CUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCE

MSc THESIS

Yasir Nussrat SHUKUR SHUKUR

THERMAL PROCESSING OF CA-BENTONITE ORE BY CALCINATION METHOD TO USE IN GEOPOLYMER CONCRETE WITH ADDITIVE MATERIALS

DEPARTMENT OF MINING ENGINEERING

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We certify that the thesis titled above was reviewed and approved for the award of degree of the Master of Science by the board of jury on 08/08/2022.

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ÖZ

YÜKSEK LİSANS TEZİ

CA-BENTONİTİN ISIL İŞLEM İLE KALSİNASYONU VE KATKI MALZEMELERİ İLE HAZIRLANAN GEOPOLİMER BETONDA KULLANIMININ ARAŞTIRILMASI

Yasir Nussrat SHUKUR SHUKUR

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Bu çalışmada, geopolimer beton (GPC) üretiminde ince agrega olarak uçucu kül ile kısmi ikame için kalsine kalsiyum bentonit kili kullanılmıştır. Ayrıca, metalürji fabrikalarından çıkan artıkların geri dönüştürülmesi için, ferrokrom cürufu kaba agrega olarak kullanıldı ve hafif geopolimer beton üretiminde ise uçucu kül ile birlikte 3 mm, 5 mm ve 7 mm boyutlarında genleşmiş polistiren (EPS) kullanılmıştır. Bazik aktivatör olarak NaOH ve Na_2SiO_3 kullanılmıştır. NaOH konsantrasyonu 14 M'de ve Na_2SiO_3 konsantrasyonu 5 M'de sabitlendi. En iyi sonuç veren oranların değerlendirilmesi için tek eksenli basınç dayanımı (UCS), nokta yük indeksi (PL), ses hızı (PSS) ve shore sertliği (SH) testleri deneysel numuneler üzerinde ölçülmüştür. Deneyler %5 kalsine kalsiyum bentonit (CCB), %5 ferrokrom cürufu (SG) ve uçucu kül (FA) karıştırılarak gerçekleştirilmiştir. GPC'nin ortalama özellikleri aşadaki gibidir 28 gün sonra test edilen; 1792 kg/m^3 birim hacim ağırlık, 51.33 MP tek eksenli mukavemet, 14.05 KN nokta yük dayanımı, 6.41 km/s ses hızı ve sertlik 63.17mm olarak elde edilmiştir. EPS'li hafif betonun birim hacim ağırlık (1592 - 1264) kg/m^3.

Anahtar kelimeler: Kalsiyum Bentonit, Kalsinasyon, Geopolimer, Uçucu kül, Cüruf, Alkali aktivatörler, Genişletilmiş Polistiren.

ABSTRACT

MSc. THESIS

THERMAL PROCESSING OF CA-BENTONITE ORE BY CALCINATION METHOD TO USE IN GEOPOLYMER CONCRETE WITH ADDITIVE MATERIALS

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In this study, a calcined calcium bentonite clay was used as a partial substitute with fly ash as fine aggregate in the production of geopolymer concrete (GPC). Besides, to recycle the tailings from metallurgic factories, ferrochrome slag was used as coarse aggregate and fly ash was used to production of lightweight geopolymer concrete with expanded polystyrene (EPS) with a size of 3mm, 5mm, and 7mm. NaOH and Na_2SiO_3 were used as basic activators. The NaOH concentration was fixed at 14 M and the Na_2SiO_3 concentration was fixed at 5 M. Uniaxial compressive strength (UCS), point load strength (PL), sonic speed (PSS), and shore hardness (SH) were measured on experimental samples to evaluate the ratios that to obtain the best results. The experiments were carried out by mixing 5% calcined calcium bentonite (CCB), 5% ferrochrome slag (SG), and fly ash (FA). The average properties of GPC tested after 28 days are as follow; bulk density was obtained at 1792 kg/m^3, with a uniaxial strength of 51.33 MP, a point load resistance of 14.05 KN, and a speed of sound of 6.41 km/s, and a shore hardness of 63.17 mm. The bulk density of lightweight concrete with EPS was (1592 - 1264) kg/m^3.

Key words: Calcium Bentonite, Calcination, Geopolymer, Fly ash, Slag, Alkaline activators, Expanded Polystyrene.

EXTENDED SUMMARY

The cement industry faces many challenges, the most important of which is its consumption of large quantities of limestone. araştırmacılar, jeopolimer beton adını verdikleri betonda çimentoya alternatifler bulmak için yola çıktılar. Geopolymer concrete is based on natural pozzolan materials that contain a high percentage of silica and alumina like alkali activator, coal factory residues, iron slag, and others. Geopolymer concrete has many advantages, the most important of which are its high resistance to fire and corrosion, resistance to chemical acids, its lightweight, and environmental advantages resulting from the usage of some wastes, such as fly ash and blast furnace slag. Lightweight geopolymer concrete is a modern building material obtained by replacing ordinary aggregate with lightweight aggregate. Calcium bentonite clay, which is rich in silica and alumina, Initially, calcium bentonite ore was analyzed by Manipal Panalytical X-ray fluorescence XRF device to know the chemical composition of the materials, XRD analysis to know the mineral composition of the materials; TGA/DTA analysis to know the thermogravimetric analysis, thermal differential analysis and FTIR analysis to analyze the chemical composition; EDX analysis to determine the chemical composition; and analysis SEM to take a picture of the materials showing the internal composition. Calcined calcium bentonite clay is obtained by processing calcium bentonite ore taken from the Yeni Ozdemir, Iskenderun mine in Turkey. Calcium bentonite clay was prepared by a crushing and grinding process and purified from quartz by a sieving process. NaOH and Na_2SiO_3 were used as basic activators in the production of geopolymer concrete. An experimental Box-Behnken design was applied to determine the effective parameters. NaOH concentration was fixed at 14 M and Na_2SiO_3 concentration was fixed at 5 M. Fly ash from the Sugozu thermal power station in the district of Adana served as the study's main component of the geopolymer concrete. Ferrochrome slag from company in the Elazig region will be used as heavy aggregates. (UCS) test, (PL) test, (PSS) test, and (SH) test were

performed on geopolymer concrete to evaluate the ratios that give the best properties of geopolymer concrete. An alkaline activator was prepared using tap water and a mixing device. The concrete mixture is poured into molds with dimensions of 5 cm * 5 cm * 5 cm. In the experiments using fly ash and alkali-activated only, experiments were designed based on factors affecting the properties of geopolymer concrete. The strength of the concrete blocks was increased when the ratio of 1/1 of NaOH and Na_2SiO_3 was in the alkaline activator solution. The effect of heat curing time on the strength of geopolymer concrete was studied. It was observed that 28 days of curing achieved the highest strength of geopolymer concrete. The best properties of geopolymer concrete were obtained when adding 5% calcined calcium bentonite, 5% ferrochrome slag, and 90% fly ash with (UCS) of 51.33 MPa, (PL) of 14.05 KN, (PSS) of 6.41 km/s, (BD) of 1792 kg/m^3, and (SH) of 63.17 mm.

The second part of this study investigated the production of lightweight geopolymer concrete by replacing fly ash with polystyrene (EPS). Accumulated polystyrene waste poses a threat to the environment in abundance and poses a threat to the world. This waste can be recycled by used in many fields with the preservation of natural resources and one of them is the production of lightweight concrete. In this study, polystyrene EPS is used as lightweight aggregate after the preparation of particle sizes (3mm, 5mm, and 7mm). The bulk density of lightweight concrete was obtained (1592 – 1264) kg/m^3.

GENİŞLETİLMİŞ ÖZET

Çimento endüstrisi en önemlisi büyük miktarlarda kireçtaşı tüketimi olan birçok zorlukla karşı karşıyadır. Araştırmacılar geopolimer beton adını verdikleri betonda çimentoya alternatifler bulmak için harekete geçtiler. Geopolimer beton, yüksek oranda silika, alümina, alkali aktivatör, kömür fabrikası artıkları, demir cürufu vb. içeren doğal puzolanik malzemelere dayanmaktadır. Geopolimer betonun birçok avantajı vardır, en önemlileri yangına ve korozyona karşı yüksek direnci, kimyasal asitlere karşı direnci, hafifliği ve uçucu kül ve yüksek fırın cürufu gibi bazı atıkların kullanılmasından kaynaklanan çevresel avantajlardır. Hafif geopolimer beton, sıradan agrega hafif agrega ile değiştirilerek elde edilen modern bir yapı malzemesidir. Silika ve alüminaca zengin kalsiyum bentonit kili. Kalsiyum bentonit cevheri, malzemelerin kimyasal bileşimini bilmek için Manipal Panalytical X-ışını floresan XRF cihazı ile analiz edildi, malzemelerin mineral bileşimini bilmek için XRD analizi; Termogravimetrik analizi bilmek için TGA/DTA analizi, kimyasal bileşimi analiz etmek için termal diferansiyel analiz ve FTIR analizi; Kimyasal bileşimi belirlemek için EDX analizi; ve iç bileşimi gösteren malzemelerin bir resmini çekmek için SEM analizi. Kalsine kalsiyum bentonit kili Türkiye İskenderundaki Yeni Özdemir den alınan kalsiyum bentonit cevherinin işlenmesiyle elde edilmiştir. Kalsiyum bentonit kili, kırma ve öğütme işlemi ile hazırlanmış ve eleme işlemi ile kuvarstan saflaştırılmıştır. Geopolimer beton üretiminde temel aktivatör olarak NaOH ve Na_2SiO_3 kullanılmıştır. Etkili parametreleri belirlemek için deneysel Box-Behnken tasarımı uygulandı. Na_2SiO_3 konsantrasyonu 14 M'de ve NaOH konsantrasyonu 5 M'de sabitlendi. Bu çalışmada Adana'nın ilçesindeki Sugözü termik santralinden çıkan uçucu kül, geopolimer betonunun ana bileşeni olarak görev yaptı. Elazığ bölgesindeki Demir Çelik Sanayi Şirketi'nden gelen ferrokrom cürufu ağır agrega olarak kullanılacak. Geopolimer betonun en iyi özelliklerini veren oranları değerlendirmek için geopolimer beton üzerinde tek eksenli basınç dayanımı, nokta yük dayanımı, sonik hız ve sertlik deneyleri

gerçekleştirilmiştir. Musluk suyu ve bir karıştırma cihazı kullanılarak bir alkalin aktivatör hazırlandı. Alkali aktivatör, deneyler yapılmadan önce 24 saat bırakıldı. Beton karışımı 5 cm * 5 cm * 5 cm boyutlarındaki kalıplara döküldü. Yalnızca uçucu kül ve alkali ile aktifleştirilmiş deneylerde, geopolimer betonun özelliklerini etkileyen faktörler temel alınarak deneyler tasarlanmıştır. Alkali aktivatör solüsyonunda 1/1 NaOH ve Na_2SiO_3 oranı bulunduğunda üretilen beton blokların mukavemeti artmıştır. Isıl işlem ile kür süresinin geopolimer betonun mukavemeti üzerindeki etkisi incelenmiştir. 28 günlük kürlenmenin geopolimer betonun en yüksek mukavemetine ulaştığı gözlemlenmiştir. Geopolimer betonun en iyi özellikleri %5 kalsiyum bentonit ve %5 ferrokrom cürufu eklendiğinde, tek eksenli dayanım 51.33 MPa, nokta yükleme direnci 14.05 KN, ses hızı 6.41 km/s, birim hacim ağırlığı 1792 kg/m^3 ve sertlik 63.17mm olarak elde edilmiştir.

Bu çalışmanın ikinci kısmı, uçucu külü polistiren EPS ile değiştirerek hafif geopolimer beton üretimini araştırdı. Biriken polistiren atıklar, çevre için ciddi miktarda tehdit oluşturmakta ve dünya için tehdit oluşturmaktadır. Bu atıklar geri dönüştürülebilir ve birçok alanda kullanılabilir. Bu çalışmada polistiren EPS eleklerden geçirilerek (3mm, 5mm ve 7mm) boyutlarının elde edilmesi işleminden sonra hafif bir agrega olarak kullanılmıştır. Böylece (1592-1264) kg/m^3 yoğunluğa sahip hafif bir beton üretilmiştir.

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CONTENTS **PAGE**

LIST OF TABLES **PAGE**

LIST OF FIGURES **PAGE**

LISTE OF ABBREVIATIONS

BD : Bulk density
CB : Calcium Bentonite
CCB : Calcined Calcium Bentonite
DOE : Design of Experiment
DTA : Differential thermal analysis
EDS : Energy dispersive X-ray spectroscopy
EPS : Expanded Polystyrene
FA : Fly Ash
FTIR : Fourier-transform infrared spectroscopy
GPC : Geopolymer Concrete
PL : Point Load Strength
PSS : Pundit Sonic Speed
SEM : Scanning Electron Microscopy
SG : Slag
SH : Shore Hardness
TGA : Thermogravimetric analysis
UCS : Uniaxial Compressive Strength
XRD : X-Ray Diffraction Spectrometer
XRF : X-ray fluorescence Spectrometer

1. INTRODUCTION

Due to the significant increase in population growth, the demand for building materials is increasing, and cement is an important building material. The cement industry is going through several challenges, the most important of which are the large consumption of energy and the consumption of large quantities of limestone, and carbon dioxide emissions, so that globally, cement production accounts for about 5–7% of CO_2 emissions (Mclellan et al, 2011).

The researchers resorted to searching for alternative materials to replace the cement used in ordinary concrete, which is called geopolymer concrete. Geopolymer concrete is a modern concrete that was named by the scientist Davidovits in 1978, and it consists of many inorganic materials. Many geopolymers are based on industrial waste and natural materials. Industrial wastes, for example, fly ash and slag are high in silicon and aluminum. An alkaline activating solution is prepared, and aluminum taken from industrial waste is dissolved and activated, then polymerized, and then solidified. Natural materials such as metakaolinite and some types of clay must be thermally activated to produce pozzolan (Aleem and Arumairaj et al, 2012).

Fly ash is a significant component of geopolymer concrete since it can replace 15–35% of the cement. There are serious health problems associated with dealing with fly ash because it contains toxic substances such as lead and cadmium. There is a need to search for an alternative to fly ash that could play a significant role in geopolymer concrete in the future. Calcined clay is a suitable alternative to fly ash, as kaolin clay is the most commonly used clay, containing 2:1 A layer of silicate is needed, but this clay is expensive, so there is a need to look for a cheaper alternative to kaolin (Haq et al, 2021).

Geopolymer concrete has many advantages, the most important of which are its high resistance to fire and corrosion, resistance to chemical acids, its lightweight, and environmental advantages result from the usage of various wastes, such as fly

ash and blast furnace slag. NaOH and Na_2SiO_3 are used as activators in geopolymer concrete based on fly ash, slag, and metakaolin. Metakaolin has more chemical activity and activity than fly ash. Fly ash is used as the main starting material and metakaolin as a supplement in the concrete industry, and various industrial waste and raw materials are cheap and available in abundance. In geopolymer concrete, heat treatment helps to speed up the crystallization process (Hu et al, 2009).

Pozzolan, which is alumina and siliceous materials with cementitious properties, chemically reacts with activators to produce an adhesive. Pozzolans come in many different forms, including industrial pozzolans like fly ash and natural pozzolans like kaolin clay or bentonite. The sustainability of geopolymer concrete can be improved by using natural pozzolan materials as a cement alternative and improving the mechanical properties of concrete (Al-Hammood et al, 2021).

Modern construction tends to be lightweight concrete in various applications, such as tall buildings, marine structures, and long-span bridges. Lightweight aggregates are classified into two types: the first type is natural, such as pumice and volcanic ash, and the second type is synthetic, such as perlite, clay, and fly ash (Kaya and Kar, 2016).

EPS is a type of lightweight industrial material that is an insulating material and is used in many industrial applications throughout the world. After its first usage, it is difficult to get rid of it by natural means, so researchers resort to recycling it and using it in concrete as a lightweight aggregate (Benazzouk et al, 2008).

This research objective is the first to investigate the use of calcined calcium bentonite and slag as a partial substitute for fly ash in geopolymer concrete and its effect on the mechanical properties of concrete and the second to study the use of EPS as a lightweight aggregate and its effect on the properties of geopolymer concrete.

1.1. Bentonite

Bentonite is an abundant clay mineral that is heterogeneous in its composition. The term bentonite clay rock is used for the name of the mineral smectite, which is composed of calcium, sodium, magnesium, aluminum silicate, and iron. Any hue of bentonite, including the brown and olive green in (Figure 1.1), as well as blue-gray and occasionally white, can be utilized for applications that call for white (Murray et al, 2007).

Bentonite is defined as a soft, porous, easily shaped, light-colored rock, predominantly in a colloidal silica structure, consisting of clay minerals with very small crystals (mainly montmorillonite) formed by the chemical weathering and weathering of aluminum and magnesium-rich volcanic ash, tuff, and lava. It has a soft, plastic, porous, light-colored structure. It has an empirical formula, solitary $Na_{0,2}$,$Ca_{0,1}$,$Al_2Si_4O_{10}(OH)_2(H_2O)_{10}$ montmorillonite crystals have extremely fine, granular, and irregular outlines. A montmorillonite crystal usually consists of 15-20 silicate units. The thixotropy property of montmorillonite is its ability to become a gel when in contact with water and a liquid when shaken (Karnland et al, 2006).

Bentonite clay ore mainly consists of minerals, mostly smectites. Bentonite clay may contain different minerals such as kaolinite, montmorillonite, illite, and various types in addition to non-clay minerals such as iron, quartz, feldspar, gypsum, and others. The ability of smectite minerals to expand as a result of water absorption is a unique feature. Bentonite, in most situations, contains of the smectite mineral montmorillonite. As a result, bentonite can be defined as clay that is primarily composed of the mineral montmorillonite (Al-Hammood et al, 2021).

Montmorillonite is a clay mineral that has many distinctive properties, such as swelling and a unique ability to absorb. It is the important, active, and main ingredient in bentonite clay. Because of these properties, montmorillonite is widely used in industrial applications (Park, 2016).

An important feature of Na-bentonite is that it swells in water and forms a gel-like structure. For clay to be classified as Na-bentonite, it must swell at least five

times its size. Good quality Na-bentonite can swell 10 to 20 times its size, and very good bentonite can swell 25 or even 30 times. The physical properties of bentonite change with the amount of water added to it, so it can be used in many fields and industries (Clelyi et al, 2013).

Figure 1.1. Raw and ground bentonite (Benkar, 2017)

1.1.1. Bentonite Ore Deposits

1.1.1.1. World Bentonite Deposits

The world's most important and high quality bentonite deposits are mainly found in countries such as: Wyoming (USA), Tokat (Turkey), Ponza and Sardinia (Italy), Milos (Greece), Bavaria (Germany) and Almeria (Spain). Bentonite deposits in the world have very large reserve volumes. Reserve amounts prepared based on the United States Geological Survey (USGS) information are given in the (Table 1.1).

Table 1.1. Distribution of world ore bentonite reserves by country (Kok, 2017).

Country	Reserve (Million Tons)
USA	4500
Chinese	2400
India	592
Mexican	410
Turkey	350
Czech Republic	312
Azerbaijan	250
Russia	172
Ethiopia	171
Denmark	121
Germany	105
Spain	101
Romania	82
Brazil	77

1.1.1.2. Turkey Bentonite Ore Deposits

Turkey is among the leading countries in the world with its bentonite deposits given in (Figure 1.2). A reserve volume of approximately 350 million tons. The main rocks of bentonite reserves in Turkey are mostly composed of tuff, andesite, and agglomerates, which are glassy in structure. Mineralogically, it consists of montmorillonite as the main mineral, and the impurities are illite, kaolin, formed by minerals such as feldspar, quartz, cristobalite, calcite, and dolomite.

Figure 1.2. Turkey bentonite reserves map (Mta, 2017).

1.1.2. Bentonite's Physical and Chemical Properties

Bentonite comes in a wide range of colors and shapes. A few authors described the color as being brownish-green, and the bentonite used in research as greenish-gray. Bentonite's physical and chemical properties as reported by various authors, almost all of the authors reported a range of values. The reason for this attribute is that the source's location may change. Bentonite's physical and chemical properties used in various research works Shows in (Table 1.2) and (Table 1.3), (Reddy and Rao, 2019).

Table 1.2. A review of Bentonite's Physical properties (Reddy and Rao, 2019).

Specific Gravity	2.81	2.62	2.43	2.78
Average particle size μm	4.74	43	52	4.31
Blains fineness (cm^2/gm)	4800	3000	2688	4800

Table 1.3. Bentonite's chemical properties used in various research works.

Property						
(SiO_2) Silicon dioxide	54.54	49.43	64	49.62	52.11	51.1
(Al_2O_3)Aluminum Oxide	20.18	19.6	14	21.12	13.42	16.82
(Fe_2O_3) Ferric Oxide	8.61	6.21	3.1	3.24	7.57	7.64
(MgO) Megnesium Oxide	4.22	1.6	6.4	12.55	2.63	7.56
(CaO) Calcium Oxide	7.27	7.44	2.65	3.58	12.01	6.61
(Na2O) Sodium Oxide	1.26	0.86	0.11	0.43	-	0.28
(K_2O) Potassium Oxide	3.91	0.62	0.26	2.08	2.63	1.33
(P_2O_5)Phosphorus pentoxide	1.11	-	-	0.12	-	0.28
(TiO_2) Titanium Oxide	0.9	-	-	0.48	-	1.28
(LOI) Loss on Ignition	5.41	13.73	**7**	-	8.6	6.74

The majority of authors reported a higher concentration of SiO_2. Al_2O_3 is the second most abundant element in bentonite. During the hydration process, this causes a pozzolan reaction. According to ASTM C618, the majority of the authors reported chemical properties that were within acceptable limits (Reddy and Rao, 2019).

1.1.3. Bentonite Types

The geological properties of bentonite change according to the formation of Ca, Na, and Na-Ca montmorillonites. Bentonite is divided into three main headings in terms of the minerals it contains sodium bentonite, Calcium bentonite, and intermediate type bentonite. Sodium bentonite is the most common type. The chemical composition of each type is shown in (Table 1.4).

Table 1.4. Distribution of chemical compositions of bentonite species (Kok, 2017).

Component (%)	Na-Bentonite	Ca-Bentonite	Na-Ca Bentonite
SiO_2	64	59	62
Al_2O_3	21	19.73	15.91
Fe_2O_3	3.51	5.95	3
MgO	2.33	5.51	2.63
CaO	0.58	1.72	4.51
Na_2O	2.62	0.28	2
K_2O	0.41	0.29	1

1.1.3.1. Na-Bentonite

Na-Bentonite is the most commonly used type of bentonite. It is a type of bentonite rich in sodium ions. Compared to other bentonite types, it is the bentonite type with the highest swelling property in water. With water, it can reach a volume of 10–15 times its volume. These clays have a colloidal property when mixed with water, swelling in volume in water and some organic liquid media, and having high porosity, they provide a wide range of uses (Zhirong et al, 2011).

1.1.3.2. Ca-Bentonite

In this type of bentonite, calcium is present in ions that can change between layers. Its physical properties are generally the same as sodium bentonite. Although sodium bentonites provide high swelling capacity in aqueous media, calcium bentonites can swell only 3-5 times their volume with water. Calcium bentonite is available in abundance around the world and can be used as a pozzolanic agent in concrete. Calcium bentonite leads to an increase in volume when adding water to it. This property causes an increase in concrete strength as a result of the internal treatment of bentonite when it is replaced with cement in ordinary concrete or replaced with other materials in geopolymer concrete (Park at el, 2016).

1.1.3.3. Intermediate Type of Bentonite

Bentonites with sodium and calcium ions are called mixed-type or intermediate-type bentonites. It can attract heavy metals and ions. For this reason, it is used extensively in the food and cosmetics sectors (Murray, 2007).

1.1.4. Calcination of Bentonite

Calcination is a high-temperature reaction that occurs when one solid material dissociates into two solids and gas (Callister et al, 2007).

Because the mineralogy of bentonite clay varies so much, calcination temperatures can also vary a lot. The reactions that occur when smectite is heated to high temperatures have been outlined in general. When all clays are heated to 100 °C to 150 °C, pore water is lost. When heated to 100 °C to 300 °C, smectites lose their expanding lattice properties. The chemical composition and nature of exchange cation have an impact on the temperature. Smectites lose their hydroxyl water from their lattice at temperatures of between 450 °C and 700 °C. The exact temperature is determined by the chemical composition of the exchange cation and its nature. When hydroxyl water is removed from dioctahedral smectites like montmorillonite, there is little shrinkage and destruction of the lattice structure. However, when hydroxyl water is removed from trioctahedral smectites like saponite, the lattice structure is destroyed and the material shrinks. At 900 °C, the lattice structure of dioctahedral smectites is deformed (Grim and Gven, 1978).

Smectites will form a number of novel crystalline phases based on their chemical composition and structure when heated above the temperature at which the lattice structure is being destroyed. Vitrification and shrinkage of up to 20% of the volume occur during the high-temperature phases. Fusion takes place around 1000 °C for iron-rich smectites and around 1500 °C for low-iron smectites. Crystalline phase formation is rare or absent in iron-rich varieties. As mentioned in literature "Many, but not all, smectites contain enough iron to produce a red to brown firing color," (Grim and Guven, 1978).

The pozzolan activity of the materials is attributed to the presence of Portlandite, this results in the development of more calcium silicate hydrates material elements (C-S-H) (Mardani-Aghabaglou et al, 2014).

Because coal fly ash production may drop in some countries due to change in fuels sources, it will be advantageous to identify alternate pozzolan materials. Calcination clay is a potential alternative because the energy required to activate it is lower than that necessary to make cement. When a clay is calcined, various reactions take place, resulting in a succession of mineralogical crystallographic changes as hydroxyl ions are eliminated (Chakchouk et al, 2006).

The temperature at which the aluminosilicates were reactivated in clay was usually between 700 °C and 900 °C. A residual clay component forms at temperatures below 700 °C, while at temperatures above 900 °C, the aluminosilicate minerals crystallize into Al_2O_3 and SiO_2 in their spinel form, which can reduce the aluminosilicate materials' reactivity. Various calcined clays, such as smectite, kaolinite, illite, montmorillonite, muscovite, and low-purity mica clay, have been studied for their pozzolan activity (Buchwald, 2009).

1.1.5. Uses of Bentonite

Bentonite has a wide usage area due to its water-holding capacity and binding properties. Physical properties such as swelling, thixotropy, viscosity, size, and shape are important in determining the usage areas of bentonite. The drilling industry accounts for approximately 40% of bentonite consumption in our country. Protecting the string from corrosion in oil, natural gas, geothermal, and core drilling reduces the heat created by friction caused by the contact of the drill with the formation. It is used in drilling mud due to its tasks such as reducing tool and drill wear due to rotation, preventing vibration, carrying the sediment and crumbs formed in the ground to the surface, preventing tool jams, and preventing the formations from collapsing into the annulus (Arslan, 2010).

Bentonite is used by adding up to 50% of the casting sands, which are used as molding materials in the casting industry, as they provide binding properties high binding property and gas permeability when added to molding sands. It is one of the main factors in its use in the casting industry (Radhakrishna and Nidigonda, 2016).

The absorption and gelling properties of bentonite are used in the construction industry. Fine-grained, high plasticity, and thixotropy bentonites are especially preferred in the construction industry. Due to its hydration and thixotropy properties, bentonite is used to prevent water leaks and provide insulation during dam construction (Boyes et al, 1972).

The main reason for the use of bentonite as a moisture absorber is its high moisture retention. The most preferred bentonite type is calcium bentonite. It is especially used for humidity control in packages of materials that require a moisture-free environment during transportation (Grbes et al, 2013).

Bentonite clay is characterized by many properties such as water absorption and impermeability in the formation of a gel material and the ability to swell, so it is suitable for its use as pozzolan in concrete (Grim and Guven, 1978).

1.1.6. Pozzolan Materials

A pozzolan is a finely divided aluminous or siliceous substance that combines chemically with calcium hydroxide or sodium hydroxide in the presence of moisture to generate composites having cementitious characteristics. Natural pozzolans are made from mineral deposits found in the wild. To become pozzolan, some of these materials must be heated; this process is known as calcining. Others, like volcanic ash, can be used with little to no processing (such as Drying and Grinding). Natural pozzolans have been used to control temperature rise in mass concrete in North American public works projects since the early twentieth century, such as dams. They were also used to strengthen sulfate resistance. Siliceous or siliceous and alumina materials that have little or no binding property when used alone, but gain binding property when used naturally or by grinding with a binder

are called pozzolan materials. Volcanic ash and volcanic tuff are examples of natural pozzolans, such as volcanic ash, etc (Kosmatka and Wilson, 2012).

Natural pozzolans and artificial pozzolans are the two types of pozzolan materials that are commonly used. Natural pozzolans, on the other hand, almost always need to be ground to achieve the desired particle size gradation. Natural pozzolans come in a variety of shapes and sizes. Incoherent rocks (Italian pozzolan), zeolitic material (trass, Naples yellow tuff), Italian white earth, and diatomaceous earth are just a few examples. Artificial pozzolans are the result of a chemical or structural change to a material that was previously inert. Pozzolan activity is minimal to non-existent. Fly ash, activated clay, burned shale, and silica fume is examples of artificial pozzolans. The natural and artificial worlds are divided into two categories. Pozzolan isn't always easy to define because some materials, such as Danish moler, French gaze, and American rhyolitic tuffs, contain both natural pozzolans and clays (Hewlett and Liska, 2019).

1.2. Geopolymers

The use of geopolymers dates back centuries. For example, concrete used by the Romans and Greeks to build structures such as the Pantheon and Colosseum contains binder made of pozzolans such as volcanic ash, lime, and clay. It is thought that the blocks used in the construction of the Cheops Pyramid were produced by activating the alkali in the aluminosilicate-based material (Demortier, 2004).

In 1930, Kuhl investigated the setting time by activating ground slag with a potassium hydroxide alkali solution. In 1937, Chassevent investigated the reactivity of slag by activating the slag with a combination of sodium oxide and potassium oxide (Shi et al, 2011).

In 1940, Purdon activated Belgian slag with a 10% sodium hydroxide solution by weight and reached a strength of 25 MPa. It was suggested by Purdon that sodium hydroxide is effective in the setting time of the slag and acts as a catalyst in the reaction (Thomas, 2016).

Studies focused on geopolymer materials, or alternative binding materials that can be used instead of cement, called alkali-active cement. Geopolymer materials are one of the polymeric bonds synthesized from alkali activation of various aluminosilicate materials such as metakaolin, fly ash, silica fume, and blast furnace slag. When compared to cement concrete, geopolymers have better mechanical properties, fire performance, and acid resistance (Alzeer and Mackenzie, 2013).

Cement concrete emits approximately 80% less CO_2 than geopolymer concrete. This makes it attractive to use geopolymer materials in terms of environmental awareness and health (Davidovits, 1994).

Geopolymer concretes are industrial materials whose binders are sodium silicate and sodium hydroxide alkalis. We can say fly ash and blast furnace slag are materials used more in the production of geopolymer concrete. Blast furnace slag, which has replaced standard Portland cement, is used to increase concrete's physical properties, chemical composition, and strength (Swamy, 1986).

Geopolymer materials are used in the alkali activation of different sodium silicate solutions or industries, such as blast furnace slag, fly ash and metakaolin (Davidovits et al, 2020).

The polymerization process is generally accelerated with the aid of heat. At high temperatures, geopolymers produced with fly ash can gain strength in the early stages (Vijai et al, 2010).

1.2.1. Geopolymer Applications

It is possible to say that geopolymer concrete technology has started to be applied in various parts of the world. For example, 40000 m^3 of geopolymer concrete was used in Australia in 2013. The application areas of geopolymer binders are quite wide. It continues to expand with the usage areas of geopolymer binders, which have applications such as normal concrete, ready-mixed concrete, reinforced concrete, concrete pipes, mortar, and lightweight concrete (Provis, 2018).

Geopolymer concretes are used commercially in Europe, Australia, America, and India. Alkali activated binders have been known for more than 60 years. One of the large-scale studies using alkali-activated binders is residential buildings in Ukraine (Figure 1.3). These houses were built in 1960 with a geopolymer binder obtained as a result of the alkali activation of iron-steel waste at 7.5 Mpa. In the compressive strength test performed on the samples taken from the building in 2012, a compressive strength of 14 MPa was obtained (Hlavacek, 2014).

Figure 1.3. Residential structures produced using geopolymer concrete in Ukraine (Hlavacek, 2014).

1.3. Constituent of Geopolymer Concrete

1.3.1. Fly Ash

In general, 10–15% of the hard coal used to generate electricity in thermal power plants and 20–50% of the lignite coal amount occur as ash. This fly ash production, in terms of coal being burned, is also affected by the operating mode of the power plant, the type of power plant, and other factors such as combustion styles. 75-85% of the amount of ash that emerged after the combustion process was removed from the boiler together with the flue gases, and this waste is called "fly ash." In power plants, high-efficiency electro filters are generally used to capture the fly ash from the flue gas. The most obvious common aspects of the chemical,

Pozzolan, physical, and mineralogical properties of fly ash vary from one region to another, sometimes even within the same region. (Morrison et al, 1970).

Although fly ash formation is 15 million tons per year in Turkey, its use in industry is low. The main reasons for the low use of fly ash in Turkey are the lack of sufficient information about the properties of fly ash and the fact that the properties of fly ash do not show uniform characteristics according to the type of coal used (Durmus et al, 2010).

As indicated in (Figure 1.4), Fly Ash is often produced by steam producing plants and coal-fired electric power plants (Sephaku et al, 2013).

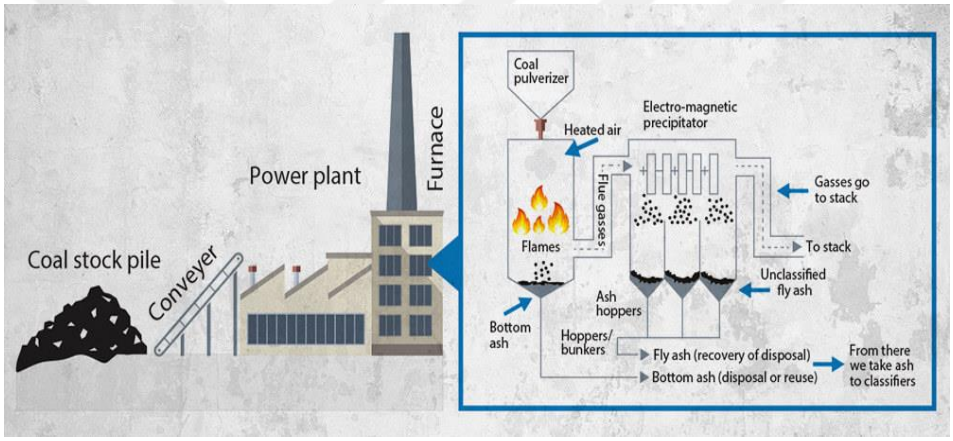

Figure 1.4. The process of production of fly ash in an electric power plant (Sephaku, 2013).

1.3.1.1. Use of Fly Ash in Geopolymer Concrete

The cement industry is one of the most common areas where fly ash is used in the construction industry. Sufficient or even superior engineering performance can be obtained by using fly ash in concrete at the appropriate rate. For example, concrete containing fly ash generally has higher workability and hydration heat with lower concrete usage. This provides significant advantages for concrete production. The early-age compressive strength of concrete produced with fly ash in this way is low when compared to concrete that does not contain it. The reason for this is that

fly ash particles may be slower to hydrate. However, at later ages, the strength may reach approximately the same or even higher levels. The concrete produced in this way is concrete that is more resistant to deterioration that may occur due to environmental effects, (Celik et al, 2013).

Fly ash is divided into two classes according to the ASTM C 618 standard, depending on the amount of Al_2O_3, SiO_2, and Fe_2O_3 it contains. Formalized class C is obtained from the combustion of anthracite and bituminous coals, and C-class ashes are obtained from lignite combustion. The fact that bituminous and anthracite coal contains less calcium compared to lignite has created a classification system that causes different pozzolan and binding properties in fly ash in the C class. Fly ash has binding properties as well as pozzolan properties. Class F ones, on the other hand, show a rare binding feature when mixed with water only (Hodson et al, 1990).

The amount of fly ash emerging in the world is about 600 million tons a year. However, this amount changes from year to year with the start of the operation of natural gas power plants. The usage quantities of these product in concrete is extremely important for our country. Storage, transportation, and subsequent burning and/or burial of fly ash in such amounts will have negative economic and environmental consequences. Since fly ash gains strength gradually, as mentioned above, the usage of 100% fly ash requires heat curing. If geopolymer concrete is used entirely by using fly ash, the concrete will last for approximately 24 to 72 hours at 70–100 °C. Various heat cures are needed. This is a problem in itself. It is extremely difficult to heat cure the concrete that is manufactured on-site to such high temperatures. For this reason, fly ashes are blown into blast furnaces with high calcium oxide content. By using slag, it is possible to produce concrete without the need for heat curing (Turker et al, 2004).

1.3.2. Slags

Ground blast furnace slag is a by-product. Slag is obtained by burning mixtures of iron ore, coke, and limestone at a temperature of 1500 °C. About 40%

of the molten slag content is CaO (calcium oxide) and between 30% and 40% SiO_2 (silicon dioxide). This chemical composition is very close to the chemical composition of conventional Portland cement. When the iron ore turns into iron, the residue or residue forms the slag that floats on the iron ore. The slag is usually removed from the casting as a molten liquid. For its production, a large volume and rapid quenching process are used. Quenching increases the cementitious properties of the slag and introduces small slag particles. After the quenching process, the slag material is dried and brought to a fine form in the form of small pieces or powder. Slag can be used in conventional Portland cement concrete by replacing 35%–70% with cement. Superior properties when the slag material is combined with other materials in the production of geopolymer concrete (Amran et al, 2020).

Blast furnace slag Geopolymer concrete has better mechanical properties and chemical durability performance at high temperatures compared to concrete with other additives. When compared to used and unused cement pastes, blast furnace slag additive reduces weight loss in concrete produced with slag and offers superior performance in terms of mechanical properties at high temperatures.

As a byproduct of a high-temperature steel making factory shown in the (Figure 1.5). In addition to existing standards, slag and all, blast furnace slag is pulverized into bits and utilized as aggregate, along with coarse material. The various qualities of aggregates are dictated by the needs. When compared to conventional values, the corrosion and breaking values for blast furnace slag aggregates are quite high. Besides, Kiln slag aggregates absorb significantly more water than crushed granite. Before using trash aggregates in concrete manufacturing, Particle sizes of feeding material should be thoroughly arranged, properly (Devi and Gnanavel, 2014).

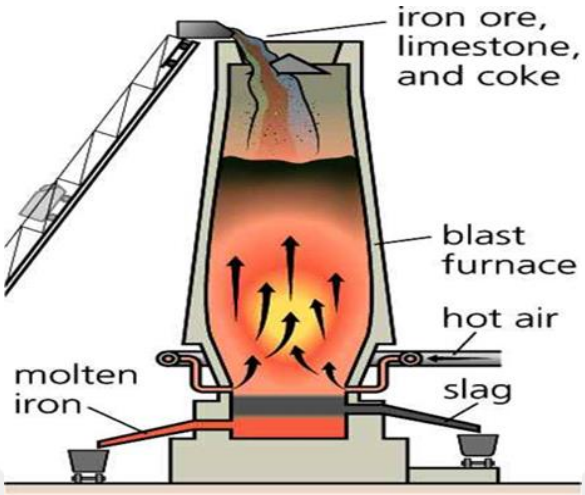

Figure 1.5. The production process of blast furnace slags (Soact, 2021).

The advantageous effect of blast furnace slag on the properties of the concrete.

- It increases the workability of new concrete and lengthens to set.
- It helps to prevent perspiration on concrete.
- It reduces hydration heat.
- Improves sulfate resistance in hardened concrete (Devi & Gnanavel, 2014).

1.3.3. Alkaline Activators

NaOH and KOH alkali activators are used for the production of geopolymer composites alone or mixed with Na_2SiO_3. The usege of NaOH alone results in a slightly weaker geopolymer, especially at the low concentrations. The use of Na_2SiO_3 leads to significant strength development (Phoo-ngernkham, 2015).

In fact, the compressive strength depends on the type of aluminosilicate raw material used (Dimas, 2009). In terms of CO_2 emissions, however, NaOH is a better choice than Na_2SiO_3. Because the electrolysis of brine is favored for producing

NaOH, and this method only produces Cl_2 and H_2. However, to produce Na_2SiO_3, $NaCO_3$ and SiO_2 must be burned at roughly 1200–1400 °C, resulting in CO_2 release (Speight, 2002).

The alkali activator most commonly used in geopolymerization reactions is obtained by mixing sodium hydroxide or potassium hydroxide with sodium silicate or potassium silicate (Davidovits, 2008).

1.3.4. Lightweight Aggregate

The general name for materials such as sand, gravel, crushed stone, blast furnace slag, baked clay, pumice, expanded perlite, and fly ash used in concrete production is "aggregate." Aggregates constitute approximately 70–75% of the volume of concrete. The use of aggregates in concrete has great benefits in terms of economic and technical properties. The longevity, porosity, impermeability, mineral structure, physical properties, gradation of the aggregate used in concrete, particle surface roughness, greatest particle size, modulus of elasticity, thermal expansion coefficient, and whether the aggregate is clay or not are all factors to consider. Many factors, such as cleanliness, have an impact on one or more categories of concrete durability. Lightweight aggregates can be made naturally or by putting natural or waste materials through a series of heating processes. (Wang et al, 2020).

Lightweight concrete was first used by the Sumerians in 3000 BC. It was used in the construction of Babylon. In the first known, lightweight concretes, volcanic rocks such as pumice, slag, and tuff were used as aggregates. The Pantheon, the Colosseum, and the Mayan pyramids are examples of ancient works that used lightweight concrete. The properties of the components that make up lightweight concrete affect the physical and mechanical properties of lightweight concrete. The density of lightweight concrete is quite low compared to normal concrete. Many factors affect the density of lightweight concrete. These are the amount of cement, the amount of entrained air, and the moisture content of the aggregate (Chandra and Berntsson, 2003).

Lightweight aggregates are obtained naturally from nature or by subjecting natural or waste materials to various thermal processes. The source of natural aggregates is rocks of volcanic origin. The lava, which cools by rising to the surface during the volcano, forms a sintered porous material. As a result of the sudden cooling of magma plum without forming a crystalline structure, an amorphous glassy material is formed. A crystalline material is formed if the magma melt cools slowly enough (Top and Vapur, 2018).

Since lava is a boiling liquid, it contains air and gas. As a result of the cooling of the lava, a hollow and spongy structure is formed with the effect of gas and air. In other words, as a result of the cooling of the lava, a hollow, light, and reactive material is formed. Such materials take names such as a volcanic aggregate of pumice, scoria, and perlite aggregate (Chandra and Berntsson, 2003).

1.3.4.1. Expanded Polystyrene (EPS)

Lightweight aggregate is a necessary component in the creation of lightweight concrete. Accumulated polystyrene waste poses a threat to the environment in abundance and poses a threat to the world. This waste can be recycled and used in many fields like the production of lightweight concrete, reducing the use of new materials, and thus preservation of natural resources (Kulkarni, 2021).

EPS is composed of 95%–98% air, with a density of (10–30) kg/m^3. Polystyrene EPS can be used as a lightweight aggregate in concrete. Construction waste comes from a variety of sources. For example, waste materials that could be utilized in civil construction but instead end up as rubble contributes to the waste stream. As a result, it's critical to look for novel materials to make concrete from unusual aggregates, particularly those that are recyclable. In the construction of concrete, expanded polystyrene (EPS) can be used to replace aggregates as well as standard components such as cement, mineral aggregates, and water, which may contain other additions and additives, such as fibers (Carvalho and Motta, 2019).

There have been trials using EPS in the form of pearls as a lightweight concrete aggregate. EPS is made of concrete that has been engineered and reinforced with expanded polystyrene to achieve variable densities and strengths. The results demonstrated that for the same density, the compressive strength of concrete with EPS increases as the diameter of the EPS pellets decreases (Kulkarni et al, 2021).

2. LITERATURE REVIEW

Use complementary components of cement in ordinary concrete to improve its properties and save natural resources. Bentonite is clay with pozzolanic properties that has been activated by heat and added as a partial substitute in concrete. by 5%, 10%, 15%, 20%, 25%, 30%, and 35% good results were obtained, especially for the thermal reactive bentonite (Rehman, 2019).

Alkaline liquids, and source materials are used in Geopolymer concrete. The source materials for alumino-silicate-based geopolymers should be rich in aluminum and silicon. Natural minerals (kaolin, clay, etc.) or by-product materials (fly ash, silica fume, slag, etc.) can be source materials for geopolymers. The cost of selecting source material for geopolymers, there are many parameters, such as suitability and application types. Alkaline liquids are generally preferred over soluble liquid metals based on potassium or sodium. In geopolymerization, sodium hydroxide or mixtures of potassium hydroxide and sodium silicate or potassium silicate are commonly used as liquid alkalin (Lloyd and Rangan, 2010).

This geopolymer concrete is prepared by using alkali-active binders and pozzolan materials (blast furnace slag, fly ash, etc.). The use of these materials as binders in geopolymers has the potential to solve the problems associated with the storage and disposal of these wastes. Alkali-activated binders consume 60% less energy and emit 6 times less CO_2 compared to portland cement (Sun and Wu, 2013).

The addition of calcined kaolin clay to geopolymer concrete was studied to activate this clay, add it as a substitute for fly ash, and study the effects of polypropylene fibers on the mechanical properties of concrete. It was found that concrete improved by 35% when adding calcined kaolin clay (Zhang et al, 2009).

Regarding the water absorption characteristics of metakaolin concrete, it was observed that partial substitution of metakaolin for cement, due to its high pozzolanic activity, improves the durability and mechanical properties of concrete. The addition of instead of cement minimizes the possibility of negative effects by

reducing the capillary water ingress into the concrete. In cold climates, there are two basic elements of the physical deterioration mechanism of concrete. These are the deterioration of concrete exposed to freeze-thaw effects in the presence of moisture and the accumulation of de-icing salts on the concrete surface (Matalkah and Soroushian, 2018).

To reduce carbon dioxide emissions and reduce environmental pollution, there was a need to search for alternatives to replace cement. Bentonite clay is clay with pozzolanic properties that are heat-treated at different temperatures to be used as a substitute for cement, and research on its effect on the mechanical properties of concrete was found to be added at calcination at different temperatures of 650 °C, 830 °C, and 930 °C to bentonite concrete. The higher the percentage of bentonite, the higher the mechanical properties, then they decrease. It was found that the addition of bentonite, 10% at 650 °C, to concrete achieves the best mechanical results. In addition, the mixing between bentonite clay and kaolinite clay was studied, and we found results that had a good effect on the properties (Taylor-Lange et al, 2015).

The chemical and thermal activation of mortar mixtures consisting of clay and cement containing 0-25-50-80-100% (by weight) clay were tested. In the group containing 100% clay, using both NaOH and Na_2SiO_3, a thermal cure at 65 °C for 10 hours was applied, and the 7-day compressive strength reached 25 MPa. They stated that NaOH solution concentration, chemical activator ratio, and thermal curing program significantly affect the obtained strength (Saglik and Erdogan, 2010).

Faust and Konik researched the manufacturability of high-strength lightweight concrete using different lightweight aggregates, granulometry, and dosage. As a result, they stated that it is possible to produce lightweight concrete with a unit volume weight of 1000–2000 kg/m^3 and compressive strength of 15–100 MPa. At the same time, they say that breakage in high-strength lightweight concrete

occurs by shearing coarse aggregates, and therefore the breakage is more brittle than normal concrete (Faust et al, 1997).

Gao (1997) investigated the effect of fibers on the mechanical properties of high-strength lightweight concrete. In their study, it was found that the weakest component in high-strength lightweight concrete is the one that transfers stress between aggregates and cement matrices. They observed that there were coarse aggregates instead of the cement matrix. They state that the fibers are used to prevent the passage of cracks formed in the coarse aggregate into the cement matrix and that the cracks in the cement matrix are formed under greater pressure forces. The fiber does not cause a significant increase in the compressive strength of the concrete, but they determined that it causes an increase of up to 90% in tensile strength.

Bai used lytag, blast furnace slag, and fly ash. They carried out studies on the manufacturability of durable lightweight concrete. In their work, cement, sand, gravel, cement, lytag, blast furnace slag, and 70% cement, 30% fly ash and lytag mixtures were used in their work. They stated that it is possible to produce lightweight concrete with density of 1960 kg/m^3 and compressive strength of 20–40 MPa. lytag and slang state that the use of fly ash causes an increase in the porosity of the concrete, and that the use of fly ash causes a decrease in the porosity. In terms of tensile strength, fly ash, they say that while slag and lytag have a positive effect on middle-class concrete, they have the opposite effect on high-strength concrete (Bai, 2004).

3. MATERIALS AND METHODS

3.1. Materials

3.1.1. Calcium Bentonite

The calcium bentonite ore mostly contains quartz (SiO_2), calcium oxide (CaO) and montmorillonite [$Ca\ (Al, Fe, Zn)_2\ (Al, Si)_4\ O_{10}\ (OH)_2\ nH_2O$].

Figure 3.1. Calcium bentonite ore

Calcium bentonite clay collected from Yeni Ozdemir, Iskenderun, Turkey as shown in (Figure 3.1). In the beginning, calcium bentonite clay ore was analyzed by Minipal Panalytical X-ray fluorescence (XRF) device, which is presented in (Table 3.1). The mineral components of the clay were detected by the Rigaku Minflex II X-ray diffractometer (XRD) device shown in (Figure 3.2). Using carbon-coated equipment, a SEM image of the clay shown in (Figure 3.3 and Figure 3.4) was taken.

Table 3.1. XRF analysis of calcium bentonite clay.

Content	Al_2O_3	SiO_2	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3	ZnO	SrO	MgO	LOI
%	11	43.49	0.9	2.0	26.7	1.19	0.18	13.8	0.02	0.61	0.02	6.05

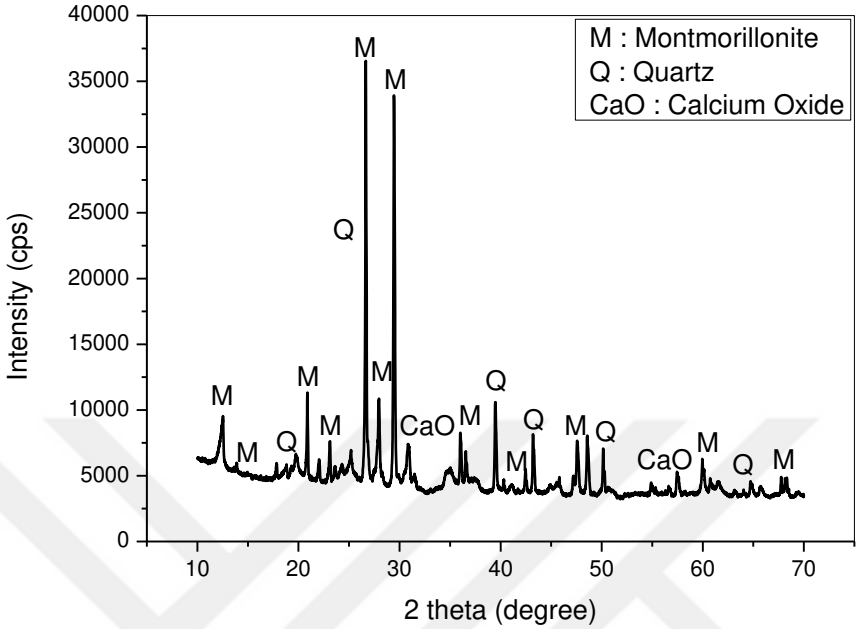

Figure 3.2. XRD diagram of calcium bentonite ore.

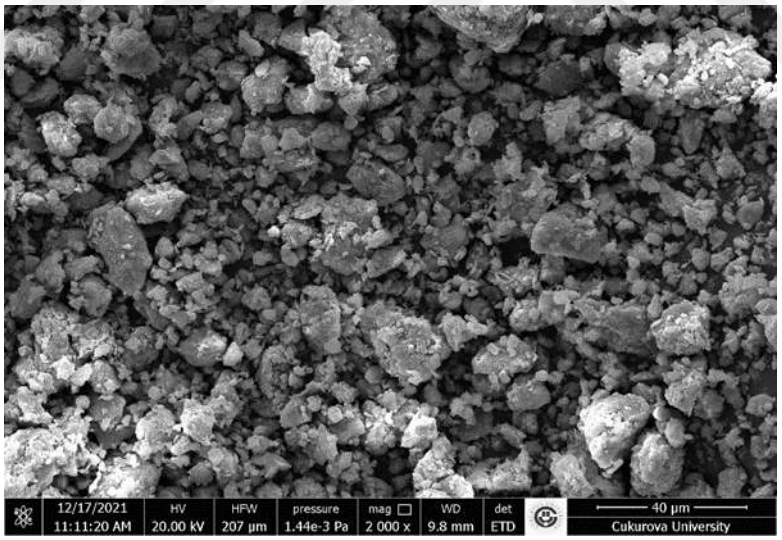

Figure 3.3. SEM images of calcium bentonite (40µm)

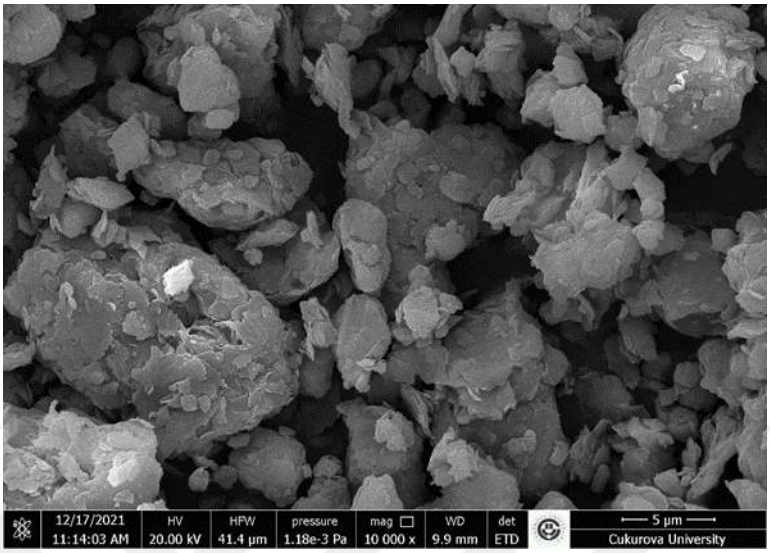

Figure 3.4. SEM images of calcium bentonite (5µm).

3.1.2. Fly Ash

Fly ash from the Sugozu thermal power station in the Yumurtal district of Adana served as the study's main component of the geopolymer concrete. The fly ash analysis was carried out using the Minipal 4 Panalytical X-ray fluorescence (XRF) system shown in (Table 3.2), the fly ash XRD (X-ray diffraction) was detected shown in (Figure 3.6). The Fly ash mainly includes quartz (SiO_2), sillimanite Al_2SiO_5, CaO, and Fe_2O_3, as well as the Fly ash SEM picture of the Sugozu thermal power plant (5µm and 4 µm), (Figure 3.5). Using carbon-coated equipment, a SEM image of the fly ash .

Table 3.2. XRF analysis of the sugozu thermic power plant fly ash.

Content	SiO_2	Al_2O_3	CaO	Fe_2O_3	K_2O	In_2O_3	TiO_2	SO_3	V_2O_5	LOI
%	51	25	8.10	9.83	2.2	0.27	1.79	1.71	0.1	2.21

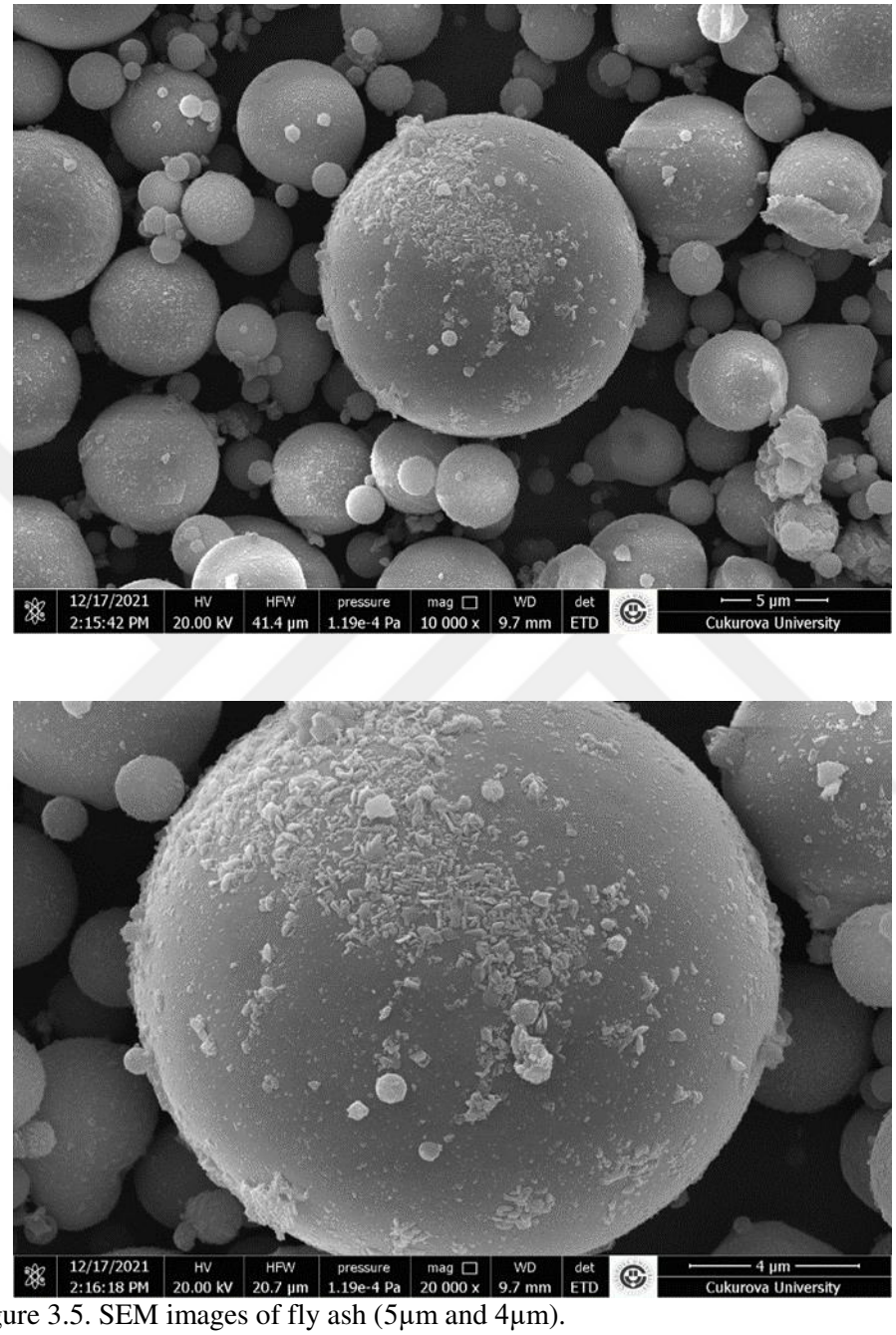

Figure 3.5. SEM images of fly ash (5µm and 4µm).

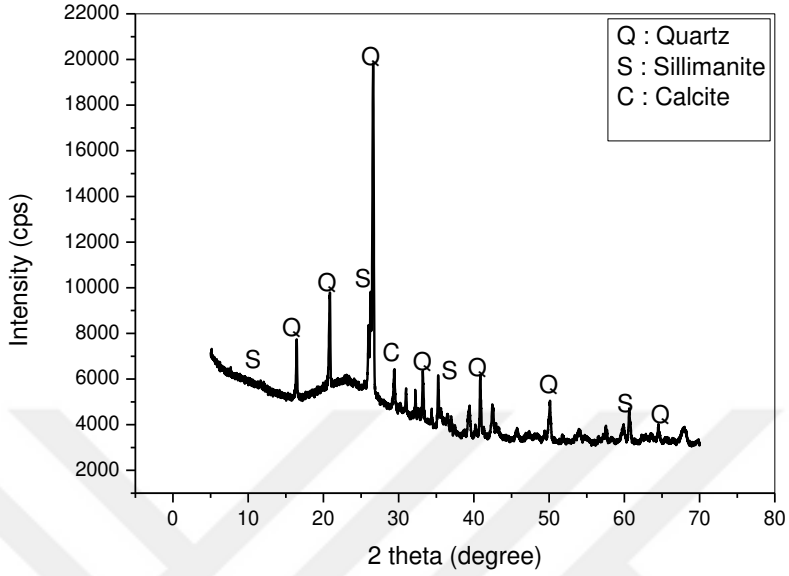

Figure 3.6. XRD diagram of the sugozu fly ash.

3.1.3. Slag

Ferrochrome slag from company in the Elazig region will be used as heavy aggregates. Ferrochrome slag is used to produce geopolymer concrete with greater long-term compressive and flexural strengths, finishing ability, lower permeability, enhanced durability and strength, more uniform efficiency, and lighter color.

The Ferrochrome slags were pulverized and evaluated using the Minipal 4 Panalytical X-ray Fluorescence system (XRF), with the XRF analysis (Table.3.3) The Rigaku Minflex II X-ray diffractometer (XRD) equipment was used to determine the inorganic material compositions of Ferrochrome slags (Figure.3.7). SEM image was taken for the slag shown in the (Figure 3.8).

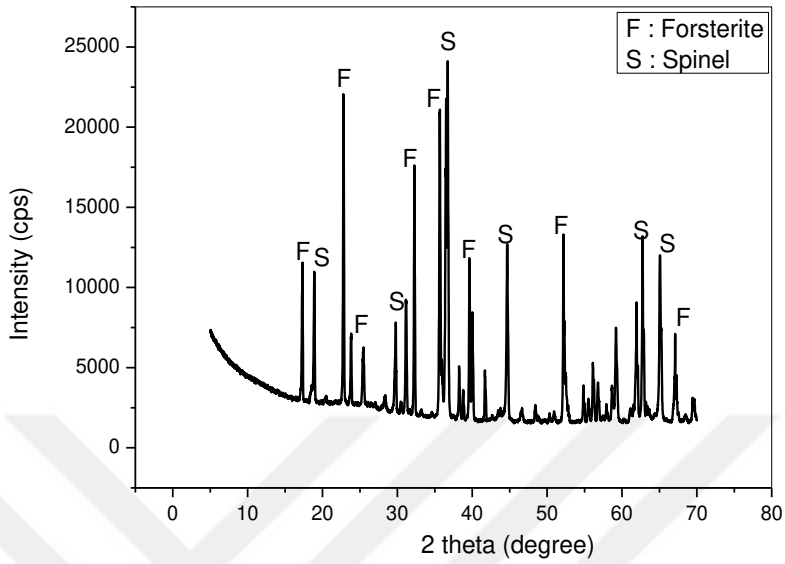

Figure 3.7. XRD diagram of the ferrochrome slags.

Table 3.3. XRF analysis of ferrochrome slags.

Content	SiO_2	Al_2O_3	Fe_2O_3	CaO	Cr_2O_3	MnO	K_2O	CuO	TiO_2	SO_3	V_2O_5	LOI
%	48	26	3.68	2.79	15.3	0.84	0.4	0.08	0.85	2	0.06	1.75

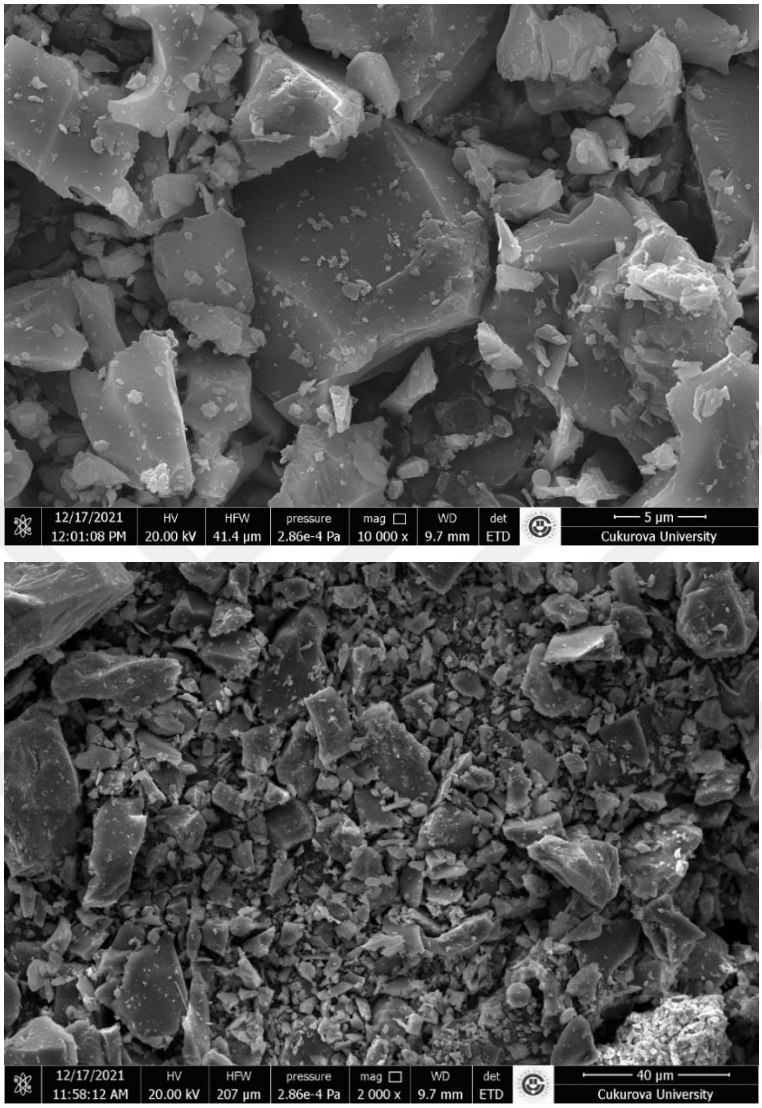

Figure 3.8. SEM images of ferrochrome slags (5µm,40 µm).

3.1.4. Expanded Polystyrene

In this study, EPS is used as a lightweight aggregate after then passing it through sieves to obtain sizes of (3mm, 5mm, and 7mm) as shown in (Figure 3.9).

Figure 3.9. Board of expanded polystyrene

3.1.5. Alkaline Activator

An alkaline activator increases the PH of the surrounding areas and speeds up the hardening process. As an alkaline activator, two compounds are used primarily in their respective proportions. The alkaline activators used in this investigation are sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3).

3.2. Methods

3.2.1. Preperation of Calcium Bentonite Ore

Calcium bentonite ore was collected from the Feke district of Yeni Ozdemir, Iskenderun, Turkey, for this study. Approximately 200 kg of calcium bentonite ore was recovered from the ore bed and transported to the mineral processing

laboratories of the mining engineering department of the faculty of engineering and architecture at Ckurova University.

3.2.1.1. Crushing

The size of the calcium bentonite ore rocks is about 9 cm, so the crushing process of these rocks is carried out using the jaw crusher laboratory device shown in (Figure 3.10).

Figure 3.10. Jaw crusher used in experiments.

3.2.1.2. Grinding

After the ore crushing process, the calcium bentonite ore is ground using a laboratory ball mill rotator device for 12 min at a speed of 60 rpm, as shown in (Figure 3.11). The ratio of ore/ball in this study was 1kg/5kg.

3.2.1.3. Sieving

To separate impurities from calcium bentonite clay, calcium bentonite samples were sieved by the RETSCH Sieve Shaker AS 200 (Figure 3.11) for 12 min at a degree of fineness of 75μm.

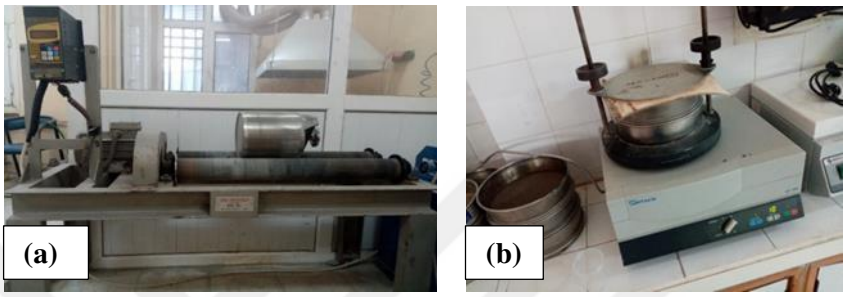

Figure 3.11. (a) ball mill rotator used in experiments, (b) retsch sieve Shaker AS 200 used in experiments.

3.2.1.4. Calcination

Calcination is a high-temperature reaction that occurs when one solid material dissociates into two solids and a gas. Because the mineralogy of bentonite clay varies so much, calcination temperatures can also vary a lot. The reactions that occur when smectite is heated to high temperatures have been outlined in general.

A laboratory electric furnace was used to carry out the calcination process shown in (Figure 3.12). Calcium bentonite (11 g) was at temperatures of (850 °C) for a period of 90 min. Previous studies were used to determine the appropriate time for calcination of calcium bentonite (Al-Hammood at el, 2021).

Figure 3.12. Electric furnace (an instrument in the Mining Engineering Department).

Particle size distribution analysis was performed on FA, CB, and CCB as shown in (Figure 3.13).

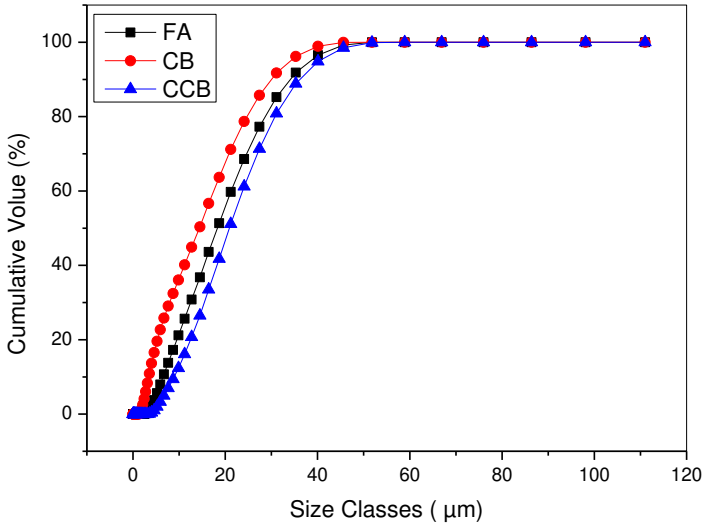

Figure 3.13. Particle size distribution of the FA, CB, and CCB.

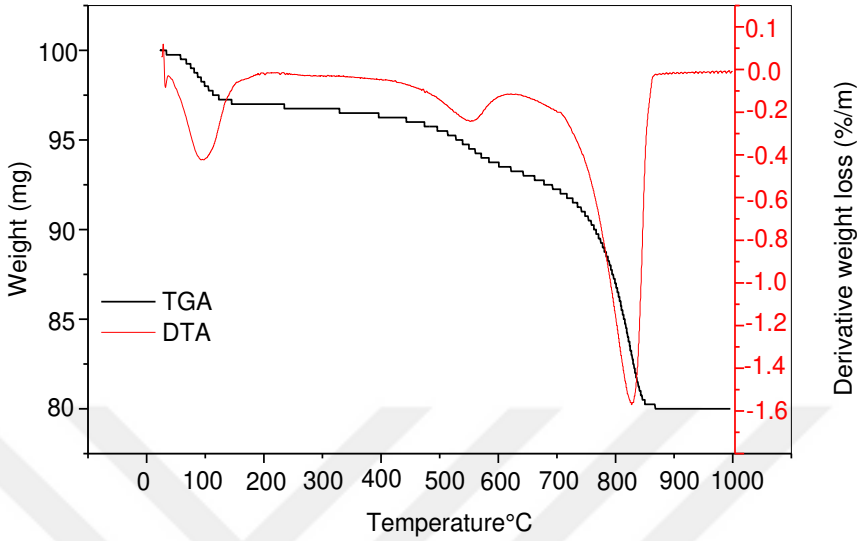

Figure 3.14. TGA/DTA curve of calcined calcium bentonite

As evidenced by the TGA/DTA analysis, when the temperature rises between 25 and 200 °C, approximately 0.3% of the mass of natural bentonite is lost due to the removal of the water it contains, a process known as dehydration. Calcium Bentonite loses more weight when the temperature reaches 830 °C due to the dehydroxylation of the smectite mineral as shown in (Figure 3.14). The absorption peak at 830 °C is depicted by the DTA analysis in the (Figure 3.14).

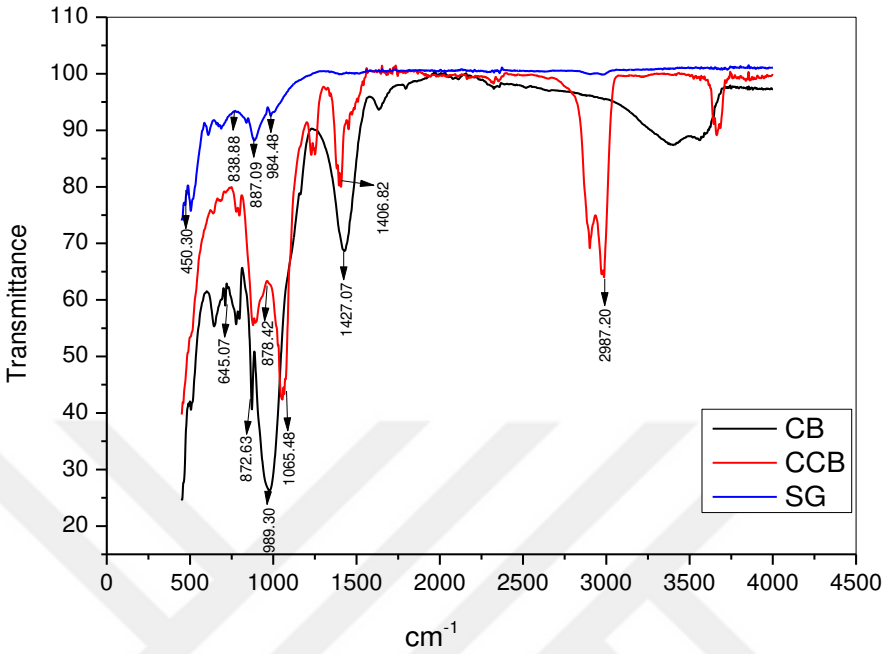

Figure 3.15. FTIR spectrum of calcium bentonite ore calcined calcium bentonite and slag.

FTIR spectra are used to elucidate the chemical structure of samples. In the FTIR spectra of the analysis natural bentonite, the band seen at 1432.85 cm^{-1} is due to the structural OH group stretching vibration in smectite. The band observed at 989.30 cm^{-1} is the band due to the OH stretching of water. The band at 872.63 cm^{-1} is that the water between the layers moves away from the structure. The band observed between 645.07 cm^{-1} is due to Si-O stretching vibration. The FTIR spectra of bentonite ore and calcined bentonite at 850 °C were not significantly different, although the band of H-O-H stretching and H-O-H bending was reduced after thermal activation. This implies that the water content in the thermally activated bentonite interlayer has decreased. FTIR analysis of slag yielded the following basic absorption bands: 450.30, 504.29, 609.40, 687.09, and 984.48 cm^{-1}). The primary bands (887.09–838.88 cm^{-1}) indicate the tetrahedron silica's expansion vibrations;

the deformation and expansion of OH was noticed at 984.48, and the expansion of aluminum ions was observed at 450.30 cm^{-1} as shown in (Figure 3.15).

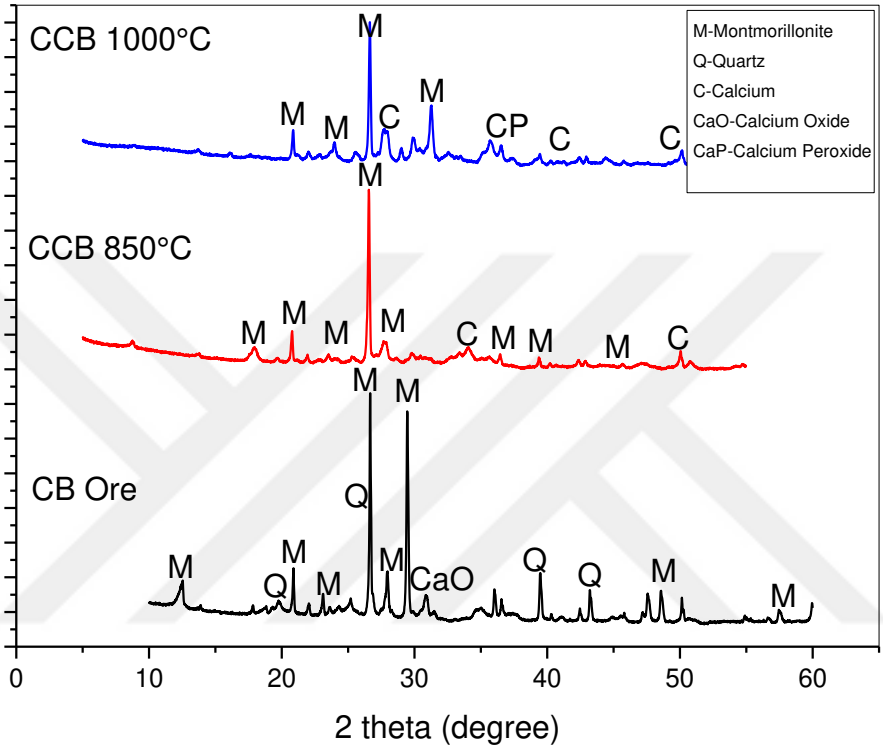

Figure 3.16. XRD patterns of calcium bentonite ore and calcined calcium bentonite at (850 °C, 1000 °C)

Table 3.4. XRF analysis of calcined calcium bentonite at 850 °C.

Content	Al_2O_3	SiO_2	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3	ZnO	SrO	MgO	LOI
%	12.41	40	1.2	1.9	28.5	1.15	0.49	13.7	0.02	0.61	0.02	1.34

After the calcination process of the calcium bentonite ore completed, free quartz minerals were separated with sieving (75 µm) for purification of calcium bentonite as shown by the XRD analysis (Figure 3.16). The purificated calcined bentonite has been used as a partial alternative for fly ash in geopolymer concrete.

The best partial replacement for fly ash in geopolymer concrete was calcined bentonite at 850 °C. Calcined calcium bentonite was analyzed by a Minipal Panalytical X-ray fluorescence (XRF) device, which is presented in (Table 3.4).

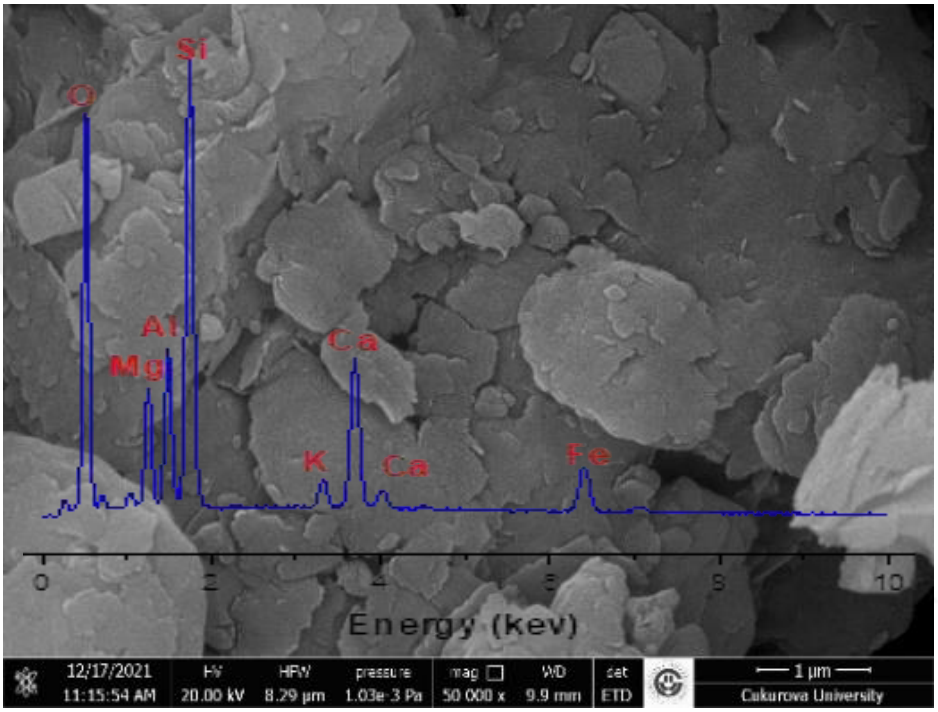

Figure 3.17. SEM and EDS images of calcium bentonite ore (1µm).

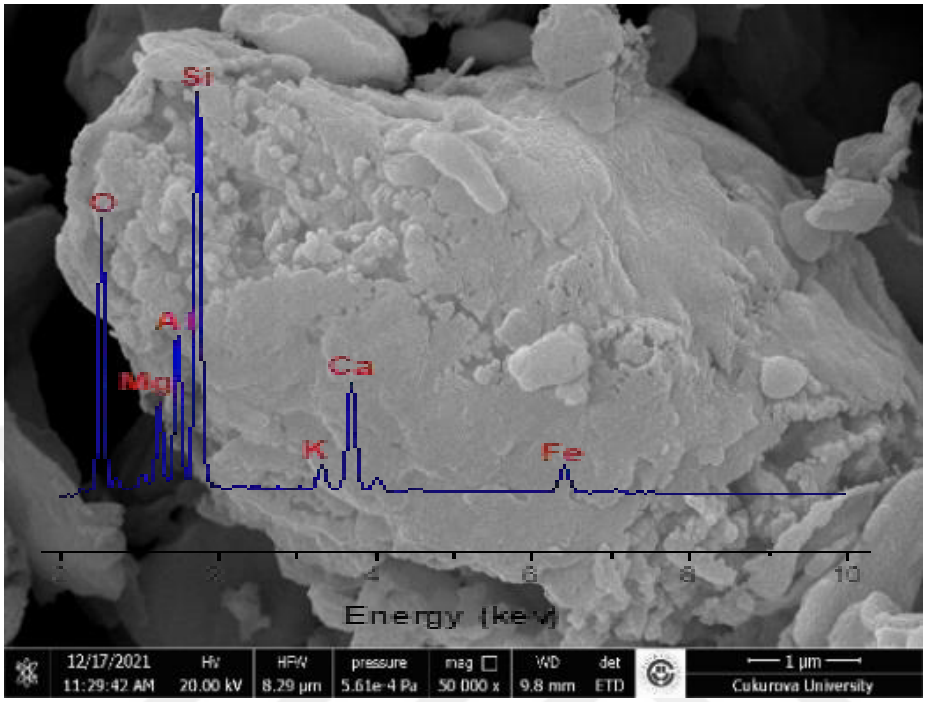

Figure 3.18. SEM and EDS images of calcined calcium bentonite at 850 °C (1µm).

The microstructure of calcium bentonite ore samples under the microscope displays plate-like patterns when analysed using SEM. It emerges in the form of thin crystals that become dense and enormous in size after calcination (Figure 3.17 and Figure 3.18).

3.2.2. Experiment Design

3.2.2.1. Box Behnken Experiment Design

The Box Behnken Experiment Design program is used for self-design of experiments according to the added factors. The filtered factors must be more than 3 factors, and the results are analyzed using 3D models. The program gives the factor response equation used to determine the percentage of the influence of the factors by comparing them with the factor coefficients.

3.2.3. Tests for Geopolymer Concrete Block Production

3.2.2.1. Uniaxial Compressive Strength (UCS)

The use of ELE brand strength measurement equipment is shown in (Figure 3.19). Cubic samples were placed in the portion to be loaded in accordance with the ASTM C109/C109M standard, and the loading process was started using the computer. 200 kgf/s was chosen as the loading speed.

Figure 3.19. Device for determining uniaxial compressive strength.

The strength values were calculated from the following formulation: P is the compression force (kgf) and A is the area (cm^2) where the strength of the sample is determined. The strength (σ) of this formulation was determined as

$$\text{MPa. } \sigma = P/A \qquad (3.1)$$

In addition, the stress-deformation (strain) curves of some samples were determined and the fracture behavior of the samples was tried to be determined. While the stress value is taken as (σ), the unit strain is calculated from the following formulation. The deformation of the material with the increase in pressure was

carefully noted and the amount of deformation as a result of the loading was calculated.

3.2.2.2. Point Load Strength (PL)

The point load strength of concrete blocks was measured with the ELE brand point load strength device (Figure 3.20). Cubic specimens were placed on the pointed end of the instrument and pressure was loaded until the piston rod of the instrument broke the specimen. The point load strength value (KN) was determined by reading the value on the instrument when the cubic sample was broken. Two measurements were taken from each sample and the average was determined.

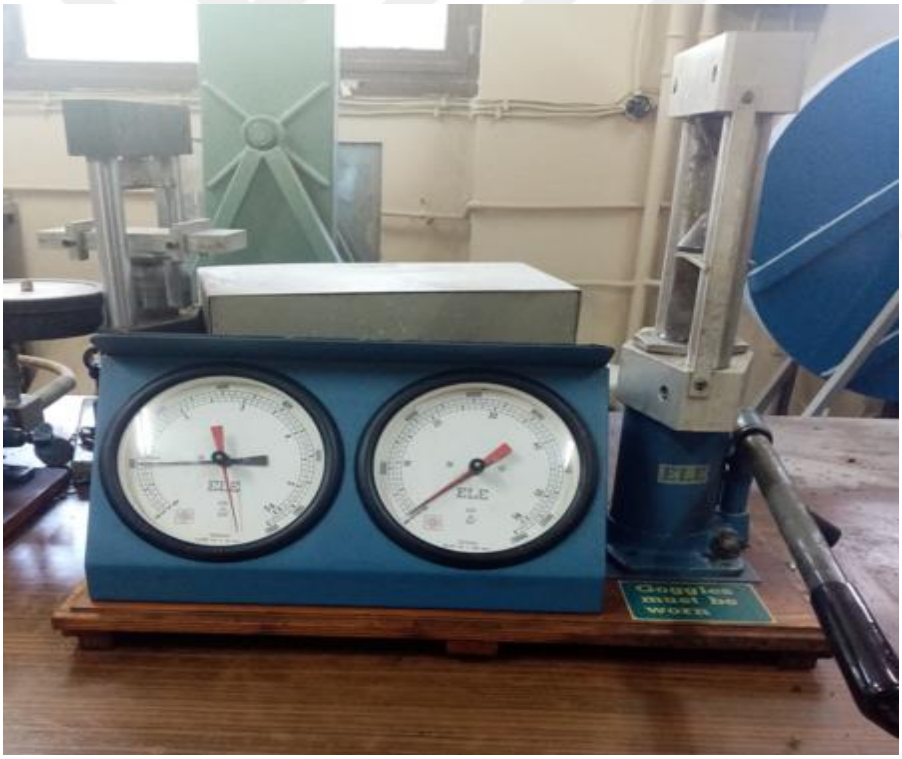

Figure 3.20. Point load strength measuring device

3.2.2.3. Pundit Sonic Speed (PSS)

The sonic velocity apparatus in (Figure 3.21) was used to calculate the sonic velocities of the samples. First, the device's reference sample, which calibrates it, was positioned between its transmitter and receiver and its calibration was confirmed. Following that, cubic samples were positioned between the transmitter and the receiver, and three separate dimensions of velocity were recorded. For improved wave transmission, grease the samples' surfaces. The Pundit sonic velocity value was determined by computing the average value of the readings and applying the algorithm below.

$$VP == L/Tp \qquad (3.2)$$

L is the length of the sample (mm), Tp is the value measured from the instrument (μs), and Vp is the propagation speed of the P wave (km/s).

Figure 3.21. Pundit sonic speed tester used in the experiments.

3.2.2.4. Determination of Shore Hardness (SH)

Use the Shore Scleroscope to determine the hardness of samples (Figure 3.22). In the Shore scleroscope, the plastic behavior of the material whose hardness is to be measured is used. The diamond tip in the hammer, which is dropped from a certain height, rises to a certain height after contact with the material, depending on the hardness. The surface of the material to be measured must be flat. At the end of 28 days, 2 grains from each surface of the cubic samples measurements were taken and the averages of these values were recorded as Shore hardness.

Figure 3.22. Device for measuring shore hardness

3.2.4. Preparation of Alkaline Activator and Mix Process

Initially, in order to create geopolymer concrete, preliminary experiments must be conducted in order to research and understand the topic better. The alkaline activator was prepared in the laboratory using a 5 M of sodium silicate solution and 14 M of sodium hydroxide. The alkaline activator was left for 24 hours before the experiments were carried out. The concrete mixture is poured into molds with dimensions of 5 cm x 5 cm x 5 cm. As shown in (Figure 3.24), the molds are painted to facilitate the process of removing concrete later. The concrete is left for 24 hours, after which it is removed. An alkaline activator was prepared using tap water and a mixing device was used as shown in (Figure 3.23).

Figure 3.23. Preparation of the alkaline activator of NaOH and Na_2SiO_3

After the alkaline activator is prepared, the other materials are prepared. Fly ash and slag are passed through a sieve to get a size of 2 mm, and calcined calcium bentonite is used to a size of 75 μm. First, fly ash is added with alkali activator and mixed for 10 minutes. Then it is poured into moulds (Figure 3.25). Fly ash is added as the main grade with percentages of calcined calcium bentonite and slag mixed with the alkaline activator. Lightweight geopolymer concrete is produced by adding fly ash as a base grade with percentages of calcined calcium bentonite and EPS. Because of the size of the EPS, it occupies a place inside the mold, and thus the weight of the geopolymer concrete is reduced.

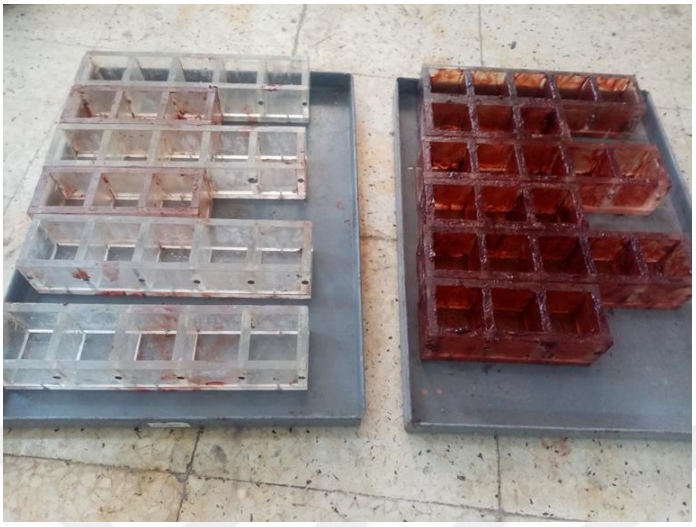

Figure 3.24. Geopolymer concrete casting molds

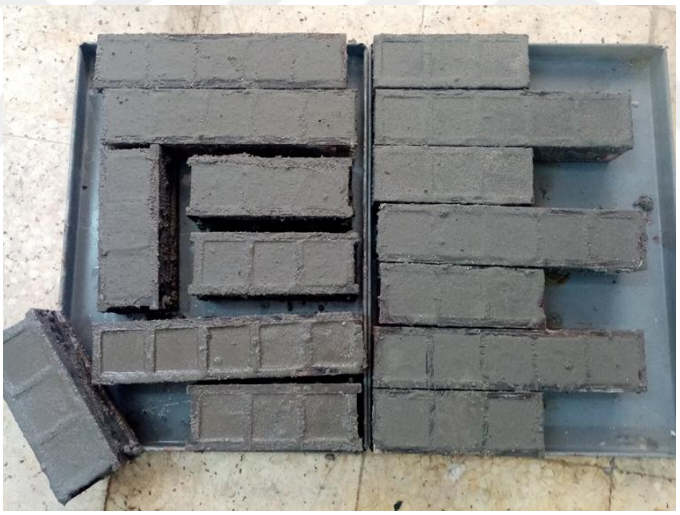

Figure 3.25. Geopolymer concrete mixture in cast moulds

4. RESULTS AND DISCUSSION

4.1. Preliminary Experiments

In the experiments using fly ash and alkali-activated only, experiments were designed based on factors affecting the properties of geopolymer concrete as shown in (Table 4.1).

Table 4.1. Preliminary experiment design.

EXP.NO	FA/Liquid	$NaOH/Na_2SiO_3$	Curing temperature	Heat treatmente time(days)
A	65	1/1	25 °C,90 °C	28
B	65	0/1,1/2,1/1,1/3	90 °C	28
C	65	1/1	90 °C	3,7,28
D	60,63,64,65	1/1	90 °C	28

Figure 4.1. Geopolymer concrete samples

Experiments were carried out for the alkaline solution at the (3 M, 5 M)concentration of sodium hydroxide and the (12 M, 14 M) concentration of sodium silicate. The concentration of NaOH was fixed at 14 M and the concentration of

Na_2SiO_3 was fixed at 5 M because the highest values were obtained from the UCS test (Figure 4.2 and Figure 4.3).

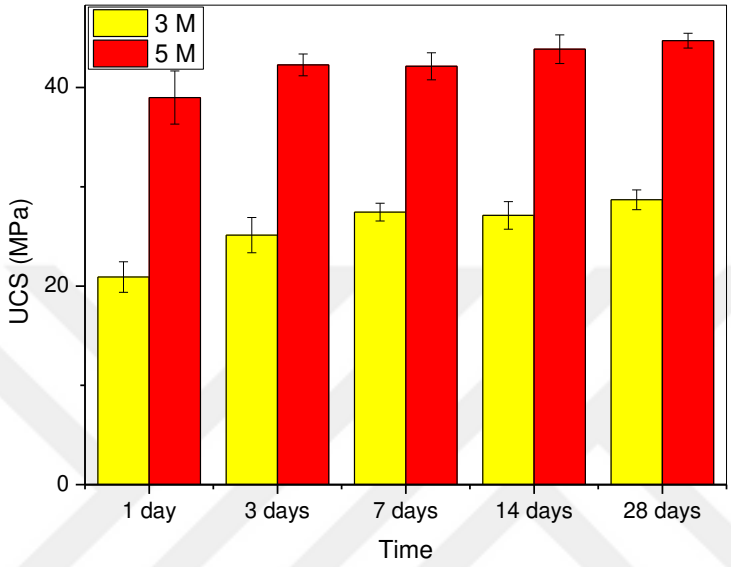

Figure 4.2. UCS test results for 3 M and 5 M of NaOH

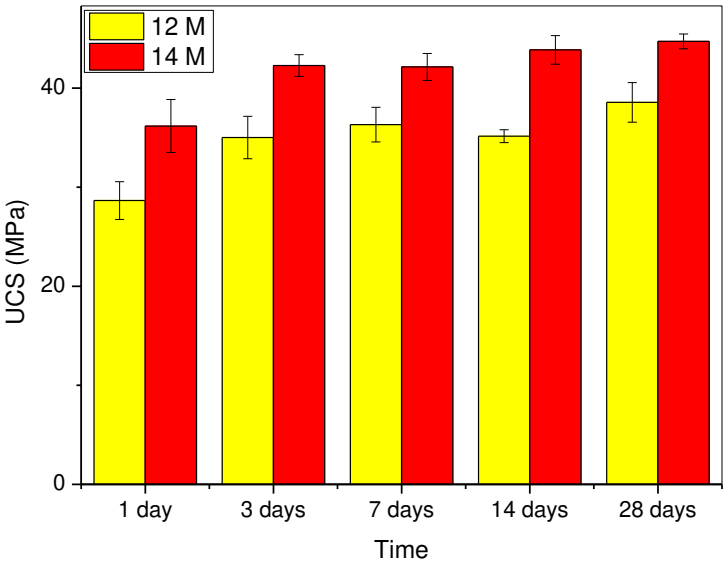

Figure 4.3. UCS test results for 12 M and 14 M of Na2SiO3

Series A, the effect of heat curing on the strength of geopolymer concrete was studied.

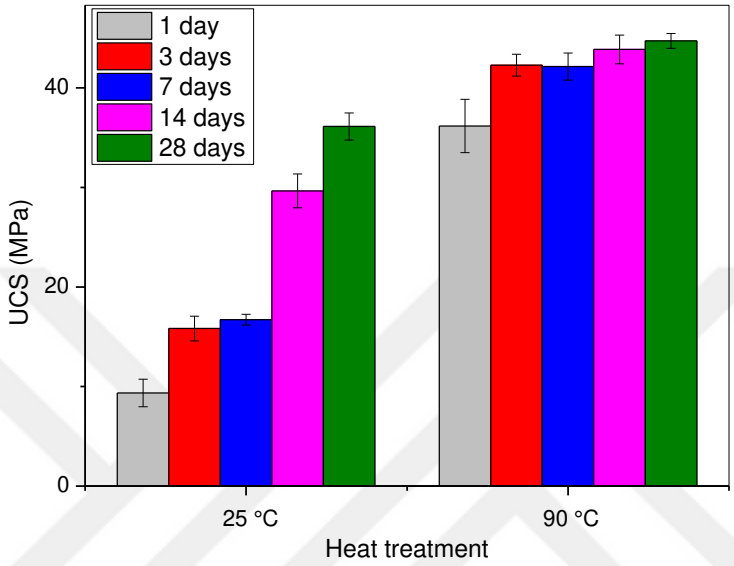

Figure 4.4. UCS test results for Series A experiments

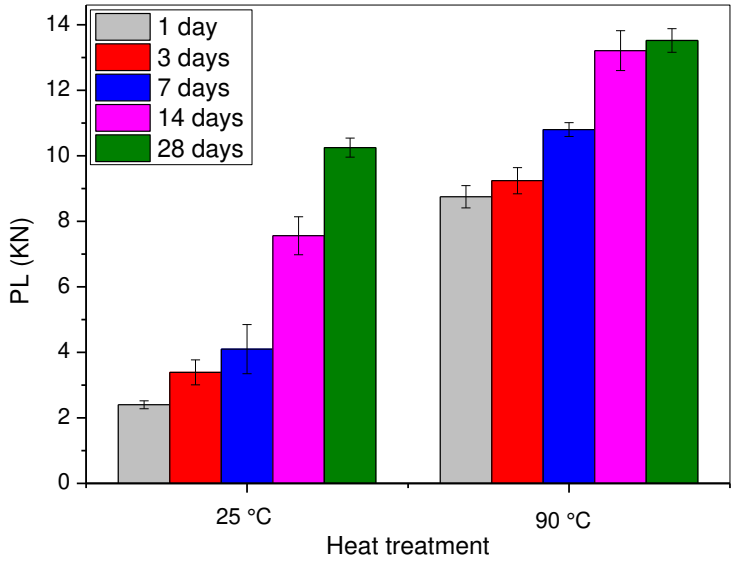

Figure 4.5. PL test results for Series A experiments

Table 4.2. PSS and SH tests results for Series A experiments

Curing Temperature	PSS (km/s)	SH (mm)
25 °C	6.22	43.90
90 °C	6.13	50.37

It was noticed from the results of the UCS test that are clear in (Figure 4.4) that the effect of heat treatment at a temperature of 90 °C was achieved better than leaving the samples at room temperature. It was noticed by test the clear PL in (Figure 4.5) that the results were increased by the effect of heat treatment.

Through the test of SH was increased by the effect of heat treatment but PSS test decreased (Table 4.2).

In Series B, the effect of the proportion and type of $NaOH/Na_2SiO_3$ alkaline steroids was studied.

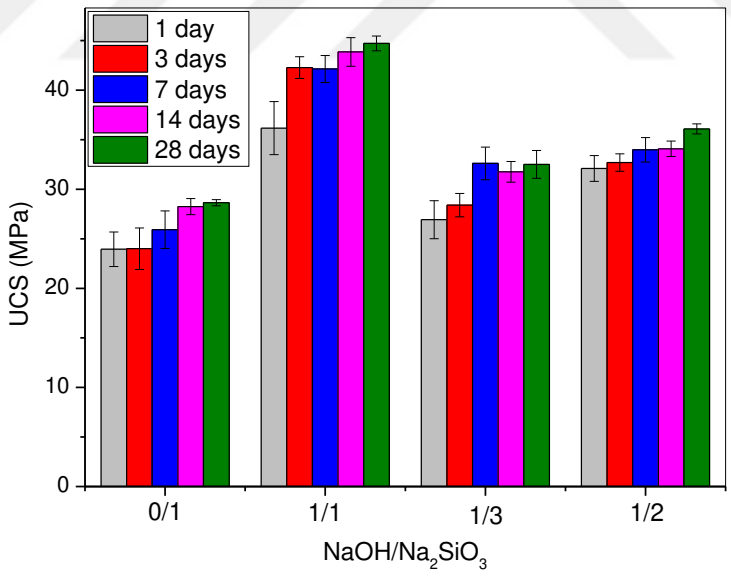

Figure 4.6. UCS test results for Series B experiments

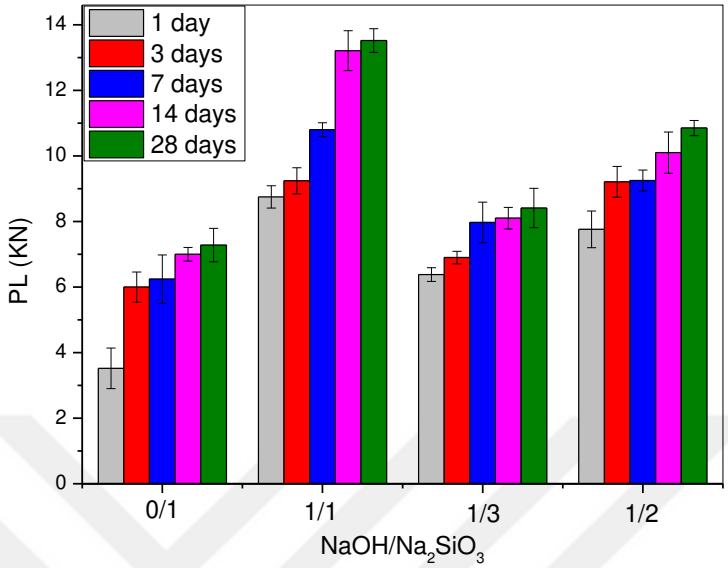

Figure 4.7. PL test results for Series B experiments

Table 4.3. PSS and SH tests results for Series B experiments

$NaOH/Na_2SiO_3$	PSS (km/s)	SH (mm)
0/1	6.25	22.18
1/1	6.13	50.37
1/2	6.32	28.45
1/3	6.34	36.22

These experiments were conducted with a percentage of fly ash of 65% and an alkaline activated of 35%. The ratio of the alkaline activator was 1:1 ($NaOH/Na_2SO_3$). After leaving the sample in the furnace heat treatment at 90 °C and checking the results after days 1, 3, 7, 14, and 28, this ratio achieved the highest value from the UCS test as shown in (Figure 4.6). Achieved a ratio of 1/1 ($NaOH/Na_2SO_3$), the highest value of the PL test after leaving the sample in the furnace heat treated at a temperature of 90 °C and measured after days 1, 3, 7, 14, and 28 as shown in (Figure 4.7). Due to the sound taking longer to pass through the

sample during the PSS test, the speed of sound decreased at a value of 1/1 ($NaOH/Na_2SO_3$). Due to the sample's surface completely hardening as revealed in the SH test, the alkaline activator 1/1 ($NaOH/Na_2SO_3$) ratio attained the best value (Table 4.3).

In the C Series, heat treatment time and its effect on concrete properties are studied.

Figure 4.8. Heat curing furnace for geopolymer concrete samples

These experiments were carried out with 65% fly ash and 35% active alkali. The ratio of alkaline activator was 1/1 ($NaOH/Na_2SO_3$) after the sample was left in the furnace by heat treatment at 90 °C for 28 days as shown in (Figure 4.8). After checking the results after days 1, 3, 7, 14, and 28, this ratio achieved the highest value from the UCS test as shown in (Figure 4.9). After 28 days of heat treatment,

he obtained the highest PL value as determined by the PSS test on days 1, 3, 7, 14, and 28 as indicated in (Figure 4.10). The velocity of sound decreased after 28 days in the heat-treated oven at 90 °C because sonication takes longer to pass through the sample. Through a 28 day SH test in a heat-treated furnace at 90 °C, the best value was achieved due to the complete solidification that appeared on the sample surface as shown in (Table 4.4).

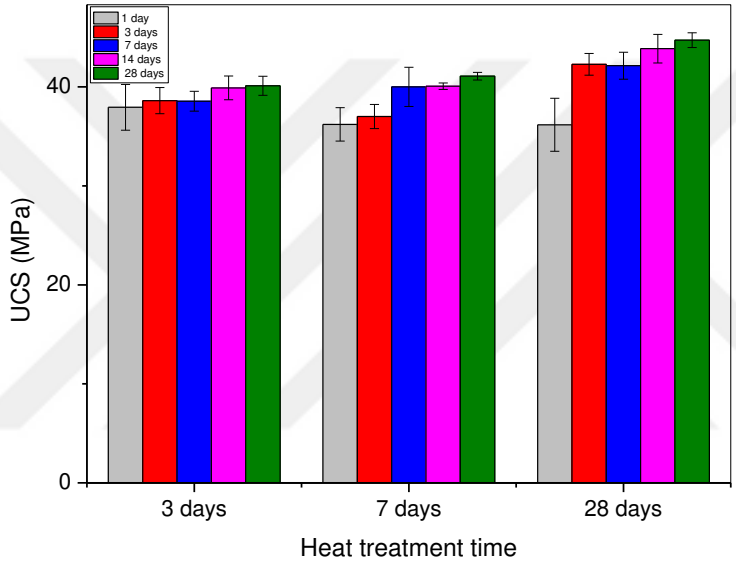

Figure 4.9. UCS test results for Series C experiments

Table 4.4. PSS and SH test results for Series C experiments

Heat treatment time (day)	PSS (km/s)	SH (mm)
3	6.21	41.97
7	6.17	44.83
28	6.13	48.26

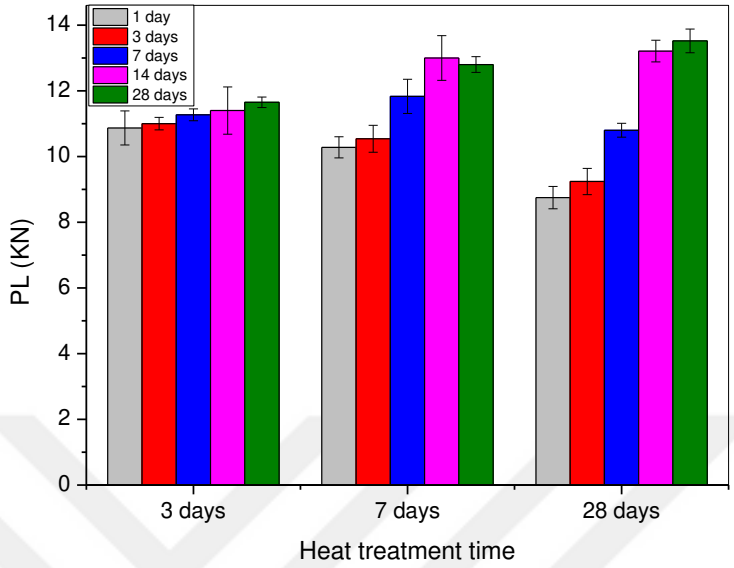

Figure 4.10. PL test results for Series C experiments

In the D Series, the percentage of fly ash to alkali liquid and its effect on the properties of concrete are studied.

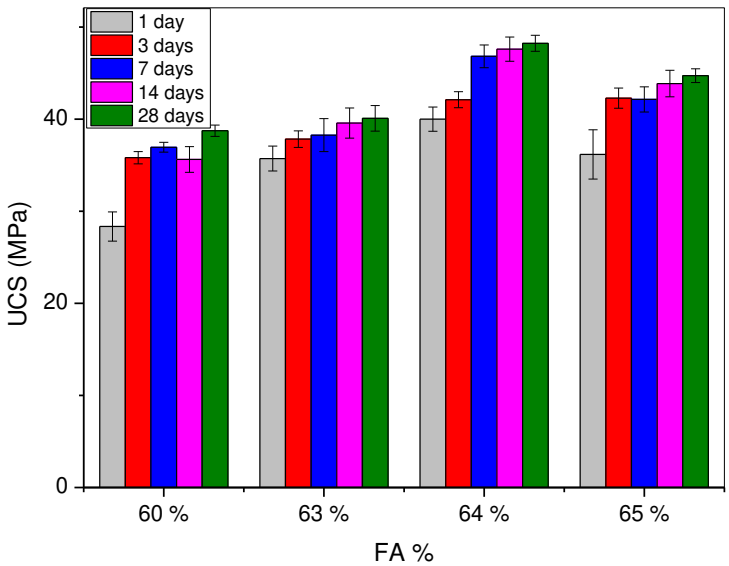

Figure 4.11. UCS test results for Series D experiments

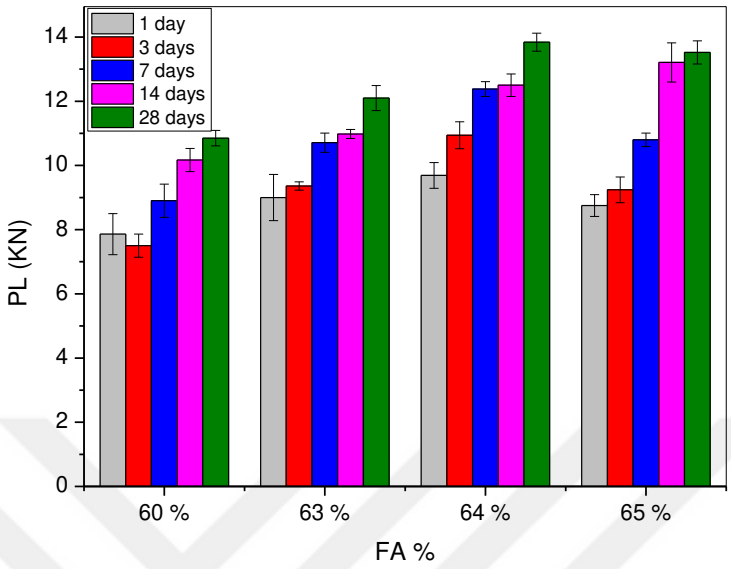

Figure 4.12. PL test results for Series D experiments

Table 4.5. PSS and SH test results for Series D experiments

FA/Liquid	PSS (km/s)	SH (mm)
60	6.51	43.28
63	6.29	45.16
64	6.24	56.71
65	6.13	50.37

The ratio of fly ash to the alkaline liquid was studied, which gives high results for the sample, and it was found that 64 % achieved the highest value for UCS, as shown in (Figure 4.11), and also in the PL test, 64% of fly ash on the alkaline activator achieved the highest values, as shown in (Figure 4.12). And when the sample was left for 28 days, the values were found to improve over time. As shown in (Table 4.5), the values of PSS test decreased and SH test increased at a rate of 64% of fly ash on the alkaline activator.

4.2. Production of Geopolymer Concrete Using the Box-Behnken Design (DOE)

Experiments were conducted using the Box Behnken design technique to find out the percentages of NaOH/Na_2SiO_3 on the alkaline activator that give high results for the sample and the appropriate heat treatment time, at 65% of FA at 36% of alkali activator as shown in (Table 4.6).

Table 4.6. Applied box behnken experiment design

Run	NaOH	Na_2SiO_3	Heat treatmente time(days)	UCS Mpa	PL KN	PSS km/s	SH mm
1	1	1	3	36.14	11	6.18	42.01
2	0	1	3	24.91	5.16	6.80	18.63
3	0	1	28	28.64	7.28	6.73	22.17
4	2	3	7	29.56	7.63	6.52	23.65
5	1	3	28	36.09	10.81	6.25	35.22
6	0	1	7	27.42	7	6.69	20.73
7	1	2	3	30.24	8.16	6.45	25.38
8	2	1	7	15.97	4	7.05	14.40
9	1	1	7	41.15	12.7	6.08	48.26
10	1	1	28	44.72	13.52	6.13	50.37
11	1	2	28	32.59	8.41	6.31	28.45
12	1	3	3	33.78	9	6.38	31.02

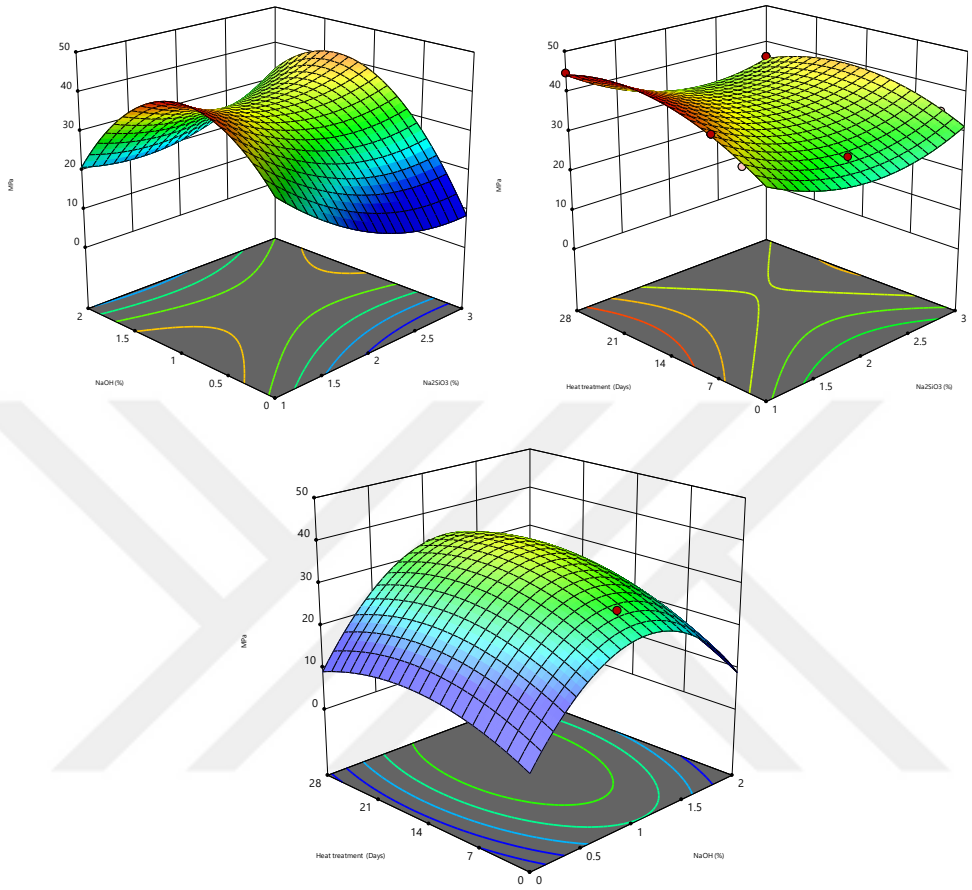

Figure 4.13. 3D graphics created according to UCS of 28 days

The ratio of 1/1 alkaline activated NaOH/Na_2SiO_3 achieved the highest value in the UCS test, then the values of the UCS test increased with the effect of heat treatment as shown in (Figure 4.13). Na_2SiO_3 had an effect by heat treatment, and as a result, the UCS test increased. NaOH had no obvious effect by heat treatment. The best UCS test value of 44.72 MPa is obtained when the NaOH/Na_2SiO_3 ratio is 1/1 and the sample is left in a heat treatment furnace for 28 days at a temperature of 90 °C respectively. According to the values, Experiment 10 is the ideal combination in particular.

UCS response (%)=35.84+3.62 X_1-2.66 X_2+3.70 X_3+8.61X_1X_2+1.87X_1X_3-

$1.69X_2X_3-18.81X^2_1+6.40X_2-6.01X^2_3$

Where X_1=NaOH, X_2=Na_2SiO_3, X_3=Heat treatment. (4.1)

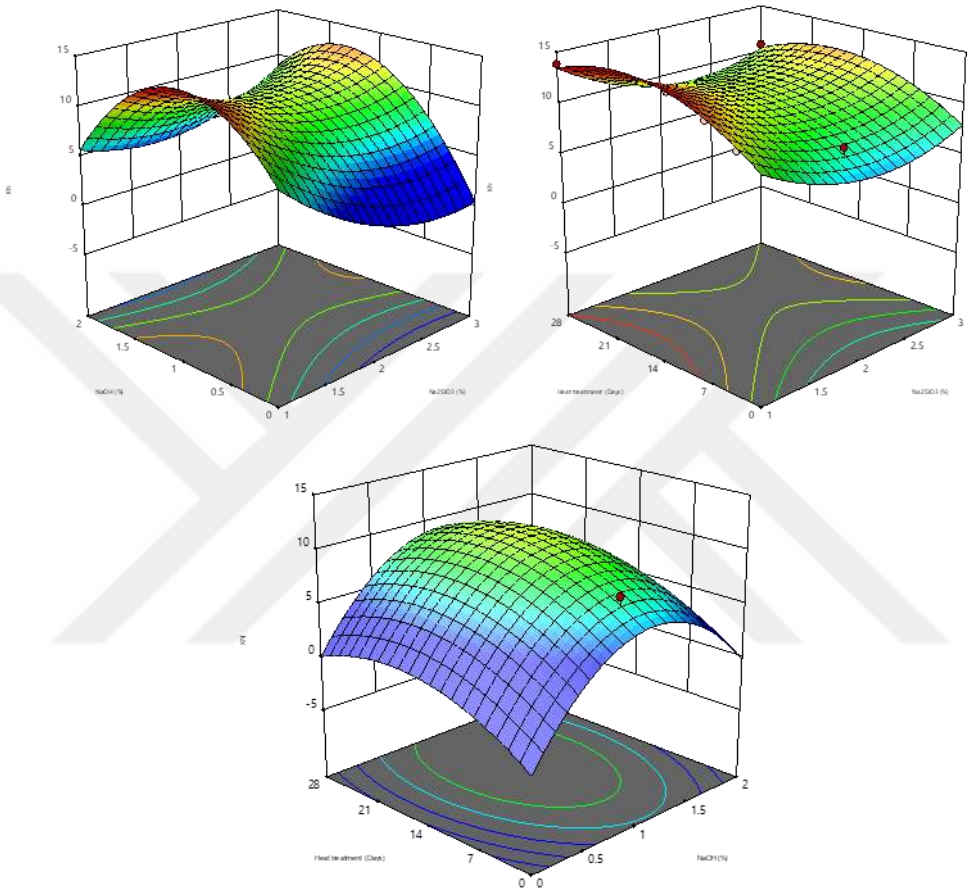

Figure 4.14. 3D graphics created according to PL of 28 days

In the PL test, the ratio of 1/1 alkaline activated NaOH/Na_2SiO_3 had the highest value, and the values of the PL test rose with the influence of heat treatment as shown in (Figure 4.14). The PL test increased as a result of the Na_2SiO_3 having an effect after heat treatment. After heat treatment, NaOH had no discernible effect. When the NaOH/Na_2SiO_3 ratio is 1/1 and the sample is placed in a heat treatment

furnace for 28 days at a temperature of 90 °C, the best PL test value of 13.52 KN is obtained. Experiment 10 appears to be the best combination based on the results.

PL response (%) = $10.59+1.45X_1-1.19X_2+1.58X_3+2.85X_1X_2+0.0856X_1X_3-0.2993X_2X_3-7.47X^2_1+2.84X^2_2-3.03X^2_3$,

Where X_1= NaOH, X_2= Na_2SiO_3, X_3= Heat treatment. (4.2)

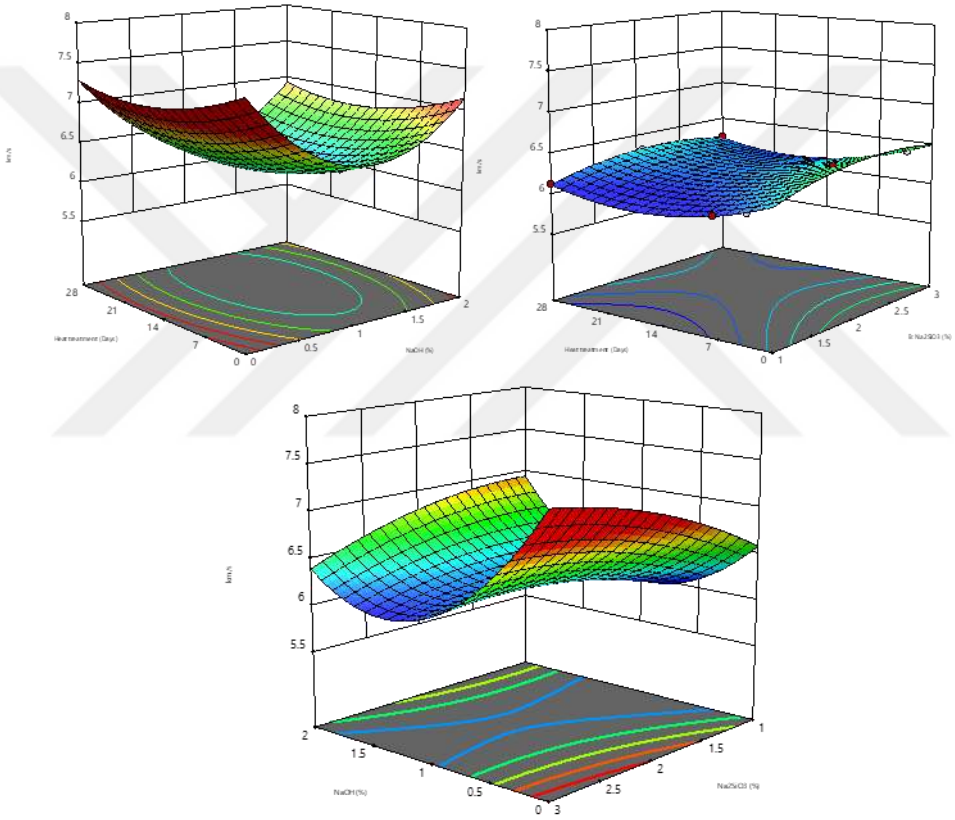

Figure 4.15. 3D graphics created according to PSS test of 28 days

The PSS test yielded the minimum value when the ratio of 1/1 alkaline activated NaOH/Na_2SiO_3 was used, and then the PSS test values slightly decreased as heat treatment was applied as shown in (Figure 4.15). The PSS test decreased as

a result of the Na_2SiO_3 impact during heat treatment. Heat treatment had no discernible effect on NaOH. When the NaOH/Na_2SiO_3 ratio is 1/1 and the sample is heat treated for 28 days at 90 °C, the best PSS test value of 6.13 km/s is obtained. Experiment 10 appears to be the best match based on the results.

PSS response (%) = $6.21+0.1778X_1+0.0823X_2-0.1089X_3-0.3585X_1X_2-0.0223X_1X_3+0.7905X_2X_3+1.46X^2_1+0.3592X^2_1-0.0869X^2_3$.

Where X_1= NaOH, X_2= Na_2SiO_3, X_3= Heat treatment. (4.3)

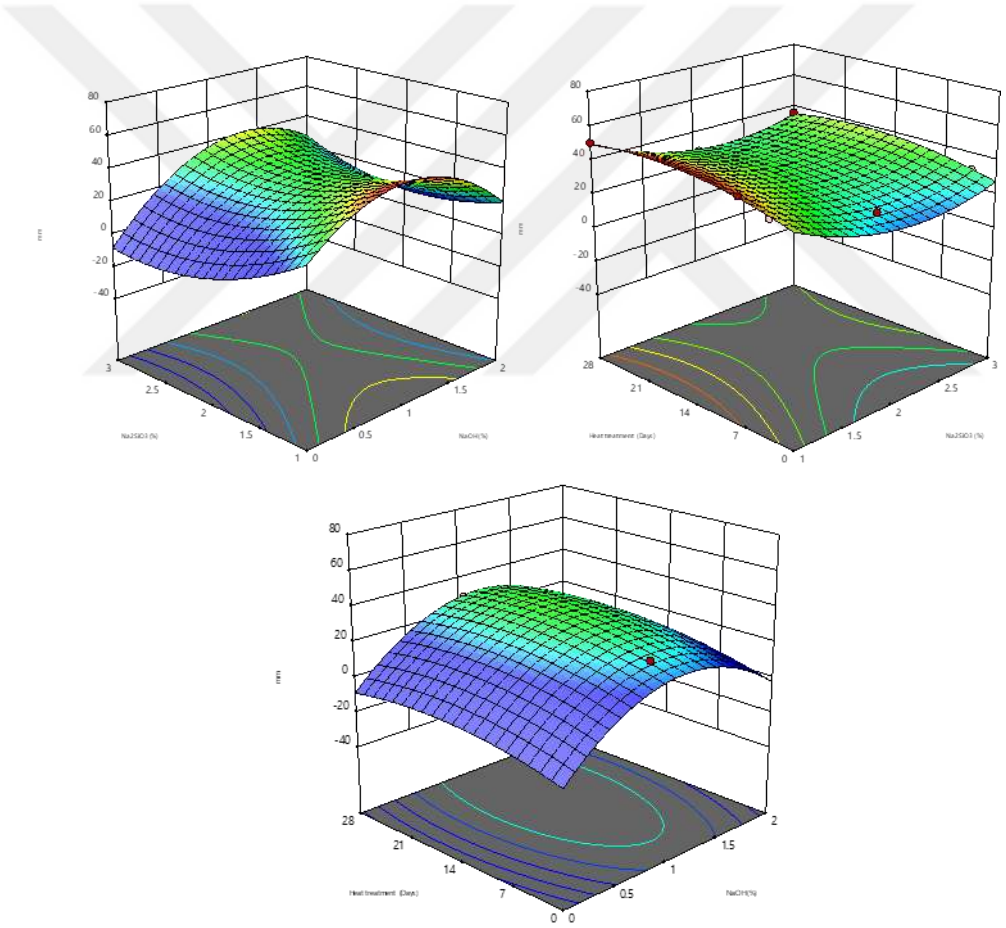

Figure 4.16. 3D graphics created according to SH of 28 days

The SH test yielded the maximum value when the ratio of 1/1 alkaline activated NaOH to Na_2SiO_3 was used, and then the SH test values grew when the heat treatment effect was applied as shown in (Figure 4.16). The SH test improved as a result of the Na_2SiO_3 having an effect after heat treatment. After heat treatment, there was no discernible effect of NaOH. When the NaOH/Na_2SiO_3 ratio is 1/1 and the sample is placed in a heat treatment furnace for 28 days at 90 °C, the best SH test result of 50.37 mm is obtained. Experiment 10 appears to be the optimal combination based on the results.

SH response (%) = $32.18+7.78X_1-6.42X_2+4.52X_3+10.18X_1X_2+1.41X_1X_3-0.7297X_2X_3-28.88X^2_1+13.20X^2_2-7.10X^2_3$.

Where X_1= NaOH, X_2= Na_2SiO_3, X_3= Heat treatment. (4.4)

Figure 4.17. Geopolymer concrete samples

4.3. Production of Geopolymer Concrete Using CCB

Experiments were conducted to add calcined calcium bentonite as an alternative to fly ash at 5%, 10%, 15%, 20%, and 25% to determine the duration of the effect on the properties of geopolymer concrete. The sample was left under heat treatment at a temperature of 90 °C for 28 days.

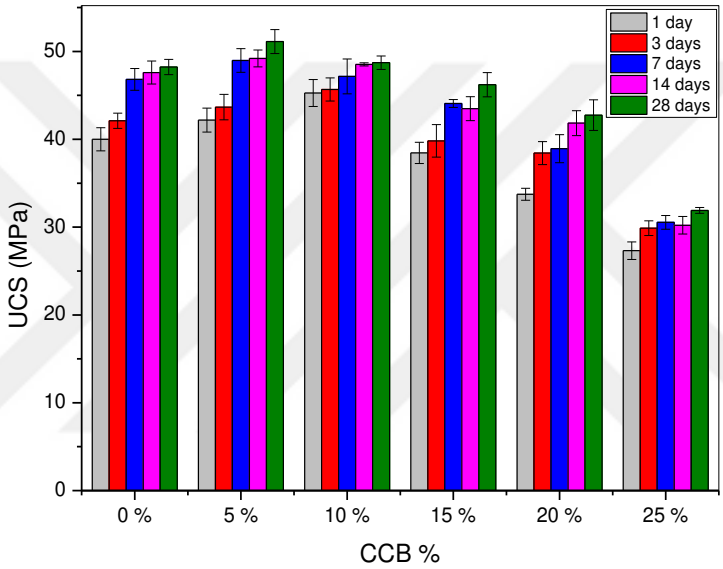

Figure 4.18. Effect of calcined Ca-Bentonite addition on UCS

These experiments were carried out by adding 64% of fly ash and 36% of alkali activator in a ratio of 1/1 of NaOH and Na_2SO_3. The addition of calcined calcium bentonite was a substitute for fly ash at a ratio of 5%, 10%, 15%, 20%, and 25%. The sample was left in a heat treatment furnace at a temperature of 90 °C. Tests were carried out after 1, 3, 7, 14, and 28 days.

When calcined calcium bentonite is added at 5% and 10%, the UCS values increase, and then the UCS values decrease when added by 15%, 20, and 25% as shown in (Figure 4.18).

When adding 5% of calcined calcium bentonite, the PL test decreases slightly, but when adding 10%, 15%, 20%, and 25% of calcined calcium bentonite, it decreases significantly as shown in (Figure 4.19).

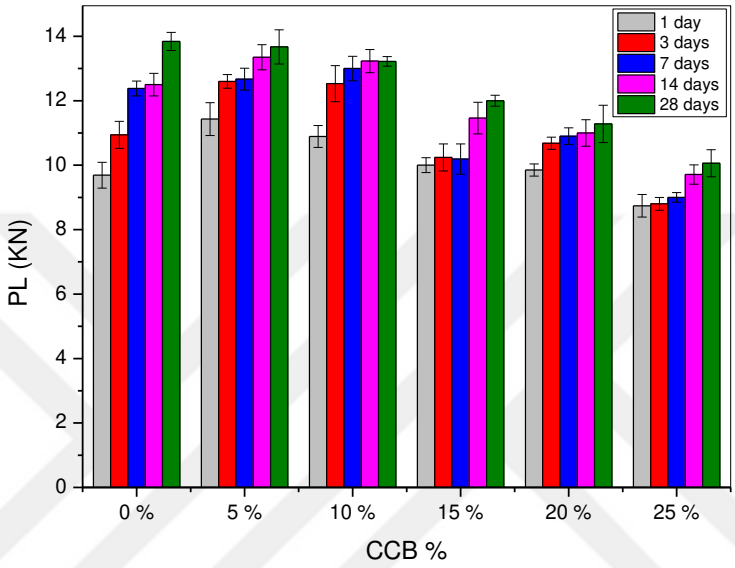

Figure 4.19. Effect of calcined Ca-Bentonite addition on PL

An increase in the UCS test is due when 5% of CCB is added to the polymerization reaction, which makes it more active and cohesive. When there is an increase in the addition of CCB material in the concrete mixture, the UCS and PL test readings decrease due to the large addition of the material. This leads to the absorption of large quantities of alkaline activator due to the special inflation of CCB, and this leads to a decrease in the readings.

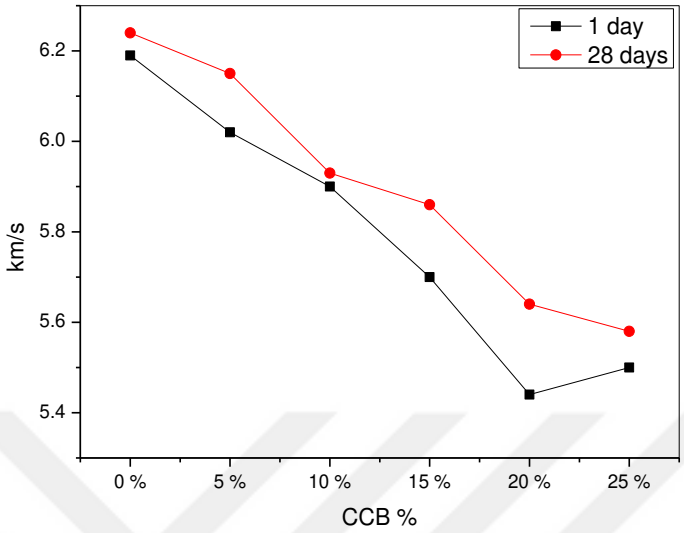

Figure 4.20. Effect of calcined Ca-Bentonite addition on PSS

When calcined calcium bentonite is added at 5%, 10%, 15%, 20%, and 25%, the PSS and SH values decreased. At 1 day, and 28 days, the PSS and SH tests values were computed as shown in (Figure 4.20 and Figure 4.21). When CCB is added to the concrete mixture, the reading of the PSS test decreases because CCB occupies voids and cracks within the concrete, and this leads to the difficulty of sound passing. Concrete weight slightly increases when calcined calcium bentonite is added as shown in (Figure 4.22).

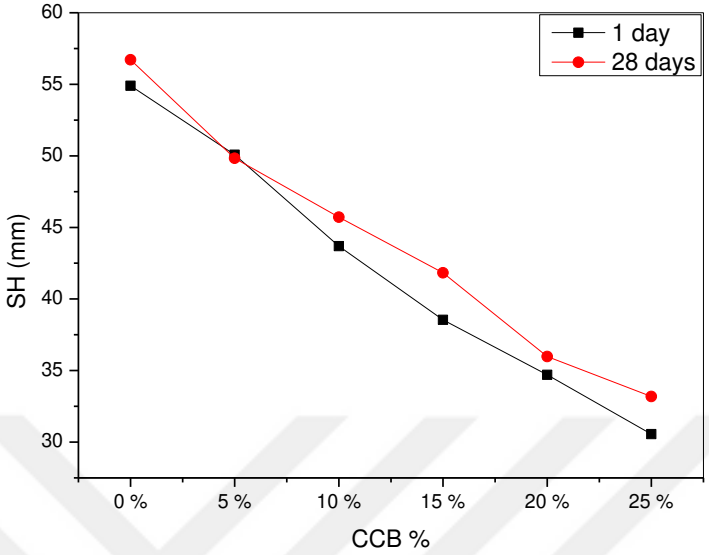

Figure 4.21. Effect of calcined Ca-Bentonite addition on SH

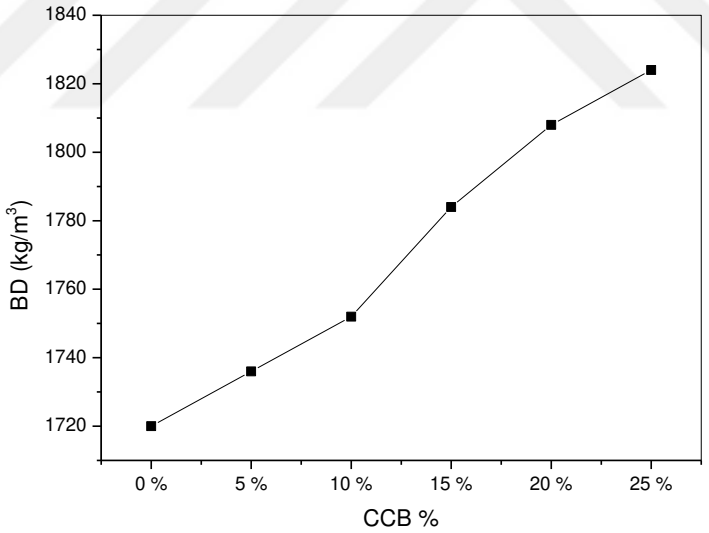

Figure 4.22. Effect of calcined Ca-Bentonite addition on the density of concrete

4.4. Production of Geopolymer Concrete Using SG

Experiments were conducted to add slag as an alternative to fly ash at 5%, 10%, 15%, 20%, and 25% to determine the duration of the effect on the properties

of geopolymer concrete. The sample was left under heat treatment at a temperature of 90 °C for 28 days.

The studies were carried out by mixing 64% fly ash with 36% alkali activator in a 1/1 ratio of NaOH and Na_2SO_3. At a ratio of 5%, 10%, 15%, 20%, and 25%, slag was used to replace fly ash. The sample was placed in a heat treatment furnace at a temperature of 90 °C. Tests were performed after 1, 3, 7, 14, and 28 days.

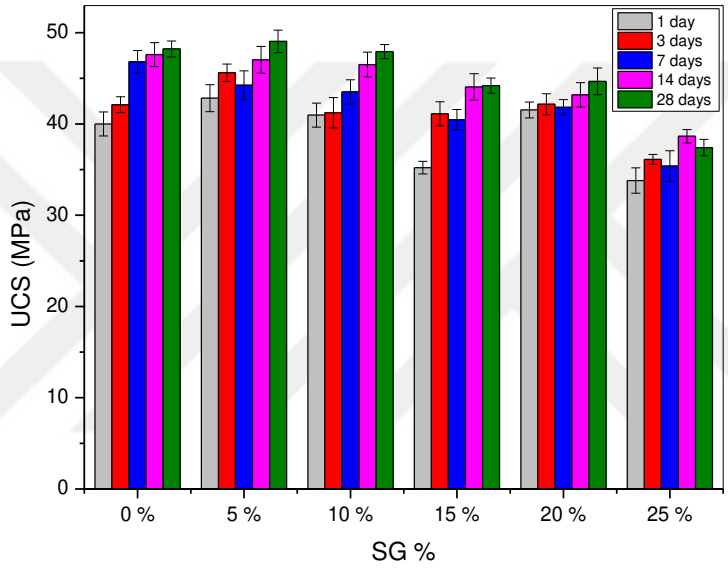

Figure 4.23. Effect of slag addition on UCS

When slag is added at 5% the UCS values increase, but when added at, 10%, 15%, 20%, and 25%, the UCS values decreased as shown in (Figure 4.21). When adding 5% of slag, the PL test decreases slightly, but when adding 10%, 15%, 20%, and 25% of slag, it decreases significantly as shown in (Figure 4.22). At 1 day,3 days,7 days, 14 days, and 28 days, the UCS and PL values were computed. When the sample was heat treated for a longer period of time, the UCS and PL values increased. The highest UCS and PL values were reached after 28 days of therapy.

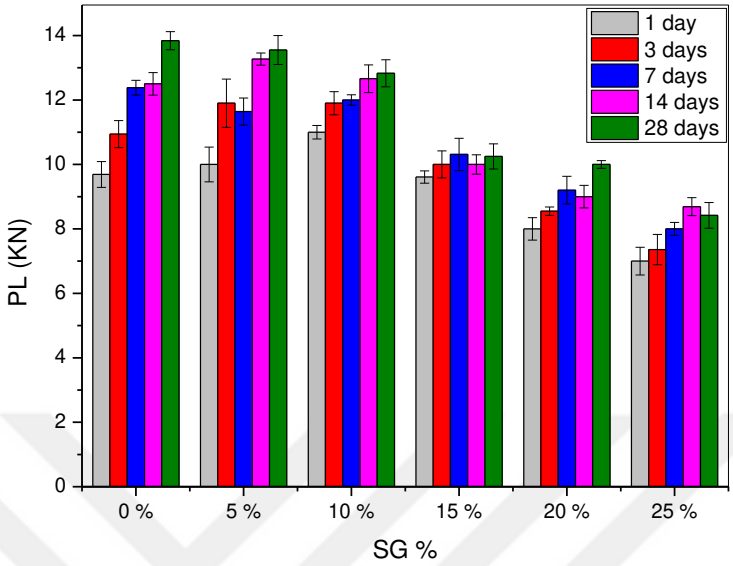

Figure 4.24. Effect of slag addition on PL

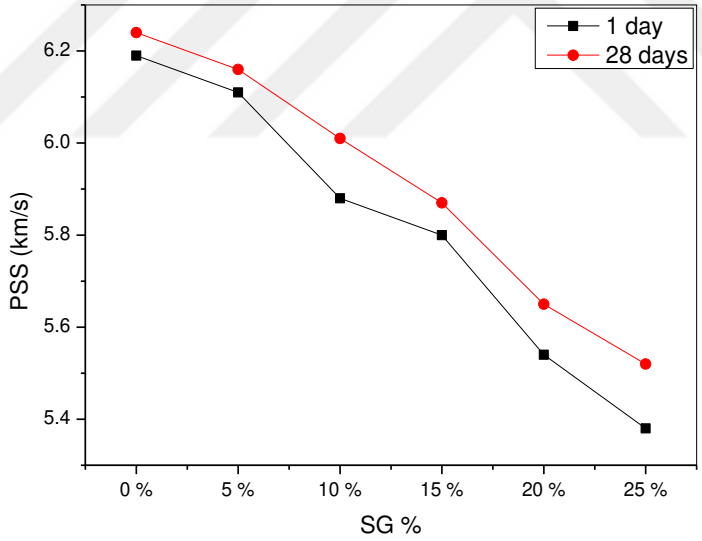

Figure 4.25. Effect of slag addition on PSS

When slag is added the PSS and SH values decreased. The PSS and SH values were calculated after 1 day, and 28 days as shown in (Figure 4.23 and Figure 4.24). Concrete weight increases when slag is added as shown in (Figure 4.25).

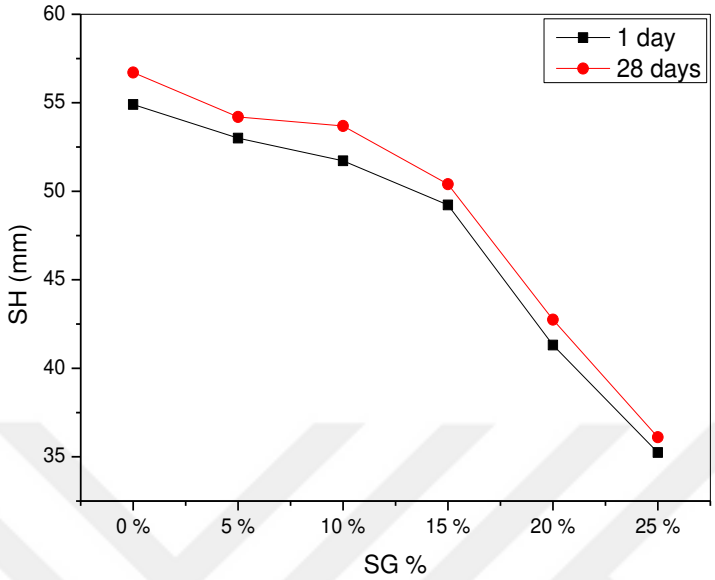

Figure 4.26. Effect of slag addition on SH

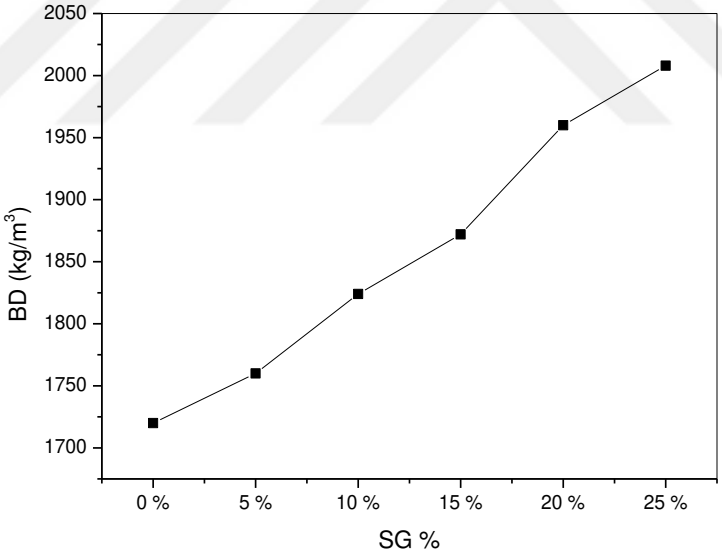

Figure 4.27. Effect of slag addition on the BD of concrete

4.5. The Box-Behnken Design was Used to Create Geopolymer Concrete from Calcined Calcium Bentonite and Slag.

Experiments were carried out using the box behnken design program to create geopolymer concrete based on replacing fly ash with slag and calcined calcium bentonite to obtain the best properties of concrete as shown in (Table 4.7). The samples were left for 28 days, and then the samples' properties were examined.

Table 4.7. Applied Box Behnken experiment design

Run	Solid/Liquid	CCB %	SG %	UCS MPa	PL KN	PSS km/s	SH mm	BD kg/m^3
1	64	5	5	51.33	14.05	6.41	63.17	1792
2	63	10	5	42.29	7.4	4.01	31.65	1820
3	64	10	10	48.27	11.86	6.02	57.11	1884
4	65	10	15	43.84	8	4.53	35.16	1920
5	63	10	15	45.41	9.35	5.48	50.36	1868
6	63	5	10	44.97	9.07	5.32	46.2	1836
7	64	15	15	43.58	9.63	4.27	33.81	1892
8	64	15	5	47.19	10.21	5.82	55.69	1868
9	65	10	5	42.35	7.88	3.68	21.76	1884
10	64	10	5	50.08	13.41	6.29	60.11	1852
11	64	5	15	44.89	8.57	4.96	40.31	1884
12	63	15	10	44.87	8.16	4.75	37.9	1852
13	65	15	10	39.41	7.11	3.90	25.56	1900
14	63	10	10	45.16	8.9	5.13	43.59	1844
15	65	5	10	46.71	10	5.6	51.67	192

Calcined calcium bentonite has a high content of silica and alumina, which are important in geopolymer concrete. EDX analysis of a concrete sample shows

that it mainly contains silica, alumina, and calcium oxide, in addition to magnesium and iron (Figure 4.26).

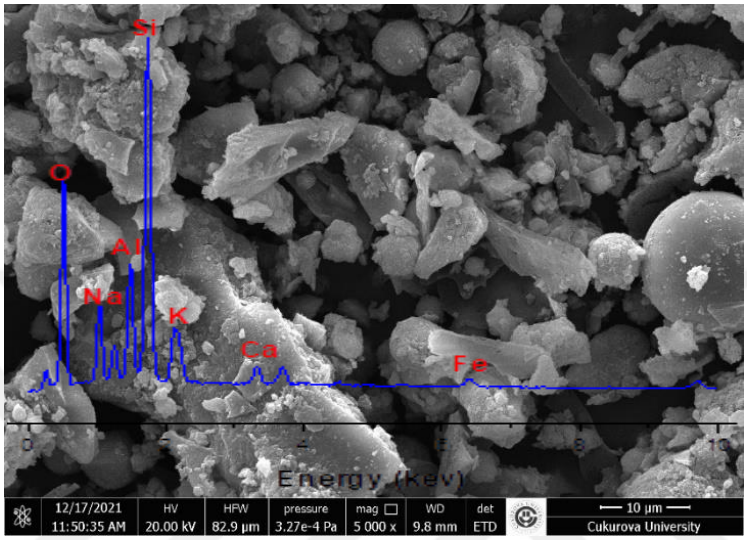

Figure 4.28. SEM and EDX diagram of geopolymer concrete

Figure 4.29. Geopolymer concrete samples

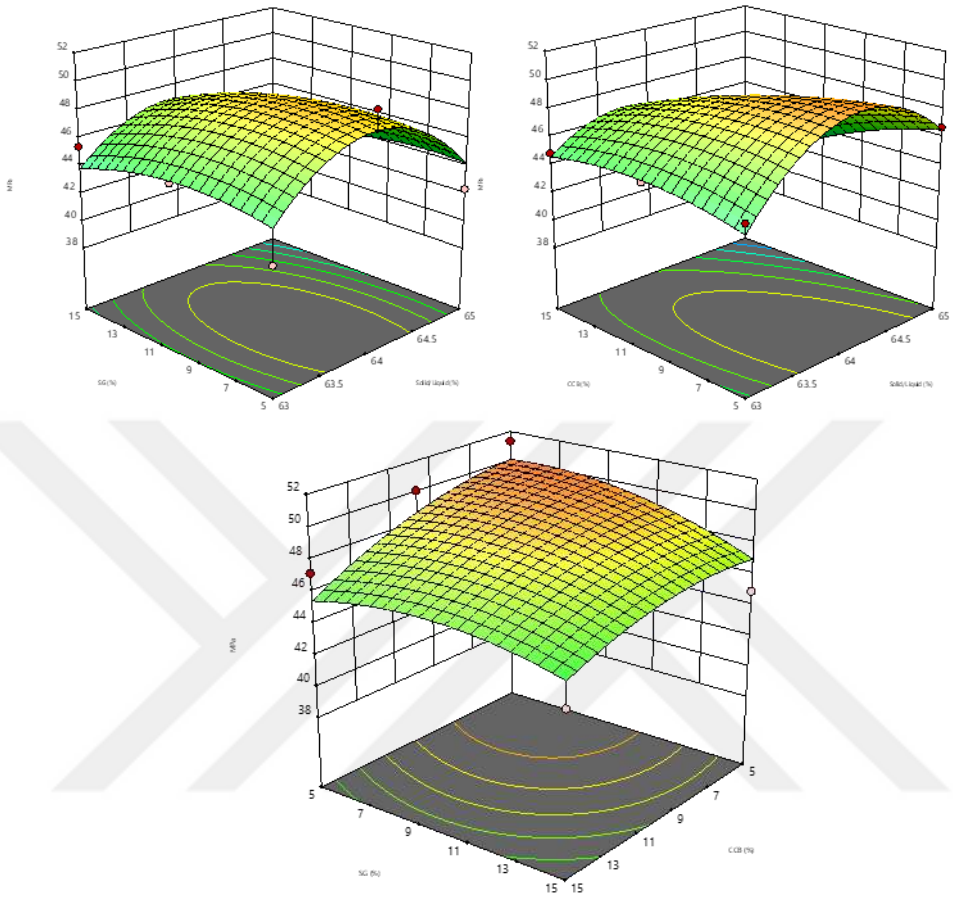

Figure 4.30. 3D graphics created according to UCS of 28 days

The results showed that 64% of solid, 36% of alkali activator, plus 5% of calcium bentonite, 5% of slag and 90% of fly ash got the highest value from the UCS test after 28 days of leaving the samples in the heat treatment furnace as shown in (Figure 4.28). When the percentage of slag and the percentage of calcined calcium bentonite increase by more than 10 %, the value of the UCS test decreases. The best UCS test result of 51.33 MPa is obtained when 5% CCB and 5% SG are added to the sample, which consists of 64% of solid and 36% of liquid, and placed in a heat treatment furnace for 28 days at 90 °C. Based on the results, Experiment 1 appears to be the optimal combination.

UCS response (%) = $48.89-0.6340X_1-1.61X_2-0.8531X_3-1.80X_1X_2-0.4075X_1X_3+0.7050X_2X_3-4,20X^2_1-0.8879X^2_2-1.06X^2_3$.

Where X_1= Solid/Liquid, X_2= CCB%, X_3=SG%. (4.5)

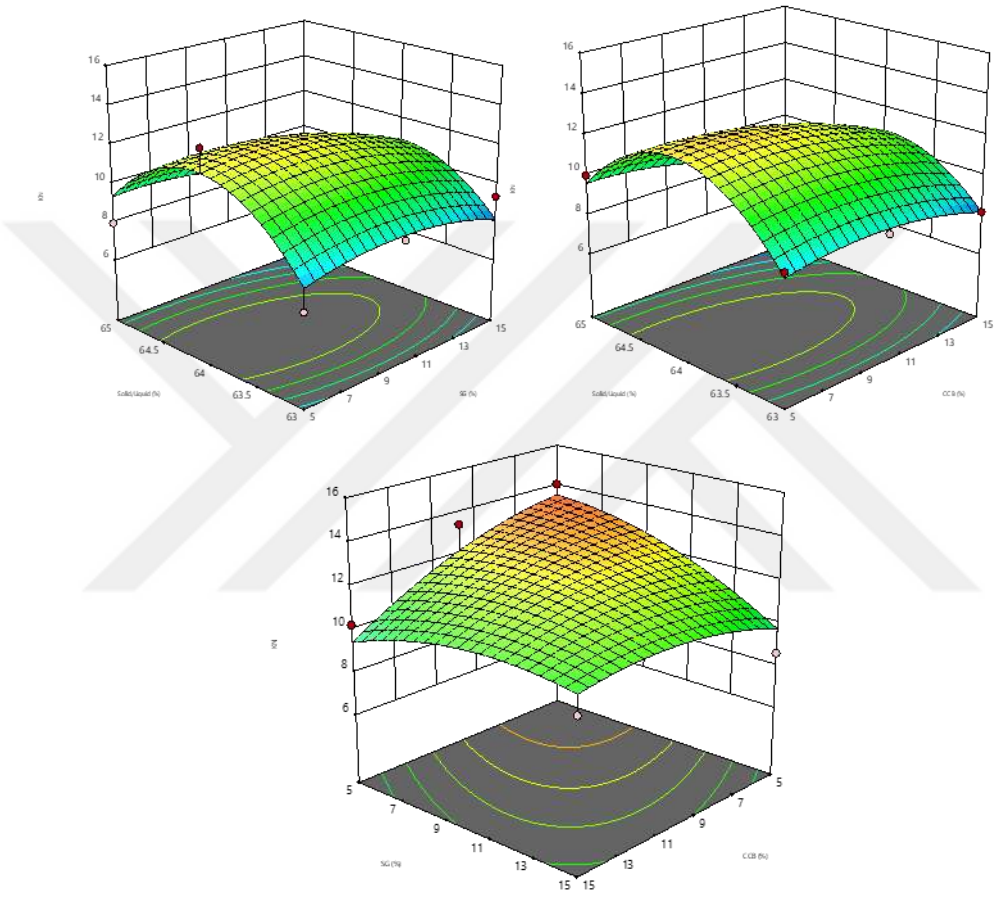

Figure 4.31. 3D graphics created according to PL of 28 days

After 28 days of leaving the samples in the heat treatment furnace, the PL test revealed that 64 % of fly ash, 36% of alkali activator, plus 5% of calcium bentonite, 5% of slag and 90% of fly ash had the greatest value as shown in (Figure 4.29). The value of the PL test drops when the percentages of slag and calcined calcium bentonite increase by more than 10%. The best PL test result of 14.05 KN

is obtained when 5% CCB and 5% SG are added to the sample, which consists of 64% of solid and 36% of liquid, and placed in a heat treatment furnace for 28 days at 90 °C. Based on the results, Experiment 1 appears to be the optimal combination.

PL response (%) = $12.33-0.0801X_1-0.8162X_2-0.6569X_3-0.4950X_1X_2-0.4700X_1X_3+1.23X_2X_3-3.23X^2_1-0.7020X^2_2-0.8056X^2_3$,

Where X_1= Solid/Liquid, X_2= CCB%, X_3=SG%. (4.6)

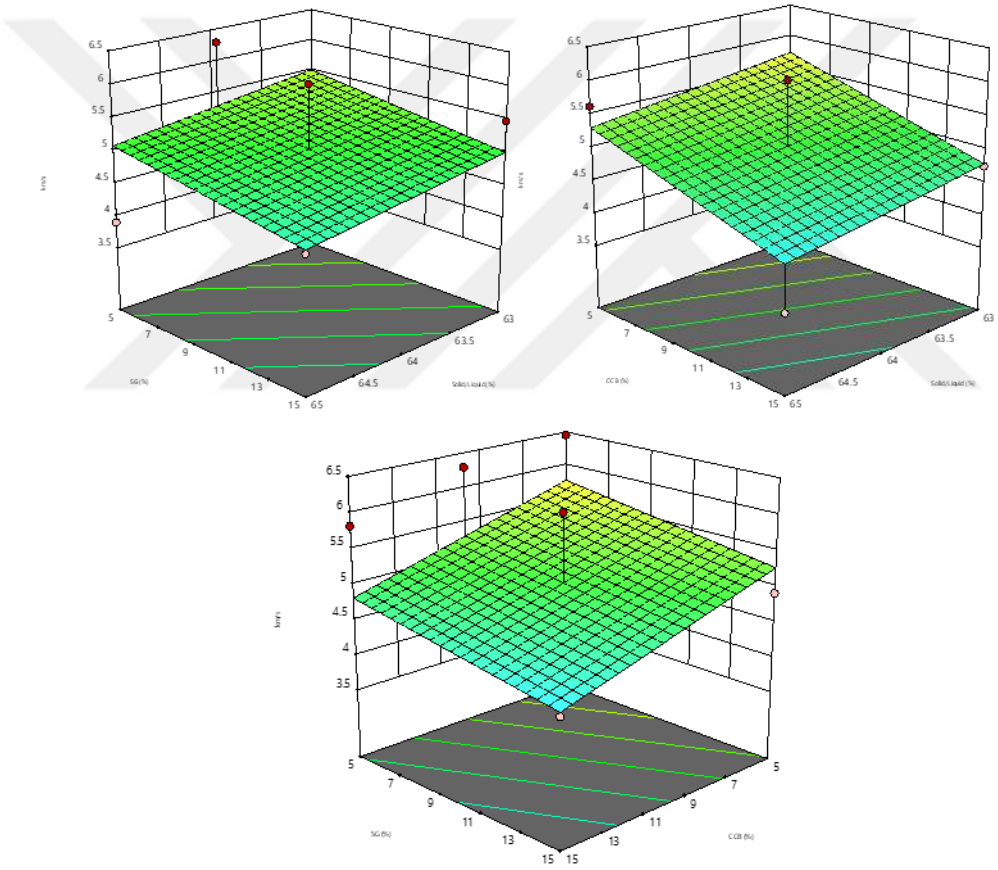

Figure 4.32. 3D graphics created according to PSS of 28 days

After 28 days in the heat treatment furnace, the PSS test revealed that 64% of fly ash, 36 % of alkali activator, plus 5% of calcium bentonite, 5% of slag and

90% of fly ash had the maximum value as shown (Figure 4.30). When the percentages of slag and calcined calcium bentonite increase by more than 10%, the value of the PSS test decreased. The best PSS test result of 3.68 km/s is obtained when 10% CCB and 5% SG are added to the sample, which consists of 64% of solid and 36% of liquid, and placed in a heat treatment furnace for 28 days at 90 °C. Based on the results, Experiment 9 appears to be the optimal combination.

PSS response (%) = $5.05-0.2124X_1-0.4725X_2-0.2480X_3$,

Where X_1= Solid/Liquid, X_2= CCB, X_3=SG. (4.7)

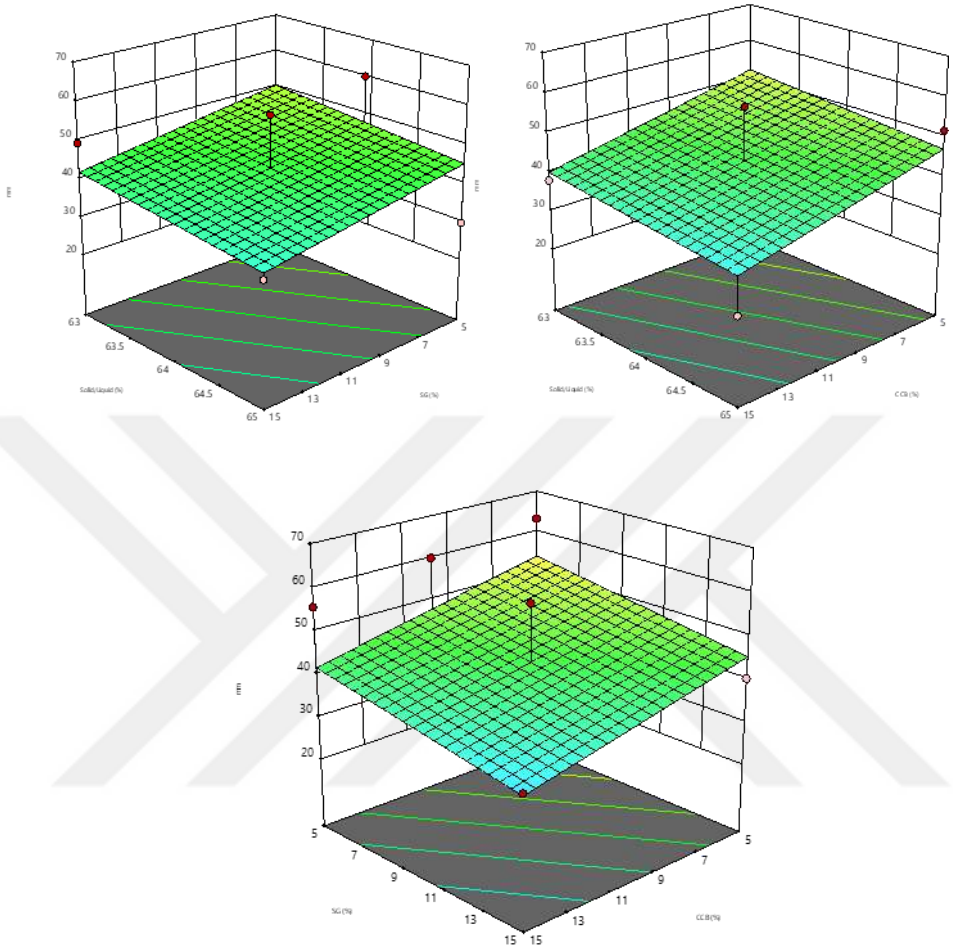

Figure 4.33. 3D graphics created according to SH of 28 days

After 28 days in the heat treatment furnace, the SH test revealed that 64% of fly ash, 36% of alkali activator, plus 5% of calcium bentonite, 5% of slag and 90% of fly ash had the maximum value as shown in (Figure 4.31). The value of the SH test drops when the percentages of slag and calcined calcium bentonite increase by more than 10%. The best PSS test result of 63.17 mm is obtained when 5% CCB and 5% SG are added to the sample, which consists of 64% of solid and 36% of liquid, and placed in a heat treatment furnace for 28 days at 90 °C. Based on the results, Experiment 1 appears to be the optimal combination.

SH response (%) = $43.62-2.55X_1-6.04X_2-4.23X_3$,

Where X_1= Solid/Liquid, X_2= CCB%, X_3=SG%. (4.8)

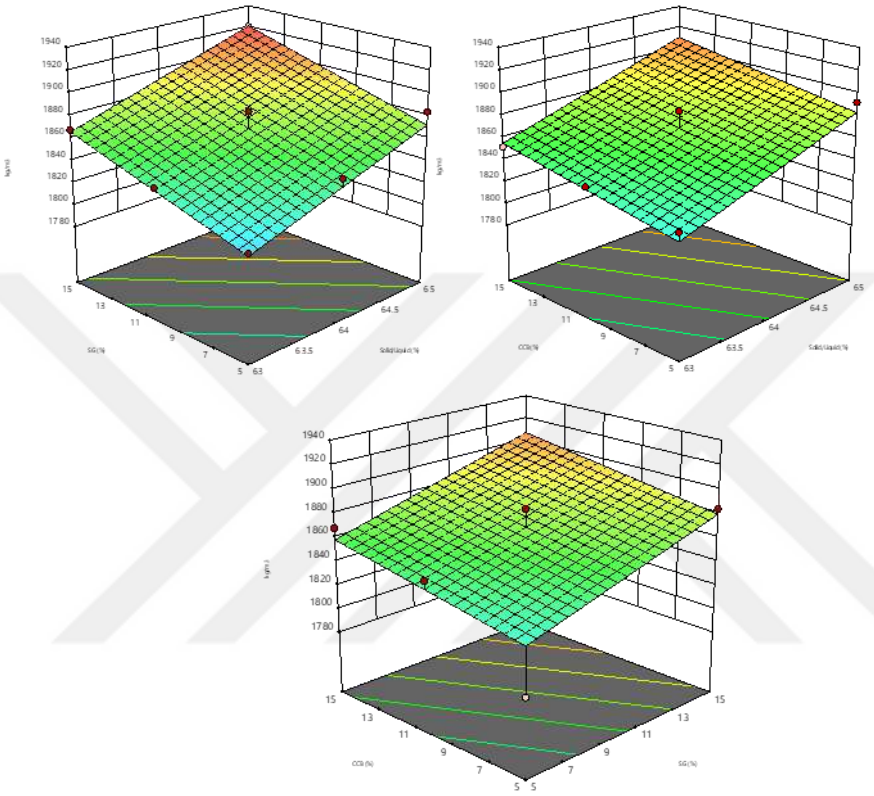

Figure 4.34. 3D graphics created according to the BD of concrete

The weight of concrete increases with the increase in the percentage of slag in the basic grade and the percentage of calcined calcium bentonite in geopolymer concrete as shown in (Figure 4.32). The weight of geopolymer concrete increases when the percentage of fly ash is increased and the percentage of alkali activator is reduced.

BD response (%) =$1771.46+27.50X_1+9.00X_2+20.38X_3$,

Where X_1= Solid/Liquid, X_2= CCB%, X_3=SG%. (4.9)

4.6. The Box-Behnken Design was Used to Create Geopolymer Concrete from Expanded Polystyrene (EPS) and Calcined Calcium Bentonite.

Experiments were carried out using the Box Behnken design program to create geopolymer concrete based on replacing fly ash with Expanded Polystyrene (EPS) and calcined calcium bentonite as shown in (Table 4.8). The samples were left for 28 days, and then the samples' properties were examined.

Table 4.8. Applied Box Behnken experiment design

Run	CCB %	Size Of EPS mm	EPS %	UCS MPa	PL KN	PSS km/s	SH mm	BD kg/m^3
1	5	5	0.1	27.08	3.17	9.35	23.16	1392
2	5	7	0.5	21.93	2	10.44	16.02	1264
3	15	5	0.3	21.05	1.9	9.07	15.22	1460
4	5	3	0.1	28.56	3.49	8.45	24.97	1560
5	15	5	0.5	19.74	1.38	9.32	12.36	1444
6	10	5	0.5	23.69	2.4	9.17	18.54	1400
7	10	5	0.3	25.02	2.7	8.95	20.08	1420
8	5	5	0.3	25.73	2.99	9.65	18.61	1384
9	10	3	0.1	27.86	3.4	8.43	22.74	1584
10	10	7	0.3	22.16	1.89	10.11	16.80	1300
11	5	3	0.5	26.71	2.9	8.65	20.01	1520
12	5	5	0.5	24.89	2.5	9.83	17.59	1368
13	15	3	0.1	25.31	2.8	8.37	18.94	1592
14	15	7	0.1	20.15	1.64	9.86	13.11	1320
15	5	7	0.1	23.62	2.2	10.18	16.44	1292

This study investigated the production of lightweight geopolymer concrete by replacing fly ash with expanded polystyrene EPS with a size of 3mm, 5mm, and 7mm and quantity (0.1%, 0.3%, and 0.5%). The percentage of fly ash was 64% and

the percentage of alkali activator was 36%, in addition to calcined calcium bentonite with an amount of (5%, 10%, and 15%) which was replaced by fly ash. Lightweight concrete with a density of 1592-1264 kg/m^3 was obtained.

Figure 4.35. Geopolymer concrete samples

Lightweight geopolymer concrete is produced by adding fly ash as a base grade with percentages of calcined calcium bentonite and EPS. Because of the size of the EPS, it occupies a place inside the mold, and thus the weight of the geopolymer concrete is reduced as shown in (Figure 4.35).

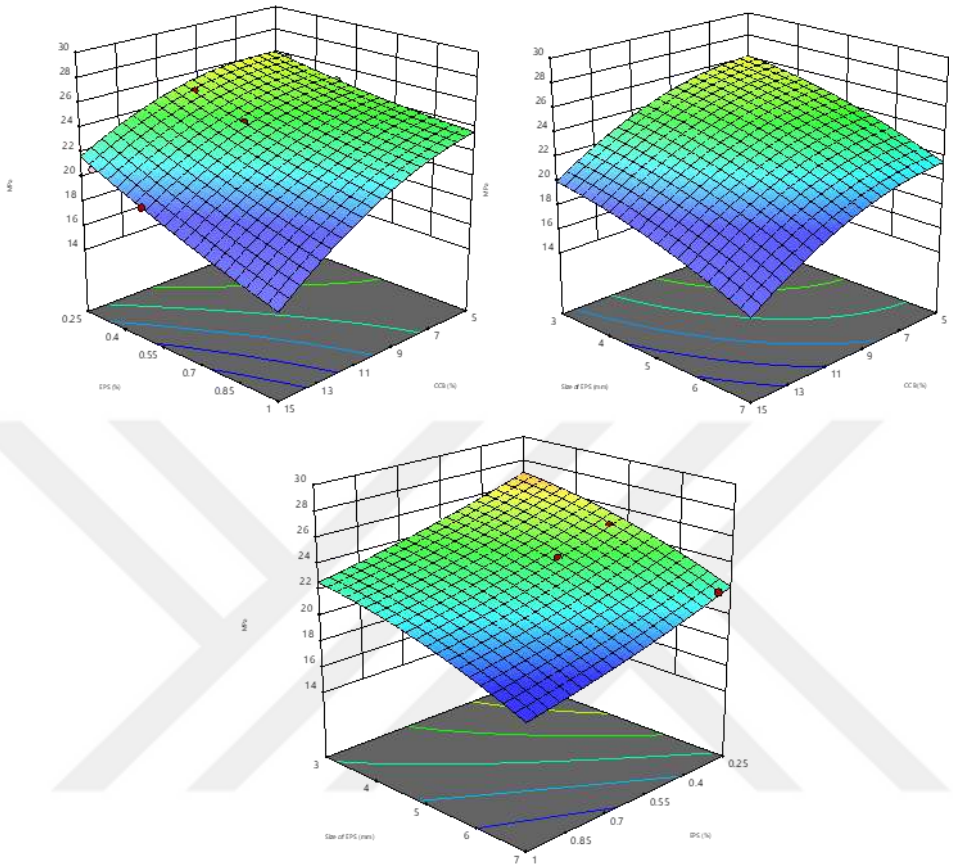

Figure 4.36. 3D graphics created according to UCS of 28 days

The proportion of 5% of calcined calcium bentonite and 0.1% of EPS size 3mm got the highest value from the UCS test as shown in (Figure 4.36). The UCS test values decline when the volume and proportion of EPS in the geopolymer concrete mix are increased. The reason for the decrease in the value of the UCS test is the formation of voids filled with EPS pieces inside the geopolymer concrete sample. The best UCS test result of 28.56 MPa is obtained when 5% of CCB and 0.1% of EPS at a thickness of 3mm are added to the sample, which consists of 64% solid and 36% liquid, and placed in a heat treatment furnace for 28 days at 90 °C. Based on the results, Experiment 4 appears to be the optimal combination.

UCS response (%) = $22.88-3.10X_1-2.34X_2-2.14X_3-0.0248X_1X_2-0.9535X_1X_3+0.0474X_2X_3-1.43X^2_1-0.6682X^2_2+0.3099X^2_3$,

Where X_1= CCB%, X_2= Size of EPS, X_3= EPS%. (4.10)

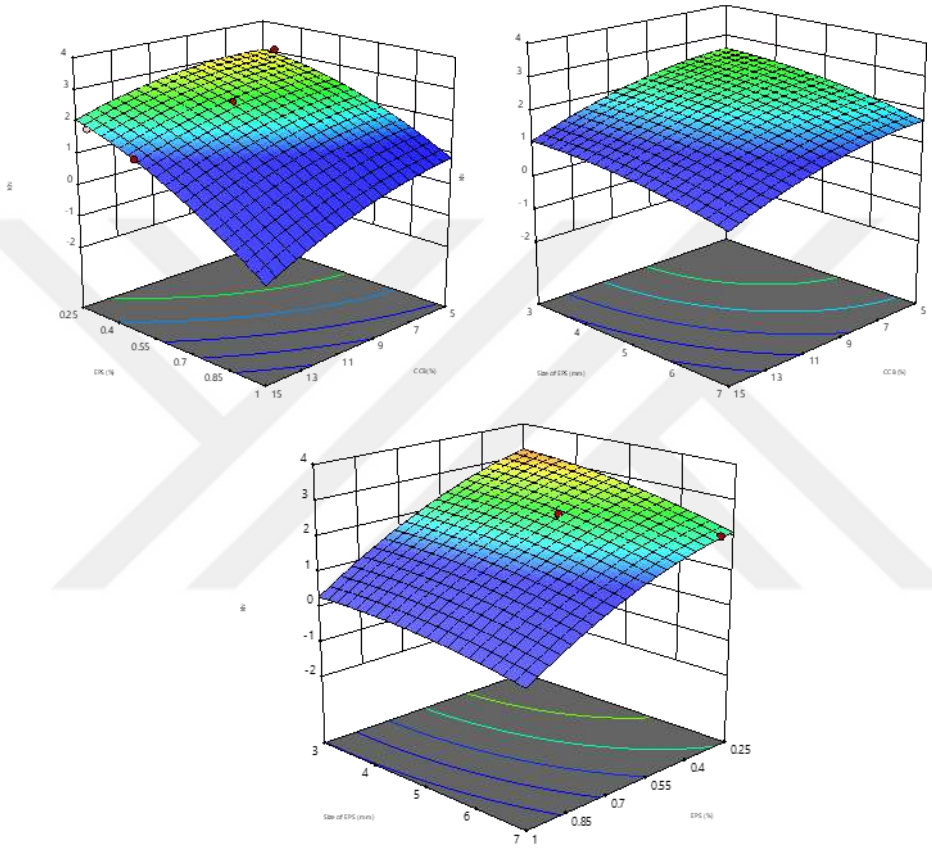

Figure 4.37. 3D graphics created according to PL of 28 days

The PL test gave the highest score to the mixture of 5% of calcined calcium bentonite and 0.1% of EPS at size 3mm as shown in (Figure 4.37). When the volume and fraction of EPS in the geopolymer concrete mix are increased, the PL test values decrease. The formation of cavities filled with EPS fragments inside the geopolymer concrete sample is the cause of the decline in the value of the PL inspection. The best PL test result of 3.49 KN is obtained when 5% of CCB and 0.1% of EPS at a

thickness of 3mm are added to the sample, which consists of 64% solid and 36% liquid, and placed in a heat treatment furnace for 28 days at 90 °C. Based on the results, Experiment 4 appears to be the optimal combination.

PL response (%) = $1.92-0.71X_1-0.41X_2-1.32X_3+0.03X_1X_2-0.2390X_1X_3+0.1396X_2X_3-0.2961X^2_1-0.1831X^2_2-0.3832X^2_3$,
Where X_1= CCB%, X_2= Size of EPS, X_3= EPS%. (4.11)

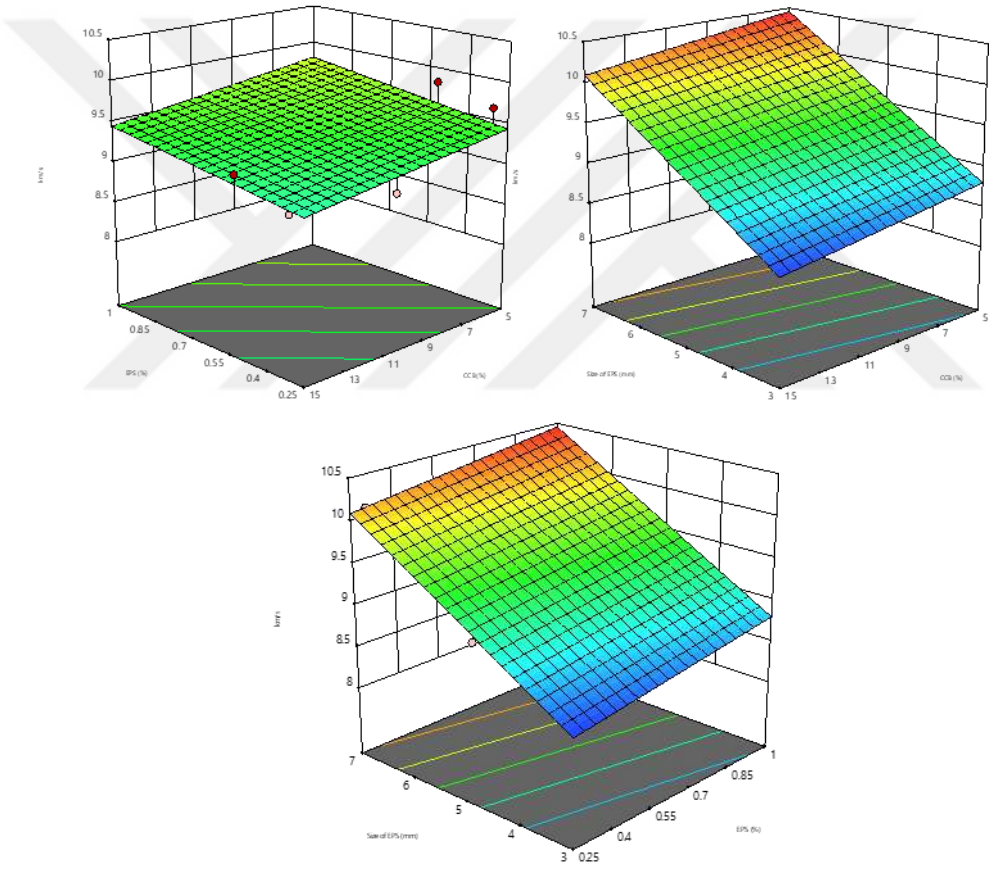

Figure 4.38. 3D graphics created according to PSS of 28 days.

When the volume and ratio of EPS were increased, the PSS test in the sample increasd due to the formation of sound inside the concrete by the action of

EPS. The formation of cavities filled with EPS fragments within the geopolymer concrete sample is the cause of the decline in the value of the PSS inspection. The best PSS test result of 8.37 km/s is obtained when 15% of CCB and 0.1% of EPS at a thickness of 3 mm are added to the sample, which consists of 64% solid and 36% liquid, and placed in furnace for 28 days at 90 °C as shown in (Figure 4.38). Based on the results, Experiment 13 appears to be the optimal combination.

PLS response (%) = $9.45-0.1785X_1+0.8242X_2+0.1808X_3$,

Where X_1= CCB%, X_2= Size of EPS, X_3= EPS%. (4.12)

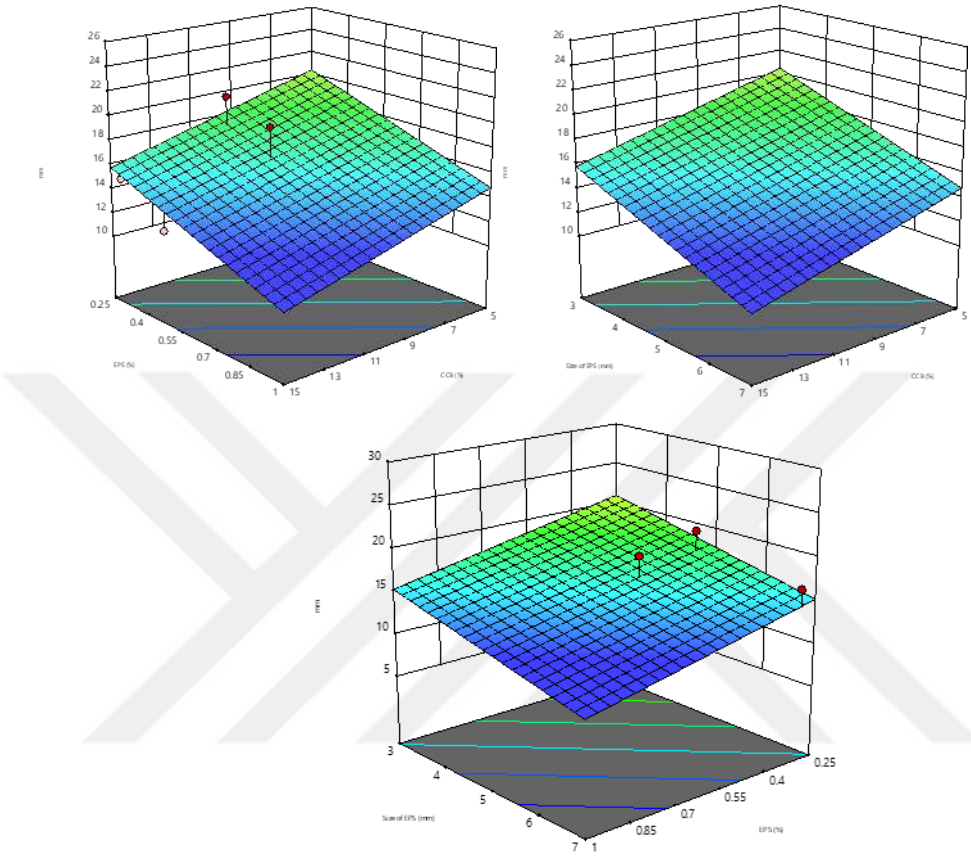

Figure 4.39. 3D graphics created according to SH of 28 days

The SH test gave the highest score to a mixture of 5% calcined calcium bentonite and 0.1% of EPS at size 3mm as shown in (Figure 4.39). When the volume and proportion of EPS in the geopolymer concrete mix is increased, the SH test values decrease. The reason for the decrease in the value of the SH test is the formation of voids filled with EPS pieces inside the geopolymer concrete sample. The best SH test result of 24.97 mm is obtained when 5% of CCB and 0.1% of EPS at a thickness of 3mm are added to the sample, which consists of 64% solid and 36% liquid, and placed in a heat treatment furnace for 28 days at 90 °C. Based on the results, Experiment 4 appears to be the optimal combination.

SH response (%) = $15.33-2.31X_1-2.85X_2-2.80X_3$,

Where X_1= CCB%, X_2= Size of EPS, X_3= EPS%. (4.13)

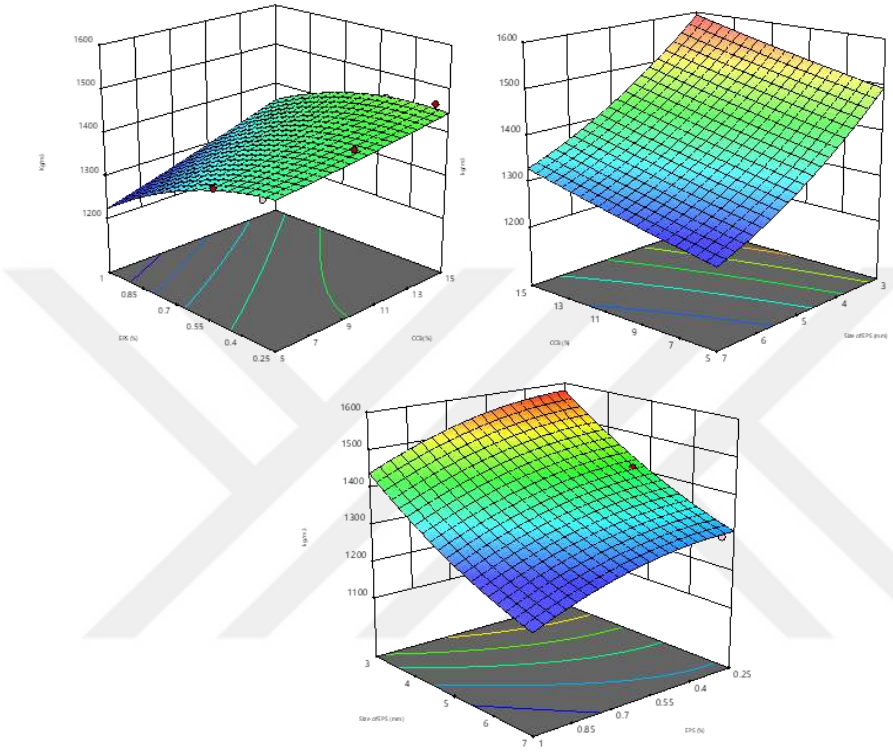

Figure 4.40. 3D graphics created according to the BD of concrete

When the proportion of calcined calcium bentonite increases, the weight also increases slightly, but when the size and quantity of EPS increase, the weight decreases more as shown in (Figure 4.40). When the volume and proportion of EPS are increased, the weight is significantly reduced due to the occupancy of the EPS volume inside the geopolymer concrete.

BD response (%) = $1385.11+47.95X_1-130.07X_2-63.86X_3-1.9712+21.10X_1X_3+5.56X_2X_3+2.90X^2_1+25.86X^2_2-31.50X^2_3$,

Where X_1= CCB%, X_2= Size of EPS, X_3= EPS%. (4.14)

5. CONCLUSIONS

This study confirms that the resources of fly ash, calcined calcium bentonite, slag, and EPS can be used economically for the development of geopolymer concrete.

The partial replacement of calcined calcium bentonite and slag in geopolymer concrete based on fly ash was studied. 36% alkaline activator plus 64% fly ash were combined and replaced with 5%, 10%, and 15% of calcined calcium bentonite and 5%, 10%, and 15% of slag.

To obtain lightweight geopolymer concrete, fly ash was incorporated in addition to its replacement with 5%, 10%, and 15% calcined calcium bentonite and 0.1%, 0.3%, and 0.5% EPS with a size of 3 mm, 5 mm, and 7 mm.

- Geopolymer concrete with the properties UCS of 48.23 MPa, PL of 13.84 KN, PSS of 6.24 km/s, SH of 56.71 mm, and BD of 1720 kg/m^3 can be produced using 64% fly ash and 36% alkaline activators consisting of NaOH and Na_2SiO_3 in a 1-1 ratio by leaving the sample in a curing oven at 90 ° C for 28 days.
- Geopolymer concrete with the addition of 5% calcined calcium bentonite, and 95% fly ash can be produced with the properties UCS of 51.13 MPa, PL of 13.67 KN, PSS of 6.15 km/s, SH of 49.83 mm, and BD of 1736 Kg/m^3.
- The geopolymer concrete is produced with the inclusion of 5% slag and 95% fly ash and has the following properties: UCS of 49.05 MPa, PL of 13.55 KN, PSS of 6.17 km/s, SH of 54.20 mm, and BD of 1760 Kg/m^3.
- The geopolymer concrete is produced with the inclusion of 5% calcined calcium bentonite, 5% slag, and 90% fly ash and has the following

properties: UCS of 51.33 MPa, PL of 14.05 KN, PSS of 6.41 km/s, SH of 63.17mm, and BD of 1792 Kg/m^3.

- Lightweight geopolymer concrete can be produced by adding 0.5% EPS at size 7mm, 5% calcined calcium bentonite, and 94.5% fly ash that has the properties of UCS of 21.93 MPa, PL of 2 KN, PSS of 10.44 km/s, SH of 16.02 mm, and BD of 1264 Kg/m^3.

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