ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCE

MASTER THESIS

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INVESTIGATION OF GEOPOLYMER CONCRETE PRODUCTION BY USING CALCIUM BENTONITE

DEPARTMENT OF MINING ENGINEERINING

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ABSTRACT

MSc. THESIS

INVESTIGATION OF GEOPOLYMER CONCRETE PRODUCTION USING CALCIUM BENTONITE

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In this study, fly ash based geopolymer concretes were created by using a mixture of arc furnace slag and basic basaltic pumice as aggregates, a fly ash (Class F) and alkaline activator for lightweight concrete production. Box Behnken test design (Design Expert11) was concluded to discover the active curing parameters. This study focused on the possibility of fly ash based geopolymer concrete to which calcium bentonite has been added. Sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) solution were used to produce the alkaline activator. The concentration of NaOH solution was fixed at 12 Molar, ratio of fly ash/alkaline activator and sodium silicate/NaOH fixed at 1.5 and 2.5, respectively. Calcium bentonite was added in range 5% - 15% from the mass of mixture and all the samples were cured at room conditions. The uniaxial compressive strength, Point load resistance, and pundit sonic speed were conducted on geopolymer concrete to assess the proportions that provide the best properties of the concrete. Uniaxial compressive strength, Point load resistance, and pundit sonic speed results have been attained. It is revealed that 5% replacement of calcium bentonite contributed to maximum uniaxial compressive strength, point load resistance, and pundit sonic speed of 50.03 MPa, 13,2 kN and 4 Km/sn at 28 days.

Key words: Calcium Bentonite, Geopolymer, Fly ash, Concrete, alkaline activators, slags, strength, sodium silicate.

ÖZ

YÜKSEK LİSANS TEZİ

KALSIYUM BENTONIT KULLANILARAK JEOPOLIMER BETON ELDESININ ARIŞTIRMASI

Salah ELAVVAD

ÇUKUROVA ÜNİVERSİTESİ
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Bu çalışmada, hafif beton üretimi için agrega olarak ark fırın cürufu ve bazal bazaltik pomza karışımı, uçucu kül (Sınıf F) ve alkali aktivatör kullanılarak uçucu kül esaslı jeopolimer betonlar oluşturulmuştur. Box Behnken test tasarımı (Design Expert11), aktif kürleme parametrelerini keşfetmeye karar verilmiştir. Bu çalışma, kalsiyum bentonitin ilave edildiği uçucu kül bazlı jeopolimer beton olasılığına odaklanmıştır. Alkali aktivatörü üretmek için sodyum silikat (Na_2SiO_3) ve sodyum hidroksit (NaOH) çözeltisi kullanılmıştır. NaOH çözeltisinin konsantrasyonu 12 Molar'da sabitlenmiştir, uçucu kül / alkalin aktivatör oranı ve sırasıyla 1.5 ve 2.5'te sabitlenen sodyum silikat / NaOH oranı. . Karışım kütlesinden% 5 -% 15 aralığında kalsiyum bentonit ilave edilmiş ve tüm numuneler oda şartlarında kürlenmiştir. Tek eksenli basınç dayanımı, Nokta yük direnci ve pundit sonik hızı, betonun en iyi özelliklerini sağlayan oranları değerlendirmek için jeopolimer beton üzerinde gerçekleştirilmiştir. Tek eksenli basınç dayanımı, Nokta yük direnci ve pundit sonik hız sonuçları elde edilmiştir. Kalsiyum bentonitin% 5 ikamesinin 28 günde maksimum tek eksenli basınç dayanımı, nokta yük direnci ve 50.03 MPa, 13,2 kN ve 4 Km / sn'lik pundit sonik hızına katkıda bulunduğu ortaya çıkmıştır.

Anahtar Kelimeler: Kalsiyum Bentonit, Jeopolimer, Uçucu kül, Beton, alkali aktivatörler, cüruflar, dayanma, sodyum silikat.

EXTENDED SUMMARY

The desire for more eco-friendly building tools has been a major driver for researchers to advance and consider alternatives such as the use of coal factory waste products and natural resource decomposition. The importance of geopolymer concrete has been produced by early compressive power, strong chemical resistance and low permeability properties. Geopolymer concrete has now been turned into a standard material since it does not use Portland cement as a binder. But it uses materials such as metakaolin and fly ash (FA) that are natural and waste. The natural material used to substitute Portland cement for geopolymer concrete must contain a high percentage of silica and alumina. Calcium Bentonite (CB), which has a high silica and alumina content, reacts to alkaline solutions such as sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) or to form a paste to stabilize the aggregates. For matrix bonding, geopolymer concrete does not require any water, as the alkaline solution replacement reacts with silicon and aluminum in the CB or FA presence. An alkali-activated material consists mainly of one or more mineral components and one or more activators. The polymerization process requires a substantially rapid chemical reaction of Si-Al minerals under an alkaline reaction. These elements respond to the advancement of a polymerization method by producing Geopolymer concrete with alkaline liquids. Via a mixture of aggregates, FA (Class F) and alkaline activator for lightweight concrete processing, FA-based geopolymer concretes were produced in this research. Simple basaltic pumice (BP) and arc furance slags are used as aggregates. BP samples from the province of Nevşehir were collected to be used as light aggregates with 50 percent of the weight of all aggregates. Arc furnace slags were gathered in the Iskenderun Area from Ekinciler Iron and Steel Industry Inc. Where FA from Sugözü Thermal Power Plant were obtained from Yumurtalık District of Adana. Picked up CB clay from Yeni Özdemir Ltd Şti, Iskenderun, Turkey. The sample was crushed by a jaw crusher-type laboratory. The Minipal 4 Panalytical X-ray fluorescence (XRF)

device examined all materials and the inorganic material composition was determined by the Rigaku Minflex II X-ray diffractometer (XRD) device. To observe the successful curing parameters, the Box Behnken test design (Design Expert11) has been concluded. This study concentrated on the feasibility of geopolymer concrete based on fly ash to which CB has been applied. Sodium silicate and sodium hydroxide (NaOH) solution were used to get the alkaline activator. The NaOH solution concentration was set at 12 Molar, the fly ash/alkaline activator ratio and the sodium silicate/NaOH ratio at 1.5 and 2.5, respectively. CB from the mass of the mixture was applied in the range of 5 percent to 15 percent and all the samples were cured under room conditions. On geopolymer concrete, the uniaxial compressive strength, point load resistance and pundit sonic velocity were performed to determine the proportions that give the concrete concrete the best properties. Uniaxial compressive strength, Point load resistance, and pundit sonic speed results have been obtained. It shown that 5% replacement of CB contributed to maximum uniaxial compressive strength, point load resistance, and pundit sonic speed of 50.03 MPa, 13.2 kN and 4 km/sn at 28 days. The collected data from the experimental work carried out obviously shows the reduction in Compressive Strength, the point load resistance and the Pundit sonic speed of fly ash based Geopolymer Concrete with the increase in percentage of used metakaolin in concrete mixture. The results show that fly ash-based geopolymer with Fly ash 0.75 Kg, aggregates 1 Kg and CB 5% (exp 6) give the highest compressive strength 50.03 MPa. Instead of standard concrete, the use of geopolymer concrete means that 80% less greenhouse gases are produced. In reality, geopolymer concrete production uses five times less CO_2 (carbon dioxide) compared to the concrete causes of Portland cement-based production. Sodium hydroxide solution (NaOH solution) and sodium silicate solution (Na_2SiO_3 solution) alkaline activator contribute to stronger mechanical properties, including compressive forces, than using only NaOH solution as an activator. Also, the Na_2SiO_3 solution percentage in the alkaline activator has a significant rol.

GENİŞLETİLMİŞ ÖZET

Çevre dostu bina araçlarına duyulan istek, araştırmacıların kömür fabrikası atık ürünlerinin kullanımı ve doğal kaynak ayrıştırması gibi alternatifleri ilerletmesi ve düşünmesi için önemli bir itici güç olmuştur. Jeopolimer betonun önemi, erken basınç gücü, güçlü kimyasal direnç ve düşük geçirgenlik özellikleriyle üretilmiştir. Jeopolimer beton, bağlayıcı olarak Portland çimentosu kullanmadığı için artık standart bir malzemeye dönüştürülmüştür. Ancak doğal ve atık olan metakaolin ve uçucu kül (FA) gibi malzemeleri kullanmaktadır. Jeopolimer beton yerine Portland çimentosunun yerine kullanılan doğal malzeme, yüksek oranda silika ve alümina içermelidir. Yüksek silika ve alümina içeriğine sahip olan Kalsiyum Bentonit (CB), sodyum hidroksit (NaOH) ve sodyum silikat (Na_2SiO_3) gibi alkali çözeltilere reaksiyona girer veya agregaları stabilize etmek için bir macun oluşturur. Matris yapıştırma için, jeopolimer beton, alkali çözelti ikamesi CB veya FA varlığında silikon ve alüminyum ile reaksiyona girdiğinden su gerektirmez. Alkali ile aktifleştirilen bir materyal, esas olarak bir veya daha fazla mineral bileşen ve bir veya daha fazla aktivatörden oluşur. Polimerizasyon işlemi, alkali bir reaksiyon altında Si-Al minerallerinin önemli ölçüde hızlı bir kimyasal reaksiyonunu gerektirmektedir. Bu elemanlar, alkali sıvılar ile Jeopolimer beton üreterek bir polimerizasyon yönteminin ilerlemesine yanıt vermektedir. Bu araştırmada agrega, FA (Sınıf F) ve hafif beton işleme için alkali aktivatör karışımı ile FA bazlı jeopolimer betonlar üretilmiştir. Agregalar olarak basit bazaltik pomza (BP) ve ark fürans cürufları kullanmaktadır. Nevşehir ilinden BP numuneleri, tüm agregaların ağırlığının yüzde 50'si ile hafif agregalar olarak kullanılmak üzere toplanmıştır. İskenderun Bölgesi'nde ark fırın cürufları Ekinciler Demir Çelik Sanayi A.Ş.'den toplanılmıştır. Sugözü Termik Santrali'nden FA Adana'nın Yumurtalık İlçesinden temin edilmiştir. Yeni Özdemir Ltd Şti, İskenderun, Türkiye'den CB kili alındı. Numune, çeneli kırıcı tipi bir laboratuvarda ezilmiştir.

Minipal 4 Panalytical X-ray fluorescence (XRF) cihazı tüm materyalleri inceledi ve inorganik materyal kompozisyonu Rigaku Minflex II X-ray difraktometre (XRD) cihazı ile belirlenmiştir. Başarılı kürleme parametrelerini gözlemlemek için Box Behnken test tasarımı (Design Expert11) tamamlanmıştır. Bu çalışma, CB'nin uygulandığı uçucu kül bazlı jeopolimer betonun fizibilitesine odaklanmıştır. Alkalin aktivatörü elde etmek için sodyum silikat ve sodyum hidroksit (NaOH) çözeltisi kullanıldı. NaOH solüsyon konsantrasyonu 12 Molar, uçucu kül / alkalin aktivatör oranı ve sodyum silikat / NaOH oranı sırasıyla 1.5 ve 2.5 olarak ayarlanmıştır. Karışımın kütlesinden CB yüzde 5 ila yüzde 15 aralığında uygulanmış ve tüm numuneler oda koşullarında kürlenmiştir. Jeopolimer beton üzerinde, betona en iyi özellikleri veren oranları belirlemek için tek eksenli basınç dayanımı, nokta yük direnci ve pundit sonik hızı gerçekleştirilmiştir. Tek eksenli basınç dayanımı, Nokta yük direnci ve pundit sonik hız sonuçları elde edilmiştir. CB'nin% 5 değiştirilmesinin maksimum tek eksenli basınç dayanımına, nokta yük direncine ve 28 günde 50.03 MPa, 13.2 kN ve 4 km / sn'lik pundit sonik hızına katkıda bulunduğunu göstermiştir. Gerçekleştirilen deneysel çalışmalardan toplanan veriler, beton karışımında kullanılan metakaolin yüzdesindeki artışla birlikte uçucu kül esaslı Jeopolimer Betonun Basınç Dayanımı, nokta yük direnci ve Pundit sonik hızındaki azalmayı açıkça göstermektedir. Sonuçlar, 0.75 Kg Uçucu kül içeren uçucu kül bazlı jeopolimerin, 1 Kg ve CB% 5 (exp 6) agregalarının en yüksek basınç dayanımını 50.03 MPa verdiğini göstermektedir. Standart beton yerine jeopolimer beton kullanılması,% 80 daha az sera gazı üretilmesi anlamına gelmektedir. Gerçekte, jeopolimer beton üretimi, Portland çimentosu bazlı üretimin beton nedenlerine kıyasla beş kat daha az CO2 (karbondioksit) kullanır. Sodyum hidroksit çözeltisi (NaOH çözeltisi) ve sodyum silikat çözeltisi (Na2SiO3 çözeltisi) alkalin aktivatörü, aktivatör olarak sadece NaOH çözeltisinin kullanılmasına kıyasla, sıkıştırma kuvvetleri dahil daha güçlü mekanik özelliklere katkıda bulunmaktadır. Ayrıca alkali aktivatördeki Na2SiO3 çözelti yüzdesi önemli bir role sahiptir.

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CONTENTS **PAGE**

LIST OF TABLES **PAGE**

LIST OF FIGURES **PAGE**

LISTE OF ABBREVIATIONS

FA	: Fly Ash
CB	: Calcium Bentonite
XRF	: X-ray fluorescence Spectrometer
XRD	: X-Ray Diffraction Spectrometer
UCS	: Uniaxial Compressive Strength
PLS	: Point Load Strength
PSS	: Pundit Sonic Speed
DOE	: Design of Experiment
Fig	: Figure
BP	: Basaltic Pumice
LOI	: Loss on Iignition
Si	: Silicon
RH	: Relative Humidity
CK	: Calcined Kaolin
IR	: Insoluble Residues

1. INTRODUCTION

Because of the changes the planet has made, including the growth in the world's population, environmental pollution and other changes, all of this has produced several factors that have raised environmental awareness around the world in order to minimize all the harm caused by these changes (Ciullo P.A. (Ed), 1996). In addition to maintaining speed through the changing design and technical characteristics of the products produced, this led to a re-study and assessment of the eco-friendly variables. Thus, in many studies, the search for alternative materials has been a goal. Among the materials invented and produced are geopolymers (Wypych G, 2000).

The increase in energy use in economically developing countries has contributed to an increase in environmental emissions and thus to an increase in concern for renewable energy sources in direct proportion to the increase in global warming, however it has shown that it is important to make more proficient use of existing resources. In the research and development of geopolymers, all this led to an increase in focus and encouragement for other construction materials and energy reuse studies (Flick E.W, 1989). An alkaline alumina silicate bond formation molded by activating alumina silicate-based materials with alkaline silicates is the term geopolymer, the earliest used by Davidovich in 1979. Due to their role in minimizing environmental damage, geological and inorganic base polymers are considered as modern and environmentally friendly engineering tools.

Although alkaline activated alumina silicates release very little CO_2 emissions at the same time as Portland cement for a short period of time, they form a broad range of different application fields. Due to the concentration temperature, the formless structure of the geopolymer used is (Baikun W., Hao D., Yanxi D., 2010).

Because of the nature of the environmental problems described above, in combination with the development of geological polymerization and the creation of

an advanced material, the geopolymer will keep pace with advanced modern technology and the needs of new materials (Lin H., Dong Y., Jiang L., 2009).

More than 70 years ago, the Ukrainian researcher Glukhovsk carried out initial studies of organic matter. Where it has promoted its worth in building construction. The geopolymers were named alkaline activated cement by Glukhovsky, (Lu Z., et al, 2009).

There are also a number of studies made by Purdon in the 1940s where the blast furnace slag is activated with sodium hydroxide in two steps. The first step contains the relief of silicon, aluminum, and calcium hydroxide, and in the second step silica and alumina hydrate are molded (Yuan J., et al, 1998).

As a result of the labors targeted at carrying about developments in the concrete industry, industrial wastes and power factories or by-products are used as additives, and this is prepared by replacing them in part proportions with cement (Yuan J., et al, 1998).

Where FA, blast furnace slag and silica smoke are used to obtain concrete mixtures with the required specifications and physical and chemical properties. Metakaolin is also used and can be considered a new mineral additive compared to these industrial by-products and cannot be considered as a completely natural material as well as it is variable in composition, unlike other pozzolan. Metakaolin can be produced according to size, mineral composition and whiteness (Lu Z., et al, 2009). Most those waste materials contain alumina and silica, so they are considered suitable materials to be used as raw materials in geopolymerization processes. Many Al Si containing materials such as FA, arc furnace slag and metakaolin were used as addictives materials for the composite of geopolymers (Narayan R., Raju K.V.S.N., 2000).

In this study, the curing temperature of self-compacting geopolymer concretes which containing metakaolin effects have been investigated. The main purpose of the study is to determine the amount of metakaolin and curing

conditions. So the ability to determine the effects of high strength geopolymer concrete on mechanical properties.

1.1. Bentonite

Since the groundbreaking work of Veder (1953), bentonite support fluids have been used for the construction of diaphragm walls and boring piles. It is now recognized that the stabilizing mechanism involves the creation of a filter cake on side walls in permeable soils such as sand and gravel. Rheological blocking, i.e. penetration of the slurry into the earth, will assist cake formation until the gel strength of the slurry acting over the penetrated area of soil particles is adequate to prevent further penetration of slurry. It decreases the loss of fluid in the soil and provides a barrier against which the slurry's hydrostatic pressure can act to stabilize the excavation (Nash, 1974). A safe excavation with bentonite slurry in permeable soils includes the creation of a filter cake. However the filter cake produces an undesirable layer of soft interface material between concrete and soil for friction piles and barrettes, and can decrease interfacial resistance. Fig. 1 shows a panel of the diaphragm wall built at a London site, exposed to the top few meters of the wall surface. On the wall surface below the level of the guide wall, a layer of filter cake with adhering soil can be seen.

While the impact of bentonite filter cake on interface resistance has been investigated in several studies, a conclusive understanding has not yet been established and unsatisfactory pile output continues to be recorded. Randolph (2003), for example, defined load test results of twbored piles built in Vietnam using bentonite fluids. The shaft resistance of the first test pile was below plan, so many changes were made to the second pile construction process, including a) steps to minimize the gap between excavation and concreting; (b) a reduction in the bentonite head above the level of the river; (c) mechanical scarification of the side wall before casting the pile. These steps were all aimed at reducing the filter cake thickness and were stated to have resulted in a shaft resistance improvement of

approximately 30 percent. The history of this case raises concerns as to whether such measures are also appropriate for other projects and if not, whether current requirements are already sufficient to mitigate the weakening impact of the concrete-soil interface bentonite filter cake. The latest UK specification (Institution of Civil Engineers, 2007) specifies that concrete should be put within 12 hours of the start of excavation for the construction of bored piles. There may also be a time requirement in the USA, but it is defined somewhat differently. For instance, Brown et al. (2010) suggest that less than 4 hours should be the period during which the bentonite fluid in a pile bore is left undisturbed. In the foundation manuals of countries such as Canada and Hong Kong, however, no such time constraint can be found (Canadian Geotechnical Society, 2006; Geotechnical Engineering Office, 2006). The differences between or lack of these criteria suggest that more work is required to measure the impact of fluid support time in order to better monitor quality. The findings of a laboratory investigation into the effect of support fluids on the interface shear strength between sand and cast in situ concrete are discussed in this report. First a summary of the relevant literature, followed by a description of the equipment used and the results of the test, is given. The research programme contained both bentonite and polymer fluids, with water as the control fluid. Help fluid filtration time, concrete surface roughness, and concrete curing cycle were the main impacts of concern.

1.1.1. Chemical and Physical Structure of Bentonite

In general, bentonite is available in various colors and forms. A Few authors reported about the color, (J. Mirza, et al, 2009) - greenish gray & browning green, (Juniad Akbar, et al, 2013) bentonite used in research work was light yellow colored bentonite. Table I shows the over view of physical properties of bentonite reported by some authors. Nearly all authors had different values published. The explanation behind this attribute is that the source position varies.

Table 1.1. Physical properties of bentonite used in various research works.

Property				
Specific Gravity	2.82	2.63	2.44	2.79
Average particle size	4.75 µm	17% retained on # 325 mesh	13.5% retained on # 325 mesh	4.32 µm
Blains fineness (cm2/gm)	4800	--	2689	4800

Cement chemical composition shows a huge influence on concrete mechanical properties (Nevelli, A M., 2011). The study of the chemical properties of bentonite was shown in Table 1.2.

Table 1.2. Chemical properties of bentonite used in various research works.

Property						
Silicon dioxide (SiO2)	54.55	49.44	65	49.63	52.1	51.11
Aluminum Oxide (Al2O3)	20.19	19.7	15	21.11	13.4	16.83
Ferric Oxide (Fe2O3)	8.60	6.2	3	3.23	7.5	7.65
Megnesium Oxide (MgO)	4.20	1.61	6.5	12.56	2.64	7.57
Calcium Oxide (CaO)	7.28	7.45	2.66	3.59	12.0	6.60
Sodium Oxide (Na2O)	1.27	0.87	0.12	0.44	-	0.29
Potassium Oxide (K2O)	3.92	0.63	0.27	2.09	2.64	1.34
Phosphorus pentoxide (P2O5)	1.107	-	-	0.11	-	0.29
Titanium Oxide (TiO2)	0.91	-	-	0.49	-	1.29
Loss on Ignition (LOI)	5.42	13.74	6	-	8.61	6.75

The majority of authors reported a higher level of SiO_2 presence in bentonite Al_2O_3 as the second major component. These contribute to the occurrence of pozzolanic response during the process of hydration. Most of the authors mentioned chemical properties according to ASTM C618 as within the limits.

1.1.2. Effect of Bentonite on the Properties of Concrete

With the increased volume of Bentonite with the equivalent water-cement ratio due to the fineness of bentonite, the workability of the concrete is greatly decreased. Nevertheless, the use of water-reducing admixtures (plasticizers) or the combination of FA in mixes can be accounted for (M. S. Shetty, 2012). The use of bentonite in concrete provides the development of early age strength because in addition to pozzolanic effect, it has good filler effect, provides certain densification of the concrete micro structure due to the pozzolanic and hydraulic reaction and leads to greater impermeability, decreases the permeability of chloride. The higher is the quantity of the bentonite, less is the permeability. It also offers stronger resistance to the attack of sulphates and other aggressive materials, such as mineral and organic acid, and due to alkali-silica reaction, the minimal substitution of bentonite has greater resistance to extension (Sunny A. et al, 2017).

1.1.3. Advantages and Disadvantages of Bentonite

Bentonite is granulated smectite clay which when it absorbs water, provides waterproofing capabilities by swelling to nearly 15 times its dry volume. The swelling is caused by the molecular structural structure of the material, which is composed of expansive sheets that can expand depending on the compositions of grading and clay. Usually, bentonite sheets contain 85% to 90% montmorillonite clay and a maximum of 15% natural sediments such as volcanic ash.

In recent times advanced technology of polymer chemistry has increased the use of bentonite by making it a more versatile material. It is currently offered in four forms:

1. Prefabricated panels.
2. Prefabricated geotextile sheets.
3. High density polyethylene sheets.
4. Trowelable mixtures used for detailing.

Advantages of Bentonite

Bentonite waterproofing systems offer the following advantages (M. S. Shetty, 2012):

- Easy installation.
- No VOC restrictions.
- Safe application - even at extreme temperatures.
- Easy leak detection.
- Can bridge cracks up to 1/4 inch.
- Adapts to complex geographic shapes.

Disadvantages of Bentonite

Bentonite waterproofing systems have the following disadvantages (M. S. Shetty, 2012):

- Need for constant (high) hydrostatic pressure.
- Lack of dependable resistance to vapor migration.
- Limited options for future repairs or replacement.

1.1.4. Uses of Bentonite

The increased use of bentonite as a system for waterproofing stems from the material's flexibility and the fact that it can be used in demanding environments. Bentonite is not ideal for all applications; however, it is well matched for complex situations such as blindside applications in deep excavations (Ferraz, E; et al. 2015). The material is often widely used and has a long history of waterproofing New York City basements in tunnels and subways. The primary mode of application is with prefabricated panels or boards. Slabs-onground mounting is achieved by simply laying the panels or sheets on the substrate and lapping the joints of the slab. The panels or sheets are nailed onto the substrate on vertical surfacesA smooth surface without deformations or shark fins is needed for application on concrete substrates. Until panel or sheet application, all honeycombs, indentations or rock pockets should be repaired with wheelable bentonite (Ferraz, E.; et al. 2015). Trowelable bentonite is also used on both wall penetrations and wall bottoms. After installation, backfill should be done immediately. Usually, installation is done after every course in 8-foot to 10-foot lifts with backfill. The backfill should be compacted to a protective density of at least 85 percent and applied within 2 inches of the top of the panels or sheets. In order to prevent moisture from reaching the bentonite, backfill should be placed directly against the panels or sheets or a protection course (film or insulation) is required. Benonite can be applied for blindside applications over concrete, steel, lagging walls, slurry, retaining walls, and earth retaining diaphragm walls. Most applications simply involve nailing of the sheet or panel to the substrate. With these applications, the one difference is the need for block outs for tieback plates or rakers in walls. The information for these block outs should be in line with the requirements of the manufacturer.

1.2. Geopolymers

Inorganic materials dependent on aluminum silicate are geopolymers. It is formed as an alkaline solution from the polymerization process between aluminosilicate precursors. Throughout the sequence, their arrangement includes SiO_4 and Al_2O_4 settled tetrahedra. Geopolymers may define the balance between the electrical charges by the presence of alkaline ions within the hollows. Geopolymers are known to be binders, so this attribute is one of its most important characteristics, and therefore an ideal alternative to ordinary Portland cement, as it has good mechanical characteristics, flammability, strength and high durability. One of the benefits of geopolymers is that, at room temperature, they can be created. The use of geopolymers helps minimize CO_2 emissions by approximately 80% associated with Portland cement (Alzeer M, Mac Kenzie K, 2013).

Geopolymers are made from a community of consumables, industrial by-products, energy waste, and thermoelectric plants, and this feature can be considered one of the important characteristics of industuial geopolymers. Pellets can be made using FA, rice husk ash, biogas ash sugar cane, blast furnace slag, dead kaolin, and other mineral waste containing adequate amounts of alumina and silica (Reed M, et al, 2014).

The most popular factors that can influence and decide the budgets for geopolymers are the source and type of raw material, the resources used and the means of transporting the materials used to manufacture geopolymers. The budget of forming and processing geopolymers may be more expensive than Portland cement, depending on these factors. Despite these factors, their outstanding characteristics such as their low density ($\leq$1800 kg / m^3), easy handling, low process temperature, and contributing to reducing environmental pollution and reducing geopolymers of CO_2 emissions have become important to the industries. Numerous studies have been performed on fiber-reinforced geopolymers, as these fibers have led to the enhancement and growth of geopolymer strength and stiffness due to the fragile and weak geopolymer structure (Yan S, et al, 2016).

1.2.1. The Chemical Composition of Geopolymers

Geopolymers are known to be substances called pozzolan, based on polymerized aluminosilicate oxide. Soluble cations, typically based on sodium or potassium, are sometimes present and the basis used is generally sodium hydroxide (NaOH) or potassium hydroxide (KOH), which is mixed with sodium or potassium silicate to obtain Al and Si dissociated geopolymers in an alkaline medium. A gel is formed from a 3 D structure after a multiple condensation reaction, which is then hardened to form a stable and mechanically strong matrix (Khale D, Chaudhary R, 2007).

Another nomenclature for geopolymers is polysilates, which is the terminology approved as a contraction for polycarbonate (silico aluminate) (Kriven WM, 2010). Its structure is mainly based on the ratio of Si/Al: poly (sialate) – Si-O-Al-O- (Si: Al = 1),

Poly (sialate-siloxo) – Si-O-Al-O-Si -O - (Si: Al = 2),

Poly (sialate-disiloxo) -Si-O-Al-O-Si-O-Si-O- (Si: Al = 3),

Poly (sialatemultisiloxo) (Si: Al >> 3).

The following formula describes the different structures:

Mn [- (Si-O2) z-Al-O] n. WH_2O (Thomas A, Tripathi RK, Yadu LK, 2018).

Geopolymers and zeolites have a structure somewhat similar to each other (Lolli F et al, 2018). Zeolites are aluminosilicates of alkaline (like Na, K, Mg, and Ca) consisting of 3 D, porous crystal structures, a tetrahedron of SiO_4 and AlO_4 connected at the head by oxygen particles.

There is a big difference between geopolymers and zeolites despite the great similarity between them in terms of chemical composition. Zeolite is highly crystalline while geopolymers are amorphous or considered as semi-crystalline. Zeolite is formed during the geological polymerization process, which is a hydroxyodalite ($Na_6Al_6Si_6O_{24}.8H_2O$) an example of a kind of zeolite formed by the

activating between metakaolin (MK) and NaOH. Thermodynamically, zeolite A – $Na_{12}Al_{12}Si_{12}O_{48}$. $27H_2O$ is an unstable phase and thus tends to convert to hydroxyiodalite by time (Maia AAB, et al, 2007).

The formation and fabrication of geopolymers are determinants of the hardening and curing process, as well as of the final mechanical behavior. Geopolymers solidify at room temperature, have high compressive strength, and are stable at temperatures above 1400 ° C. However, it is brittle and requires fibers to prevent the formation of microcracks during geological polymerization (Papa E, et al, 2018).

Geopolymers comprise following molecular units (or chemical groups) (Barbosa VFF, et al, 2000):

-Si-O-Si-O- siloxo, poly (siloxo)
-Si-O-Al-O- sialate, poly (sialate)
-Si-O-Al-O-Si-O- sialate-siloxo, poly (sialate-siloxo)
-Si-O-Al-O-Si-O-Si-O- sialate-disiloxo, poly (sialate-disiloxo)
-P-O-P-O- phosphate, poly (phosphate)
-P-O-Si-O-P-O- phospho-siloxo, poly (phospho-siloxo)
-P-O-Si-O-Al-O-P-O- phospho-sialate, poly (phospho-sialate)
-(R)-Si-O-Si-O-(R) organo-siloxo, poly-silicone
-Al-O-P-O- alumino-phospho, poly (alumino-phospho)
-Fe-O-Si-O-Al-O-Si-O- ferro-sialate, poly (ferro-sialate)

1.2.2. Usage Areas of Geopolymer

The properties possessed by geopolymers is depending upon the Si / Al atomic proportion, which in turn allow specific uses as having the advantages and characteristics appropriate for these uses. With an increase in the Si / Al ratio, the polymeric character suitable for applications requiring materials with high fire resistance increases. In the case of adhesives, applied in civil construction, they are

mostly amorphous and usually polysiloxylate (Gunasekera C, et al, 2017). Geopolymers have great application potential due to their high initial pressure resistance, rapid stiffness, and low volumetric variation. They can be used in pre-cast industries, as well as in airport or road corridor repainting, mechanical block manufacturing and oil well cementing (Gunasekera C, et al, 2017).

The development in the study of geopolymer properties with regard to activator concentration, solid / liquid dose in the mixture, time and curing temperature using geopolymer slurry for the manufacture of products such as concrete slurry, geopolymer foam and solids (Souza FG, et al, 2015). Carbon fiber reinforced geopolymers can be used in environments requiring high burn resistance, such as other aircraft components. The results were favorable for burn resistance, and toxicity (Hung TD, et al, 2011).

Portland cement has many drawbacks, the most important of which is the carbon dioxide emitted, as well as the use of fossil fuels during the calcination process (Malenab RAJ, et al, 2017). All these factors make geopolymers a suitable alternative to Portland cement, as they are heat-resistant, low in costs, sound absorbing and environmentally friendly (Lirer S, et al, 2017). These features differed in geopolymers with the different Si: Al ratio (Wan Q, et al, 2017).

Geopolymers are presently developed and applied in 10 main classes of materials (Singh B, et al, 2015):

- Waterglass-based geopolymer, poly(siloxonate), soluble silicate, Si:Al=1:0
- Kaolinite / Hydrosodalite-based geopolymer, poly(sialate) Si:Al=1:1
- Metakaolin MK-750-based geopolymer, poly(sialate-siloxo) Si:Al=2:1
- Calcium-based geopolymer, (Ca, K, Na)-sialate, Si:Al=1, 2, 3
- Rock-based geopolymer, poly(sialate-multisiloxo) 1< Si:Al<5

- Silica-based geopolymer, sialate link and siloxo link in poly(siloxonate) Si:Al>5
- FA-based geopolymer.
- Ferro-sialate-based geopolymer.
- Phosphate-based geopolymer, AlPO4-based geopolymer.
- Organic-mineral geopolymer.

1.3. Fly Ash (FA)

FA is a byproduct from burning pulverized coal in electric power generating plants (Fig.1.1) (Dong M, et al, 2017). Through burning, mineral layers in the coal fuse in postponement and float out of the burning chamber with the exhaust gases. As the fused material rises, it cools and solidifies into spherical glassy particles termed FA. FA is collected from the exhaust gases by electrostatic precipitators. The fine powder does look like Portland cement but it is chemically dissimilar (Chen R, et al, 2014). FA color depends upon its essential elements. In the FA, lime content informs light colors, iron content provides brownish color and carbon and characteristically raised un-burnt content features a dark grey to black color. Specific surface area of FA is range among 250 to 600m^2/kg whereas the specific surface area of cement is 225 m^2/kg. FA chemically reacts with the byproduct calcium hydroxide released by the chemical reaction between cement and water to make additional cementitious products that increase several required properties of concrete (Yang C. et al, 2017). All fly ashes exhibit cementitious properties to variable degrees depending on the chemical and physical properties of equally the FA and cement. Compared to cement and water, the chemical reaction between FA and calcium hydroxide characteristically is slower resulting in delayed hardening of the concrete. Postponed concrete hardening joined with

the variability of FA properties can generate important challenges for the concrete producer and finisher when placing steel-troweled floors.

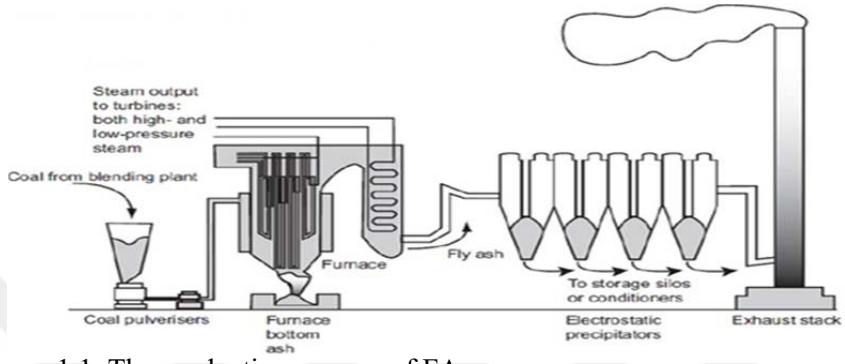

Figure 1.1. The production process of FA

As shown in Fig.1.1 coal is initially pulverized in grinding mills before being blasted with air into the market for boiler burning. Coal combusts produce heat in this area with temperatures reaching around 1500°C. At this temperature, the non-combustible inorganic minerals such as quartz, calcite, gypsum, pyrite, feldspar and clay minerals melt and blend together as small molten droplets in the furnace. Exhaust gases from the combustion chamber of a furnace bear these droplets. When free from the burning area, the droplets cool to form spherical glassy particles called FA. The FA is derived from the exhaust gases by mechanical and electrostatic precipitators (Thomas, M.D.A., 1996).

1.3.1. The Types of Fly Ash

Two categories of FA are generally used in concrete: Class C and Class F. Class C are frequently high-calcium FA s with carbon content fewer than 2%; Class F are mostly low-calcium FA s with carbon contents fewer than 5% but sometimes as high as 10% (Casarez CAR, et al, 2018). Generally, Class C ashes are formed from burning sub-bituminous or lignite coals and

Class F ashes bituminous or anthracite coals. Act properties between Class C and F ashes differ depending upon the chemical and physical properties of the ash and how the ash networks with cement in the concrete. Several Class C ashes once exposed to water will react and convert hard just alike cement, but not Class F ashes. Greatest, if not all, Class F ashes will only react with the byproducts made when cement reacts with water. Class C and F FAes were used in this research project (Shi C, Qian J, 2003). FA can be classified into two classes based on its source and composition as labeled in Table.1.3 (ASTM C618-05, 2005). Presently, further than 50% of the concrete placed in the U.S. contains FA. Quantity rates differ depending upon the class of FA and its reactivity level. Characteristically, Class F FA is used at amounts of 15% to 25% by mass of cementitious material and Class C FA at 15% to 40% (Swamy, R.N., and Mahmud, H.B., 1986). Nevertheless, FA has not been used in interior, steel-troweled slabs because of the inherent difficulties associated with FA changeability and delayed concrete hardening. Proportion and uniformity of concrete hardening are critical parameters in establishing the window-of-finishability and can affect right the quality of final floor finish (Yuan, R.L. and Cook, 1983).

Table 1.3. Classification of FA based on its source.

Class	Description in ASTM C 618	Chemical Requirements
F	FA is commonly derived from the combustion of anthracite or bituminous coal, which provides this class with the relevant requirements. Pozzolanic properties have this class of FA.	$SiO_2 + Al_2O_3 + Fe_2O_3 \geq 70\%$
C	FA is typically manufactured from lignite or sub-bituminous coal that meets the relevant class specifications. This FA class also has cementitious properties, in addition to having pozzolanic properties.	$SiO_2 + Al_2O_3 + Fe_2O_3 \geq 50\%$

Delayed concrete hardening meaningfully raises the hazard of premature or improper finishing causing in poor quality steel-troweled finishes. Up to now, concrete suppliers, and finishers have been unwilling to substitute cement with FA in steel-troweled floors because of the increased hazards associated with the FA. These hazards consist of surface stickiness, delayed concrete hardening, and initial volume shrinkage cracking caused by delayed setting.

1.3.2. Uses of Fly Ash

FA can be used as major material in several cement-based products, such as poured concrete, concrete block. One of the most common applications of FA is in Portland cement concrete roadway. Road construction projects using Portland cement concrete can use a countless deal of concrete, and substituting FA provides significant economic advantages. FA has also been used as embankment and pit fills, and it has progressively increased reception by the Federal Highway Administration. The rate of replacement of FA for Portland cement usually quantified is 1 to 3/2 Kg of FA for 1 Kg of cement. Hence, the quantity of fine aggregate in the concrete mix must be compacted to provide the added volume of the FA (Atis, C.D, 2002).

FA is chosen for an extensive variability of uses and it is used in:

- Producing of Portland Pozzolana Cement. As per the (Mustard, J.N. and MacInnis, C., 1959) (Portland-Pozzolana Cement Specification), the FA ingredient should be 10- 25 % by mass of Portland Pozzolana Cement.
- In mass concreting, like dams, pavements etc.
- Engineering of bricks, blocks, asbestos sheets, asbestos pressure pipes etc.
- Floodable fill in embankments, methods of flyover, bridges etc.
- Creating of high-performance concrete.

- Cold weather concreting.
- Manufacturing of High Volume FA Concrete which includes of more than 40- 50% of FA content by mass of the entire cementitious materials. It is commonly used for making roads and pavements.
- In the preparation of Geopolymer concrete.

Geopolymer concrete is an alternate to Portland cement concrete. It decreases the use of ordinary Portland cement responsible for high CO_2 emission. It is prepared by the utilization of waste materials like FA and ground granulated blast furnace slag etc. So, it is innovative and environmentally friendly.

1.3.3. The Advantages and Disadvantages of Fly Ash

FA can be a cost-effective substitute for Portland cement in several markets. FA is also known as an eco-friendly material because it is a byproduct and has little embodied energy, the amount of how much energy is consumed in producing a construction material. Whereas, Portland cement has a very high embodied energy because its production needs a great deal of heat. FA needs less water than Portland cement and is easier to use in cold weather. Other advantages include (Bilodeau, A., et al, 1991):

- Creates various set times.
- Cold weather resistance.
- High strength increases, depending on use.
- Can be used as an admixture.
- Considered a non-shrink material.
- Yields dense concrete with a smooth surface and sharp detail.
- Great workability.
- Decreases crack problems, permeability, and bleeding.

- Decreases heat of hydration.
- Allows for a fewer water-cement ratio for alike slumps once compared to no-fly-ash mixes.
- Decreases CO_2 emissions.

Smaller builders and housing contractors may not be familiar with FA products, which can have different properties depending on where and how it was got. Moreover, FA applications may face resistance from traditional builders due to its tendency to effloresce along with concerns about freeze/thaw performance. Further fears about using FA in concrete include (Bilodeau, A., et al, 1991):

- Slower strength increase.
- Seasonal limitation.
- Increased need for air-entraining admixtures.
- Increase of salt scaling produced by higher proportions of FA.
- Class C FA is sensitive to temperature; therefore in the mass concreting or when temperature rises to about 200°C, it does not offer high strength.
- Use of Pulverized fuel ash decreases the water request; so, the use of plasticizers/superplasticizers or air entraining admixtures converts necessary to get good workability of FA concrete.

1.4. Slags

The usage of slags rose with the growing production of solids in the world, with production getting more than 1 billion tons yearly. Slag is a remainder of several metallurgical processes where it was collected and not used. However, the increasing amounts of its production fortified its use in different fields, including adding it to concrete in order to improve and develop concrete specifications (Peter W.C. Leung, Wong H.D., 2010).

Slag is definite as siliceous melt that arises in large amounts from the different processes used in the production of iron and steel, and more specially the solids that form when these materials cool. These materials are produced in large tons and the main use of ferrochrome is in steelmaking (Slag Cement Association Report, 2005).

In initial processes, slag was primarily collected of impurities that were present in the iron ore; in modern times, there is also a great impact of additives to help in the basic process or to remove some specific risky elements. An early example of this was lime added to feed for blast furnaces to provide more liquid slag, to decrease the loss of iron as oxide in the slag, and to eliminate much of the sulfur that enters the coke (Veena G, 2012).

At current, blast furnace slag is the most common sort and slag from basic oxygen steelmaking and electric arc furnace processes is also found. Various other processes such as external steel desulfurization might generate large amounts of slag in some plants but in general they represent only a small percentage of the entire slag production in the world. In a few parts of the world, ancient slag may be available in large amounts and hence it can be considered a significant industrial resource and can be used and used in various applications (K Wah, 1992).

Iron and steel slag can be approximately classified into blast furnace slag that is produced when iron ore is melted and reduced in a blast furnace, and steelmaking slag that is produced throughout the steelmaking processes used to adjust the components of iron (Chidiac .S.E. and Panesar .D.K., 2008).

Blast furnace slag is a combination of silica and other non-ferrous components of iron ore, ash from coke used as a reducing material, and limestone auxiliary material. Because its specific gravity is less than that of pig iron, during the heating process the molten slag rises above the pig iron allowing it to be easily separated and recovered (Fig.1.2) (Veena G, 2012).

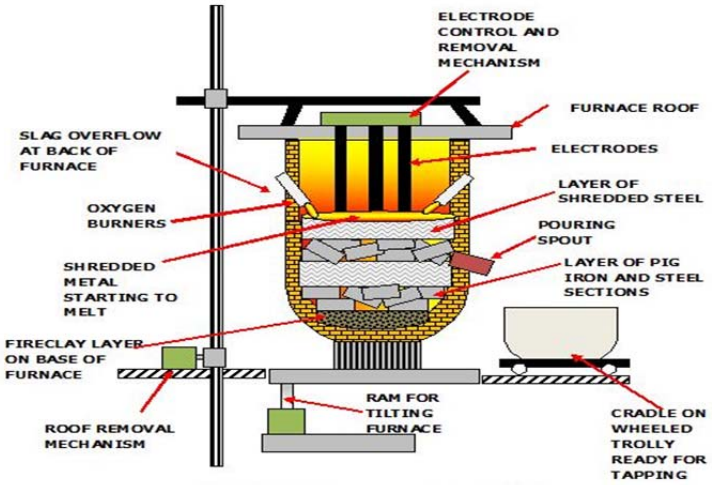

Figure1.2.The Production Process of Arc Furnace Slags.

Steelmaking slag is produced by the process that turns pig iron generated by a blast furnace into tough and highly workable steel. Converter slag is the oxidized material that is generated when lime and further auxiliary materials are added and oxygen is blown onto the pig iron in order to eliminate carbon, phosphorous, sulfur, and other components from the pig iron and refine it to generate strong steel. The other class of steelmaking slag, electric arc furnace slag, is produced when iron scrap is melted and refined (Veena G, 2012).

1.4.1. Chemical Composition of Slags

The main constituents of iron and steel slag are limestone (CaO) and silica (SiO_2). Other constituents of blast furnace slag involve alumina (AL sub>$2O_3$) and magnesium oxide (MgO), as well as a small quantity of sulfur (S), whereas steelmaking slag includes iron oxide (FeO) and magnesium oxide (MgO) (Chidiac .S.E. and Panesar .D.K., 2008). In the situation of steelmaking slag, the slag encloses metal elements in oxide form, but because the refining time is short and the quantity of limestone contained is huge, a

portion of the limestone auxiliary material may stay undissolved as free CaO (Venkateswaran D., et al, 2007).

These constituents occur in the natural world in places like the Earth's crust, natural rock, and minerals, and the chemical composition is alike to that of ordinary Portland cement. The shape and physical features of iron and steel slag are alike to ordinary crushed stone and sand, however due to differences such as the chemical components and cooling processes, it is possible to provide different kinds of slag with a wide range of unique properties. E.g., there are some categories of slag that harden when alkali stimulation occurs. Many applications using the physical and chemical properties of slag have been improved and are being ready to use in a wide range of applications (Chidiac .S.E. and Panesar .D.K., 2008).

1.4.2. Features and Applications of Slags

Currently, iron and steel slag is used in several applications where its unique properties can be ready to operational use. As a result of rising environmental awareness, iron and steel slag is highly stared as a recycled material that can decrease influences on the environment due to its resource-conservation and energy-saving effects(Chidiac .S.E. and Panesar .D.K., 2008), and there aree seeral types of iron and steel slags (Fig.1.3). Air-cooled blast furnace slag hardens when it reacts with water, with a hydraulic property that offers growing strength over time. As its large load-bearing capability, it is used in road base course material in the similar way as gravel, there is no hazard of alkali-aggregate reaction, and this slag covers no clay or organic impurities. Consequently, it is also used as a concrete aggregate in the same way as natural aggregate (Veena G, 2012).

Granulated blast furnace slag has a hydraulic property and there is no hazard of alkali-aggregate reaction. As the influential latent hydraulic property that results from fine grinding, this slag is used in products such as Portland blast

furnace slag cement. When combined with cement, the ground granulated blast furnace slag becomes Portland blast furnace slag cement with the same properties as ordinary cement. The advantages of this blast furnace slag cement, like increasing strength over long (K Wah, 1992).

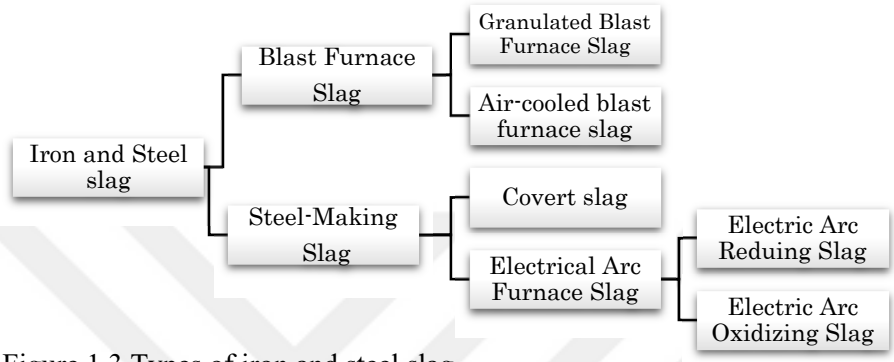

Figure 1.3.Types of iron and steel slag.

Periods of time, low heating speed when reacting with water, and high chemical stability, are ready to effective use in a broad range of applications (Hogan, F.J., and J.W.Meusel, 1981). As of its hydraulic property and the large bearing capability it can offer, steelmaking slag is used as a road base course material. With high particle density and hardness, this slag has more wear resistance and thus is used as an aggregate for asphalt concrete. Furthermore, as its high angle of shearing resistance, high particle density, and large weight per unit volume, it is also used as a material for civil engineering works (Venkateswaran D., et al, 2007). Chromite is the only ore of chromium in profit-making use, and as deposits of this mineral are lightly dispersed across the globe there are far fewer production sites for ferrochrome than for iron and steel. Production is usually in an electric arc furnace, and the slag rises from the other constituents present inside the chromite. These constituents are primarily oxides of Fe, Mg and Al, in proportions that differ widely between different ore deposits. Such arrangements alone will not provide a good fluid slag and so silica is typically added to support melt formation (Fig.1.3) (Venkateswaran D, et al, 2007).

1.5. Aggregates

Aggregates are small particulate rock containing a collection of particles with a size varying from 0.1 mm to 50 mm, for example. Gravel, broken rock, sand, and recycled concrete, and slags, are ivolved. Aggregate is a coarse material used to render concrete fit for hydraulic cementing, including sand , gravel , crushed stone, crushed hydraulic cement concrete, or iron blast-furnace slag.. Aggregate forms include coarse aggregate and fine aggregate. The aggregate classifications of each type are classified into multiple categories based on their scale. The Sieve proposed approach is used for the gradation of the aggregate to be sufficient for use in concrete and for other uses. When used without cement or binding substances, aggregate is considered to have been unbound, and when blended with cement or binding materials it is considered to be a bound substance. (Kerkhoff, 2001). Aggregates can generally be created by grinding naturally occurring rock. Aggregates may depend on the source rock to be igneous, sedimentary, or metamorphic. In order to determine their suitability for many applications, aggregates are evaluated via experiments. Mineralogy is used to determine health, grain size and texture, and to define rock samples petrographically (Houston, 1962).

1.5.1. Classification of Aggregates Based on Source

Aggregates can be divided into natural aggregates, crushed aggregate, Artificial aggregates and recycled aggregate according to their source (Litvin, et al, 1965.). Rock residues that are used in their original state are covered by natural aggregates, or are treated with crushing, washing, and sizing. Some usual aggregate bonds, named pit-run gravel, involve gravel and sand which can be freely used in concrete after minor treating. Natural gravel and sand are typically mined or scoured from a quarry, river, lake, or seabed (Litvin, et al, 1965.).

The excavated or extracted stones that have been crushed and extracted to the desired standard particle size and distribution are crushed aggregates. The

crushed aggregate units have full contact. It gives good compaction and load-bearing properties to the products. Crushed stone aggregates are primarily ideal for the improvement of highways, roads and other traffic-unprotected areas. (www.lemminkainen.com/Infrastructure-construction/mineral aggregates/Crushed-rock aggregates/). Of some remaining resources, artificial aggregates are set. Artificial aggregates are rarely generated for specific objectives (P. Priyadharshini, et al, 2012):

- Producing lightweight concrete: roasted clays, synthetic cinders, frothed slag, expanded shales and slate, sintered FA exfoliated vermiculite are used.
- Producing heavy- weight concrete: steel rivet punching and iron minerals have been recycled.

Recycled aggregate is formed by crushing inert production and processing waste. It may be regarded as treated concrete aggregate when comprising mainly crushed concrete or additional general recycled aggregate when it covers large amounts of materials other than crushed concrete. Now, only the use of coarse aggregate follow-on from manufacturing or waste destruction is recommended for use in new concrete production. The original concrete could identify the accuracy of recycled aggregates as the original concrete was known as absorbent, tough and high-strength concrete for their drives. Concrete recycling is a relatively easy operation. This involves cracking, removing and crushing the predominant concrete into a substance of recognized size and consistency. Steel reinforcement and other incorporated materials, if any, must be removed and caution must be taken to prevent other tough substances such as concrete, soil and clay balls, chlorides, glass and roofing materials from being manipulated. (http://www.cement.org/for-concrete-books-learning/concretetechnology/concrete-

design-production/recycled-aggregates). Generally, uses of recycled aggregates without any processing consist of:

- Several kinds of bulk fill.
- Bank protection.
- Base or fill for drainage constructions.
- Road structure.
- Noise barriers and embankments.

Uses of new concrete with recycled aggregates cover:

- Roadways, paths, curbs and gutters.
- Bridge basics.
- Concrete bases.
- Bituminous concrete.

1.5.2. Classification of Aggregates Based on Weight

The variance in the density of aggregates can be used, shown in Table 1.4, to describe aggregates of roughly different weights. Lightweight, medium weight and heavy weight aggregates are the most common classification of aggregates on the basis of bulk specific gravity. (Litvin, et al, 1965)

1.5.3. Classification of Aggregates Based on Shape and Surface Texture

The shape and surface texture of the particular aggregate particles explain precisely how the material is stored in a dense arrangement and how the stones are versatile in a mixture. In the shape of the material, there are two kinds: angularity and flakiness. It is possible to categorize the shape of aggregate particles as

angular, sub angular, sub rounded or rounded. Aggregates of angular and rough-textured (Litvin, et al, 1965):

Table 1.4. Classification of aggregates based on weight.

Category	specific gravity	Characteristic uses
ultra-lightweight	-	Can be sliced, As well used for its isolating features
Light weight	G < 2.4	Essential lightweight concrete 1350 to 1850 kg/m^3. As well used for its isolating properties.
Normal weight	2.4 < G < 2.8	Used for standard concrete progresses. Create normal-weight concrete 2200 to 2400 kg/m^3
Heavy weight	G> 2.8	Create high-density concrete up to 6400 kg/m^3 • Radiation sheltering. • Counterbalances. • Other uses where a high mass-to-volume ratio is desired.

- Crushing rocks produces angular particles with sharp angles and coarse texture.
- As a result of weathering, the angles of the aggregates breakdown, creating sub angular particles and smooth texture.
- Angular and rough-textured aggregates return loose materials with higher constancy than rounded, smooth-textured aggregates.

Rounded aggregates:

- As the aggregates fall while being bearing in water, the angles can convert wholly rounded.
- Rounded aggregates will be ready to work into place than angular aggregates, as their shapes create it easy for them to slip through for each other.

For each shape have features and drawbacks depending upon the desired properties of the finalized product (Table.1.5).

Table 1.5. Classification of aggregates based on shape.

Classification for shape	Use
Rounded	Suitable for use in concrete as flaky and extended particles, workability is reduced; water consumption for growth and strength is reduced.
Partly rounded	
Angular	Many criteria for coarse aggregates used in asphalt concrete involve a limited proportion of aggregates with crushed surfaces, such as a need for replacement angularity and texture, to satisfy the specifications of angular aggregates with high texture.
Flaky	Unappealing to asphalt concrete, as it is difficult to compact and easy to crack during building.

In the aggregate compacts and relationships with the binder material, the roughness of the aggregate surface demonstrates a significant role. The surface texture is a measurement unit of the aggregate's smoothness and roughness (Table.1.6). The alignment of the aggregate is diverse and is dependent on the sample's visual inspection. Five groups (Litvin, et al, 1965), namely, Glassy, Smooth, Granular, Crystalline, Honeycombed and Porous, brand the aggregates.

1.5.4. Aggregate Uses

In construction, aggregates are used to get drainage, piping precautions, and to offer strong surfaces. They are also used in water sources filtration and waste handling. Water will penetrate more easily through a pipe filled with aggregate than it will through the surrounding soil, allowing surface water to be drained into space. This is also used on roads in order to extract insulated water from the surface of the asphalt. Spaces created during construction around the

bases of buildings are full of aggregate because it is easy to dense than the original soil that has been removed, creating another solid surface that will protect the structure. Usually, aggregates are not influenced by the weather like soils , especially clay soils, and will not influence shrinkage, particularly in dry spells (Mankiw, N, et al. 2011).

Table 1.6. Classification of aggregates based on surface texture.

Classification	Use
Glassy	This standard colorful flint is ideal for driveways, sidewalks, borders and landscaping, and more for 'spray tar' and driveway chip management.
Smooth	The strength of Portland cement concrete is characteristically assisted by the Portland cement's cementing function and the aggregate interconnects; the use of rounded and smooth aggregate particles is required to improve the workability of fresh concrete during the mixing phase.
Granular	Sandstone is also used in the manufacture of cement, building aggregate, and for road aggregate, for the manufacture of glass and ceramics and a fresh material for the production of mortar..
Rough	It strengthens bonding and increases the strength of interparticles. The resistance of asphalt concrete and foundation changes through the aggregate interlock is characteristically progressive. For asphalt concrete and base improvements, angular and rough particles are therefore needed in order to increase the strength of the materials in the field and to minimize rutting.
Crystalline	For high-grade concrete, the finest aggregate. Granite is used as a decorative stone in a similar way. It can be green, red, or pink and has several colors.

Pipes lie as cable channels to carry treated water, need to be shielded from sharp materials in the soil and are therefore put on, and previously surrounded by fine aggregate channels are backfilled. In a surface layer of concrete, unpaved roads and parking places are covered to provide cars with an additional stable surface. This prevents vehicles, mainly during rainy weather, from plummeting into the soil. Groundwater, often layers of sand and gravel, is obviously filtered by aquifers and only needs to be cleaned with chlorine before it is safe to use. In treatment industries, this natural process can be simulated to extract suspended solids from the surface or from collected water before disinfection. In addition, sand beds are used as a final filter and cleaning process during the next phases of sewage treatment operations until the water is unconfined into watercourses. In this case, reed beds are often used, where the reeds are grown on gravel (Yu, Yuan, et al. 2009).

Concrete is an aggregate, cement, and water mixture. The purpose of the aggregates in this mixture is to provide a logical structure that is inflexible and to reduce the space provided by the cement paste. Both coarse aggregates and fine aggregates are necessary, but the volumes of different coarse aggregate sizes will vary depending on the specific mixture sufficient for each particular finish use (Jesus, 2011).

The smaller the aggregate amount, the larger the area of the surface and the more cement would be needed to bind it together, producing in an upper budget. However, the heavier the quantity of cement used the more durable the concrete would be durable too (Zhang, Chao, 2017).

Sand, cement and water are part of the mortar. Lime, with admixtures and colors if needed, can also be added in some cases. They are used in walls to mix materials or concrete blocks and to facilitate weather protection (Mankiw, N, et al. 2011).

1.6. Concrete

Concrete is a combined material of fine and coarse aggregate combined with liquefied cement which, over time, reinforces. As lime putty, earlier lime-based cement binders were mostly used, but often with other hydraulic cements, such as calcium aluminate cement or Portland cement, to treat Portland concrete concrete cement (Industrial Resources Council, 2008). With other methods of linking aggregates together, several other non-cementitious types of concrete exist, counting asphalt concrete with a bitumen binder, which is mostly used for road surfaces, and polymer concretes using polymers as a binder. After the aggregate is combined with Portland cement and water, fluid slurry is simply emptied and molded into shape by the mixture processes. To build a solid matrix that fixes the materials together into a hard stone-like substance that has many applications, the cement interacts with water and other materials (Li, Zongjin, 2011). In order to establish the physical properties of the wet mixture or the finished material, additives (such as pozzolans) usually are involved in the mixture. Most concrete is vacuumed with embedded reinforced composites to provide versatile power, resulting in reinforced concrete.

It is just as necessary as before because concrete cures how concrete is kept after it has been emptied (https:/www.bobvila.com/articles/curing-concrete). Concrete is one of the building materials that are most usually used. Its global demand, ton for ton, is twice that of steel. (Cement Trust, 2010). Worldwide, by 2025, ready-mix concrete development, the largest part of the concrete industry, is projected to surpass billions in revenue (Digital Journal, 2017). Concrete is unlike mortar. Although concrete is a building material itself, mortar is a linking director who commonly embraces elements together.

1.6.1. Required Properties in Concrete

The properties of concrete are influenced by the properties of the materials structuring the concrete mixture and the quantities of these materials in the

mixture. As the characteristics of fresh concrete and hardened concrete are checked in two sections, concrete properties (D. J. Naus, 2005).

It should be easy to blend, easy to set, and compress the materials used in concrete manufacturing. The concrete temperature should be in the range of 5-33 oC during the pouring of the concrete. During the transportation, positioning and compression of the concrete, the materials holding the concrete do not depreciate the homogeneity, since coarse aggregates appear to break down during concrete placement. In high viscosity concretes, water tends to increase to the surface by rising through the concrete. In fresh concrete, 0.5-8 percent air volume is present. The quantity of air in concrete is an attribute that influences properties such as strength and density directly. In addition, the amount of air in concrete can be increased with air entraining additives due to increased freeze-thaw resistance (Gönen 2012).

1.6.1.1. Properties of fresh concrete

The most important thing about fresh concrete is its workability or flowability, since it addresses the ease with which it can be put. It is resolved via a slump test in which fresh concrete concrete is filled with a normal reduced metal conduit process. The mold is then lifted vertically, and the rapid decline of concrete conduit height, or slump quality, demonstrates the workability of the concrete. The flow test, which resembles the slump test, is performed for such liquid mixes, except that the mean mortar diameter molded by the fresh concrete is assessed. The concrete strengthens and loses its malleability a brief period after casting. The setting time can be measured by dropping a uniform needle periodically into the new concrete and evaluating the time until the needle no longer falls into the concrete production (D. Sedan, 2008).

1.6.1.2. Properties of Hardened Concrete

The most important property of hardened concrete is undoubtedly its compressive strength. As this strength continues to increase with permanent hydration of cement, it is a part of age that is the time after casting. The strength is assessed 28 days after casting, up to breakdown, by filling standardized test cylinders. The compressive strengths of most commercially produced concrete are between 20 and 40 MPa. The material fails at a stress much lower than that, usually on the order on ten percent of the compressive power, if overloaded in stress. Concrete is typically reinforced with steel bars because of this unreliable tensile strength, (Ihram Pharaoh Mullah, 2007).

The concrete volume decreases by a small amount due to shrinkage via hydration, and particularly if allowed to dry after hardening. It can lead to cracking if this shrinkage is managed somehow. Only partially upon wetting can shrinkage distortions created by drying be reversed. A concrete member or structure exposed to external load can encounter distortions that are related to the amount of load applied up to a point. If these loads remain in place for a long time, because of a material property called creep, these defects may increase. Creep distortions can be two or three times as great as the initial flexible distortions, even for standard concrete mixes, especially if the concrete is loaded at a very early age. Such creep and shrinkage distortions must be determined when designing concrete structures for (D. J. Naus, 2005).

2. PREVIOUS STUDIES

Puertas, F., et al (2000) researched alkali-activation for mixtures by means of several FA / slag ratios through their study and achieved the following mechanism relative to each sample series. The sodium hyroxide molar ratios used were 20 M percent and the FA / slag fractions were as follows: 100:0, 70:30, 50:50, 30:70, 0:100. Generated pastes were cured for evaluation at 25 ° C and 65 ° C and subsequent reaction products were investigated using HCL dissolution techniques to obtain methods of reaction point, XRD , FTIR, and MAS-NMR study. FA of mostly glass quality and a marketable blast furnace slag with high CaO and SiO_2 levels were the pozzolanic substances achieved. The materials were individually mixed in the above-measured fractions and activated with the required alkaline ratio to achieve a 35 percent liquid to solid paste range. New versions have been formed into cubic molds (10 x 10 x 60 mm) and have been cured for 5 hours at 98% (relative humidity) RH, one link at room temperature and the other at 65 ° C. Compressive strength was applied during the cure cycle of 1, 7, 28 and 90 days and found that resistance increased congruently as the slag ratio increased. In addition, the highest strength value was 70 MPa at 90 days from the samples with the highest alkaline ratio of 10 M, using the 0:100 FA / slag ratio. The activator ratio and FA / slag ratios were the most successful of the three major parameters evaluated for future strength attainment. The temperature obtained was shown to have a straightforward effect on the disbanding of the pozzolans, which involves a hydrated calcium silicate gel formed by tetrahedral, allowing a contrast - enhanced grade and less leaky, tougher matrix. So, the limited reactivity measured by experiments at room temperature was sufficient. By using HCL dissolution of activated slag and FA, the insoluble residue (IR) of the 50:50 mixtures was measured at 37 percent. It was shown that when the cure time of each sample increased, the IR was reported to decline, which was observed to be the outcome of a recurrently decreasing level of FA / slag for possible reaction and following HCL

closure. The slag would usually detach more rapidly than the FA, so the rare amount of hydrated alkaline aluminosilicts resulting from FA activation would be uncommon.

Qian and Li (2001) tested the versatile and twisting strength of 0, 5, 10, and 15 percent cement replacement MK-based concrete. They stated that the tensile strength increased with the cumulative addition of MK linearly. The bending strength has reduced somewhat where the MK replacement is 5%, when the replacement volume is 10% and 15%, the twisting strength has grown by 32% and 38% respectively.

The microstructural characteristics of FA and slag geopolymer concrete were researched by Puertas, F., et al (2003). The study of the findings was completed using XRD, FTIR, MAS-NMR, and SEM instruments. In contrast, nuclear absorption and chromatography of ions were measured. Two products were found through their research; first, a ridiculous calcium hydrate in aluminum and an alkaline aluminosilicate hydrate in 3D structure, respectively. XRD examined the slag added for use and the results reffered to that slag include a large proportion of a glass phase and a crystalline portion. Just as FA was examined, a quartz and a glass phase were accused of being involved. Additional slag experiments determined arrangements such as Akermanite and Gehlenite arrangements in some way. On 10 x 10 x 60 mm molds with an FA / slag ratio of 100:0.0, mechanical testing was performed. At 10 M, the marketed activator was sodium hydroxide. The procedure took place for 5 hours at various temperature levels: 22 ° C and 60 ° C. Each sample then, for 7 and 28 days until experiments, persisted at room temperature with 98 % RH. For each experiment, compressive strength outcomes at 7 days cure time were obtained at 30 MPa. During a 28 day cure cycle, the samples cured at room temperature 60 MPa of compressive strength; higher compared to samples cured at 65 ° C. The degree of silicate polymerization varies from conventional to reaction time, so longer cure time offer the possibility of further polymerization and greater concrete resistance. The reaction products

formed around the FA atoms, a shapeless alkaline aluminosilicate hydrate with 3 D structural features, were revealed in this search.

Chareerat, T., et al (2006), tested in the mix design the necessary characteristics of geopolymer concrete mortars relating to both cure time and temperature, clay output methos, and the resulting processes from various pozzolan ratios. The FA was from a power plant, although the clay was used to manufacture calcined kaolin. 10 M sodium hydroxide and sodium silicate, 15.3 percent Na_2O and 32.8 percent SiO_2, and 51.8 percent water by mass, were included in the activator solution. A 2.75 percentage of sand / binder used to acquire the experiment mortar and samples is shaped as cubic molds of 50x50x50 mm. In order to measure the optimum parameters for clay burn temperature, mortar curing temperature, CK / FA fractions, and delay time prior to cure, several experiments have been concluded. The clay samples were subjected to high temperature exmines between 400-800 ° C for approximately 6 hours. It was recognized that the apposite temperature and period for the processing of calcined clay is 600 ° C for 2 hours and the final compressive resistance was reduced for another time for this temperature. The substitution of the FA-CK ratio had an effect on the mortar compressive resistance. Experiments showed that the highest compressive resistance was created by a 25 percent CK replacement of 43 MPa, as CK values formed strong material in the 10-40 percent variety; greater than 40 percent replacement reduced mortar resistance. Further researchers suggest that geopolymer samples required 2 hours previously to rest at room temperatures to cure established compressive resistance measurement values. As samples at 25^{o}C temperature curing improved to 43 MPa, experimental results from a compressive sample performed immediately to temperature cure showed resistance of 34 MPa. So, 3-6 hour delay time decreased compressive resistance.

Using a blast furnace slag and metakolin (MK) mixture as the pozzolanic constituent, Buchwald, et al (2007) explained values obtained from the geopolymerization reaction. The binder was enabled with a solution of sodium

hydroxide to infer the form and quantity of reaction products formed by each material. The goal of the research was to assess how material products developed by both MK and slag interact with each other chemically, and whether they are especially enhanced. The research was conducted using 29Si and 27Al MAS-NMR spectroscopy and compared to results obtained by (XRD) and thermal analysis. Deconvolution of the signs of the MAS spectra depends entirely on the Lorentz curve to achieve the best results, and the Rietveld refinement method was used to analyze XRD. The last strength experiment was used to obtain compression and tensile bending assets for the samples produced. Slag, by mass, crystalline calcium silicate phases and calcite, was 73 percent glass. MK contains dehydroxylated kaolinite that is 84 percent shapeless. In order to acquire equivalent Na / Al fractions for both net MK and net slag, activation was established by means of a NaOH solution in unique fraction. Molds were poured and cured for a day at 40 ° C. Samples for bending strength experiments were prepared as a 10 x 10 x 60 mm cubic mold and the data were gathered for compressive strength experiments and provide a compressive area of 10 x 20 mm. The results of compressive strength experiments defined the highest value for the net slag and the reverse value set for the net MK samples. Similar patterns for the bending analysis of sample establishments were seen. For all samples, XRD analysis showed primarily amorphous states, but new crystal formation was only discovered in slag coating samples. Sample examination of known C-S -H stage crystals in small quantities. The thermal analysis showed all the samples at temperatures between 30 and 1000 ° C at a rate of 10 K / min and measured the water loss inside the device. Results similar to early prospects were identified by the 29Si NMR: the AA-M produced ASN with Q4 signs, while the sample produced Q1 and Q2 signs of the C-S - H stage attitude. For both MK and slag, the 27Al NMR spectra showed 4synchronized aluminum, and the additional slag sample showed hydrotalcite seen as 6 coordinated aluminum. XRD acknowledged this by. None the less, the entire degree of slag reaction was much greater than that mixed with MK. In short, it was

stated that the minute interacted between the two products was due to flexible dissolution kinetics and was connected to the transmission of aluminum into the CS-H phase , resulting in a Si / Al ration discount between 6-2.8 and a raise in C-S - H chain length from 6-13. The MK / slag samples were understood to generate hydrates of calcium silicate and polymer combinations, so they were used together to speed the process. Inside the blended mix, the formation of an individual reaction level was not reached. Further experiments including 1 H-27Al CP NMR and MQ27Al NMR methods have been shown to be concluded in order to develop a good explanation of the reaction products manufactured and the quantification of the MK / slag combinations.

Fernandez-Jimenez, et al, (2008) based on the basic features of hardened alkali-activated cements for analysis by using MK and a 1/1 FA/ MK mixture, cured together at various temperatures. In order to activate each mixture, the proportion of NaOH and sodium silica solution was 7.4 percent, 1.5 percent and 91.1 percent water at 1.25 MK and 0.875 FA/ MK. By burning it at 750 ° C for almost 20 hours, the MK used was produced from clay, the FA was obtained from a power plant. Molds (10 x 10 x 60 mm) were formed and originally subjected to 98 percent RH at 85 ° C for 3 hours. At multiple temperatures of 85 ° C, 150 ° C and 200 ° C, samples then underwent 5 healing hours. Formerly at 2.4 KN / s for compressive examination, the samples eventually rested at 90 percent RH for a day. XRF, Fourier Transform Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM), and 29Si MAS-NMR tools were used for microscopic mechanical observation and mineralogical configuration. Some attention-grabbing remarks were made regarding of form of sample. FA / MK curing at 150 ° C for 5 hours increased the maximum strength to 29 MPa, with the lowest reaction fraction being noted. This has been defined as the output of 2 separate parameters: An increased gel / zeolite fraction resulted in the presence of FA, and the unreacted FA acted as fine aggregates, thereby increasing compressive strength characteristics in the weaker matrix. In addition, there was a tenancy for the resulting zeolites to

enter and occupy the reacted FA's hollow shell, which reduced space and formed processes. The MAS-NMR sign analysis also revealed high Si / Al layer crystalline zeolites from inside FA / MK samples that have a positive effect on strength values. Therefore, despite the lower quantity of reactive FA in the FA / MK samples, their Si-rich zeolite layers gave the MK factor an advantage. It was strongly-minded that the mechanical features of FA activated cements are clearly affected by time and temperature. In maximum samples, elevated temperatures and longer curing times have shown stronger action. It was also noted, however, that each matrix carries a peak temperature to which the subsequent act is partial. For MK, the best temperature was between 150-200 ° C. In order to deteriorate the material and inflict opposite impacts to compressive strength, curing temperatures up until that point were explained.

Using ultraviolet spectroscopy to detect bonding behavior inside the polycondensed gel formation, Criado, M, et al research alkali-activated FA cements at micro levels. The first silicate fraction formed with the Class F FA material in the activating solution and the reaction products. Both alkali-based solutions contain both contrast NaOH and silica and have been combined with the FA for samples at a 40 percent liquid / solid proportion. Samples were healed at 85 ° C and witnessed with an ATI Mattson Genesis spectrometer device between 4000-400 cm^{-1} per KBr pellet method at 8 hours, 60 days and after those 180 days. The initial FA in a pressure applied state and similarly in a crystalline phase was encountered and observed to contain quartz and mullite. The activated FA creates zeolites and aluminosilicate layer once absorbed into solution. FTIR spectra were shown as interrelated with curing temperature and soluble silica in the initial FA to further clarify the nanostructure of the reacted FA and were identified as T-O bond asymmetric stretching band spectra in the 996-1145 cm^{-1} range. In addition, in the FA enabled solutions, external ring vibrations in the silicate and aluminosilicate cyclic structures became evident as spectra in the 800-500 cm-1 range.

Toprak, (Toprak, M.U., 2011), examined the strength, durability and microstructure properties of the geopolymer produced by using alkaline activator of the power plant based FA. According to FA, there were 12 different alkali-activated mortars containing 8, 12, 16 %Na_2O and 0, 4, 8, 12 %SiO_2 are set and cured in an oven at 85 ºC and 40% RH through 20 hours. They produced geopolymer mortars with strength above 25 MPa as a result of activation of FA with alkali containing 12% Na_2O and 8% SiO_2 by mass.

3. MATERIALS AND METHODS

3.1. Materials

3.1.1. Fly ash

FA has attracted a great deal of interest as one of the geopolymer materials and has been the subject of many researchers for very many applications (Davidovits, J, 2008). The FA (Class F according to ASTM C 618-95) obtained from the Sugozü thermal power plant in the Yumurtalık district of Adana was used as a primary substance in the geopolymerization phase in this study. The Minipal 4 Panalytical X-ray fluorescence (XRF) system (Table.3.1) was applied for the Sugozü thermal power plant fly ash and the particle size distribution of the Sugozü thermal power plant FA is shown in Figure (3.1). XRD (X-ray diffraction) study performed for the FA Sugozü thermal power plant (Fig.3.2). The Sugözü thermal power plant FA grain size distribution curve was obtained (Fig.3.3). The FA SEM picture of the Sugözü thermal power plant (5000 magnification, micron bar = 5μm) and the EDS spectrum are carried out (Fig.3.4). The FA mainly includes Quartz (SiO_2), Mullite ($Al_{4.8}Si_{1.2}O_{9.6}$), CaO and Fe_2O_3.

Table 3.1.XRF analysis of the Sugozü thermic power plant fly ash.

Content	SiO_2	Al_2O_3	CaO	Fe_2O_3	K_2O	SrO	BaO	ZrO_2	TiO_2	SO_3	LOI
%	55.20	24.10	5.50	8.11	1.62	0.27	0.26	0.19	1.44	0.72	2.34

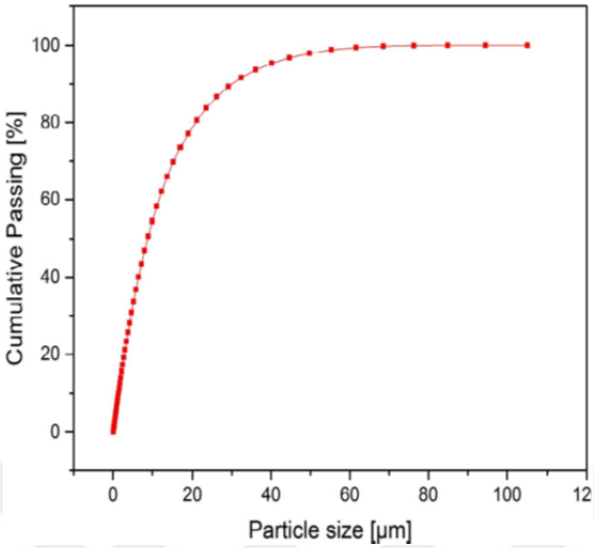

Figure 3.1.Particle size distribution of Sugozü fly ash.

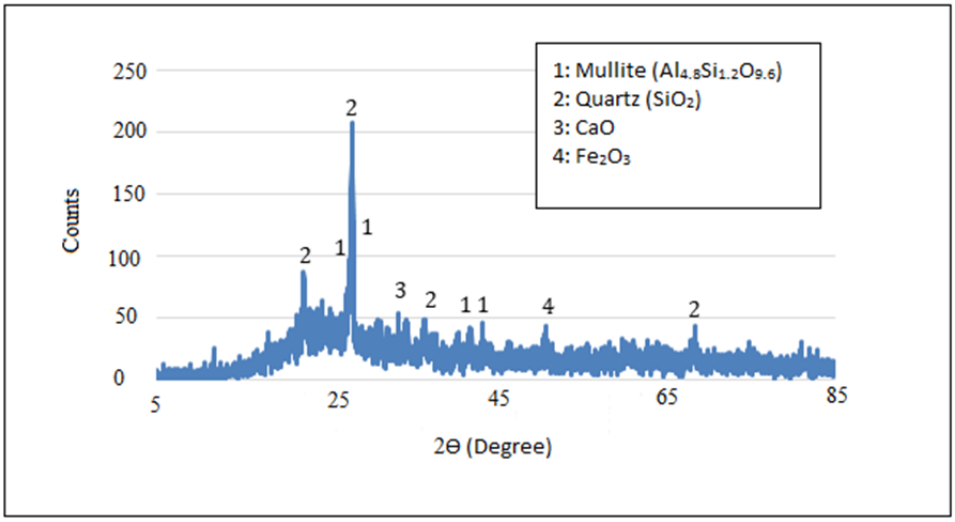

Figure 3.2.XRD diagram of the Sugözü fly ash.

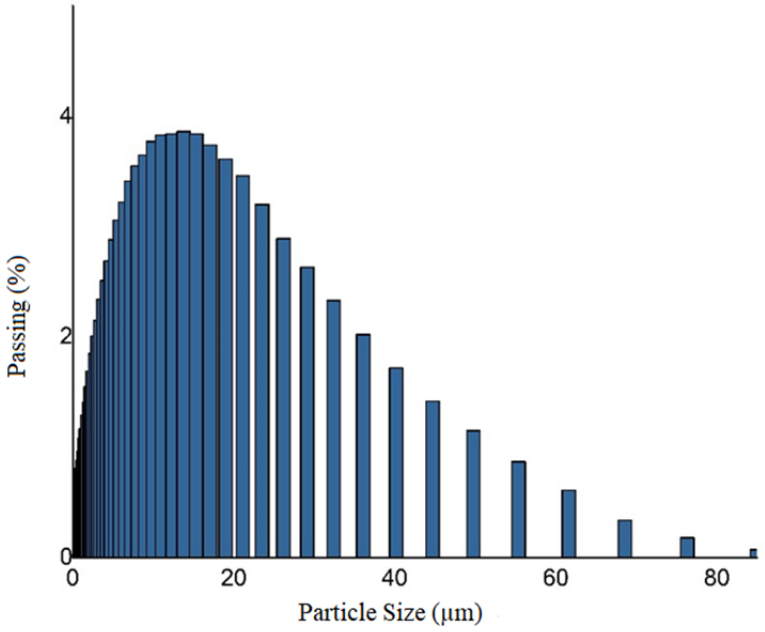

Figure 3.3. Particle size distribution curve of Sugözü thermal power plant fly ash.

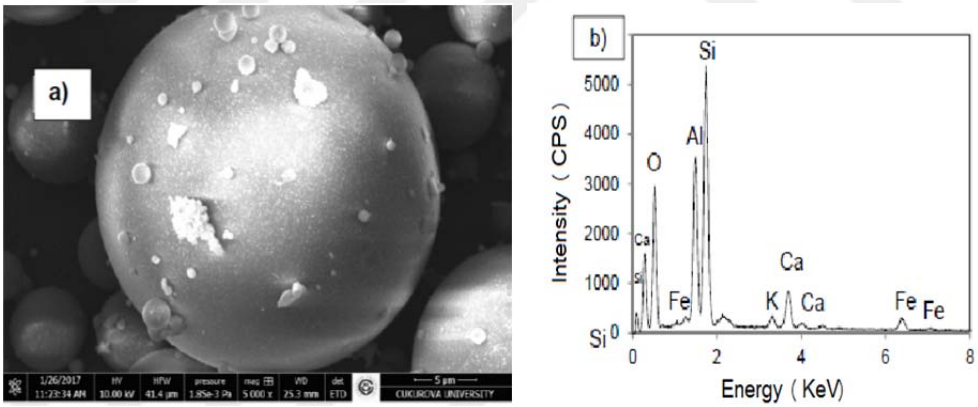

Figure 3.4. Sugözü thermal power plant fly ash (a) SEM image (5000 magnification, micron bar = 5µm), (b) EDS spectrum.

3.1.2. Aggregates

In this study, arc furnace slags and basic basaltic pumice (BP) are used as aggregates. Basic pumice samples obtained from Nevşehir Province to be used as light aggregates, whereas arc furnace slags have been provided from Ekinciler Iron and Steel Industry Inc. in Iskenderun Region. In order to be characterized by higher long-term compressive and flexural strengths, easier placeability and finishability, reduced permeability, improved durability and strength, more consistent efficiency, and lighter color, Arc furnace slag is used. Like light aggregates, the simple BP is used. Arc Furance slag is considered one of the artificial pozzolanes used as concrete mineral additives, industrial waste that occurs in iron and steel factories during iron production. The slag, which is extracted as a waste material at a temperature of 1500^{o}C from the blast furnace, can be used for any purpose only after cooling. Arc furnace slag, which includes a vast volume of silica and alumina and has an amorphous composition, exhibits various structural features according to the cooling technique used. Slag, which is subjected to a very rapid cooling process , typically in abundant water, is known as "granulated furnace slag" because particles such as sand grains (the largest size is around 4 mm) are produced. The very quick cooling of the slag gives the slag the structure of both granulated and amorphous (glassy) (Bilim, C. and Atiş, C.D, 2011). After crushing gravel, the arc furnace slags used for this project were obtained from the gradients of the particle sizes obtained after a detailed sieve analysis to achieve an average maximum size in the range of 4 mm. The coarse aggregate’s specific gravity was 2.72m2 / gr, and the absorption of water was 0.45. Since the sizes of the samples of basaltic pumice (BP) and arc furnace slag were huge, the samples were crushed until the average particle size of 4 mm using a laboratory style jaw crusher and this particle size is only suitable for simple experiment. The arc furnace slags and BP were pulverized (> 100μm) and then analyzed by the Minipal 4 Panalytical X-ray fluorescence system (XRF) where the XRF analysis using Hoechst wax C micro powder tabletting assist produced homogeneity for the samples (Table.3.2)

(Table.3.3). Inorganic material compositions of arc furnace slags and BP were determined by Rigaku Minflex II X-ray diffractometer (XRD) device (Fig.3.5) (Fig.3.6). The XRD patterns of the materials were interpreted by using PDXL XRD analysis software with current database. The arc furnace slags mostly contain Gehlenit (Ca_2 $Al(AlSi)O_7$), Larnite (Ca_2SiO_4), wustite (FeO), Magnetite (Fe_3O_4), CaO and Brownmillerite($Ca_2(Al_{0.75}Fe_{0.25})$ while BP mainly consist of diopside ($CaMgSi_2O_6$) , augite ((Ca,Na) (Mg,Fe,Al,Ti) $(Si,Al)_2O_6$) and Hematite minerals.

Table 3.2. XRF analysis of basic Basaltic Pumice (BP).

Content	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	SrO	MnO	ZrO_2	TiO_2	SO_3
%	41,50	15,52	11,71	19,34	3,11	0,39	0,25	0,35	3,88	0,29

Table 3.3. XRF analysis of arc Furnace Slags.

Content	SiO_2	Al_2O_3	CaO	Fe_2O_3	MnO	Cr_2O_3	BaO	PdO	TiO_2	ZnO	SO_3
%	11,59	7,63	31,90	37,38	3,95	1,34	0,22	3,19	0,30	0,16	0,39

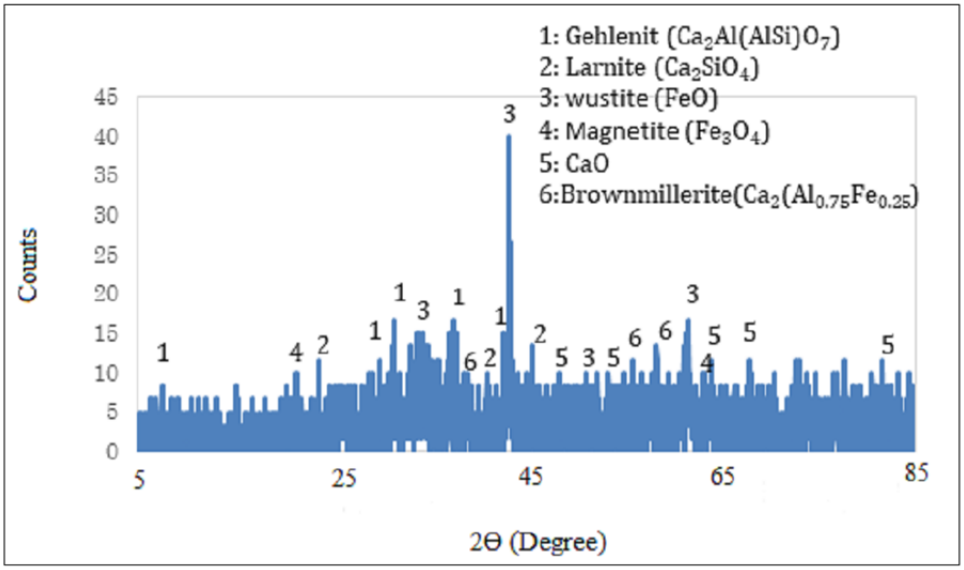

Figure 3.5. XRD diagram of arc furnace slags.

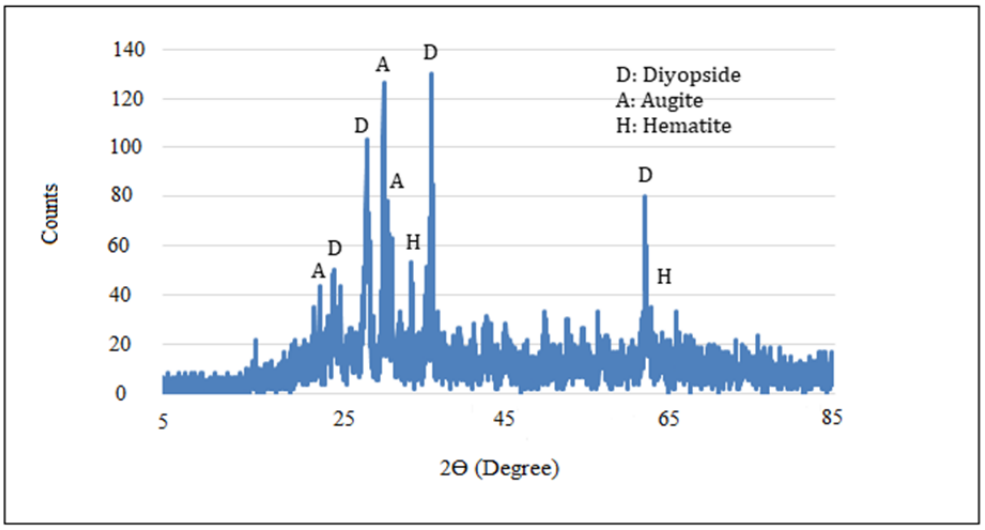

Figure 3.6. XRD diagram of Basic BP.

3.1.3. Calcium Bentonite

The use of (Calcium Bentonite) CB for pozzolan purposes in cement mortar dates back to the 1960s. Since the 1990s, its use in concrete production has become widespread due to its high strength and durability properties (Yonar, Y, 2014).

CB is a binder material, which has high puzolanic properties (Duxson, et al, 2007). For decided and determine the changes on the CB structure, high temperatures were applied on CB. The temperature at which betonite clay loses its water dehydrolyzed is in the range of 500-800 ºC (700-900 göreC according to another source). At this temperature, clay loses about 10-14% of its bound water. As a result of the transformation, the layers of alumina and silica lose their order in their crystal structure, thereby gaining kaolin, amorphous and chemically reactive structure. In case of successful heat treatment, an amorphous phase CB with highly pozzolanic properties is obtained (Yonar, Y., 2014).

CB reacts strongly with solutions used as alkali activator to form high-strength geopolymer samples (Thavorniti, P., et al, 2015) (Belmokhtar, et al, 2017).

Davidovits has examined many pozzolanic materials as the main component in the production of geopolymer, and according to the results, metakoline-slag-based gepolymers are considered to be the best produced composites in terms of acceptable mechanical and durability performance (Aygörmez, Y, 2018). Geopolymerization with CB depends on the type and amount of activator and CB, and the curing system (Roviello, et al, 2015) (Rieger, D., et al, 2015).

CB clay collected from Yeni Özdemir Ltd Şti, İskenderun, Turkey. The sample was crushed by means of a laboratory type jaw crusher. After sample reduction by quartering, the starting clay was analysed by Minipal 4Panalytical X-ray fluorescence (XRF) device (Table.3.4).The inorganic material compositions of starting CB clay was determined by Rigaku Minflex II X-ray diffractometer (XRD) device (Fig.3.7). The XRD patterns of the materials were interpreted by using PDXL XRD analysis software with current database. The starting kaolin clay mostly contains quartz [SiO_2] and mica $AlSi_2O_6(OH)_2$, Feldspar $(K,Na)Si_3O_8$,.

The CB clay grinded and then burned in furnace up to 700ºC ± 20ºC, for 1 hour. After that CB grinded to the specific surface area of 23m^2/g. The chemical XRF analysis (Table.3.5) and XRD spectrum (Fig.3.7) of CB was obtained. The CB mostly contain Quartz [SiO_2],mica $AlSi_2O_6(OH)_2$, and Montmorillonite $(Na,Ca)_{0.33}(Al,Mg)_2(Si_4O_{10})(OH)_2 \cdot nH_2O$).

Table 3.4.XRF analysis of starting CB clay.

Content	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	K_2O	TiO_2	CaO	P_2O_5	MgO	MnO	LOI
%	41.69	11.67	6.97	1.86	1.37	0.54	14.48	0.17	4.97	0.13	16.85

Table 3. 5.XRF analysis of CB after burning process.

Content	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	K_2O	TiO_2	CaO	P_2O_5	MgO	MnO	LOI
%	42.0	12.9	10.84	2.05	1.8	0.92	22.3	0.2	2.0	0.14	2.9

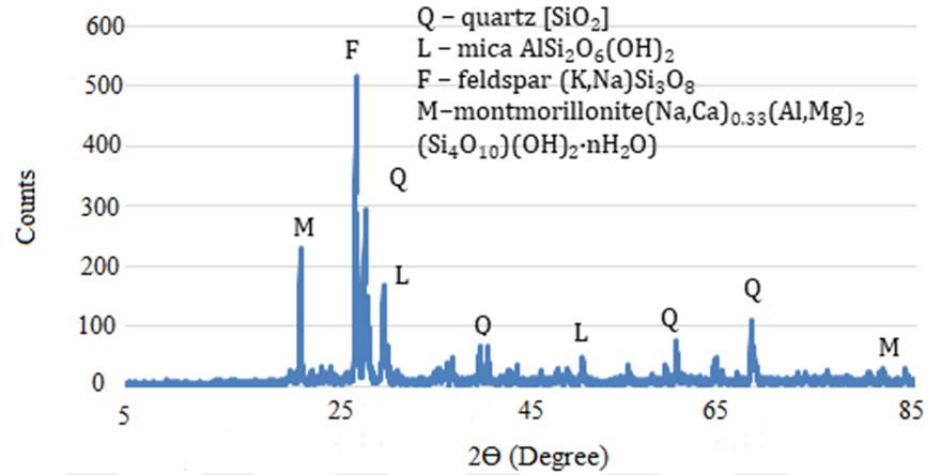

Figure 3.7.XRD diagram of starting CB clay.

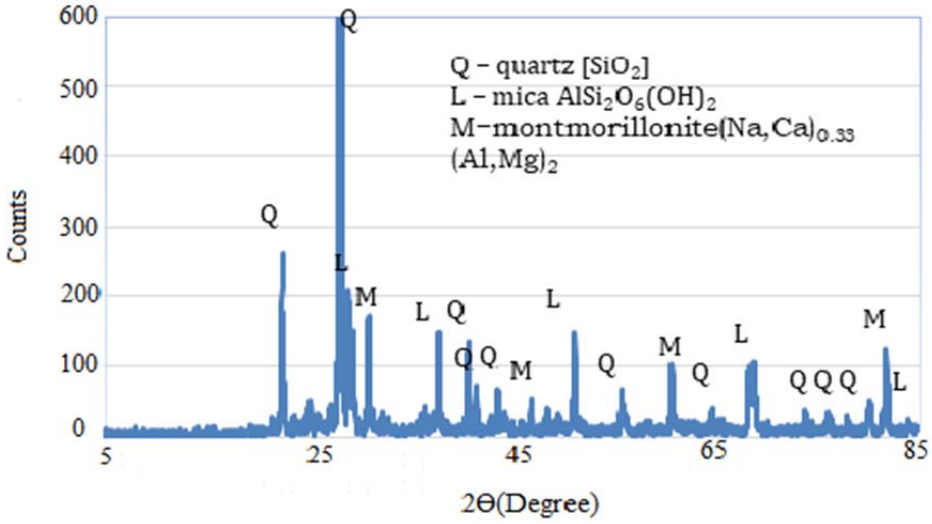

Figure 3.8.XRD diagram of CB after burning process.

3.1.4. Alkaline Activator

Alkaline activator loads to get a high pH environment and accelerates the reactions. Mainly two chemicals are used as the alkali activator in their ratio. Sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) are the alkali activator

used in this study. These alkali liquids are preparing a day before the casting of concrete.

3.1.4.1. Sodium Hydroxide (NaOH)

A white moisture absorbing content, sodium hydroxide (NaOH). It dissolves the heat in water and forms a solution that is gentle, slippery and soapy. In the laboratory, Na OH is used to arrest acidic gases like CO_2. It is used in the manufacture of various industrial chemicals, artificial silk, soap, paper, paint, detergent processing and oil refineries. Cheap, convenient and available in required quantities is one of its advantages. It is commonly used in geopolymer development processes as an alkaline activator (Luga, E., 2015).

In the solution form (98 percent pure), sodium silicates are available. For the development of the necessary degree of alkali activator solution, these solutions are used in the various NaOH fractions. Using water to create 12 molar concentrations, sodium hydroxide (NaOH) pellets were dissolved (Aygörmez, Y, 2018). The NaOH solution was prepared one day after the geopolymer sample mixing process. To create an alkaline activator, the technical grade of the sodium silicate solution was combined with the NaOH solution.

3.1.4.2. Sodium Silicate

Sodium silicate, known as glass water, is a chemical component with the formula Na_2 (SiO_2) nO. Sodium silicates are produced by fusing sand (SiO_2) with sodium or potassium carbonate (Na_2CO_3 or K_2CO_3) at temperatures exceeding 1000 ° C and dissolving the product into a semi-viscous liquid called water-glass with high pressure steam (05 April 2019, https://www.sodium.gen.tr /sodium-silikat.html). Its general form is colorless, but in its commercially used derivatives, they can become green or blue with foreign substances. Sodium silicate, which can result from the reaction of sodium carbonate and silicon dioxide substances, is the raw material of silica gels. When mixed with water, it gets a syrup-like structure.

Some sodium silicates in different groups may not easily dissolve in water. Sodium silicate is frequently used in the cement industry, textile, timber processing industry, automobiles and refractory materials (05 April 2019, https://www.sodium.gen.tr /sodium-silikat.html).

Water glass is rarely used as an independent activating unit because it alone does not have enough activation potential to initiate the pozzolanic reaction. Rather, it is mixed with sodium hydroxide (NaOH) or potassium hydroxide (KOH) as a supplement to increase alkalinity and increase overall sample strength. The most common alkaline liquid used in geopolymerization is sodium hydroxide or potassium hydroxide and a combination of sodium silicate or potassium silicate. The chemical properties of sodium silicate are given in Table 3.6. Sodium hydroxide (NaOH) available forms of pellets, flakes and in powder forms. In the study, Commercial grade Sodium Hydroxide (NaOH) is used in the flakes form (97%purity). These flakes are used to make the solution of required molarity. The Na_2SiO_3 consisted of 9.4% Na_2O, 30.1% SiO_2, and 60.5% H_2O (with a SiO_2/Na_2O weight ratio of 3.20-3.30 and a specific gravity of 1.4 at 20 ºC.

Table 3.6. Chemical properties of sodium silicate.

Na_2O (%)	SiO_2 (%)	Density (g / ml) (20 ° C)	Fe (%)	Heavy metals (such as Pb) (%)
8.2	27.0	1.360	< 0.005	< 0.005

3.2. Tests

3.2.1. Uniaxial Compressive Strength (UCS)

The ELE brand strength instrument has been used to calculate uniaxial compressive strength (Fig.3.9). Standard cubic samples were mounted in the section where the loading would take place in compliance with ASTM C109 / C109 M and the installation procedure began to be carried out using the machine. The speed of upload was selected as 100 kg_f / sec. When the cubic sample is

fractured, the UCS test is terminated. From the formulation below, strength values are calculated; P: pressing force (kg_f) and A is the area (cm^2) where the strength of the sample is determined. Power (σ) was calculated as MPa from this formulation.

$$\sigma = \frac{P}{A} \tag{3.1}$$

In addition, stress-strain curves were attempted to assess the breaking activity of the samples in certain samples. The stress value is taken as (σ), while the unit deformation (ε) has been determined from the below formulation. Consideration of the deformation of these materials with added strain. As a consequence of loading, the sum of deformation was computed.

$$\varepsilon = \frac{\Delta L}{L} \tag{3.2}$$

Where: ΔL the difference between the first dimension and the final dimension of the sample (mm).
L is the first size of the sample (mm).

Figure 3.9. ELE brand strength Device to determind the UCS value.

3.2.2. Point Load Strength (PLS)

Concrete block point load resistance as measured by the ELE brand point load resistance system (Fig.3.10). At the pointy end of the instrument, cubic samples are mounted. The pressure was charged by the rod of the piston until the sample started to crack. The point load resistance value (kN) is taken when the cubic sample is broken, by reading the value on the instrument. From each sample, two measurements were taken and the average was identified.

Figure 3.10. ELE brand point load resistance device.

3.2.3. Pundit Sonic Speed (PSS)

Using the Pundit sonic speed unit, the sonic velocities of the samples was measured (Fig.3.11). It is important to calibrate the unit. By placing the reference sample between the receiver and the system transmitter, calibration is given. For the positioning of cubic samples between the receiver and the transmitter, 3-dimensional speed measurements were then collected. Grease was suggested in order to help transfer the waves to the surface of the samples. The average value of the measurements is determined in the formulation below, according to the Pundit Sonic Velocity Value estimate.

$$V_p = \frac{L}{Tp} \quad (33.$$

Where; L, the length of the sample (mm),

Tp, the measured value (μs) from the instrument and

Vp is the propagation speed of the P wave (km / sec).

Figure 3.11.The Pundit Sonic Speed DEVICE.

3.3. Experiments Design and Mixing Process

First, it is important to determine the ideal alkaline activator ratio, so it can be implemented in all of the DOE-designed experiments. Mortars were produced using 5 different alkaline activator ratios 0.5, 1.0, 1.5, 2.0, and 2.5 (Table 6) to assess the effect of the alkaline activator ratio (Na_2SiO_3 / NaOH ratio). 5 different alkaline activator ratios 0.5, 1.0, 1.5, 2.0, and 2.5 were used. By maintaining the fly ash / alkaline activator ratio as a constant (1.5). 12 M of NaOH was prepared by using 480g of NaOH to1000 ml of tap water and after that the calculated amount of sodium silicates was added, and finally 1000 g of fly ash was added to create the fly ash-based geopolymer paste. The details of the mixtures of alkali-activated fly ash based geopolymer paste are given in Table 3.7. In order to study the effect of the percentage of Na_2SiO_3 solution content of the alkaline activator on the compressive strength (UCS) of alkali-activated fly ash-based geopolymer paste, for every Na_2SiO_3/NaOH ratio was obtained.The UCS was calculated for FA-based

geopolymer paste using different ratios of Na_2SiO_3 solution / NaOH solution. Both mixtures measured using the UCS measuring system at 3 and 7 days, respectively (Table 3.5).

Table 3. 7.Mixture details of alkali-activated fly ash-based geopolymer paste.

exp	Fly ash / Alkaline Activator	Fly ash (g)	Alkaline Liquid (g)	Sodium silicate / sodium hydroxide
exp1	1.5	1000	500	0.5
exp2	1.5	1000	500	1.0
exp3	1.5	1000	500	1.5
exp4	1.5	1000	500	2.0
exp5	1.5	1000	500	2.5

The effect of the Na_2SiO_3 / NaOH solution ratio on the UCS of the geopolymer paste based on alkali-activated fly ash, obtained at 7 days of age, is shown in figure (3.12).

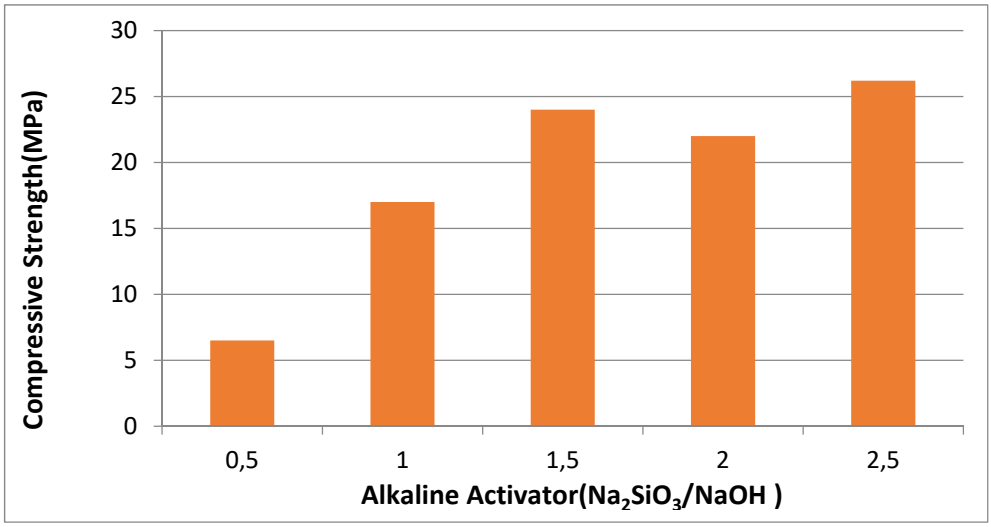

Figure 3.12. Effect of the Na_2SiO_3/NaOH solution ratio on the UCS of the geopolymer paste.

The results show that growing the degree of the sodium silicate solution in the alkaline activator greatly improves the geopolymer paste's UCS value. The sodium silicate solution offers additional forms of silicon (Si) that play an important role in the process of geopolymerisation. The perfect alkaline activator ratio was 2.5 across 7 days, which corresponds to 26.20 MPa of UCS value, whrease the lowest value of UCS was obtained at 0.5 ratio of alkaline activator and if we take a look again at Fig.3.12 a slight decrease was found and the reason of that is with the ratio of Na_2SiO_3/NaOH at 2.0, might be due to an excess of OH- concentration and the used amount of water can play an important role on that.

To obtain 12 Molar concentrations, NaOH pellets were dissolved with water. To create an alkaline activator with a ratio of 2.5, the sodium silicate and sodium hydroxide (NaOH) solution were mixed together. With regard to the workability of geopolymer concrete, the FA / alkaline activator ratio was set at 1.5 (Davidovits, J, 2008). The aggregates have been chosen of 75% to the total weight of geopolymer mixture (Davidovits, J, 2008) where the ratio of arc furnace slag/BP is 50:50. FA was replaced by CB with proportions of 5%, 10% and 15%.

In order to verify the homogeneity of the mixture, the FA was first mixed in the mixer along with CB and alkaline activator for almost 5 minutes to prepare the geopolymer mixture. And then, as aggregates were added and mixed for another 5 minutes, arc furnace slags and simple BP (50:50) (Davidovits, J, 2008). And here to make morder more workability 220 ± 20 ml of tap water was used. Geopolymer concrete was poured into a 50 mm x 50 mm x 50 mm mould and vibrated on the vibrating table for around 5 minutes to release trapped air. Experiments were completed with various quantities of aggregates, FA and CB, according to Table 3.8.

Samples were left for 5, 15 and 28 days at room temperature (Top and Vapur, 2018) and the mean values were taken into account. In order to measure the experimental error and to take the mean values of the applied test results, the mean tests were conducted four times. The tested responses were taken as mean values.

Figure 3.13. The FA Based Geopolymer Concrete Moulds.

One of the DOE techniques for the response surface, the Box Behnken test design, was used to analyze the results obtained. Due to the existence of more criteria, it was chosen. With fewer experiments in this design, it is also beneficial to determine the active parameters more quickly. DOE (Design Expert11) program (Table.3.8) was used to build the models.

After creating all of the 15 experiments as cubic blocks, they are stayed at room temperature and the UCS, The Point Load Resistance (PLR) and thePundit Sonic Speed (PSS) tests applied at 5, 15 and 28 day. After that the mean values of the results were taken. For every experiment was made, 220 ± 20 ml of tap water was used to ensure the wanted workability during the mixing peocess.For the aggregates which applied I this study, 50% BP and 50% arc furnace slags where determined.

Table 3.8.Box Behnken test design parameters.

Exp	Fly ash(kg)	Aggregates (kg) (50%BP+50%Slag)	CB (%)
1	0,75	0,75	10
2	0,75	1	15
3	0,75	0,5	15
4	1	0,5	10
5	0,5	1	10
6	0,75	1	5
7	0,5	0,75	15
8	0,75	0,75	10
9	1	1	10
10	0,5	0,5	10
11	0,75	0,75	10
12	1	0,75	5
13	1	0,75	15
14	0,5	0,75	5
15	0,75	0,5	5

4. RESULTS AND DISCUSSION

The average values of the uniaxial compressive strength, point load resistance and the Pundit sonic speed response were taken at 28 days.

4.1. The Uniaxial compressive strength (UCS)

ANOVA tests revealed that UCS could be explained by quardic models using DOE (Fig.4.1). The correlation coefficients (R^2) for UCS value is 0,9987 where P-value is 0.0005 less than 0,0500 therefor model terms are significant which is so close to the 1 value.

Table.4.1. Tha average values of the UCS obtained by Box Behnken test design.

Exp	Fly ash(kg)	Aggregates (kg) (50%BP+50%Slag)	CB (%)	Uniaxial compressive strength(MPa)
1	0,75	0,75	10	36,02
2	0,75	1	15	16,85
3	0,75	0,5	15	17,80
4	1	0,5	10	24,63
5	0,5	1	10	30,67
6	0,75	1	5	51,23
7	0,5	0,75	15	18,12
8	0,75	0,75	10	37,32
9	1	1	10	34,65
10	0,5	0,5	10	32,96
11	0,75	0,75	10	38,05
12	1	0,75	5	43,93
13	1	0,75	15	18,07
14	0,5	0,75	5	40,90
15	0,75	0,5	5	43,53

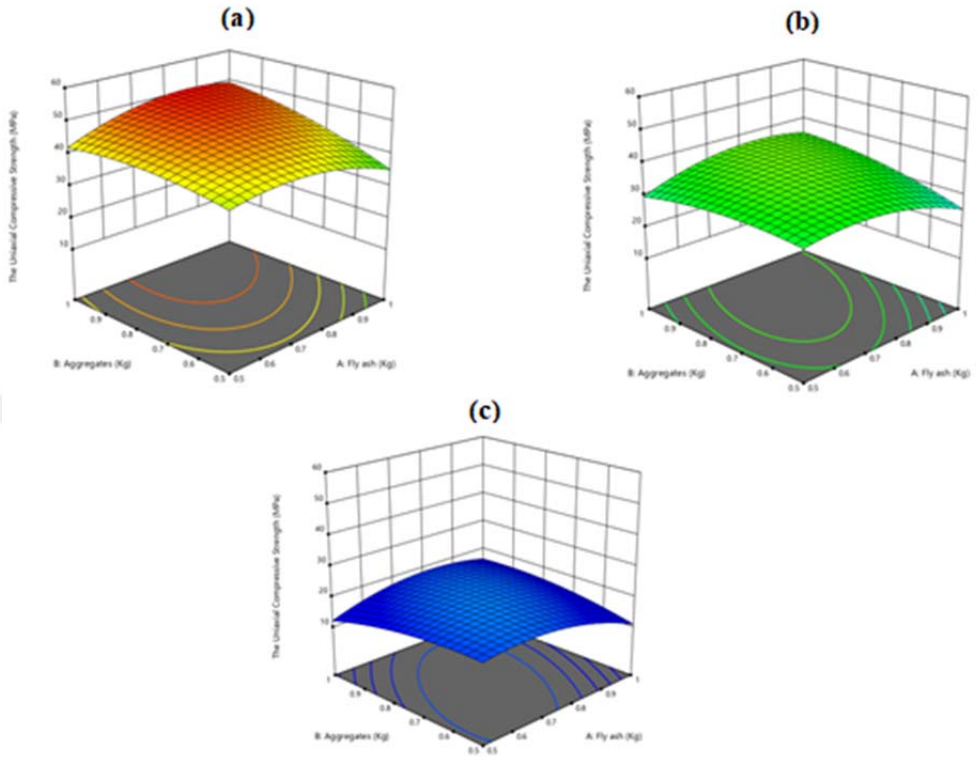

Figure 4.1. Effect of CB adding (a) 5% (b) 10% (c) 15% on the UCS value of fly ash based the geopolymer concrete.

It is clear that the UCS value goes down immediately when rising the quantity of CB. At 5 percent of the CB value, the UCS value hits the high value and then begins to decrease as the CB ratio in the mixture rises to reach the lowest UCS value at the 15 percent ratio of CB (Fig.4.1).

The best value of the uniaxial compressive strength is 50.03 MPa that can be obtained at: 0.75 Kg, 1 Kg, 5 percent of the FA, aggregates, and CB respectively. According to UCS resaults, exp 6 is the perfect mixture, particularly because it contains a large amount of arc furance slag and BP that is a low-cost material. The ANOVA model for this answer will be as follows:

Table 4.2. Analysis of the UCS response.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	1660.34	9	184.48	36.32	0.0005	significant
A-Fly ash	0.2346	1	0.2346	0.0462	0.8383	
B-Aggregates	26.21	1	26.21	5.16	0.0723	
C-Metakaoline	1478.32	1	1478.32	291.06	< 0.0001	
AB	37.88	1	37.88	7.46	0.0412	
AC	2.37	1	2.37	0.4669	0.5248	
BC	18.71	1	18.71	3.68	0.1131	
A^2	66.69	1	66.69	13.13	0.0152	
B^2	17.11	1	17.11	3.37	0.1259	
C^2	25.44	1	25.44	5.01	0.0754	
Residual	25.40	5	5.08			
Lack of Fit	23.28	3	7.76	7.34	0.1223	not significant
Pure Error	2.11	2	1.06			
Cor Total	1685.73	14				

Table 4.3. Fit Statistics for UCS response.

Std. Dev.	1.03		R^2	0.9987
Mean	32.32		Adjusted R^2	0.9912
C.V. %	3.18		Predicted R^2	0.7762
			Adeq Precision	35.9154

The uniaxial compressive strength (UCS) (%)=$37.13+0.7450\ X_1+1.69X_2-15.03X_3+3.08X_1X_2-0.7700X_1X_3-2.16\ X_2X_3-4.25\ X^2_1-2.15\ X^2_2\ -2.62\ X^2_3+0.2450\ X^2_1\ X_2+2.87\ X^2_1X_3-1.83\ X_1\ X^2_2$. (4.1)

Where X_1: fly ash (Kg)., X_2: aggregates (Kg) and X_3: CB (%).

3 experiments (exp6, exp5, exp2) were taken to study their changes over 5, 15 and 28 days for different amounts of CB, since they have almost identical proportions of fly ash and aggregates. The average UCS values were obtained at 5, 15 and 28 days each. The results of the uniaxial geopolymer concrete UCS values for the selected experiments have been summarized (Fig.4.3).

The UCS increases steadily at 5 days for exp 5 and exp 6. The uniaxial compressive strength values increase moderately by increasing curing ages.

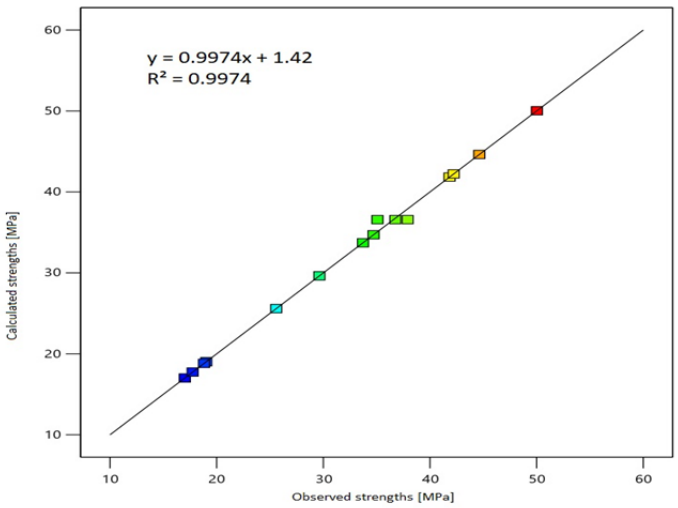

Figure 4.2. Relations between calculated and observed values

During the healing days, Exp 5 and Exp 6 have noticeable intensity improvements. It is remarkable that the UCS grew rapidly before 15 days of treatment. The early strength of geopolymer concrete increases rapidly, consistent with the previous analysis. Important shifts in geopolymer UCS with the addition of modified CB amounts can be observed at 5 days relative to exp 6 (5 percent CB). The early UCS was improved by the addition of CB to FA-based geopolymer concrete. For longer aging periods, resulting in increased UCS, especially after the addition of CB after 15 days. The addition of CB to 5 percent increased the concrete UCS, but a small decrease in strength resulted in a greater increase in CB

material. The higher CB content in FA-based geopolymer concrete has made the mixture stickier and hardening requires more time. On both 5th and 15th curing days, Exp 6 contributed to the maximum UCS of 21.1 MPa and 31.50 MPa, while exp 6 displayed an intensity of 50.03 MPa on the 28th day. Exp 5 and exp2 both showed power at 5 days of 16.1 MPa and 9.75 MPa, respectively. This means that the early UCS value of concrete can be assisted by the existence of CB in FA based geopolymer concrete. According to the statistical review, relationships between measured and observed values for UCS values were obtained (Fig.4.2).

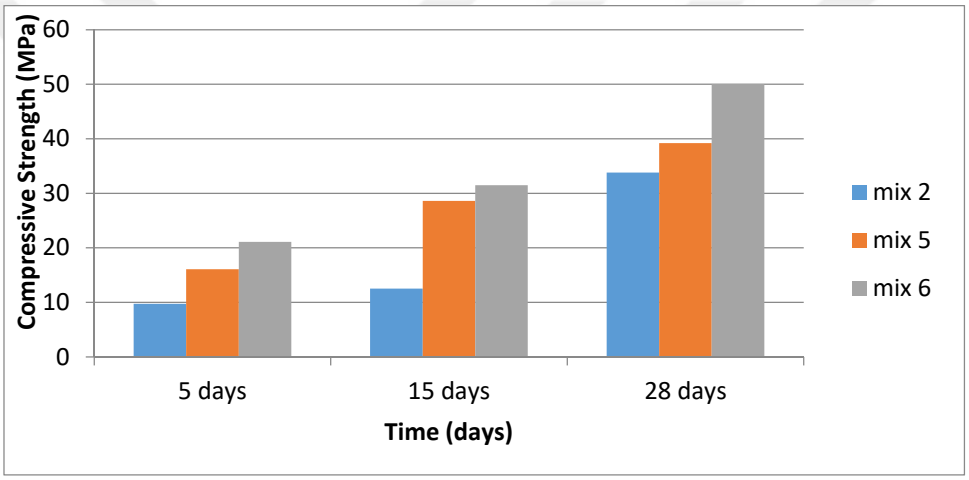

Figure 4.3. UCS values of fly ash based geopolymer concrete at different times.

4.2. The Point Load Resistance(PLR)

ANOVA tests revealed that PLR could be explained by quardic models using DOE (Fig.4.4). Tha average values of the PLR obtained by Box Behnken test design (table.4.4). The correlation coefficients (R^2) for compressive strength is 0,9838 where P-value is 0.0006 less than 0,0500 therefor model terms are significant which is so close to the 1 value. It is can said that increasing the amount of CB; makes the PLR response value dropes (Fig.4.4). The PLR response value reaches the high value at 5 % amount of the CB and then dropes when increasing the CB ratio in the mixture to reach the lowest value of the PLR response value at the 15% ratio of CB.

Table 4.4. Tha average values of the PLR obtained by Box Behnken test design.

Exp	Fly ash(kg)	Aggregates (kg) (50%BP+50%Slag)	CB (%)	Point load Resistance(kN)
1	0,75	0,75	10	9,5
2	0,75	1	15	7,5
3	0,75	0,5	15	6,9
4	1	0,5	10	9,8
5	0,5	1	10	10,3
6	0,75	1	5	13,5
7	0,5	0,75	15	7,7
8	0,75	0,75	10	10
9	1	1	10	9,6
10	0,5	0,5	10	8,4
11	0,75	0,75	10	9,2
12	1	0,75	5	12,3
13	1	0,75	15	7,1
14	0,5	0,75	5	12,9
15	0,75	0,5	5	12,8

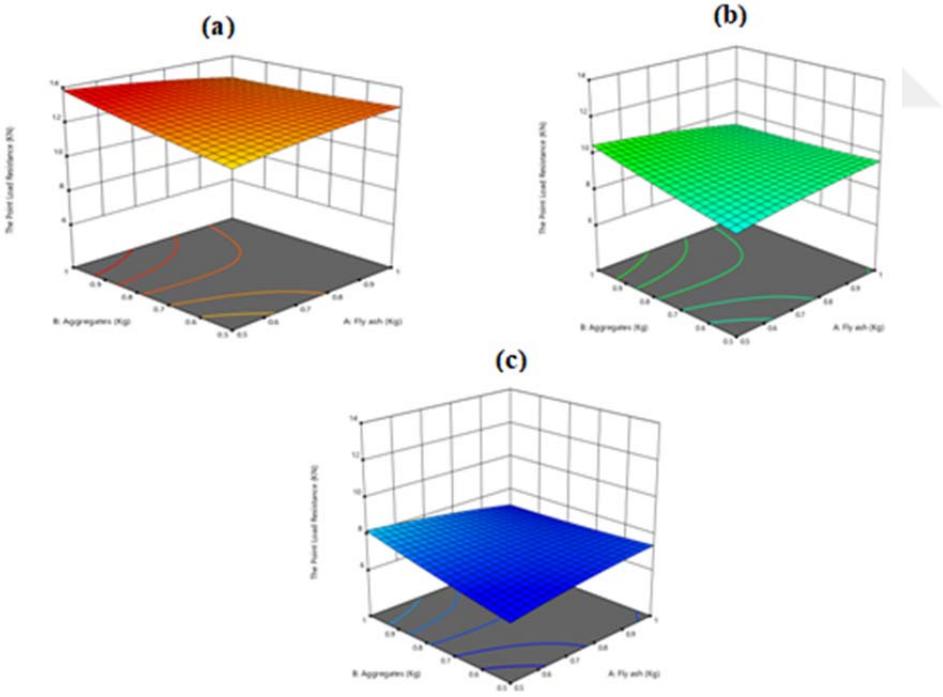

Figure 4.4. Effect of CB adding (a)5% (b)10%(c)15% on the PLR value of fly ash based geopolymer concrete.

Table 4.5. Analysis of PLR response.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	65.59	9	7.29	33.77	0.0006	significant
A-Fly ash	0.0313	1	0.0313	0.1448	0.7192	
B-Aggregates	1.13	1	1.13	5.21	0.0713	
C-Metakaoline	62.16	1	62.16	288.01	< 0.0001	
AB	1.10	1	1.10	5.11	0.0733	
AC	0.0000	1	0.0000	0.0000	1.0000	
BC	0.0025	1	0.0025	0.0116	0.9185	
A^2	0.0433	1	0.0433	0.2008	0.6728	
B^2	0.0164	1	0.0164	0.0760	0.7938	
C^2	1.08	1	1.08	5.02	0.0752	
Residual	1.08	5	0.2158			
Lack of Fit	0.7525	3	0.2508	1.54	0.4177	not significant
Pure Error	0.3267	2	0.1633			
Cor Total	66.67	14				

Table 4.6. Fit Statistics for PLR response.

Std. Dev.	0.4646		R^2	0.9838
Mean	9.83		Adjusted R^2	0.9547
C.V. %	4.72		Predicted R^2	0.8084
			Adeq Precision	16.6743

The highest value of the PLR response is 13.2 KN which can be obtained at: 0.75 Kg, 1 Kg, 5% of the fly ash, slags & aggregates, metakaolin respectively.

For this response the ANOVA model will be as the following :

The point load resistance response(PLR) (%)=$9.57-0.3000\ X_1+0.3250X_2-2.98\ X_3-0.5250X_1X_2\ -0.0250\ X_2X_3-0.1083\ X^2_1+0.0667X^2_2\ +0.5417X^2_3+0.1000X^2_1X_2+0.3750X^2_1X_3+0.4750\ X_1X^2_2$. (4.2)

Where X_1: fly ash (Kg), X_2: aggregates (Kg) and X_3: CB (%).

The PLR strength of geopolymer concrete with 5% of CB replacement have been summarised (Fig.4.5).

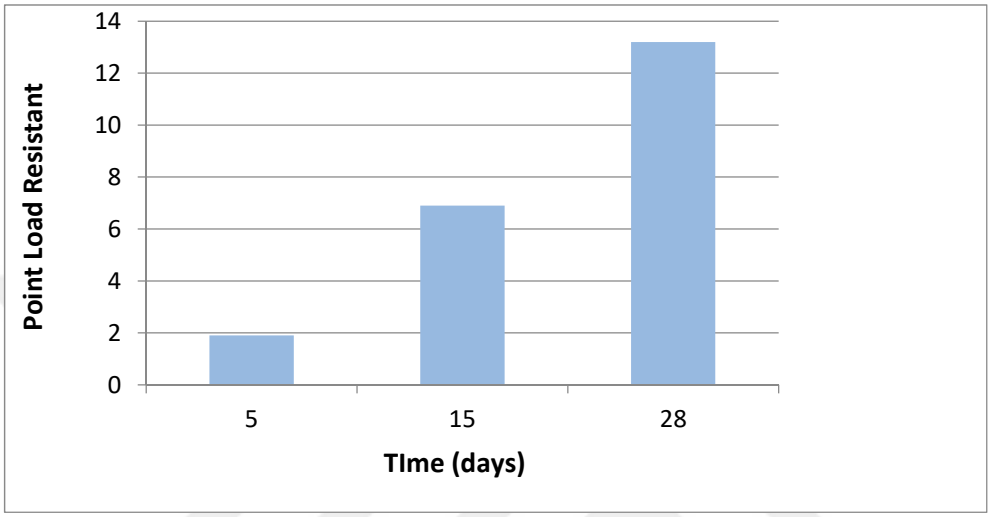

Figure 4.5. The PLR of the geopolymer concrete with 5% CB.

The PLR is 1.9 KN at the age of 5 days, then intensively increased from 6.9 KN on the 15th day to 13.20 KN on the 28th day (Fig.4.5). When the aging duration increased, which is close to the UCS trend, these samples showed an increase in PLR. The UCS and the PLR have an estimated 95 percent association for the 28 days (Fig.4.6)

4.3. Pundit Sonic Speed (PSS)

ANOVA tests revealed that PSS could be explained by Quadratic models using DOE (Fig.4.7). Tha average values of the PSS obtained by Box Behnken test design (Table 4.7). The correlation coefficients (R^2) for PSS is 0,9624 where P-value is 0.0046 less than 0,0500 therefor model terms are significant which is so close to the 1 value.

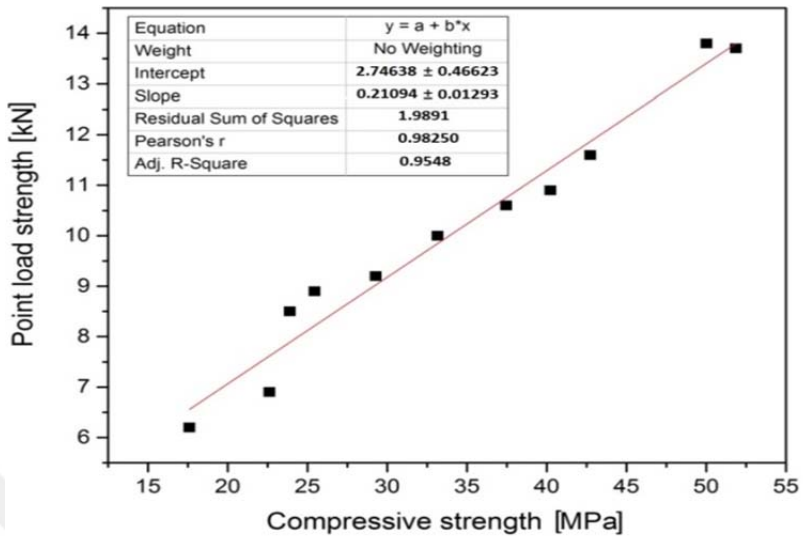

Figure 4.6. Correlation between UCS and PLR of the metakaolin added geopolymer concrete (for 28 days).

Table 4.7. Tha average values of the PSS obtained by Box Behnken test design.

Exp	Fly ash(kg)	Aggregates (kg) (50%BP+50%Slag)	CB (%)	Pundit sonic speed (km/sn)
1	0,75	0,75	10	3
2	0,75	1	15	2,8
3	0,75	0,5	15	2,3
4	1	0,5	10	3,2
5	0,5	1	10	3
6	0,75	1	5	4,1
7	0,5	0,75	15	2,3
8	0,75	0,75	10	3,4
9	1	1	10	3,2
10	0,5	0,5	10	3
11	0,75	0,75	10	3,4
12	1	0,75	5	4
13	1	0,75	15	2,9
14	0,5	0,75	5	4
15	0,75	0,5	5	3,9

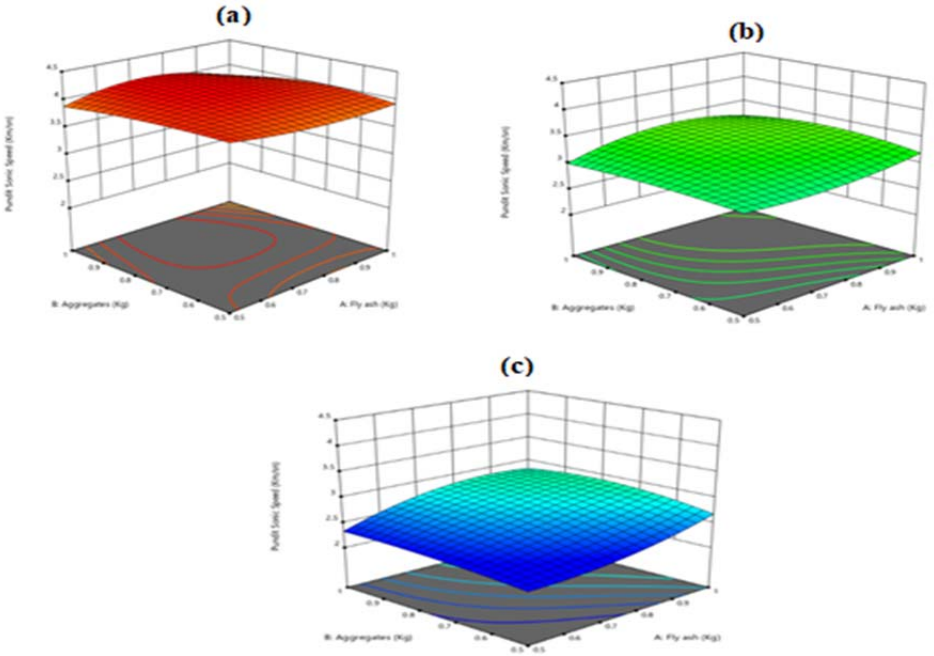

Figure 4.7. Effect of CB adding (a)5% (b)10%(c)15% on the PSS value of fly ash based the geopolymer concrete.

Table 4.8. Analysis of the PSS response.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	4.46	9	0.4955	14.22	0.0046	significant
A-Fly ash	0.1250	1	0.1250	3.59	0.1167	
B- Slag and Aggregates	0.0612	1	0.0612	1.76	0.2422	
C-Metakaoline	4.06	1	4.06	116.59	0.0001	
AC	0.0900	1	0.0900	2.58	0.1689	
BC	0.0225	1	0.0225	0.6459	0.4581	
A^2	0.0185	1	0.0185	0.5318	0.4985	
B^2	0.0339	1	0.0339	0.9735	0.3691	
C^2	0.0401	1	0.0401	1.15	0.3325	
Residual	0.1742	5	0.0348			
Lack of Fit	0.0675	3	0.0225	0.4219	0.7587	not significant
Pure Error	0.1067	2	0.0533			
Cor Total	4.63	14				

Table 4.9. Fit Statistics for PSS response.

Std. Dev.	0.1866		R^2	0.9624
Mean	3.23		Adjusted R^2	0.8947
C.V. %	5.77		Predicted R^2	0.7151
			Adeq Precision	11.3198

The further we apply CB, the value of the PSS response decreases. The high PSS response value can be obtained at 5% CB quantity and then begins to decrease as the CB ratio rises to reach the lowest PSS response value at 15% CB ratio (Fig.4.7).The best value of the PSS response is 4,00 Km/Sn which can be obtained at: 0.75 Kg, 1 Kg, 5% of the fly ash, slags and aggregates ,CB respectively, and we can reach the same value of the PSS at : 0.5 Kg, 0.75Kg, 5% of the fly ash, slag & aggregates,CB respectively. For this response the ANOVA model will be as the following :

The Pundit sonic speed response(PSS) (%)=3.27+0.1250 X_1+0.0875 X_2-0.7125 X_3+0.1500 X_1X_3+0.0750 X_2X_3-0.0708 X^2_1-0.0958 X^2_2 +0.1042 X^2_3. (4.3)

Where X_1: fly ash (Kg), X_2: aggregates (Kg) and X_3: CB (%).

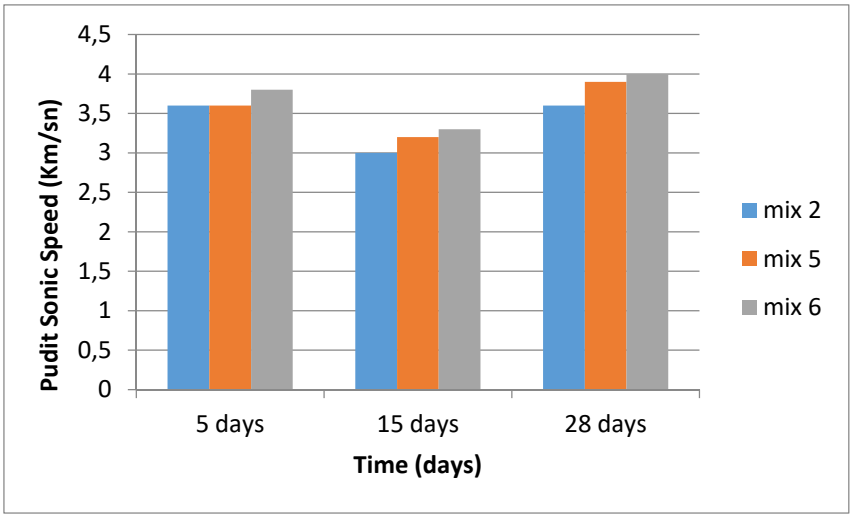

Figure 4.8. PSS values for exp2, exp5 and exp6 through 28 days.

According to the quality valuation of concrete by Saint-Pierre et al, all the mixtures can be categorized as acceptable to excellent quality concrete where their PSS values ranging from the lowest of 3.00 Km/sn to the highest of 4.00 Km/sn (Fig.4.8). The increase of PSS value in a relationship with age is a natural because of the increase of stiffness by the repolymerization process. For the same concrete samples, the quality of concretes increases day by day through repolymerization which makes it stronger and more durable concrete by the time.

5. CONCLUSIONS

The effect of partial calcium bentonite replacement in geopolymer concrete based on fly ash has been studied. Class F fly ash was combined with calcium bentonite for 5 %, 10% and 15% substitution, and the study findings are summarized below:

- Fly ash-based concretes have major benefits, such as lower CO_2 emissions, low energy requirements, low cost and the recycling of by-products from the industry. Lightweight concrete has important earthquake characteristics. This study confirms that the fly ash and calcium bentonite resources can be used economically for the development of lightweight geopolymer concrete.
- As the aging duration increased, the point load resistance of exp 6 (5 percent calcium bentonite) also showed high values. The maximum recorded strength for 28 days is 13.20 kN.
- As it has a strong early The uniaxial compressive strength, geopolymer could be considered as an effective alternative to Portland cement. At 28 days, the optimum calcium bentonite quantity of Geopolymer concrete based on The uniaxial compressive strength is 5% calcium bentonite substitution of fly ash within the mixture.
- By increasing the aging duration, the Pundit Sonic Speed (PSS) of all samples has increased. Nevertheless, the Pundit sonic speed (PSS) surprisingly showed a slight low for all samples at the age of 28 days. There is usually high quality concrete with low porosity in the geopolymer concrete. Because of the higher porosity and lower homogeneity, the consistency of the concrete was noted to decline as the percentage of calcium bentonite in the geopolymer mixture increased.

- The precise surface area of calcium bentonite plays an important role in the production of strength, which means that the relationship between the fineness of calcium bentonite and the concrete strength of the geopolymer is positive.
- The data obtained from the experimental work performed clearly shows the decrease in The uniaxial compressive strength, point load resistance and fly ash-based Geopolymer Concrete's Pundit sonic speed with the percentage increase in calcium bentonite in concrete mixtre.
- In the alkaline activator, the Na_2SiO_3 solution ratio also plays an important role, as the solution favors the polymerization process by adding more silicon (Si) atoms to the substance and thereby enhancing The uniaxial compressive strength.
- The results show that FA-based geopolymer with fly ash 0.75 Kg, aggregates 1 Kg and calcium bentonite 5% (exp 6) give the highest compressive strength.

REFERENCES

Alzeer, M., Mac K. K., 2013. Synthesis and mechanical properties of novel composites of inorganic polymers (geopolymers) with unidirectional natural flax fibres (phormium tenax). Appl Clay Sci 75- 76: 148-152.

ASTM C618-05, Standard Specification for Coal FA and Raw or Calcined Natural Pozzolan for Use in Concrete, American Society of Testing and Materials, West Conshohocken, PA, 2005.

Atis, C.D.,"High-Volume FA Abrasion Resistant Concrete," Journal of Materials in Civil Engineering, ASCE, Vol. 14, No. 3, 2002, pages 274 to 277.

Aygörmez, Y."Investigation of Mechanical and Durability Properties of Metacaolin Based Geopolymer Mortar with Colemanite Waste and Silica Fume", Ph.D. Thesis, Yıldız Technical University Institute of Science, Istanbul, 2018.

Baikun W., Hao D.,Yanxi D., 2010, Characterization of Calcined Kaolin/TiO_2 Composite Particle Material Prepared by MechanoChemical Method, Journal of Wuhan University of Technology-Mater. Sci., 25, 5, 765-769.

Barbosa VFF, MacKenzie KJD, Thaumaturgo C ,2000 Synthesis and characterisation of materials based on inorganic polymers of alumina and silica: sodium polysialate polymers. Int J Inorg Mater 2(4): 309-317.

Belmokhtar, N., Ammari, M., Brigui, J. and Ben allal, L. "Comparison of the microstructure and the compressive strength of two geopolymers derived from Metakaolin and an industrial sludge", Construction and Building Materials, 146, 621–629, 2017.

Bilim, C. and Atiş, C.D., "Abrasion and Strength Properties of Mortars Containing Ground Granulated Blast Furnace Slag", Politeknik Magazine, 14 (2), 2011.

Bilodeau, A., Carette, C.G., Malhotra, V.M. and Langley, W.S., “Influence of Curing and Drying on Salt Scaling Resistance of FA Concrete,” Proceedings of the 2nd International Conference on the Durability of Concrete, ACI SP-126, Vol. 1, Farmington Hills, MI, 1991, pages 201 to 228.

Brown, D. A., Turner, J. P. & Castelli, R. J. 2010. Drilled shafts construction procedures and LRFD design methods, Report FHWA NHI-10–016. Washington, DC, USA: National Highway Institute, US Department of Transportation, Federal Highway Administration.

Buchwald, A., Hilbig, H., Kaps, Ch., “Alkali-Activated Metakolin-Slag Blends – Performance and Structure in Dependance of their Composition”, Journal of Materials Science 42, pp. 3024-3032, 2007.

Canadian Geotechnical Society, 2006. Canadian foundation engineering manual, 4th edn. Richmond, BC, Canada: Canadian Geotechnical Society.

Casarez CAR, Rea SPA, Enríquez AC, Higuera RC, Cervantes MP, et al. 2018 Influence of size reduction of FA particles by grinding on the chemical properties of geopolymers. Appl Sci 8(3): 365.

Chareerat, T., Lee-Anansaksiri, A., Chindaprasirt, P., “Synthesis of High Calcium Fly Ash and Calcined Kaolin Geopolymer Mortar”, International Conference on Pozzolan, Concrete and Geopolymer, Khhon Kaen, Thailand, May 24-25, 2006.

Chen R, Ahmari S, Zhang L, 2014 Utilization of sweet sorghum fiber to reinforce FA-based geopolymer. J Mater Sci 49(6): 2548-2558.

Chidiac .S.E. and Panesar .D.K., "Evolution of mechanical properties of concrete containing ground granulated blastfurnace slag and effects on the scaling resistance test at 28days", CemConcr Comp 30 , 2008, 2, 63-71.

Ciullo P.A (Ed), 1996, Industrial Minerals and Their uses. A Handbook & Formulary, Noyes Publication, Westwood New Jersey, 125-136.

Criado, M., Fernandez-Jimenez, A., de la Torre, A.G., Aranda, M.A.G., Palomo, A., “An XRD Study of the Effect of the SiO_2/Na_2O Ratio on the Alkali Activation of Fly Ash”, Cement and Concrete Research 37, pp. 671-679, 2007.

Criado, M., Fernandez-Jimenez, A., Palomo, A., and Alkali Activiation of Fly Ash: Effect of the SiO_2/Na_2O Ratio. Part 1: FTIR Study”, Microporous and Mesoporous Materials 106, pp. 180-191, 2007.

D. J. Naus, "The Effect of Elevated Temperature on Concrete Materials and Structures — A Literature Review", pp (5:20), 2005.

D. Sedan, C. Pagnoux, A. Smith and T. Chotard, "Mechanical properties of hemp fiber reinforced cement: Influence of the fiber/matrix interaction ", Journal of the European Ceramic Society, 28 , 2008, pp (183:192).

Davidovits, J., Geopolymer Chemistry and Applications, 3rd edition, St. Quinten, Institut Geopolymere, 2008.

Dong M, Feng W, Elchalakani M, Li GK, Karrech A ,et al. 2017, Development of a high strength geopolymer by novel solar curing. Ceram Int 43(14): 11233-11243.

Duxson, P., Lukey, GC and Van Deventer, JSJ "Physical evolution of Na-geopolymer derived from metakaolin up to 1000 ° C”, Journal of Materials Science, 42 (9), 3044–3054, 2007.

Fernandez-Jimenez, A., Monzo, M., Vicent, M., Barba, A., Palomo, A., “Alkaline Activation of Metakaolin-Fly Ash Mixtures: Obtain of Zeoceramics and Zeocements”, Microporous and Mesoporous Materials 108, pp. 41-49, 2008.

Ferraz, E. 2015. "Pozzolanic activity of metakaolins by the French standard of the modified Chapelle test: A direct methology". Acta Geodynamica et Geometerialia Aspects. 12: 289–298.

Flick E.W., 1989, Handbook of Paint Raw Materials 2nd edition, Noyes Publications, New Jersey, U.S.A.

Gabriel Varga. The structure of kaolinite and metakaolin. Epitoanyag 59, evf.2007.1.szam.6-9.

Gamelas, J.; Ferraz, E.; Rocha, F. 2014. "An insight into the surface properties of calcined kaolinitic clays: the grinding effect". Colloids and Surfaces A: Physicochemical and Engineering Aspects. **455**: 49–57.

Gönen, T., Onat, O., Cemalgil, S., Yılmazer, B. and Altuncu, YT, "An Investigation on New Waste Materials for Concrete Technology", Journal of Building Technologies Electronics 8 (1), 36-43, 2012.

Gunasekera C, Setunge S, Law DW 2017, Correlations between mechanical properties of low-calcium FA geopolymer concretes. J Mater Civ Eng 29 (9).

Hogan, F.J., and J.W.Meusel, "Evaluation for durability and strength development of ground granulated blast furnace slag".J. of cement, concrete, and aggregates. Vol. 3(1981): 40-52.

Houston, B. J., Investigation of Gap-Grading of Concrete Aggregates; Review of Available Information, Technical Report No. 6-593, Report 1, Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, Mississippi, February 1962.

Hung TD, Louda P, Kroisová D, Bortnovsky O, Xiem NT ,2011 New generation of geopolymer composite for fire-resistance. Advances in Composite Materials-Analysis of Natural and Man-Made Materials, China, pp. 73-92.

Ihram Pharaoh Mullah, "Use fiber manufacturer of concrete reinforcement in the parts is exposed to loads of construction", Faculty of Engineering, University of Baghdad, pp (1-8), 2007.

Industrial Resources Council ,2008. "Portland Cement Concrete". Www.industrialresourcescouncil.org. Retrieved 15 June 2018.

Institution of Civil Engineers ,2007. ICE specification for piling and embedded retaining walls. London, UK: Thomas Telford.

J. Mirza, M. Riaz, A. Naseer, F. Rehman, A. N. Khan, and Q. Ali, “Pakistani bentonite in mortars and concrete as low cost construction material,” *Applied Clay Science*, vol. 45, no. 4. Elsevier B.V., pp. 220–226, 2009.

Jesus, Paulo; Baquero, Carlos; Paulo Sérgio Almeida ,2011. "A Survey of Distributed Data Aggregation Algorithms".1110.0725.

Juniad Akbar, Bashir Alam, Muhammad Ashraf, Salman Afzal, Asfandyar Ahmad, and Khan Shahzada., “Evaluating the Effect of Bentonite on Strength and Durability of High Performance Concrete,” International Journal of Advanced Structures and Geotechnical Engineering, vol. 02, no. 01. pp. 1–5, 2013.

K Wah “Blast furnace slag, concrete benefits”, Construction Materials Hong Kong Ltd, 1992.

Kerkhoff, Beatrix and Siebel, Eberhard, “Properties of Concrete with Recycled Aggregates (Part 2),” Beton 2/2001, Verlag Bau + Technik, 2001, pages 105 to 108.

Khale D, Chaudhary R , 2007, Mechanism of geopolymerization and factors influencing its development: a review. J Mater Sci 42(3): 729-746.

Kriven WM ,2010 norganic polysialates or “geopolymers.” Am Ceram Soc Bull 89: 31-34.

Li, Zongjin ,2011. Advanced concrete technology. John Wiley & Sons.

Lin H., Dong Y., Jiang L., 2009, Preparation of calcium carbonate particles coated with titanium dioxide, International Journal of Minerals, Metallurgy and Materials 16, 5, 592.

Lirer S, Liguori B, Capasso I, Flora A, Caputo D ,2017, Mechanical and chemical properties of composite materials made of dredged sediments in a fly-ash based geopolymer. J Environ Manage 191: 1-7.

Litvin, Albert, and Pfeifer, Donald W., Gap-Graded Mixes for Cast-in-Place Exposed Aggregate Concrete, Development Department Bulletin DX090, Portland Cement Association, http://www.portcement.org/pdf_files/DX090.pdf, 1965.

Lolli F, Manzano H, Provis JL, Bignozzi MC, Masoero E ,2018, Atomistic simulations of geopolymer models: the impact of disorder on structure and mechanics. ACS Appl Mater Interfaces 10(26): 22809-22820.

Lu Z., Ren M., Yin H., Wang A., Ge C., Zhang Y.,Yu L., Jiang T., 2009, Preparation of nanosized anatase TiO2-coated kaolin composites and their pigmentary properties, Powder Technology 196 122–125.

Luga, E., "Characteristics of Fly Ash and Blast Furnace Slag Geopolymer Mortars", Ph.D. Thesis, Erciyes University Institute of Science, Kayseri, 2015.

M. S. Shetty. Concrete Technology – Theory and Practice (New Delhi. S. Chand & co. Ltd. Sixth Edition Reprint , 2012.

Maia AAB, Saldanha E, Angélica RS, Souza CAG, Neves RF ,2007 Utilização de rejeito de caulim da Amazônia na síntese da zeólita A. Cerâmica 53: 319-324.

Malenab RAJ, Ngo JPS, Promentilla MAB ,2017, Chemical treatment of waste abaca for natural fiber-reinforced geopolymer composite. Materials 10(6): 579.

Mankiw, N. Gregory, and William M. Scarth. Macroeconomics. Canadian ed., 4th ed. New York: Worth Publishers, 2011. Print.

Mustard, J.N. and MacInnis, C., "The Use of FA in Concrete by Ontario Hydro." Engineering Journal, December, 1959, pages 74 to 79.

Narayan R., Raju K.V.S.N., 2000, The Use of Calcined Clay as Part Replacement of Titanium Dioxide in Latex Paint Formulations, Journal of Applied Polymer Science, 77, 1029–1036.

Nash, K. L. ,1974. Stability of trenches filled with fluids. J. Constr. Div. ASCE 100, No. 4, 533–542.

Nevelli, A M., 2011, Properties of Concrete, Pearson Education Limited, 5th Edition.

P. Priyadharshini, G. Mohan Ganesh, A. S. Santhi ,2012. A Review on Artificial Aggregates. International Journal of Earth Sciences and Engineering. ISSN 0974-5904, Volume 05, No. 03 (01).

Papa E, Medri V, Amari S, Manaud J, Benito P, et al. ,2018, Zeolitegeopolymer composite materials: Production and characterization. J Clean Prod 171: 76-84.

Peter W.C. Leung, Wong H.D., "Final Report on durability and strength development of ground granulated blast furnace slag concrete", Geotechnical Engineering office, Civil Engineering anddevelopment department, The Government of the Hong Kong, Special Administrative Region,Geo report No.258, July 2010.

Puertas, F., Fernandez-Jimenez, A., “Mineralogical and Microstructural Characterization of Alkali-Activated Fly Ash/Slag Pastes”, Cement and Concrete Composites 25, pp. 287-292, 2003.

Puertas, F., Martinez-Ramirez, S., Alonso, S., Vazquez, T., “Alkali-Activated Fly Ash/Slag Cement: Strength Behavior and Hydration Products”, Cement and Concrete Research 30, pp. 1625-1632, 2000.

Qian, X. and Li, Z ,2001. The relation ships between stres and strain for high-performance concrete with metakaolin. Cement and Concrete Research, 31: 1607–1611.

Randolph, M. F. 2003. Science and empiricism in pile foundation design. Ge´otechnique 53, No. 10, 847–875, http://dx.doi.org/ 10.1680/geot.2003.53.10.847.

Reed M, Lokuge W, Karunasena W , 2014, Fibre-reinforced geopolymer concrete with ambient curing for in situ applications. J Mater Sci 49(12): 4297-4304.

Rieger, D., Kovářík, T., Říha, J., Medlín, R., Novotný, P., Bělský, P. and Holba, P. "Effect of thermal treatment on reactivity and mechanical properties of alkali activated shale-slag binder", Construction and Building Materials, 83, 26–33, 2015.

Roviello, G., Menna, C., Tarallo, O., Ricciotti, L., Ferone, C., Colangelo, F. and Cioffi, R. "Preparation, structure and properties of hybrid materials based on geopolymers and polysiloxanes", Materials and Design, 87, 82–94, 2015.

Shi C, Qian J., 2003) Increasing coal FA use in cement and concrete through chemical activation of reactivity of FA. Energy Sources 25(6): 617-628.

Singh B, Ishwarya G, Gupta M, Bhattacharyya SK (2015) Geopolymer concrete: A review of some recent developments. Constr Build Mater 85: 78-90.

Slag Cement Association Report, 2005.

Snellings, R.; Mertens G.; Elsen J.,2012. "Supplementary cementitious materials". Reviews in Mineralogy and Geochemistry. **74**: 211–278.

Soner Top, Hüseyin Vapur, "Effect of basaltic pumice aggregate addition on the material properties of fly ash based lightweight geopolymer concrete", 2018.

Souza FG, Andréa Maria, Oliveira GE, Costa RM, Fernandes ER, et al. ,2015, Conducting and magnetic mango fibers. Ind Crops Prod 68: 97- 104.

Sunny A. Jagtap, Mohan N. Shirsath & Sambhaji L. Karpe , 2017, Effect of Metakaolin on the Properties of Concrete. International Research Journal of Engineering and Technology (IRJET).

Swamy, R.N., and Mahmud, H.B., "Mix Proportions and Strength Characteristics of Concrete Containing 50% Low Calcium FA", Proceedings of the Second International Conference on the Use of FA, Silica Fume, Slag and Natural Pozzolans in Concrete, ACI SP-91, Vol. 1, American Concrete Institute, Detroit, MI, 1986, pages 413 to 432.

Thavorniti, P., Chindaprasirt, P., Balyore, P., Tippayasam, C., Chaysuwan, D., Leonelli, C. and Kamseu, E. "Potassium alkali concentration and heat treatment affected metakaolin-based geopolymer" , Construction and Building Materials, 104, 293–297, 2015.

Thomas A, Tripathi RK, Yadu LK, 2018, a laboratory investigation of soil stabilization using enzyme and alkali-activated ground granulated blastfurnace slag. Arab J Sci Eng, pp. 1-10.

Thomas, M.D.A., “Field Studies of FA Concrete Structures Containing Reactive Aggregates.” Magazine of Concrete Research, Vol. 48, No. 177, 1996, pages 265 to 279.

Toprak, M.U., 2011. Geopolymer Production of Thermal Power Plant Base Ashes with Alkali Activation, Civil Engineering. Dumlupınar University, Kütahya.

Veder, C. ,1953. Method for the construction of impermeable diaphragms at great depth by means of thixotropic muds. Proceedings of the 3rd international conference on soil mechanics and foundation engineering, Zurich, vol. 2, pp. 91–94 (in French).

Veena G. Pathan, Vishal S, Ghutke and Gulfam Pathan, "Evaluation of concrete properties using ground granulated blast furnace slag", International journal of innovative research in science, Engineering and technology Vol. 1,Issue 1, November , 2012.

Venkateswaran D., Sharma D., Mhmoud L. and Vitta S., "Treatment and characterization of electric arc furnace (EAF) slag for its effective utilization in cementitious products", Indorama Cement Ltd, Indian Institute of Technology, Monday 01 October , 2007.

Venkateswaran D., Sharma D., Mhmoud L. and Vitta S., "Treatment and characterization of electric arc furnace (EAF) slag for its effective utilization in cementitious products", Indorama Cement Ltd, Indian Institute of Technology, Monday 01 October , 2007.

Verdolotti L, Iannace S, Lavorgna M, Lamanna R ,2008, Geopolymerization reaction to consolidate incoherent pozzolanic soil. J Mater Sci 43(3): 865-873.

Wan Q, Rao F, Song S, García RE, Estrella RM, et al, 2017, Geopolymerization reaction, microstructure and simulation of metakaolin-based geopolymers at extended Si/Al ratios. Cem Concr Compos 79: 45-52.

Wypych G., 2000, Handbook of Fillers 2nd Edition ChemTec Publishing Toronto Canada.

Yan S, He P, Jia D, Yang Z, Duan X, et al. ,2016, Effect of fiber content on the microstructure and mechanical properties of carbon fiber felt reinforced geopolymer composites. Ceram Int 42(6): 7837-7843.

Yang C , 2017, Prediction of the compressive strength from resonant frequency for low-calcium FA-based geopolymer concrete. UVicSpace, pp. 1-41.

Yonar, Y., "High Temperature Resistance of Geopolymer Cemented and Polyvinyl Alcohol Fiber Concretes", Master Thesis, Fırat University Institute of Science, Elazig, 2014.

Yu, Yuan; Gunda, Pradeep Kumar; Isard, Michael ,2009. Distributed aggregation for data-parallel computing: interfaces and implementations. ACM SIGOPS 22nd symposium on Operating systems principles. ACM. pp. 247–260.

Yuan J., Garforth W.L., Pruett R.J., 1998, Influence of dispersants on the solubility of calcined kaolin, Applied Clay Science 13, 137–147.

Yuan, R.L. and Cook, R.E., "Study of a Class C FA Concrete", Proceeding of the First International Conference on the Use of FA, Silica Fume, Slag, and Other By-Products in Concrete, ACI SP-79, Vol. 1, American Concrete Institute, Detroit, MI, 1983, pages 307 to 319.

Zhang, Chao ,2017. Symmetric and Asymmetric Aggregate Function in Massively Parallel Computing (Technical report).

http://www.cement.org/for-concrete-books-learning/concrete-technology/concrete-design-production/recycled-aggregates.

http://www.lemminkainen.com/Infrastructure-construction/mineral aggregates/Crushed-rock-aggregates/

http://www.sustainableaggregates.com/overview/uses.htm.

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