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INVESTIGATION OF PHYSICAL, MECHANICAL AND THERMAL PROPERTIES OF MINERAL ADMIXED AUTOCLAVED FOAM CONCRETE

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Keywords
Foam Concrete,
Autoclaving,
Mineral Admixture,
Physical and Mechanical Properties,
Thermal Properties.

Abstract

In this study, the aim was to develop a non-combustible, economical, and entirely domestically sourced and technology-based autoclaved foam concrete thermal insulation material. In autoclaved foam concrete (AFC) with a density of 300 kg/m^3, which meets thermal insulation material standards, the density, capillary water absorption coefficient, compressive and flexural strengths, ultrasonic pulse velocity, dynamic modulus of elasticity, thermal conductivity, and the mineralogical properties of hydration products based on XRD of some silica-based mineral additives (fly ash, amorphous silica, and metakaolin) substituted at different ratios (5%, 10%, and 15%) for cement were investigated. Autoclaving improved the physico-mechanical properties of mineral-added foam concrete. Among the mineral additives, the highest strength values were obtained in the foam concrete with 5% metakaolin, while the lowest thermal conductivity and capillary water absorption values were obtained in the foam concrete with 5% fly ash. The study concluded that autoclaving is highly effective in producing a sustainable thermal insulation material in foam concrete.

MİNERAL KATKILI OTOKLAVLANMIŞ KÖPÜK BETONUN FİZİKSEL, MEKANİK VE TERMAL ÖZELLİKLERİNİN İNCELENMESİ

Anahtar Kelimeler
Köpük Beton,
Otoklavlama,
Mineral Katkı,
Fiziksel ve Mekanik Özellikler,
Termal Özellikler.

Öz

Bu çalışmada, yanmaz, ekonomik ve tamamen yerli kaynaklara ve teknolojiye dayalı bir otoklavlanmış köpük beton ısı yalıtım malzemesi geliştirilmesi amaçlanmıştır. Isı yalıtım malzemesi standartlarını karşılayan 300 kg/m^3 yoğunluklu otoklavlanmış köpük betonda (AFC) çimento ile farklı oranlarda (%5, 10 ve 15) ikame edilen silika esaslı bazı mineral katkıların (uçucu kül, amorf silika ve metakaolin) yoğunluk, kılcal su emme katsayısı, basınç ve eğilme dayanımları, ultrasonik darbe hızı ve dinamik elastisite modülü, ısı iletkenliği, XRD esaslı hidratasyon ürünlerinin mineralojik özellikleri incelenmiştir. Otoklavlama, mineral katkılı köpük betonun fiziko-mekanik özelliklerini iyileştirmiştir. Mineral katkılar arasında en yüksek dayanım değerleri %5 metakaolin katkılı köpük betonda elde edilirken, en düşük ısı iletkenliği ve kapiler su emme değerleri %5 uçucu kül katkılı köpük betonda elde edilmiştir. Çalışmada, otoklavlamanın sürdürülebilir ısı yalıtım malzemesi köpük beton elde edilmesinde oldukça etkili olduğu sonucuna varılmıştır.

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INVESTIGATION OF PHYSICAL, MECHANICAL AND THERMAL PROPERTIES OF MINERAL ADMIXED AUTOCLAVED FOAM CONCRETE

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Highlights

- The effect of autoclaving in foam concrete.
- Effect of fly ash, metakaolin and amorphous silica substituted with cement on foam concrete properties.
- Investigation of obtaining autoclaved sustainable thermal insulation material foam concrete.

Purpose and Scope

This research aims to develop a non-combustible, economical and autoclaved foam concrete thermal insulation material developed by fully utilising domestic resources and technology.

Design/methodology/approach

This research represents a comprehensive study to determine the effects of replacing cement with different mineral admixtures in autoclaved foam concrete with a density of 300 kg/m^3. In this context, the production of autoclaved foam concrete with the use of materials such as amorphous silica, metakaolin or fly ash was targeted.

Findings

The autoclaving process increased the compressive and flexural strengths of the mineral admixed foam concrete series. Autoclaved mineral admixed foam concretes containing 5% fly ash admixture had the lowest coefficient of thermal conductivity and conformed to the required standards.

Research limitations/implications

In this study, the effect of using three different mineral admixtures in different proportions on autoclaved foam concrete was investigated. Future work aims to explore various mineral admixtures and to carry out further experiments to provide more comprehensive information on the performance and properties of the samples produced.

Practical implications

The samples obtained and the tests performed show that thermal insulation material can be produced from low density foam concrete. It is observed that this material has more potential and usability. Therefore, it can be foreseen that there may be developments in the future that will allow mass production of this material in an economical and easily applicable way.

Originality

The literature on autoclaved foam concrete is limited and studies on aerated concrete have generally been more widely carried out. However, this study can make a significant contribution to the foam concrete literature as it involves the investigation of low-density foam concrete and the effect of mineral admixtures. The results of this study can help us to better understand and develop the potential of autoclaved foam concrete by shedding light on future research.

1. Introduction

Foam concrete is considered as a relatively homogeneous lightweight cellular concrete that contains a cement-based binder, fine aggregates such as sand and foam obtained from a foaming agent to provide air recovery (Amran et al., 2015; Jalal et al., 2017). While the fact of earthquakes, which are frequently experienced in the world and in Turkey, reveals the need to reduce the load on buildings, the interest in foam concrete is increasing in the context of saving energy in heating-cooling purposes. It is extremely important in terms of sustainability that the use of coarse aggregate is not required in the production of foamed concrete and the possibility of replacing the fine aggregate partially or completely with recycled or secondary materials (Jones and McCarthy, 2006; Awang et al.,2012).

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Today, thermal insulation in buildings with housing and industrial functions is considered as a set of systems covering many branches of science, requiring precision and multi-dimensional detail work from material production to application. The most basic feature that distinguishes thermal insulation materials from each other is the heat transmission coefficients and according to the application, density, mechanical strength, fire resistance class, water vapor diffusion resistance, operating temperature, water absorption and dimensional stability are considered as other features (Papadopoulos, A.M., 2005). Petroleum-derived (EPS, XPS) and mineral-based products (such as multipore, lithapor) constitute over 70% of the insulation material sector in Turkey, but there is foreign dependency in the supply of necessary raw materials. On the other hand, the fact that some of them are petroleum derivatives leads to a situation that restricts their use and is questionable in terms of the environment. (Kilincarslan et al., 2023; Işıldar, 2023)

Although intensive industrial efforts have been made for the production of wall and floor elements from foam concrete in Turkey, it has not been successful in solving some technological problems, especially the drying shrinkage problem. Likewise, the use of different additives in foam concrete in varying proportions can cause a great variability in the mechanical and structural properties of the concrete. It is accepted that drying shrinkage is generally seen in the first 20 days after mortar pouring and occurs 4-10 times more than normal concrete depending on the aggregate type, cement ratio, water content and mineral additives in the mixture design (Amran et al., 2015). It is known that the addition of fiber reduces the drying shrinkage of foam concrete due to water retention and delays evaporation (Raj et al., 2019), and again, the increase in foam volume causes the mortar to absorb less water and reduces shrinkage (Nambiar and Ramamurthy, 2009). On the other hand, the curing method, temperature, and time significantly influence the hydration process of the concrete mix, leading to variations in solid-phase chemical processes and pore structure formation. This, in turn, shapes properties such as drying shrinkage, mechanical performance, and thermal conductivity. Wang et al. (2024) emphasized the need to adjust steam curing regimes and include certain mineral and chemical additives to prepare high-quality steam-cured foam concrete and mitigate thermal degradation caused by the steam curing process. Curing is mostly conducted in water and air, with varying temperature and relative humidity levels. Additionally, different curing materials can be used, such as cellophane coating (Falliano et al., 2018; Falliano et al., 2022), steam (Alnkaa et al., 2018), polyethylene sheeting, wet burlap, acrylic-based, water-based or bitumen-based, or coal tar epoxy (Maslehuddin et al., 2013).

Due to its inorganic nature, foam concrete offers a significant advantage over traditional polymer-based insulation materials, as it is non-combustible. If the thermal conductivity of foam concrete can be reduced while maintaining its mechanical properties, it could serve as an alternative to conventional construction materials. This study represents a comprehensive investigation into the effects of various mineral additives replacing cement in autoclaved foam concrete with a density of 300 kg/m^3. Consequently, the aim was to produce autoclaved foam concrete using materials such as amorphous silica, metakaolin, or fly ash.

2. Experimental

2.1. Materials

Within the scope of the study carried out at Süleyman Demirel University Natural and Industrial Building Materials Research and Application Center; lime was obtained from Turkey-Antalya-Dirmil, micronized quartz Turkey Aydın-Çine (Polat Mining Company), fly ash from Kütahya-Tavşanlı Çelikler Tunçbilek thermal power plant, metakaolin from Faridabad (India). Other components used are Lightcon 28 synthetic foaming agent (1.03 kg/l ± 0.02 density and pH 5.0 ± 1, Aydos Chemical Company), CEM-I-42.5 R type (Çimsa Company) cement.

2.2. Sample Production Process

In the production of foam concrete samples, apart from the control samples, cement, gypsum, micronized quartz, and three different types of mineral additives were used. In the samples with mineral additives, fly ash (FA), amorphous silica (AS), and metakaolin (MK) were substituted for cement at 5%, 10%, and 15% by weight. A slurry was prepared by adding water to the powder mixture, foam was added to the mixture from the foam generator, and the mixing process was continued for an additional 5 minutes. The prepared foam concrete was poured into plastic molds and left in the molds under laboratory conditions for 1 day before being demolded. The foam concrete samples are shown in Figure 1. Components of the control and mineral admixed foam concrete samples are given in Table 1.

Figure 1. Fresh (left) and hardened (right) foam concrete samples

Table 1. Components of the control and mineral admixed foam concrete samples

Water/ solid = 0.60								
Series	**Cement (kg)**	**Lime (kg)**	**Micronized quartz (kg)**	**Fly Ash (kg)**	**Amorphous silica (kg)**	**Metakaolin (kg)**	**Water (kg)**	**Foam (dm³)**
AFC	92.50	23.12	185	-	-	-	180	710
AFCFA-5	87,87	23.12	185	4.8	-	-	180	710
AFCFA-10	83.25	23.12	185	9.6	-	-	180	710
AFCFA-15	78.62	23.12	185	14.4	-	-	180	710
AFCMK-5	87,87	23.12	185	-	-	4.8	180	710
AFCMK-10	83.25	23.12	185	-	-	9.6	180	710
AFCMK-15	78.62	23.12	185	-	-	14.4	180	710
AFCAS-5	87,87	23.12	185	-	4.8	-	180	710
AFCAS-10	83.25	23.12	185	-	9.6	-	180	710
AFCAS-15	78.62	23.12	185	-	14.4	-	180	710

The samples, which were cured in air, were kept at 20±5 °C at 95% relative humidity for 28 days in a climate cabinet with adjustable temperature and humidity values (Figure 2).

Figure 2. Foam concrete samples cured in climate chamber

After being kept in the mold for a day, the foam concrete samples were cut and prismatic samples with dimensions of 40x40x160 mm were obtained. Three of these samples were placed in an autoclave and autoclaved at 170 °C and 14 bar pressure for 12 hours. The autoclaved device shown in Figure 3.

Figure 3. Autoclave device

The temperature and pressure regime of the autoclave device depending on the time was given in Figure 4.

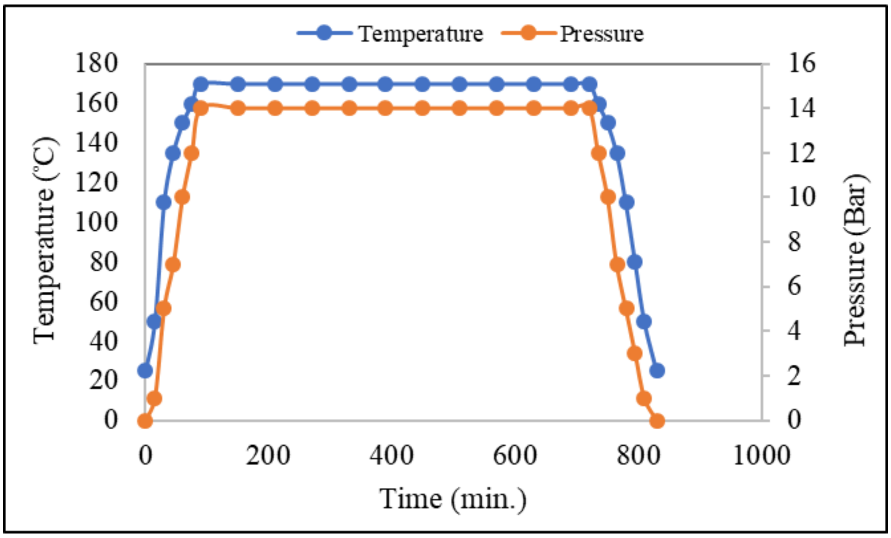

Figure 4. Time-dependent temperature and pressure regime of the autoclave device

The demolded samples were precisely sized using a diamond blade cutting device. Sample dimensions were measured with the help of an electronic caliper with an accuracy of 1/100 mm.

2.3. Methods

Densities of solid components were calculated by gas pycnometer (Micromeritics Accupyc II 1340) and their specific surface areas were calculated using the specific surface areas given in TS EN 196-6 standard (Equation 1). The apparent densities of foam concrete samples were determined aacording to TS EN 1602 standard.

$$S = \frac{K}{\rho} \times \frac{\sqrt{e^3}}{(1-e)} \times \frac{\sqrt{t}}{\sqrt{10 \times \eta_1}} \quad \text{cm}^2/\text{g} \qquad (1)$$

In equality; K is the device constant, e is the porosity of the bed, t is the time (s), ρ is the cement density (g/cm^3) and η is the viscosity (Pa.s) of the air at the test temperature (20 ± 2 °C).

Flexural strength tests of the samples were performed on 3 prism samples of 40x40x160 mm dimensions according to TS EN 196-1 standard and calculated using the relation given in Equation 2.

$$\boldsymbol{f_c} = \frac{\mathbf{1{,}5} \times \boldsymbol{F} \times \boldsymbol{l}}{\boldsymbol{b} \times \boldsymbol{h}^2} \qquad (2)$$

In equation: f_c is the flexural strength (MPa), where F is the maximum applied flexural load (N), L is the distance between the supports (mm), b and h are width and height (mm) of the samples ens under test respectively.

Compressive strength of the samples was carried out on 6 40 mm cube samples according to TS EN 196-1 standard. In the test, the loading rate of the compression tester was selected as 2400 N/s. The compressive strengths of the samples were calculated with the help of the relation given in Equation 3.

$$\boldsymbol{f_c = \frac{f}{A_c}} \qquad (3)$$

In equation: Fc is the compressive strength (MPa), F is the maximum load (N), Ac is the cross-sectional area (mm^2) of the sample in the load direction.

Ultrasonic pulse velocities (UPV) of the samples were determined according to. The sound transmission velocities (Vp) of non-autoclaved (FC) and autoclaved foam concrete (AFC) samples were calculated according to Equation 4 and the dynamic moduli of elasticity (Ed) were calculated according to Equation 5.

$$V = \frac{L}{t} \qquad (4)$$

In equality, V is the longitudinal wave velocity (km/s), L is the sample length (m), and t is the ultrasonic sound wave transmission time (s).

$$Ed = 10^5 \times V^2 \times \frac{\Delta}{g} \qquad (5)$$

In equality, Ed is the dynamic modulus of elasticity (MPa), V is the longitudinal wave velocity (km/s), Δ is the dry apparent density of samples (kg/dm^3) and g is the acceleration of gravity ($kgf\ cm/s^2$).

Capillary water absorption tests on foam concrete samples were carried out according to TS EN 1015-18 standard and capillary water absorption coefficients of the samples were calculated by using Equation 6.

$$c = 0{,}1 \times (M_2 - M_1) \qquad (6)$$

In equality, c is the capillary water absorption coefficient of the sample ($kg/m^2.\ min^{0.5}$), M_1 is the mass of the sample at the end of the 10th minute (g) and M_2 is the mass of the sample at the end of the 90th minute (g).

Thermal conductivity tests of the samples were carried out according to TS EN 12664 standard. The surfaces of the Ø 60 x 30 mm circular shaped samples were smoothed and dried at 105 °C in an oven with air circulation until reaching constant mass. The dimensions of the samples were measured with an electronic caliper with an accuracy of 1/100 mm and the masses were weighed with an electronic balance with an accuracy of 0.01 g. Then, the coefficient of thermal conductivity (λ10, dry) was measured using a Lasercomp Fox 50 instrument with the difference between hot and dry temperatures and cold plates (ΔT) was 10 K.

The mineralogical properties of the hydration products formed at the end of curing in foam concrete samples were determined by XRD device at Süleyman Demirel University Innovative Technologies Research Center. The analysis findings of cement (Çimsa Company), micronized quartz (Polat Mining Company), fly ash and synthetic foaming agent (Aydos Chemical Company) used in the study were obtained from the manufacturers. Metakaolin and slaked lime were analyzed at Afyon Kocatepe University Natural Stone Laboratory. Chemical components of amorphous silica were taken from the literature Davraz and Gündüz (2005).

3. Results And Discussion

3.1. Features of Foam Concrete Components

Specific gravity and specific surface area values of binders and mineral additives used in foam concrete production were given in Table 2. Among the mineral additives used in the study, fly ash had the lowest density (2.05 g/cm^3) and metakaolin had the highest density (2.72 g/cm^3). Among the binders, slaked lime has a specific surface area about 4 times higher than Portland cement. When the specific surface area values of mineral additives were analyzed, fly ash exhibited the lowest value (3305 cm^2/g) and metakaolin the highest value (16661 cm^2/g).

Table 2. Specific gravity and specific surface areas of foam concrete components

Components	Specific Gravity (g/cm³)	Specific Surface Area (cm²/g)
Cement	3.123	3772
Lime	2.307	12188
Micronized quartz	2.640	4167
Fly ash	2.049	3305
Metakaolin	2.724	16661
Amorphous silica	2.446	11399

Chemical compositions of components were given in Table 3. Among the mineral additives, amorphous silica (90.84%) had the highest silica content and metakaolin (43.97%) had the highest aluminum tri oxide content.

Table 3. Chemical compositions of foam concrete components

Chemical components	Mikronized quartz	Cement	Lime	Amorphous silica	Metakaolin	Fly ash
SiO_2	98.50	18.90	0.13	90.84	52.89	58.07
Al_2O_3	0.60	5.15	0.05	2.66	43.97	20.04
Fe_2O_3	0.06	3.36	0.05	0.15	0.49	8.96
TiO_2	0.04	0.00	0.00	1.24	1.58	0.00
CaO	0.00	63.59	70.42	0.18	0.35	2.69
MgO	0.00	1.57	0.39	0.00	0.03	3.94
SO_3	0.00	2.65	0.07	0.06	0.00	0.42
Na_2O	0.10	0.40	0.04	1.12	0.08	1.19
K_2O	0.10	0.77	0.01	0.09	0.09	1.66

3.2. Physical Properties of Autoclaved Foam Concrete

3.2.1. Apparent Density

The apparent densities of autoclaved foam concrete (AFC_s) samples with mineral additives samples were given in Table 4.

Table 4. Avarage apparent densities of foam concrete samples

AFC_s	Apparent Density (kg/m³)
AFC	309
AFCFA-5	285
AFCFA-10	291
AFCFA-15	280
AFCMK-5	314
AFCMK-10	301
AFCMK-15	316
AFCAS-5	305
AFCAS-10	301
AFCAS-15	305

Depending on the type of mineral admixture, there are minor differences in the density values of the autoclaved foam concrete samples. The decrease in density of AFCFA samples was attributed to the low specific gravity of fly ash (2.05 g/cm³). In addition, the partial increase in density of AFCFA samples was attributed to the relatively high specific gravity of metakaolin (2.72 g/cm^3). Although the slight differences between the densities of foam concrete were due to the types of mineral admixtures, it is theoretically possible for a density difference to occur within the same mineral additive type depending on the selected admixture ratios. Therefore, it would be a more accurate approach to evaluate the findings of this study in terms of acceptable levels of consistency and differences between fresh density, designed density, and dry density, as some researchers have pointed out. (He et al., 2019; Peng et al., 2022; Yuan et al., 2022).

3.2.2. Capillary Water Absorption Coefficient

Capillary water absorption coefficients increased for all mineral additives depending on the usage rate (Figure 5). The replacement of fly ash, one of the mineral additives, with cement at the rates of 5 and 10% decreased the capillary water absorption coefficient compared to the control. It has been evaluated that the efficiency of amorphous silica is lower than other mineral additives in terms of dose-capillary water absorption coefficient differences for mineral additive types. The capillary water absorption coefficients increased from 1.32 to 1.46, from 0.7 to 1.0 for fly ash, and from 1.0 to 1.6 for metakaolin, depending on the amorphous silica doses. As a matter of fact, It has been reported that fly ash exhibits a variable (increasing and decreasing) characteristic within the scope of the effects of curing regime (7 and 28-day standard curing and autoclave curing) and water curing time on water absorption of foam concretes using different foam content (0, 31 and 47%) and some mineral admixtures (fly ash and silica fume- 0, 10 and 20 % cement substitutes) (Gökçe et al., 2019).

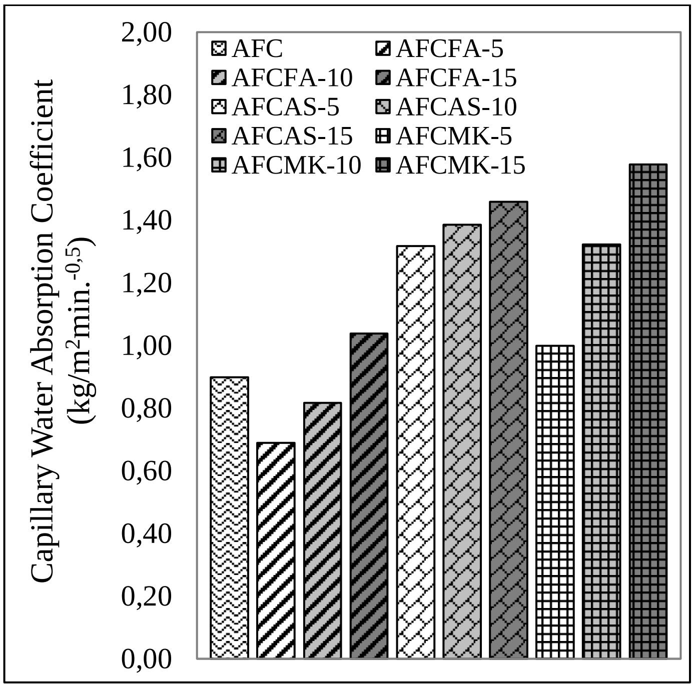

Figure 5. Capillary water absorption coefficients in mineral-added AFCs

3.3. Mechanical Properties

3.3.1. Compressive and Flexural Strengths

The compressive strengths of different mineral admixtures across all usage rates varied between 0.40-1.15 MPa (Figure 6). Fly ash compressive strengths are lower than control, regardless of usage rate. The highest compressive strengths are specific to metakaolin additives. The increase in the usage rate of all mineral additives led to a decrease in the compressive strength. However, the contribution-decrease ratio relationship differs in this change. The compressive strengths, where there is not much difference for the 5% and 10% admixtures of fly ash, are very close to each other for 10% and 15% metakaolin admixtures this time. The flexural strengths of autoclaved mineral-added foam concretes were found to be between 0.21-0.4 MPa (Figure 6). The flexural strengths for all mineral additives and proportions are higher than the control, except for fly ash and 15% of amorphous silica. The activities of the mineral additives were shaped as fly ash<amorphous silica<metakaolin. Although there were minor differences for the 5% and 10% ratios of all mineral additives, the main change was realized for the 15% ratio. The effects of fly ash, amorphous silica and metakaolin additives substituted with cement in this study on compressive and flexural strength are in agreement with the results of previous studies. As a matter of fact, it was stated that SEM data of river sediment and

expanded polystyrene added low carbon ultralight foam concrete confirmed the compatibility between expanded polystyrene particles and alkali-activated metakaolin-river sediment paste, and that the strength decreased with the increase of the said materials in the composition (Shi et al., 2021). Again, in autoclaved cellular concrete using 75% kaolinite clay, 25% Portland cement and 0.2-8% foaming agent (aluminum powder) by weight, lower mechanical strength (maximum 0.62 MPa) was associated with higher aluminum content (Gugluelmi et al., 2010). Kim et al. (2017) reported that as the replacement ratio of waste concrete powder with silica powder, which acts as a SiO_2 source and filler, increases during autoclave curing, the strength decreases, but meets the required strength requirement of 14 MPa for the 50% level.

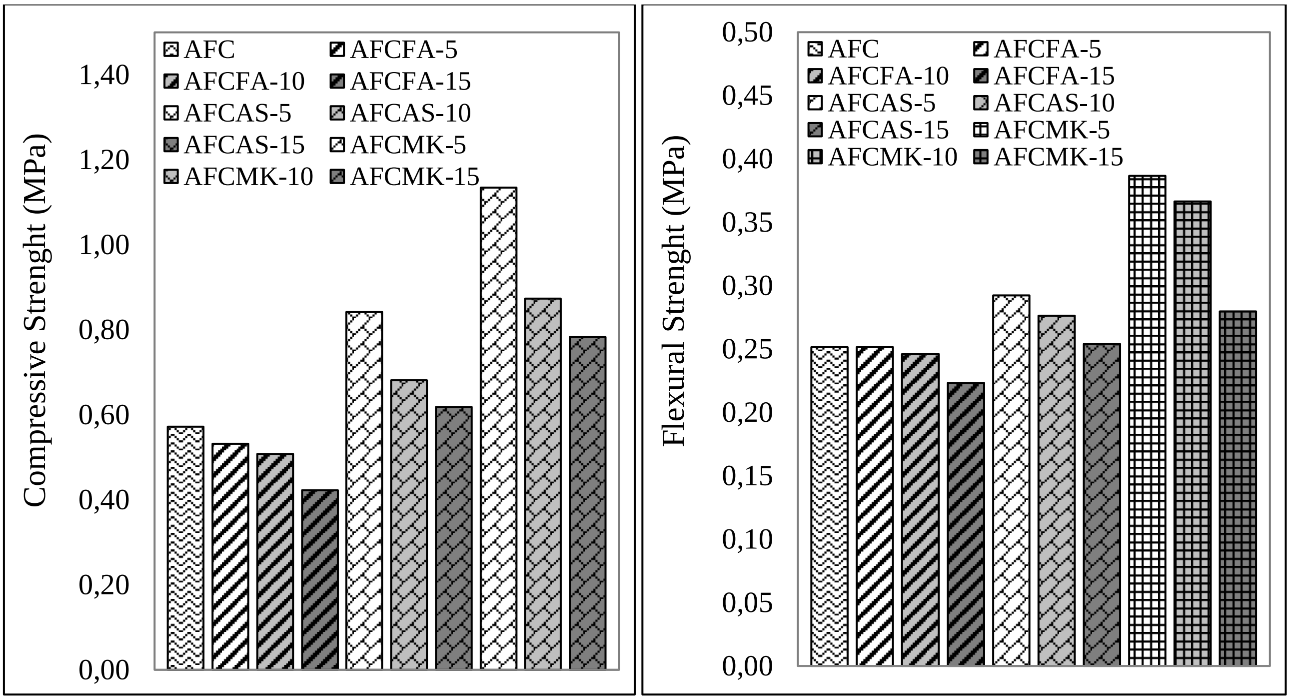

Figure 6. Compressive and flexural strengths of mineral-added AFCs

3.3.2. Ultrasonic Pulse Velocity and Dynamic Elasticity Modulus

The dynamic elasticity modulus in autoclaved mineral-added foam concretes varied between 0.344-0.369 GPa for fly ash, 0.457- 0.502 GPa for amorphous silica, and 0.495- 0.624 GPa for metakaolin. High coefficients of determination (R^2= 0.8445- 0.9958) were obtained for dynamic elasticity modulus -compressive strength relationships (Figure 7.). It has been observed that ultrasonic pulse transmission velocity values, which vary between 1.10-1.13 km/s for fly ash, 1.21-1.27 km/s for amorphous silica, and 1.24-1.40 km/s for metakaolin, increase with the increase in compressive strength (Figure 7). The biggest difference is between autoclaved foam concrete with 5% fly ash and 15% metakaolin. In a study by Gencel et al. (2021), 25, 50, 75 and 100 percent of sand was replaced with recycled concrete aggregate. It was determined that the recycled concrete aggregate increased the apparent porosity and caused higher water absorption than the sum of the increases obtained for the other utilization rates due to the higher capillary microcrack density for the 100% replacement rate. In addition, the recycled concrete aggregate decreased the dynamic elasticity modulus, ultrasonic pulse velocity and thermal conductivity of foam concrete.

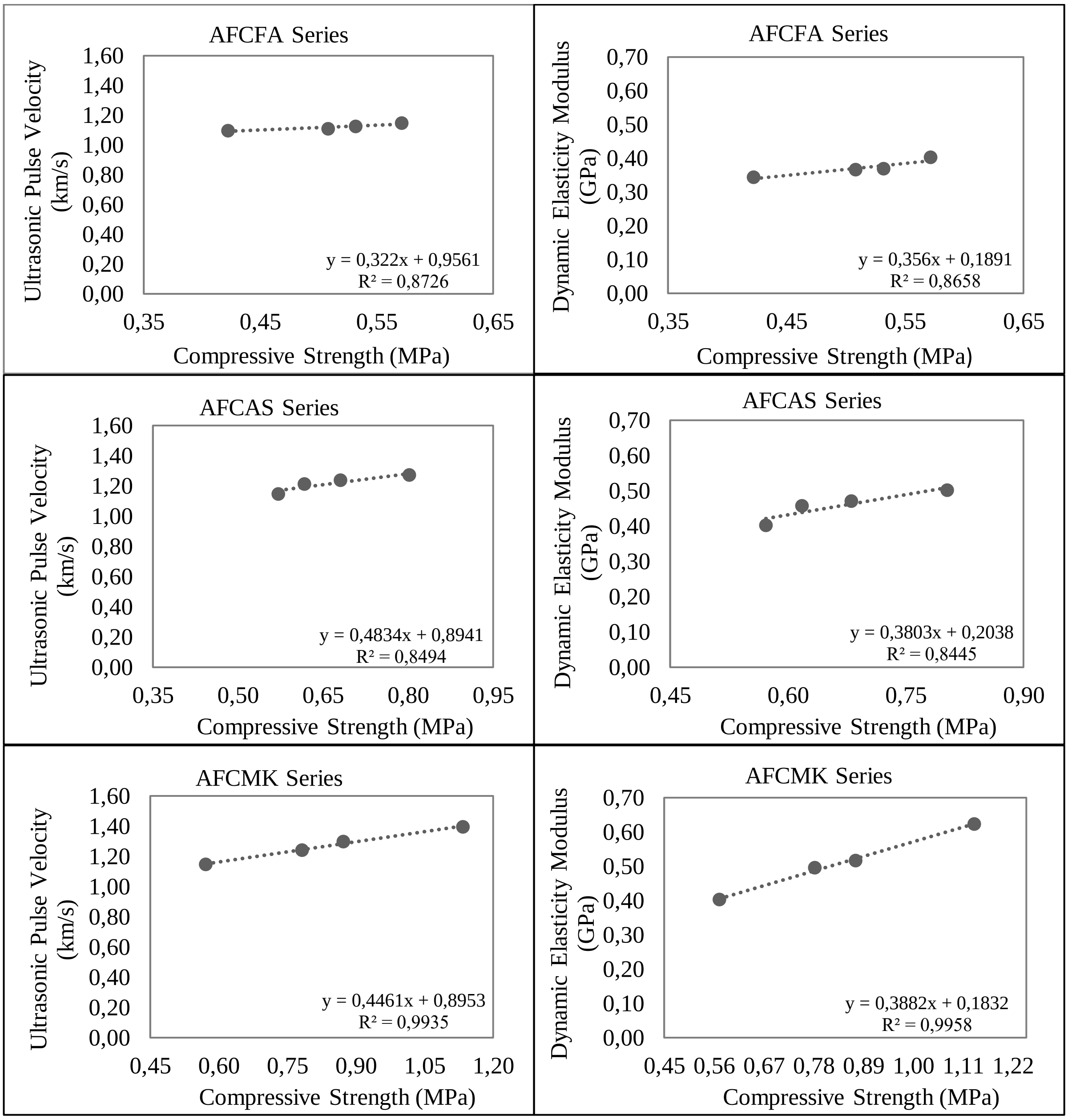

Figure 7. Dynamic elasticity modulus-compressive strength and ultrasonic pulse velocity-compressive strength relationships

3.4. Thermal Properties

The thermal conductivity coefficients for foam concrete samples using different types of mineral admixtures were given in Figure 8. The thermal conductivity coefficients (k) of the non-autoclaved foam concrete sample were approximately 15% higher than the the values of autoclaved foam concrete samples. The thermal conductivity coefficients of AFCFA samples (avg 0,059 W/mK) are lower than AFC values (avg 0,063 W/mK). Among the samples produced in this study, only FA ans AS mineral doped AFC met ISO and CEN standards (<0.065 W/mK). The thermal conductivity coefficients (avg.) of the AFC samples to which amorphous silica and metakaolin were added were measured as 0,063 W/mK and 0,071 W/mK, respectively. Mashkin et al. (2018) mentioned that the lowest density and thermal conductivity coefficient values of some mineral admixtures (wollastonite and diopside) in non-autoclaved concrete are specific to the minimum admixture ratios and also the decisive role of the mineral admixture type.

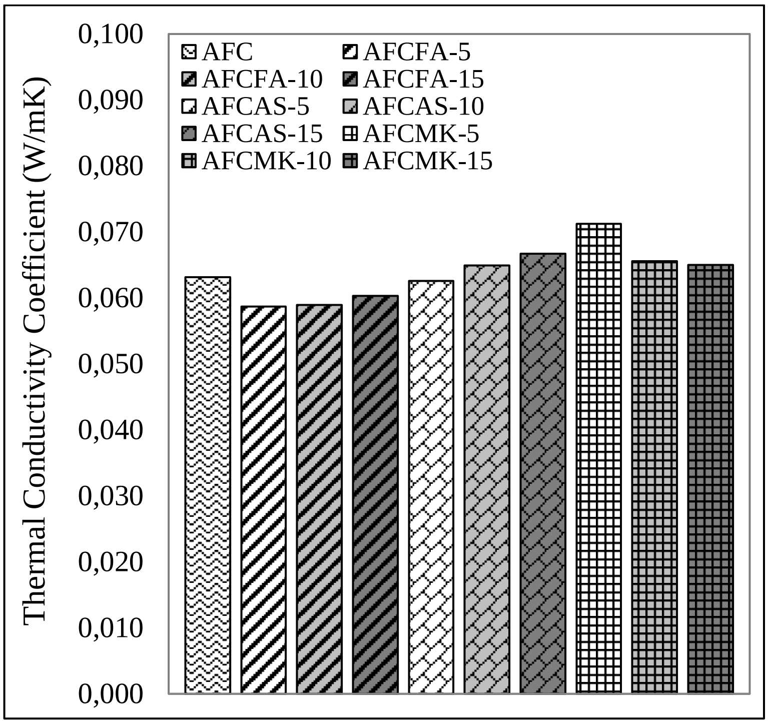

Figure 8. Thermal conductivity coefficients of AFC series with autoclaved mineral additives

3.5. Microstructure Properties

It has been evaluated that the differences in quartz peak densities for mineral additives are not really significant and this may be related to the differences in silica content due to the Si ratios of tobermorite and anorthite minerals. In some studies, it is observed that SEM images and XRD data provide a relatively qualitative evaluation (Abd Elrahman et al., 2021, Alnahhal et al., 2022). Compared to FC samples, the ratio of tobermorite increased in AFC samples (12.9% and 17.7% respectively) and the ratio of Portlandite decreased (11.3% and 4.8% respectively). Calcite mineral is considered to originate from unburnt $CaCO_3$ in slaked lime. The highest tobermorite ratio was observed in AFC samples containing AS (24.6%). The samples of AFCFA, AFCAS and AFCMK were found to have a decrease in SiO_2 ratio compared to AFC samples. This decrease in SiO_2 content indicates that reactive SiO_2 in the composition of micronized quartz and mineral additives reacts with $Ca(OH)_2$ to form tobermorite (Figure 9).

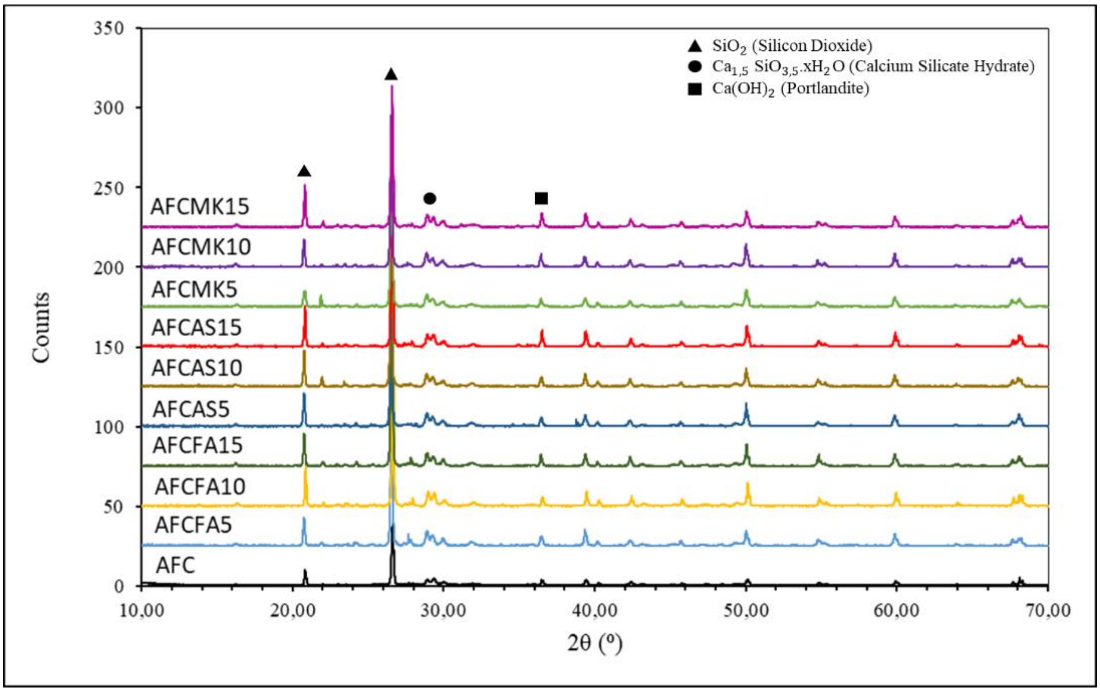

Figure 9. XRD analysis data of autoclaved foam concrete

4. Conclusions

In this research, the effect of autoclaving on the physical, thermal, and mechanical properties of foam concrete samples with a density of 300 kg/m^3 was investigated. Additionally, the effects of mineral additives on AFC (Autoclaved Foam Concrete) samples were also studied.

The thermal conductivity coefficients of both mineral-added and non-added AFC samples (except AFCMK) were ≤ 0.065 W/mK. Compared to FC samples, autoclaving reduced the thermal conductivity coefficients of the samples by approximately 15%. Fly ash (FA) was found to be the most effective mineral additive in reducing thermal conductivity, while metakaolin (MK) increased thermal conductivity.

The aim of this study was to improve the mechanical, physical, and thermal properties of mineral-added AFC samples. The addition of fly ash did not significantly affect the mechanical strengths, while metakaolin showed the highest increase in strength (1.14 MPa). Overall, the autoclaving process reduced the capillary water absorption values in foam concrete (32%). However, due to its colloidal structure, the addition of amorphous silica increased the capillary water absorption values in AFC samples.

The mineralogical properties of the samples were examined using XRD analysis. According to the XRD analysis results, autoclaving reduced the amount of portlandite, a hydration product, in the foam concrete and increased the amount of tobermorite. The increase in mechanical strength in the AFC samples was associated with this finding. The autoclaving process did not have a significant effect on pore sizes.

Foam concrete, with its inorganic structure, has a significant advantage over traditional polymer-based insulation materials, as it is non-flammable. If the mechanical properties of foam concrete are maintained while reducing the thermal conductivity to some extent, it can become an alternative to traditional construction materials. Further research can be conducted by producing foam concrete samples with different mineral additive ratios and autoclaving them under various pressure and temperature levels to obtain different physical, thermal, and mechanical results.

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Conflict of Interest

No conflict of interest was declared by the authors.

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