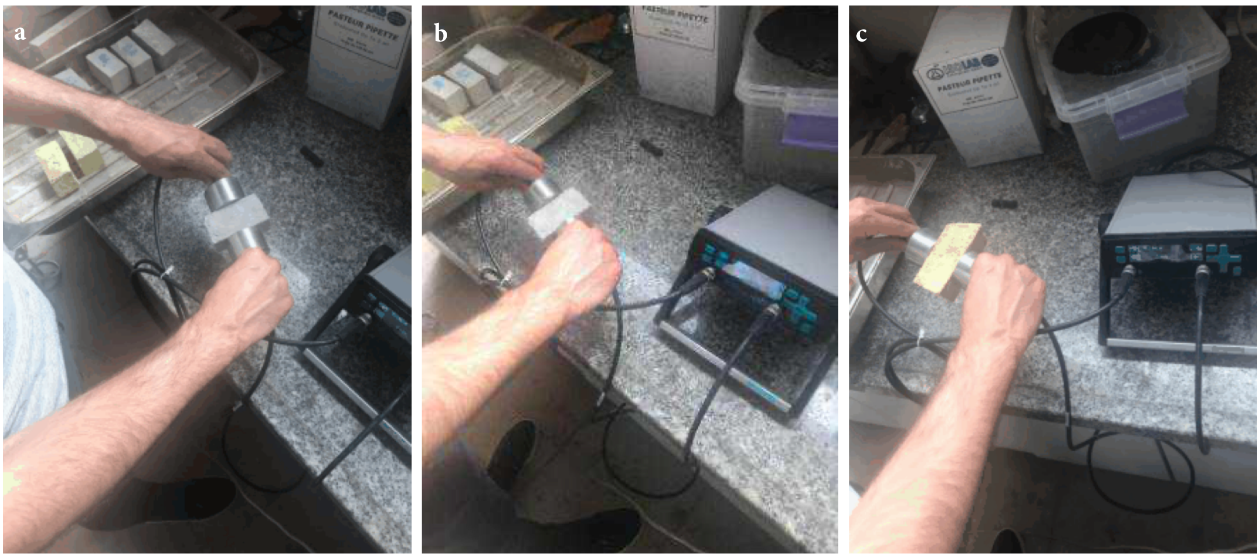

Figure 9. Ultrasonic measurement of three different mortar samples **(a)** A mortar **(b)** B mortar **(c)** C mortar.

Table 5. Physical and mechanical properties of the samples

Mortar Type	Density (β, g/cm³)	Weight Water Absorption Rate (%)	Volume Water Absorption Rate (%)	Capillarity Coefficient, Kk (cm²/s)	Flexural Strength (MPa)	Compressive Strength (MPa)	Ultrasound pulse velocity (V, mm/µs)
Standard Cement Mortar (A)	1.97±0.01	7.74±0.02	15.23±0.06	1,5.10-7	8.54±0.15	34.72±1.20	2,84
Cement Mortar (same ratio as Sulfur Mortar) (B)	1.96±0.01	8.42±0.05	16.53±0.10	1,5.10-7	6.97±0.07	33.68±1.94	2,88
Sulfur Mortar (C)	2.10±0.03	1.00±0.03	2.02±0.60	It has almost not absorbed any water.	3.98±0.47	14.75±0.06	1,94

cm^3, and the density of sulfur mortar was 2.10±0.03 g/cm^3. It was understood that the densities of all types of mortar were like each other, but the density of sulfur mortar was slightly higher than that of the cement mortars.

As a result of the water absorption tests by weight and volume, the water absorption ratio by weight for standard cement mortar was found to be 7.74±0.02%, and the water absorption ratio by volume was 15.23±0.06%; the water absorption ratio by weight for the cement mortar with the same mixing ratio as sulfur mortar was 8.42±0.05%, and the water absorption ratio by volume was 16.53±0.10%; the water absorption ratio by weight for sulfur mortar was 1.00±0.03%, and the water absorption ratio by volume was 2.02±0.60. Lin et al. (2025) demonstrated that modifications such as alkali treatment and silica fume incorporation reduced water absorption in sulfur concrete by 50%, while also enhancing its mechanical performance. The results of this study confirm that increased density in sulfur concrete leads to improved durability and reduced microcracking (Lin et al., 2025). It has been observed that the water absorption by weight and volume of sulfur mortar remained very low compared to cement mortars. In this context, it can be said that the open voids in sulfur mortar are significantly fewer compared to cement mortar.

As a result of the capillary water absorption test, the capillarity coefficient of standard cement mortar and the cement mortar with the same mixing ratio as sulfur mortar was found to be 1.5×10^{-7} cm^2/s. However, it was observed that the capillarity coefficient of sulfur mortar was 0 cm^2/s due to its almost negligible water absorption. Similarly, Vlahovic et al. (2011) reported that sulfur concrete exhibited minimal mass loss when exposed to NaCl and acidic solutions, while Portland cement-based concrete lost up to 20% of its mass within two months. The findings of this study align with these results, confirming the superior durability of sulfur concrete in corrosive environments (Vlahovic et al., 2011).

In this context, when the capillary water absorption test is evaluated together with the water absorption tests by weight and volume, it can be stated that the water absorption of the material is very low and slow, and that sulfur mortar is significantly less permeable compared to cement mortar.

As a result of the flexural test conducted on the 28th day, the flexural strength of standard cement mortar was found to be 8.54±0.15 MPa, the flexural strength of the cement mortar with the same mixing ratio as sulfur mortar was 6.97±0.07 MPa, and the flexural strength of sulfur mortar was 3.98±0.47 MPa. Amanova et al. (2024) reported that modified sulfur concrete exhibited 40% faster setting time and 25% greater chemical resistance compared to traditional sulfur concrete. The results obtained in this study align with these findings, indicating that modifications to sulfur concrete significantly improve its durability and applicability in construction (Amanova et al., 2024). In this context, it was observed that the flexural strength of sulfur mortar is lower than that of the cement mortars. However, considering that the flexural strengths of lime mortars range between 0.5 MPa and 0.9 MPa, it can be stated that sulfur mortar possesses sufficient flexural strength for use in construction.

As a result of the compressive test conducted on the 28th day, the compressive strength of standard cement mortar was found to be 34.72±1.20 MPa, the compressive strength of the cement mortar with the same mixing ratio as sulfur mortar was 33.68±1.94 MPa, and the compressive strength of sulfur mortar was 14.75±0.06 MPa. It was observed that the compressive strength of sulfur mortar is lower than that of cement mortars. However, considering that the compressive strengths of lime mortars range between 0.4 MPa and 1.5 MPa, and that the concrete used in lean concrete production is classified as C16 (with a compressive strength of 16 MPa), it can be stated that sulfur mortar possesses sufficient compressive strength for use in construction.

As a result of the ultrasound test, the ultrasound pulse velocity speed in standard cement mortar was found to be 2.84 mm/μs, in the cement mortar with the same mixing ratio as sulfur mortar it was 2.88 mm/μs, and in sulfur mortar, the ultrasound pulse velocity was 1.94 mm/μs. In this context, it was observed that the ultrasound pulse velocitys in cement mortars were higher than those in sulfur mortar. Since ultrasound pulse velocitys are slower in porous materials, it can be suggested that sulfur mortar is a more porous material, or that while there are no visible cracks on the exterior, there are more micro-cracks within it compared to cement mortars. Given that the void ratio is known to be directly related to the material's strength, it can be expected that the strength of sulfur mortar is also lower than that of cement mortars based on the results of the ultrasound pulse velocity. The flexural and compressive strength tests conducted so far also show similar results to those of the ultrasound pulse velocity. Physical experiments have demonstrated that the open voids in sulfur mortar are significantly fewer compared to cement mortars. In this context, when all experiments are evaluated, it is understood that the voids observed as a result of the ultrasound pulse velocity are closed voids within the material.

CONCLUSION

In conclusion, it has been observed that while the mechanical properties of sulfur mortars are lower than those of cement mortars, they are still at a sufficient level for use in construction. Considering that literature studies indicate that the mechanical strength of sulfur concrete is directly affected by the aggregates used, it is thought that improvements can be made in the mechanical strength of sulfur mortars produced with different aggregates (such as basalt, etc.) (Crow & Bates, 1970). The material has significantly lower permeability compared to cement mortars, which can be regarded as a positive feature in terms of water insulation.

The use of waste materials in the construction industry is of great importance for sustainability. Incorporating alternative materials such as wood fibers in mortars enhances their mechanical properties while reducing environmental impact (Lin et al., 2025). When employing special binders like sulfur mortar, investigating their compatibility with alternative sustainable materials remains a critical area for future research. However, the requirement for high temperatures during the production of the material complicates its application in the field and also increases energy consumption. Additionally, the harmful gases emitted by the sulfur element during the material production can be considered among the difficulties of application.

The literature review and experimental study conducted in this work aim to contribute to future research, and in this context, the experiments were limited to unit volume weight, weight-based and volume-based water absorption, capillary water absorption, flexural strength, compressive strength, and ultrasound pulse velocitys. However, to better understand the pore structure of sulfur mortars, it is suggested that parameters such as specific weight, compactness, and porosity should also be investigated. Additionally, to analyse more detailed applications in construction, it is proposed to examine their permeability under pressurized water conditions and to carry out permeability measurements as a subject for future studies.

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