**Nile Higher Institute for**
**Engineering & Technology**

**Department of**
**Civil Engineering**

# “Eco-efficient Geopolymer bricks”

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# *Contents*

## ***Abstract: -***

* Bricks has stand for many years as durable construction substantial, especially in the area of civil engineering to construct buildings. Brick commonly used in the structure of buildings as a construction wall, cladding, facing perimeter, paving, garden wall and flooring. The contribution of ordinary Portland cement (OPC) in cement bricks production worldwide to greenhouse gas emissions. Due to this issue, some researchers have done their study with other materials to produce bricks, especially as a by-product material.

*The current study aims to investigate the feasibility of producing geopolymer bricks using the waste materials that we would use in our process, which we will talk about in detail.

*Geopolymer is a material created by inorganic condensation as a result of the activation of alkalis (sodium hydroxide and sodium silicate) and pozzolanic materials (fly ash and silica fume).

*It seems that geopolymer bricks are beneficial because of the low energy demand for their production and the inclusion of waste in a large way, as well as less damage than ordinary or cement bricks. However, few studies have been done on materials such as waste from aggregate industries to produce geopolymers.

*The physical and mechanical properties of geopolymer bricks were studied according to ECP 203-2018 ***using:-***

1-Compressive strength.
2-Water absorption.
3-Bulk density.

## *1.1 Introduction:*

Geopolymer bricks is a particular type of concrete used to construct all civil engineering and structural engineering works. It plays an essential role in the construction. The combination of different inorganic molecules produces this type of concrete. It is a good alternative and one of good innovative material compared to standard conventional concrete. It can be famous for reducing Co2 emissions, so it can also be known as Green Concrete. It is also known as one of the exemplary sustainable construction materials. Geopolymer concrete was first used in the 19th century, and Joseph Davidovits can name it. He is the first person to obtain this type of concrete from the reaction of fly ash and geopolymerization. So later, he named geopolymer as that product. It is the one of finest good sustainable construction material. This type of concrete can be obtained from wastes. It can also be used for the replacement of cement in the concrete mixture. So, we can reduce the cost of construction easily. Almost by using geopolymer concrete, we can reduce eighty percentage of Co2 emissions. So, day by day, the importance of geopolymer concrete is increasing. A lot of researches going on this type of concrete. Most Research Scholars are also interested in this Research Area only. We can see a lot of Research Papers on Geopolymer Concrete every year.

## *1.2 The importance of bricks:*

### 1.2.1 The use of natural base materials

Bricks are the result of a combination of purely natural elements: clay, sand, water, air, and fire. No toxic substances are added to bricks. In addition, bricks are inert material: it does not or hardly react to other substances and also does not release toxic substances or allergens. Therefore, there is absolutely no risk of soil pollution.

### 1.2.2 Economical base material policy

Clay and loam are natural and seemingly inexhaustible base materials. Excavation is limited and excavated sites reconstructed for agriculture or recreation. Starting materials are used that are released during infrastructure work and building projects in order to keep down the exploitation rate of the pits.

### 1.2.3 Clay extraction creates new possibilities

The excavation of clay is temporary by nature. The exploitation covers a limited surface that never grows in time, but merely moves. After extraction the site is reconstructed. This often leads to added value for the biodiversity, among other things, as a result of constructing nature reserves.

### 1.2.4 Environmentally friendly manufacturing processes.

The production process of bricks is continuously being optimised to respect the environment. For decades, manufacturers have been taking numerous measures to decrease energy consumption:

- High-performance tunnel ovens that work on natural gas
- Strict observance of the baking process by means of computer programs
- Recycling heat from the oven in the drying rooms
- Own production of electricity by means of total energy plants

In every step of the production process people continuously search for a level of energy consumption that is as low as possible. The reason that the production of bricks has such a low and specific energy consumption is due to the fact that only the preparation, drying, and backing of the clay needs to be calculated. There is absolutely no environmental impact as a result of water contamination or residual waste.

### 1.2.5 Short transport distances

Brick kilns are often located near the quarry. This way the clay does not need to be transported across long distances. Some brick kilns sometimes add clay from other quarries in order to expand their product assortment. But even then, transport remains rather limited.

### 1.2.6 Long lifespan without maintenance

Bricks are made to last for generations. The average lifespan of a building made from bricks is estimated at more than 100 years. The impact of the building on the environment is also much smaller because it does not need maintenance.

### 1.2.7 Durable and precious

Their lifespan and limited environmental impact make bricks unbeatable if you want to build a durable building. Bricks make it possible to create beautiful buildings with limited spending and a long lifespan. Brick offers lasting value. It does not rot, dent, or need to be painted. Unlike other materials, bricks actually look better with age.

### 1.2.8 Comfortable and sturdy

The superior thermal mass qualities of brick have been known for centuries. Bricks keep out the weather and the wind due to their good heat absorption. What’s the secret? In winter, bricks store the heat on sunny days and then slowly release it. During the summer they buffer the heat and the brick building stays cool on the hottest days. In addition, bricks are non-flammable and solid as well as absorb noise which is an acoustic advantage over other materials.

### 1.2.9 Good recycling possibilities

Brick walls can be dismantled. Bricks are reusable after removing mortal residues, for example, for restoration or for the construction of new houses and projects. Also brick rubble from demolition sites can be recycled and reused. For example as:

- Filling and stabilising material for infrastructure work
- Ingredients for poured concrete and prefabricated mortar on site
- Ingredients for bricks from calcium silicate
- Red ‘grounded bricks’ (clay) on tennis courts
- Plant substrates

### 1.2.10 Flexibility of brick buildings

Buildings made from bricks are extremely flexible.

They can be adjusted during the entire building process and during the entire lifespan of the building. Hardly ever does a building need to be taken down because the bricks cause a problem.

## *1.3 Types of bricks:*

1-Red Bricks.
2-Glass Bricks.
3-Refractory Bricks.
4-Sand Brick (Pink).
5-Grilled Clay Bricks.
6-Pumice Brick.
7-Silica Refractory Bricks.
8-Solid Brick.
9-Asphalt Bricks.
10-concrete bricks.
11-geopolymer bricks.

## *1.4Environmental pollution:*

### 1.4.1Plastic

pollution is everywhere, not just in the oceans. There is plastic, a lot of plastic, in the Himalayas and the Sahara. There is even plastic on Mars, left by the Curiosity Rover. The average person in a modern society breathes in and drinks hundreds of tiny particles of plastic every day. Plastic also pollutes beyond just being littered. In the process of making it, or when the chemicals used to make it seep out, plastic releases toxins into the environment. These chemicals are now in the blood of nearly every person on Earth, even the unborn. Some are known or suspected of causing a broad range of health problems including birth defects and brain damage. For all of that, we need plastic. It is not merely a convenience. It would be virtually impossible to make modern electronic devices without plastic. Plastic packaging reduces product weight, transportation costs and fossil fuel use. Plastic is essential to the design of medical equipment. As just one example, at the time this is written (July 2020) there are thousands of patients around the world who are victims of the Covid 19 pandemic intubated with ventilators in a desperate attempt to keep them alive.

### 1.4.2The cement

manufacturing industry was an EPA New Source Review/Prevention of Significant Deterioration (NSR/PSD) national enforcement initiative in fiscal years 2008-2010 and was continued as a Reducing Air Pollution from the Largest Sources national enforcement initiative for fiscal years 2011-2013. The cement sector is the third largest industrial source of pollution, emitting more than 500,000 tons per year of sulfur dioxide, nitrogen oxide, and carbon monoxide. Beginning in 2008, EPA has pursued a coordinated, integrated compliance and enforcement strategy to address Clean Air Act New Source Review compliance issues at the nation's cement manufacturing facilities.

## *1.5 objectives of the research:*

- Recycling of waste materials as plastic&Rubber in bricks.
- Reduce cement content by replacing cement with Geopolymer.
- preservation of the environment.

## *Outlines :*

This book consists of five chapters. Each chapter can be summarized as below:

**Chapter (1):** is an introduction that contains the scope of work and the objectives of the research.

**Chapter (2):** presents reviews of the previous experimental research in this project.

**Chapter (3):** explains, in detail, the experimental program conducted on the specimens.

**Chapter (4):** contains the experimental results from testing specimens.

**Chapter (5):** presents the summary and the conclusions of the present research, as well as recommendations for future studies.

# *Chapter (2): literature Review*

## *2.1 Introduction:*

The history of bricks making dates to 7000 BCE, when the bricks used to be in the form of sun-dried mud blocks. Since then, a lot of modifications have been done in the composition of bricks and in brick making procedures. As a result, in today's world, brick is considered as one of the most sought-after materials used in the construction of various civil engineering structures. Now-a-days, bricks are mostly made of clay and sand mixed in suitable proportion, to which binder is added. Many-a-time, the bricks are also made-up earth blocks stabilized with different materials. The stabilized block is then pressed to a suitable shape and size that can be either fired or sun-dried. However, much variation is observed in the properties of bricks and especially in its compressive strength, depending upon the composition of bricks and the manufacturing procedures (viz., moulding, pressing, firing, autoclaving, cementing, geo-polymerization etc.). Moreover, the bricks are specified and classified differently in various international standard codes, depending upon the importance of structures and the severity of environmental conditions. Hence, a thorough review of the composition and properties of bricks and the various factors related to its manufacturing process is highly required for better standardization of bricks. The same has been done in the present study. A better understanding of different wastes as the brick composing material is supposed to act as a catalyst in the utilization of various mining, industrial as well as solid municipal wastes in brick industry, which will help in achieving the goal of sustainable development.

.Many researchers have been conducting a wide range of studies regarding sustainable and innovative bricks, to mitigate the large carbon footprint of brick industry. To better understand the development and current context of sustainable and innovative bricks during the past several decades, this paper provides an up-to-date review on the recent studies of bricks, categorizing these publications according to the materials used and methods employed to produce innovative bricks. This review found that firing is still the most common method to produce bricks, while this process involves enormous energy consumption and carbon footprint. Considering that cement and lime-based calcium-silicate-hydrate bricks are also not sustainable, Geopolymerisation is a preferable way to produce bricks, but corresponding cost and benefit analyses need to be conducted for relevant research. In addition, this paper suggests that clay-based geopolymer bricks could be one of the focuses of future brick-related research, and the key challenge is to improve the reactivity of clay at a low cost.

## *2.2Types Of The Bricks:*

### 2.2.1 Red Bricks:

Are known as one of the oldest and oldest types of bricks, they are simple in production with high specifications and excellent quality in construction, and any brick factory can make red bricks with high productivity.

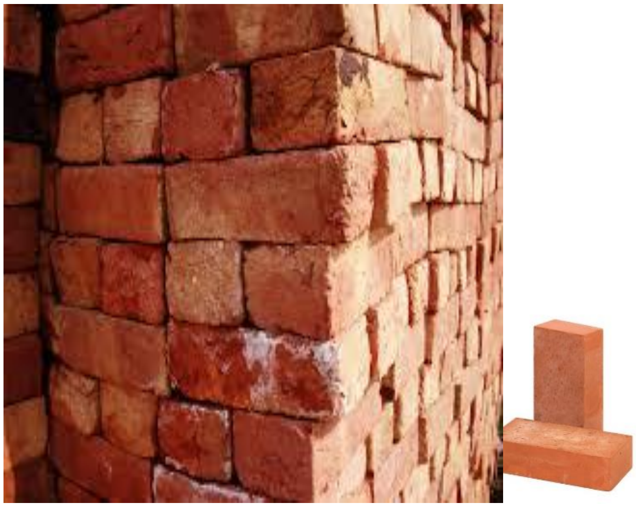


***Figure 2.1***

The history of the use of red bricks in construction dates back decades, as it represented the beginning of construction and architecture, as red bricks were used in the past in construction for several advantages, *Including:*

- ***Good Heat Insulator:***

Where red brick is made of clay and becomes like pottery, it insulates heat significantly better than many other building materials, and it also provides a large percentage of thermal insulation, which affects the rationalization of electrical consumption nowadays.

- ***It Bears The Pressure Of Cold And Heat:***

The red brick is characterized by this characteristic that it is not affected by climate change, as it is used in cold regions such as cold European cities, and in hot regions such as the Arabian Gulf.

Resistant–For heat and fire, where red brick is known for its use in ovens, where it is used in the construction of the inner wall of the ovens to preserve heat and not be affected by it.

These are some of the old features in which red bricks were used, but with the architectural development, red bricks were known for other advantages compared to modern materials used in modern construction, so engineers knew that the use of red bricks in the construction of building foundations is of strength, durability and hardness, red bricks withstand great pressure and have a much lower cost than other materials and the prices of red bricks are not compared to their counterparts in hardness.

But with the new development, red bricks have different uses than before, now red bricks are used in the design, theoretical and structural engineering of buildings, so it is used in decoration.

***Figure 2.2***

### 2.2.2Glass Bricks:

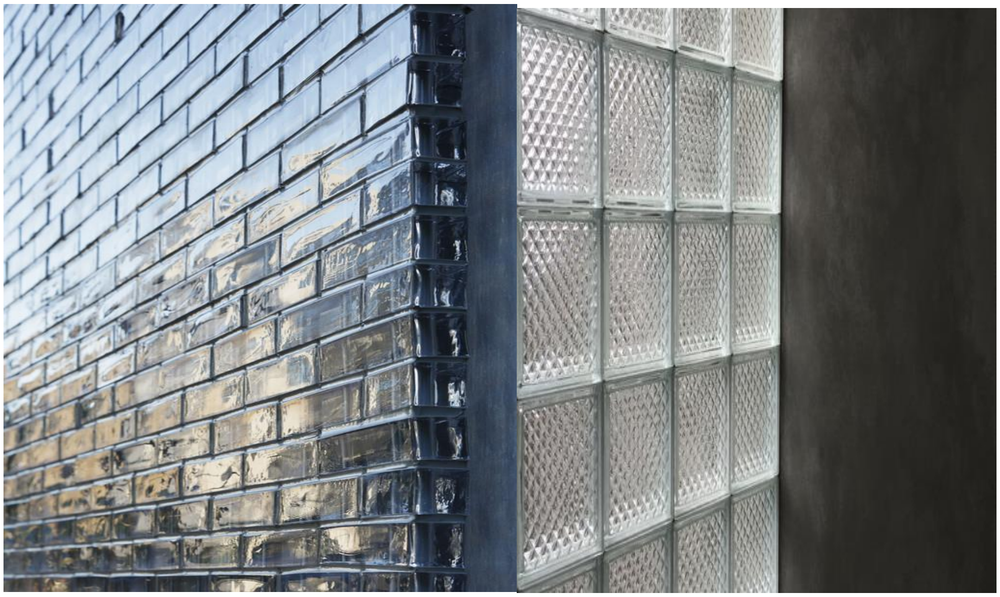


*Figure 2.3*

Glass bricks are the great importance for there are using them in architecture, and they have a long history. Its manufacturing stages developed since its inception in the year 1800 AD in the form of semi-automatic manufacturing until it reached the current well-known shape, which works to pass light through it and provides an optical veil. The glass brick industry has developed based on the principles of ergonomic lighting in the early 1900s to provide natural light in greenhouses for plants. Glass bricks are used in walls, partitions, ...etc. Glass bricks have two types according to the automatic forming method, whether by pressing into a mold or casting in a mold to take the desired decorative shape, and it has more than one method of installation according to each type. For the second, glass bricks have more than one form and method of production according to the semi-automatic method of production, such as the method of melting inside a mold in the oven to form sculptural glass tiles. Glass bricks have advantages, *including**:*** -

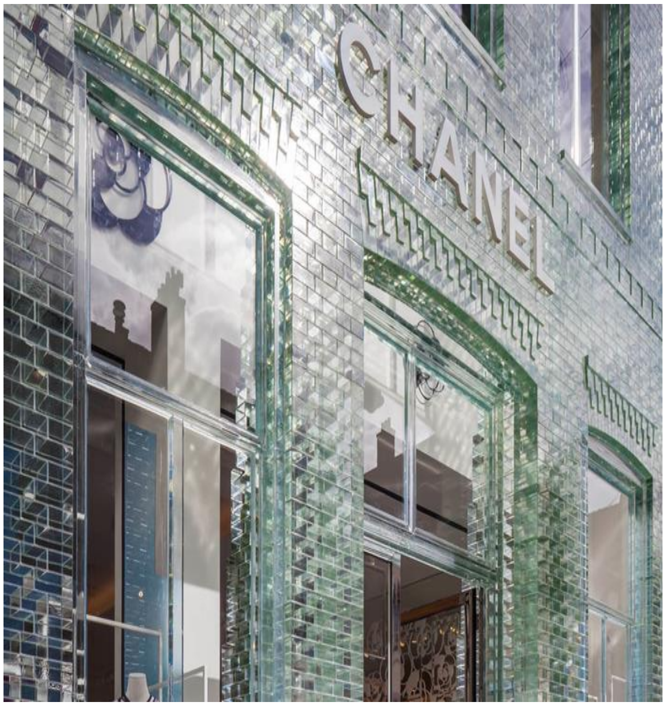


***Figure 2.4***

***Figure 2.5***

The hollow glass bricks manufactured by the automatic pressing method do not need finishing or polishing immediately after production, unlike the other type (designed glass bricks), the uses of glass bricks recently varied from before, and their shape developed a lot to suit modern uses and became represented in most of the interior and exterior designs. Glass bricks are used in design. The interior of the architecture and the architectural facades in the past and in the contemporary time, to give a functional and aesthetic aspect.

***Figure 2.6***

### 2.2.3-Refractory Bricks: -

One of the distinctive and widespread types of building bricks in Egypt, as it is used in the manufacture of ovens, facades, and kitchens. It is also used in decoration, and its shapes vary as follows:

Small refractory bricks that look like regular masonry bricks.

Wide refractory bricks of various sizes.

This type of brick is installed very easily by stacking the bricks and gluing them with cement mortar, and one of its decorative features is that it can be painted in any color you want and used to make interior or exterior decoration that matches the colors of the house furniture and finishing.

## *Characteristics Of Refractory Bricks: -

It has many advantages that may make you prefer it and use it in various uses, and these features are ***as follows:***

***A***-Resists corrosion.

***B***-Easy to clean.

***C***-Not water absorbent.

***D***-Dust does not stick to it.

***E***-Inexpensive when installed.

***F***-Moisture and heat resistant.

***Figure 2.7***

***Figure 2.8***

### 2.2.4 Sand Brick (Pink): -

The sand-lime brick consists of a homogeneous mixture of silica sand (silicone sand) by 90%, lime by 10%, and water by 5% by weight, then formed under a pressure of 400 kg per cm2.

#### ****Characteristics: -***

- Uniformity of shape and accuracy of dimensions, attractiveness of the surface and the external appearance replaces the whiteness.
- Strength and durability with a compressive strength of up to 25 Newtons per mm2.
- Good sound and heat insulation.
- The possibility of using it internally and externally without default.
- Wide possibility of custom formation.
- Sand bricks are used in construction as load-bearing walls as well.
- Supplied in mortar materials.

#### ****Sizes: -***

***1-*** 25 x 12 x 6 cm.

***2-*** 25 x 20 x 13 cm.

As for the colors, there are light pink bricks, dark pink bricks, and white, pink bricks.

#### ****Storage method: -***

It is stored on large pallets in the form of rows and columns next to each other.

*Figure 2.9*

*Figure 2.10*

### 2.2.5-Grilled Clay Bricks:

They are made from clay and water, then after drying they are fired in special ovens. This type of clay is formed either by extrusion; In this method, the bricks are made in the form of a long, continuous strip, which is cut to the required size using moving wires, or by the mold method.

### 2.2.6-Pumice Brick:

Is considered a lightweight brick compared to other types. It is a good heat and sound insulator, and its efficiency in that is equivalent to 6 times that of concrete stone. Its surface needs to be treated after applying the plaster layer. It is used in building walls and ceilings, and it is expensive.

***Figure 2.11***

### 2.2.7 Silica Refractory Bricks: -

they are mostly imported from Italy, its main component is silica sand, and its color is white, and the materials used in its manufacture are the same materials that are used in the manufacture of ordinary hollow bricks, but it is not hollow at all, and its uses are to build arches and decorations because of its durability.

***Figure 2.12***

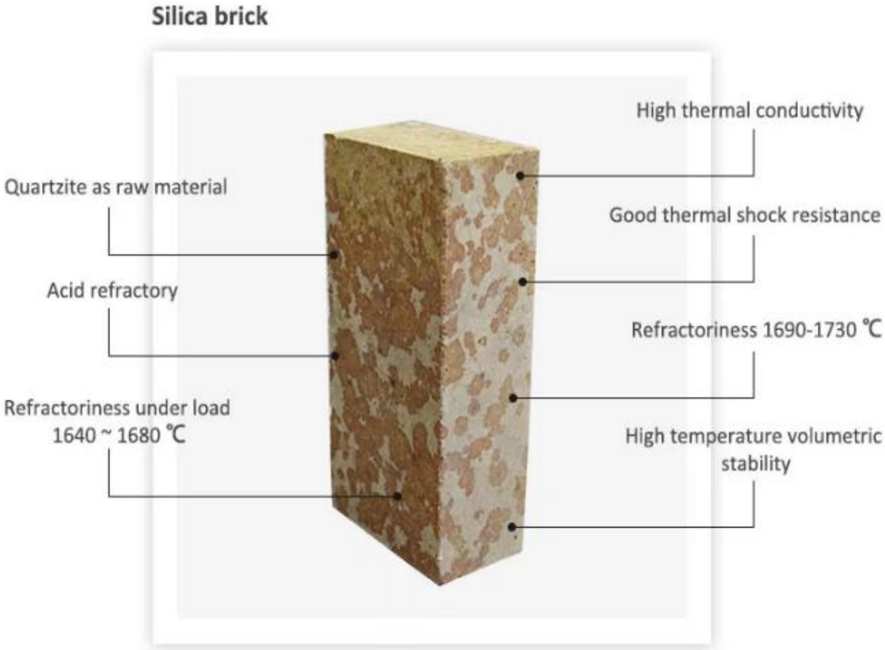


*Figure 2.13*

## 2.2.8 Solid Brick: -

This brick does not have internal voids except for two circular holes only, and it is characterized by its high resistance to fracture, and therefore it was used in the construction of the load-bearing wall, but it is rarely used at the present time, due to its high cost, heavy weight, and retention of moisture for a long time.

*Figure 2.14*

### 2.2.9Asphalt Bricks: -

It is made automatically from hot-pressed asphalt powder, and it is characterized by its resistance to moisture and acids. Therefore, it is used in stables, livestock pens, and the like. Its dimensions are usually 23 * 11 * 5 cm, and its density is 1.7.

It is used in floors that have traffic pressure

*Figure 2.15*

*Figure 2.16*

## *2.3 Geopolymer Concrete:*

The geopolymer binder is an inorganic polymer obtained from the polycondensation reaction of aluminosilicates with alkalis. The geopolymers possess amorphous/semi-crystalline 3-dimensional aluminosilicate framework structures created by the accompanying $(SiO_4)^{-4}$ and $(AlO_4)^{-5}$ tetrahedral. Recently, geopolymers have gotten significant attraction in the research and construction industry due to the outstanding performance in terms of mechanical and durability properties. As a result of these outstanding properties, geopolymer has been utilized as an alternative to Portland cement composites in various specialized applications such as fire-resistant coats, fiber reinforced composites and waste immobilization.

To encourage more application of geopolymer concrete and increase sustainability awareness in the construction industry, this study was undertaken to explore various studies where geopolymer concrete has been utilized for various applications. In this review paper, the properties of the composition of geopolymer concrete discussed. In contrast to review papers on geopolymers, potential applications of geopolymers based on their performance are discussed.

### *2.3.1Recommendations: -*

Though the literature has established that geopolymer concrete can be utilized for various construction applications. However, there is a need for more studies to be carried out in the following areas in order to encourage more use of geopolymers:

***A***-Evaluating the environmental impacts and the economic aspects of using GPC. Carrying out a comprehensive assessment of the impacts of GPC in terms of cost and sustainability would help to create more awareness on GPC which would propel its application. In addition, such studies would offer insights about various innovative ways that can be incorporated to further reduce the environmental impacts and cost of GPC.

***B***-Despite GPC being around for a while, there is need for more long-term studies should be carried out. Compared to OPC concrete, there is limited understanding of the long term, performance of GPC especially in terms of durability and GPC made with unconventional precursors. Thus, in addition to the short-term studies, more studies should focus on the long-term performance. The use of various accelerated tests could also help in evaluating the long-term performance of GPC. Geopolymer cement concrete for highway infrastructure.

Yang, Song, Ashour and Lee established that geopolymer concrete produced with slag can gain strength if cured at ambient temperatures. Several studies have shown that geopolymer can be utilized as a repair material for highway infrastructures. Despite these promising findings, the utilization of geopolymer concrete in highway infrastructure is still limited. Initial experiments into its operation in light pavement applications have been tested by an Australia-based geopolymer cement concrete producer. In the initial application, visual observation of footpaths, precast walkways and cycle lanes which are immediately in operation (formed of geopolymer concrete) has been produced. The produced geopolymer concrete showed no sign of distress, cracking or other failures.

As a result of the outstanding performance evident in the initial applications, geopolymer concrete; initiatives have been put into place to incorporate geopolymer concrete in the regional highway authority specification. A study has likewise been undertaken in Thailand, where geopolymer made with FA, palm ash and para wood ash as precursors were cured at 80 °C and used in the repair of highways. Laboratory studies have also shown that geopolymer is a good repair material due to its higher compressive and bond strength.

Wilkinson et al. stated that highway pavement applications are one of the specialized areas where geopolymer concrete would revolutionize.

Potholes on pavements are common issues all over the world and a high cost is always associated with the repair or replacement of these pavements. Geopolymer concrete offers a cost-effective and sustainable way to repair or reconstruct these pavements thereby increasing its overall service life.

### 2.3.2Applications Of Geopolymer Concrete: -

The development of geopolymer started in Ukraine in the late '50 s when Ukrainian scientist Glukhovsky first discovered the possibility of producing synthesized binders using aluminosilicates (clays, rocks, slags) and solutions of alkali metal. He called the binder "soil cement" and the corresponding concrete "soil silicates". This material was used in Mariupol, Ukraine in the 1960 s to build two 9-storeys residential buildings. Over 50 years later those buildings are still standing. There were a couple more buildings made with the use of this technology. However, the first residential building made of alkali-activated concrete without any Portland cement was built in 1989 in Lipetsk, Russian Federation and has 20 floors Fig. 8.

The term geopolymer was first used in 1979 by Joseph Davidovich as a binder synthesized by the reaction of an aluminosilicate powder (e.g., fly ash, slag) with an alkaline solution (sodium hydroxide and sodium silicate). The fly ash-based geopolymer concrete produced by Davidovich contains also aggregate (70–80% by mass) and plasticizers. Generally, the production is carried out by using ordinary concrete technology methods. Since that time researchers have conducted extensive studies on the strength and durability performance of geopolymer concrete.

Geopolymer technology is more advanced in precast applications due to the relative ease of controlled requirements in handling sensitive materials in addition to the controlled high temperature curing environment which is beneficial to geopolymers. As a result of this, earlier applications of geopolymer concrete were in the production of railway sleepers and sewer pipes. However, structural elements such as columns beams and even tunnel segments can also be made of geopolymer concrete. High durability and resistance to the aggressive environment, which is typical for geopolymer concrete, are very desired in sewer pipes production. Many soils contain aggressive acids (i.e., acid sulphate soils). Those acids are influencing concrete and steel members placed underground by causing corrosion.

Dawczyński, Krzywon, Górski, Dubińska and Samoszuk mentioned that geopolymer concrete is a great alternative for Portland cement concrete even in applications where steel reinforcements are used. Geopolymer concrete has been reported to satisfy the requirement of concrete in harsh environments such as sulphate soils. Thus, geopolymer concrete can be used as a sustainable alternative in the production of durable structures and for various repair applications. Geopolymer concrete has a high resistance to chloride resulting in lesser damage in the winter seasons when salt is used to melt the ice cover. Due to its high resistance to chloride corrosion, geopolymer concrete may be used for concrete structures such as piers, coastal bridges, and underwater concrete supports that will be under constant attack from saltwater.

### 2.3.3Flexural Strength: -

Flexural strength of concrete is the resistance offered by the concrete when subjected to bending (flexure) loads. Wilkinson, Magee, Woodward and Tretsiakova-McNally established that the majority of 28-day flexural strength results were around 4% of the comparable 28 day compressive strengths. However, no trend between 28-day compressive strength and 28-day flexural strength was visible from this analysis. Nevertheless, like the compressive strength, the study by Dave, Sahu and Misra Anil showed that the combined use of GGBS and SF with FA as precursors resulted in an enhancement in the flexural strength. Geopolymer made with 70% GGBS+ 20% FA+ 10% SF as precursor exhibited the highest flexural strength.

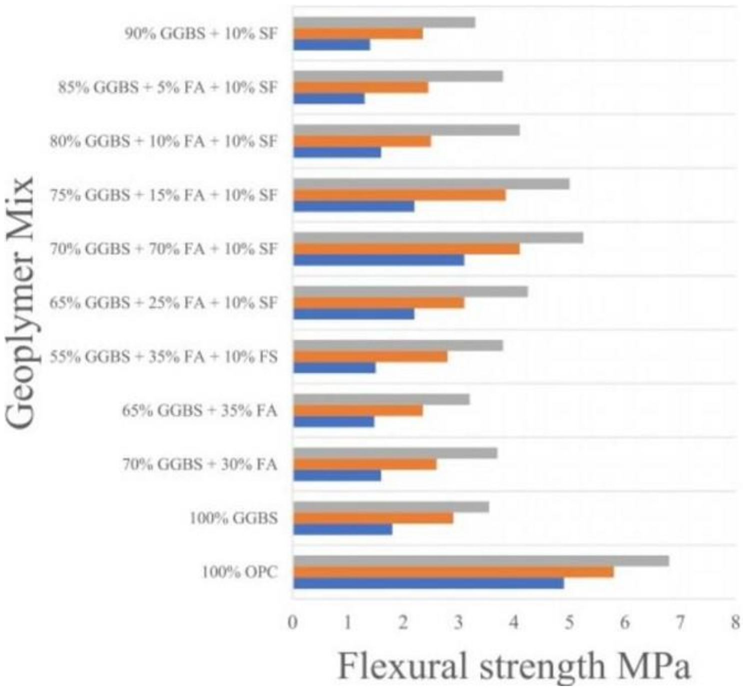


*Figure 2.17*

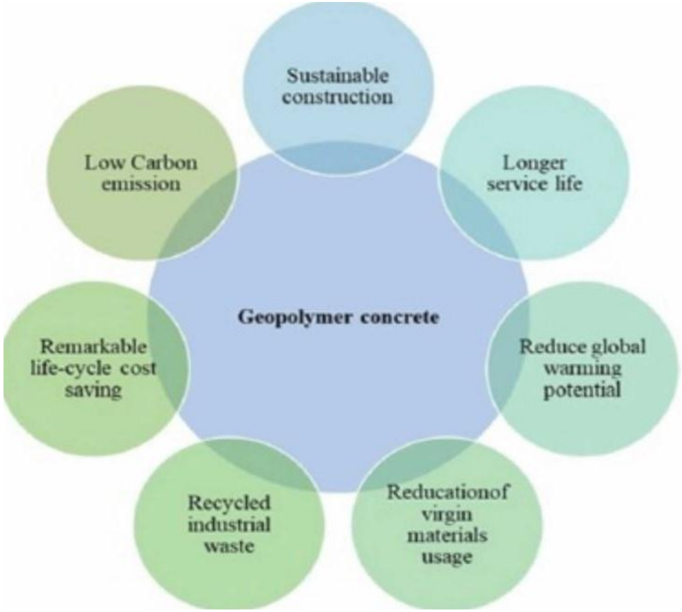


*Figure 2.18*

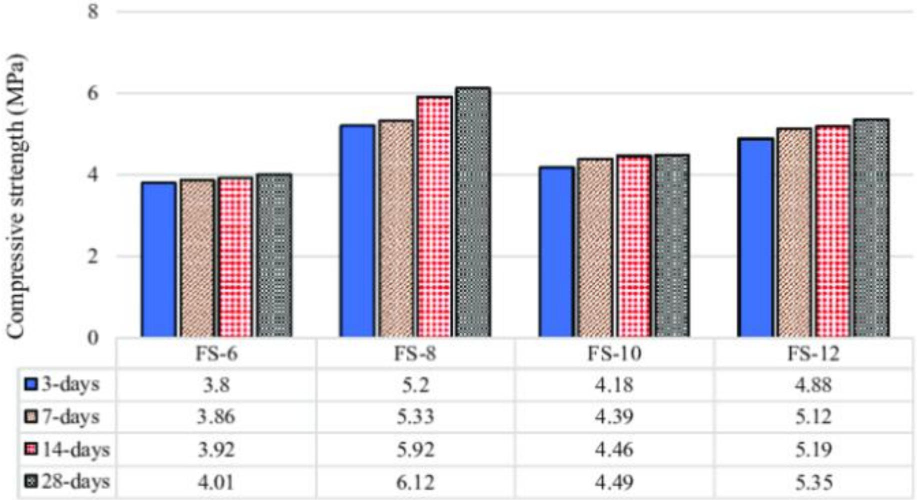
### *2.4:(Geopolymer Bricks): -*

The current study aims at investigating the production feasibility of the geopolymer bricks using the waste materials emanated from the washing process of sand and gravel in aggregate industries.

Geopolymer bricks made from less active waste materials. Geopolymer is a material originated by inorganic polycondensation as a result of the alkali activation of aluminosilicate materials. Geopolymer bricks seem to be advantageous due to the low demand for energy and the significant incorporation of wastes. The production of geopolymers from pozzolanic or aluminosilicate rich materials is very common. However, few studies have been carried out on the less-active materials such as waste materials of aggregate industries as raw materials for producing geopolymers. For this purpose, the influence of three parameters, sodium hydroxide concentration (4, 8 and 12 M), calcium hydroxide content (5%,10%, and 15%), and curing temperature (70 °C and 105 °C), on the physical and mechanical properties of geopolymer bricks was investigated using compressive strength, SEM micrographs, XRD analysis, water absorption, and bulk density. The results indicate that higher sodium hydroxide concentration caused forming a less porous and a more amorphous microstructure and yielded higher strengths and lower water absorption. The mixtures with higher calcium hydroxide content had higher compressive strengths (up to 75 MPa and 36 MPa at dry and wet conditions, respectively) and a more stable microstructure, however, incorporation of calcium hydroxide at levels higher than 20% results in lower compressive strengths, lower densities, and higher water absorption contents. Increasing curing temperature from 70 °C to 105 °C increased significantly the compressive strength.

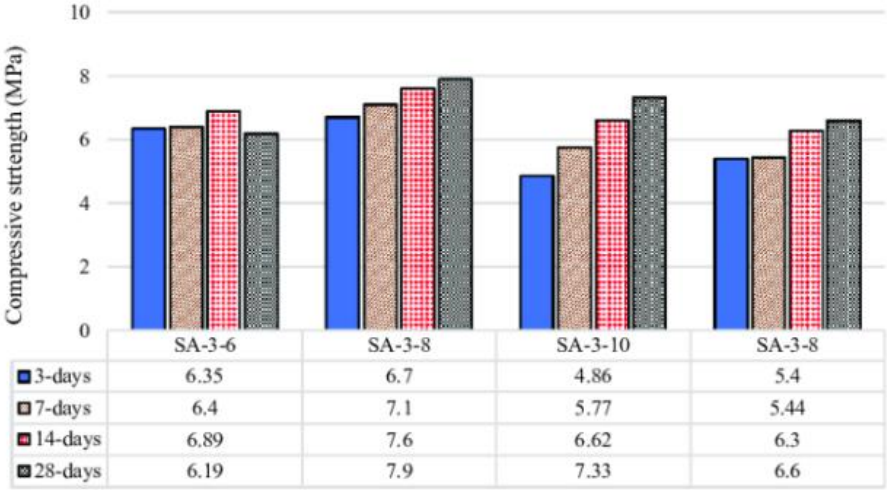
*Figure 2.19*

Disposal of mine tailings (MT) in impoundments may have adverse environmental impacts such as air pollution from dust emissions and release of heavy metals to surface and underground water. Geopolymerization as an environmentally friendly and sustainable method has been used to stabilize MT so that they can be used as construction material. In this paper, the durability and leaching behavior of MT-based geopolymer bricks are studied by measuring unconfined compression strength (UCS), water absorption, weight loss, and concentration of heavy metals after immersion in pH = 4 and 7 solutions for different periods of time. Microscopic/ spectroscopic techniques, SEM, XRD and FTIR, are also employed to investigate the change in microstructure and phase composition of MT-based geopolymer bricks after immersion in the solutions. To describe the leaching behavior of MT-based geopolymer bricks, the first order reaction/diffusion model (FRDM) is used to analyze the leaching test data. The results indicate that although there is a substantial strength loss after immersion in pH = 4 and 7 solutions, the water absorption and weight loss are small. The strength loss is mainly due to the dissolution of geopolymer gels as indicated by the microscopic/spectroscopic analysis results. The leaching analyses show that the heavy metals are effectively immobilized in the MT based geopolymer bricks, which is attributed to the incorporation of heavy metals in the geopolymer network. The FRDM can satisfactorily describe the leaching behavior of heavy metals in the MT-based geopolymer bricks, and the analysis results indicate that the solubility or reaction rate is an important factor controlling the leaching behavior.



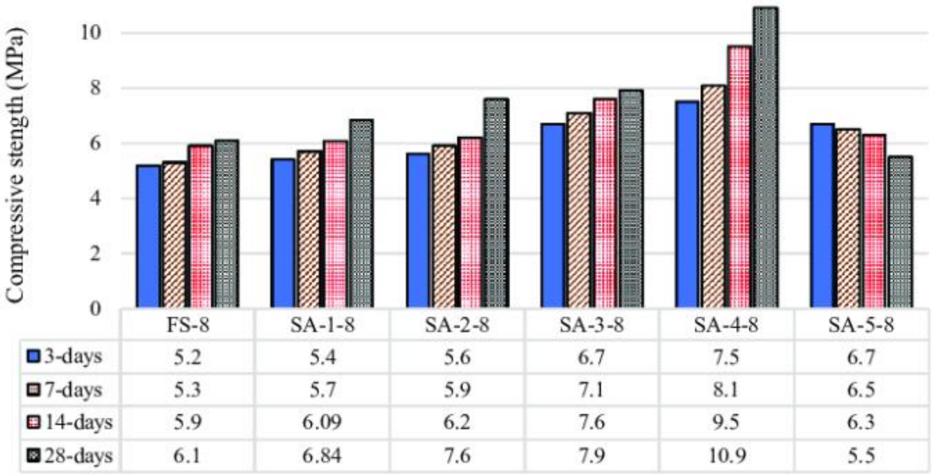
(a) Compressive strength of geopolymer brick at different NaOH concentration and FS

***Figure 2.20***



(b) Compressive strength of geopolymer brick at different NaOH concentration and Si/Al =3.4

***Figure 2.21***



(c) Compressive strength at different Si/Al ratios with 8M NaOH

***Figure 2.22***

The fine dust waste from the cyclones connected to the spray dryer in ceramic tiles manufacture was used in the preparation of geopolymer bricks. Dust was characterized after firing using XRD, XRF, PSD, and its bulk density was determined. Caustic soda was used at 1% NaOH level together with slaked lime at Ca (OH)2 percentage ranging from 6 to 10%. These were mixed with the fine dust waste and molded to form geopolymer bricks. The properties of produced bricks were studied after 28 days. Results indicated that the 28 days compressive strength increased with the degree of geopolymerization. It was found that the results abide by the Standard ASTM C 62/2013 for a recipe consisting of 1% NaOH, 10% Ca (OH)2 and 38% water. The results were confirmed by SEM imaging. The use of waste raw materials (except for caustic soda) resulted in a substantial reduction in the estimated production cost of the bricks.

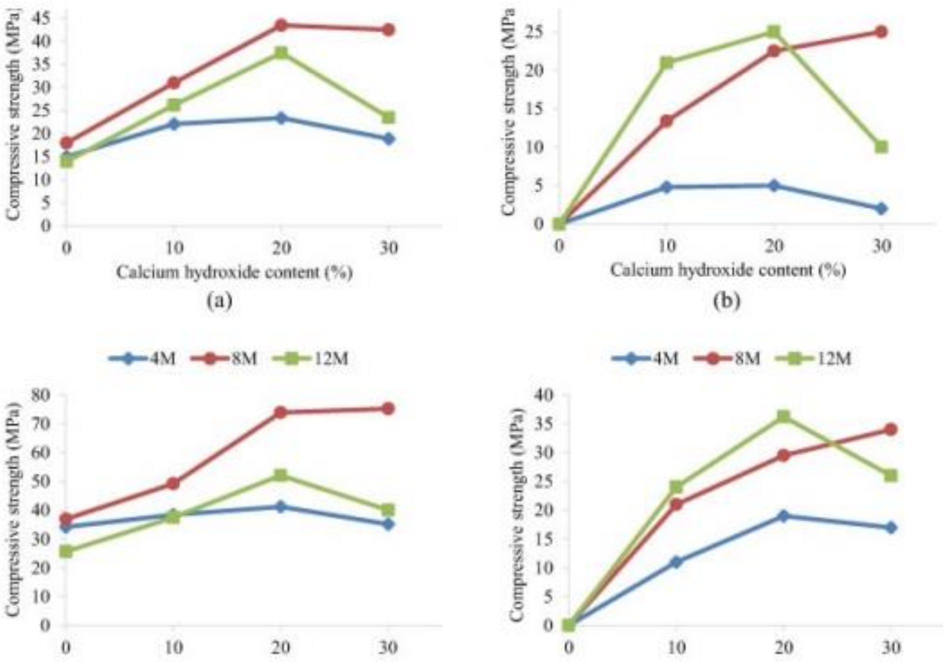


***Figure 2.23***

Bricks are the most predominant masonry units that are consumed globally. Brick manufacturing is energy consuming process and generates large amount of air pollution. The main objective of this paper is to synthesis geopolymer bricks made of Ground Granulated Blast Furnace Slag (GGBS), M-Sand and Alkaline solution. The significance of this research work is the designing of geopolymer brick under economic condition with properties equivalent to the Class A first class bricks. The various factors that affect the geopolymerization such as proportions of raw materials, ratio of alkaline solution and molarity of the sodium hydroxide solution are optimized in this research work. Compressive strength and water absorption test were conducted over the brick specimens as per IS 3495 (Part 2): 1992. The results report that GGBS based geopolymer bricks could be designed with better engineering properties. This extends the scope of geopolymerization in the arena of bricks.

Mechanical performances of weathered coal fly ash based geopolymer bricks in this paper weathered coal fly ash has been used in polycondensation processes aimed at the production of geopolymer–based low temperature ceramic bricks.

The ash has as received” and after drying, showing “been employed both favorable reactivity in any case.

Different curing conditions with a variable period at 60 °C have been tested. Samples obtained have been characterized by measuring Unconfined Compressive Strength (UCS) and by SEM observations.

Good strength values have been obtained with the systems tested. Furthermore, it has been found that mechanical performance increases as the time during which samples are kept at 60 °C increases. Utilization of iron ore mine tailings for the production of geopolymer bricks This study presents a methodology for making bricks, in a cost-effective and environmentally friendly manner, using the tailings produced from iron ore mines in Western Australia (WA). The study was based on the geopolymerisation process, which is known to conserve energy by reducing the emission of greenhouse gases. The reduction is accomplished by avoiding the processes of high temperature kiln firing, traditionally utilized when making bricks from sandy soils with high clay content. In this study, the sodium silicate was added to the mine tailings in powder form, as an activator for the formulation of the geopolymer bricks. The effects of the initial setting time, curing temperature, curing time and activator content on the unconfined compressive strength (UCS), water absorption and other durability properties of the bricks were investigated. X-ray diffraction analysis was performed to investigate the phase composition of the geopolymer bricks. The bricks achieved an UCS as high as 50.53 MPa for the optimum values of the parameters. Technically, the geopolymer bricks that were produced met both the American Society of Testing and Materials and the Australian Standards (AS) requirements for bricks. A cost analysis of the geopolymer bricks is also presented, and this shows that the cost of geopolymer bricks is lower than that of the commercial, fired clay bricks.

***Figure 2.24***

The present study introduces the preparation of thermal insulation geopolymer bricks using ferrosilicon slag and alumina waste. Compressive strength, bulk density, cold and boiling water absorption, apparent porosity, thermal conductivity, and Fourier transform infrared spectroscopy were used to characterize the geopolymer bricks. Ferrosilicon slag suffers from low alumina content. Thus, alumina is added to compensate for this deficiency. Pristine ferrosilicon slag and the SiO2/Al2O3 (Si/Al, ratio = 2) sample were prepared at different NaOH concentrations (i.e., 6, 8, 10, and 12 M: Na2SiO3/NaOH ratio = 2.5), different curing times (i.e., 3, 7, 14, and 28 days), and room temperature. The 8 M NaOH concentration achieved the best compressive strength. Accordingly, different Si/Al ratios were prepared and tested at 8 M NaOH, room

temperature, and different curing times (i.e., 3, 7, 14, and 28 days). Results indicate that increasing the alumina content enhances the geopolymer properties but reduces the compressive strength of the prepared geopolymer. The sample with Si/Al ratio = 1 exhibited a higher compressive strength (10.9 MPa) than the other Si/Al ratios (i.e., 4, 3, 2, and 0.5) and the pristine ferrosilicon slag after 28 days of curing and at 8 M NaOH. The obtained value is consistent with the ASTM C62 and Egyptian standards. Furthermore, the addition of alumina waste decreased the thermal conductivity of the prepared geopolymer bricks.

***Figure 2.25***

## *3.4.1Processing and characterization of fly ash-based geopolymer bricks*:-

Using fly ash as raw material to produce ground polymer bricks seems to be a logical solution that allows natural resources to be conserved, reduces further pollution and preserves the environment. Fly ash-based geological polymers have been studied by many researchers around the world for several decades due to their excellent mechanical properties. This study was conducted to produce fly ash-based ground polymer bricks by forming pressure without firing and low energy consumption. Experiments were conducted on fly ash-based geopolymer polymer bricks by changing the ratio of fly ash to sand (1:2-1:5, depending on the mass ratio), the processing time (1-24 hours) and the processing temperature (room temperature -80°C). Compressive strength of up to 20.3 MPa was obtained by processing at 70°C for 24 hours at 60 days of aging. The density of ground polymer bricks ranged from 1800 kg/m3 to 1950 kg/m3. The microstructure properties of fly ash-based geological polymer bricks have been investigated. using XRD and SEM analysis Utilization of cement kiln dust (CKD) to enhance mine tailings-based geopolymer bricks This paper studies the feasibility of enhancing the physical and mechanical properties and the durability of copper mine tailings (MT)-based geopolymer bricks with cement kiln dust (CKD).

The effects of CKD content (0–10%), sodium hydroxide (NaOH) concentration (10 and 15 M) and initial water content (12–20%) on unconfined compressive strength (UCS), water absorption, and weight and strength losses after immersion in water are studied. To shed light on the mechanism for the contribution of CKD to geopolymerization, microscopic and spectroscopic techniques including scanning electron microscopy/energy-dispersive X-ray spectroscopy (SEM/EDX), X-ray diffraction (XRD), and Fourier transform infrared (FTIR) spectroscopy are used to investigate the micro/nanostructure and the elemental and phase composition of geopolymer brick specimens. The results show significant improvement of UCS and durability when CKD is used. Water absorption, however, slightly increases due to the hydration of Ca in the added CKD. The enhancement of UCS and durability is attributed to the improving effect of CKD on dissolution of aluminosilicate species, formation of $CaCO3$, and integration of Ca into the geopolymer gel.

### *3.4.2Mechanical properties on geopolymer brick:*

A review Bricks has stand for many years as durable construction substantial, especially in the area of civil engineering to construct buildings. Brick commonly used in the structure of buildings as a construction wall, cladding, facing perimeter, paving, garden wall and flooring. The contribution of ordinary Portland cement (OPC) in cement bricks production worldwide to greenhouse gas emissions. Due to this issue, some researchers have done their study with other materials to produce bricks, especially as a by-product material. Researchers take effort in this regard to synthesizing from by-product materials such as fly ash, bottom ash and kaolin that are rich in silicon and aluminum in the development of inorganic alumina-silicate polymer, called geopolymer Geopolymer is a polymerization reaction between various aluminosilicate oxides with silicates solution or alkali hydroxide solution forming polymerized Si-O-Al-O bonds. This paper summarized some research finding of mechanical properties of geopolymer brick using by-product materials.

***Figure 2.27***

# *Chapter (3): Material Characterization*

## *3.1 Introduction:*

This chapter presents an elaborated characterization of the utilized specimens, testing setup, instrumentation, and the testing procedure. Materials for this research were procured from the available local materials including pozzolanic materials, Alkaline solution, waste materials, Coarse aggregate, sand, and water.

The experimental program included 3 brick molds with a length of 26cm, 13cm width and 7cm height.

Specimens were loaded up to failure under increasing static loads. Bricks were tested in terms of compressive strength and flexure strength. The compressive and bending strength tests were carried out according to ECP 203-2018. One of the specimens was considered as a control specimen. The other specimens were added to it waste materials such as plastic and rubber by replacement of sand according to table to test it. All experiments were carried out in the Nile higher institute`s lab.

## *3.2 Geopolymer concrete materials:*

The materials used were pozzolanic materials, Alkaline solution, waste materials, Coarse aggregate, sand, and water.

### *3.2.1 Pozzolanic materials:*

The pozzolanic materials used in this experimental study are Fly Ash and Silica fume.

#### 3.2.1.1 Fly Ash:

Fly ash is produced by coal-fired electric and steam generating plants. Typically, coal is pulverized and blown with air into the boiler's combustion chamber where it immediately ignites, generating heat and producing a molten mineral residue. Boiler tubes extract heat from the boiler, cooling the flue gas and causing the molten mineral residue to harden and form ash. Coarse ash particles, referred to as bottom ash or slag, fall to the bottom of the combustion chamber, while the lighter fine ash particles, termed fly ash, remain suspended in the flue gas. Prior to exhausting the flue gas, fly ash is removed by particulate emission control devices such as electrostatic precipitators or filter fabric bag houses. Fly ash particles are generally spherical in shape and range in size from 0.5 μm to 300 μm.

***Figure* 3.1:** fly ash

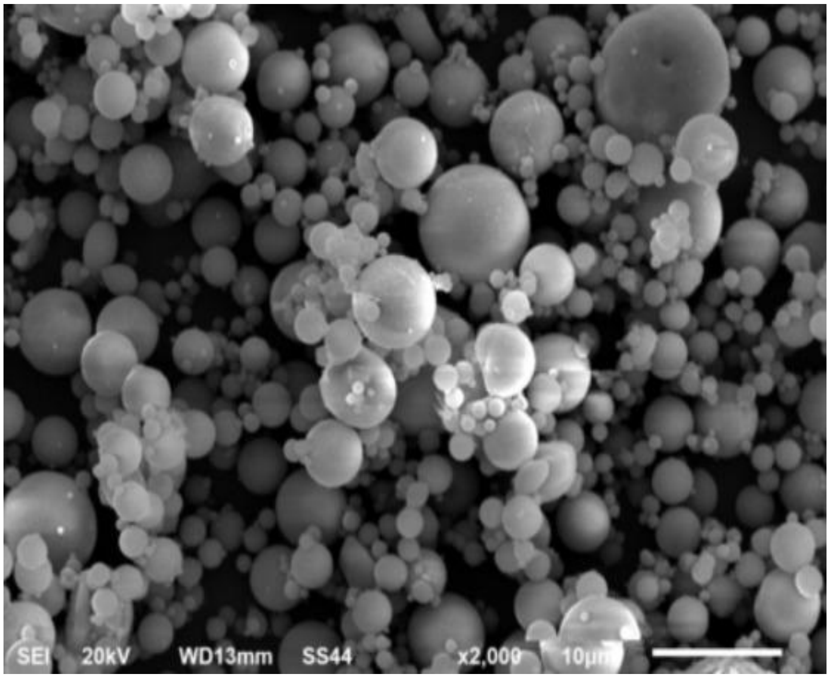


***Figure* 3.2:** Micrograph showing spherical fly ash particles.

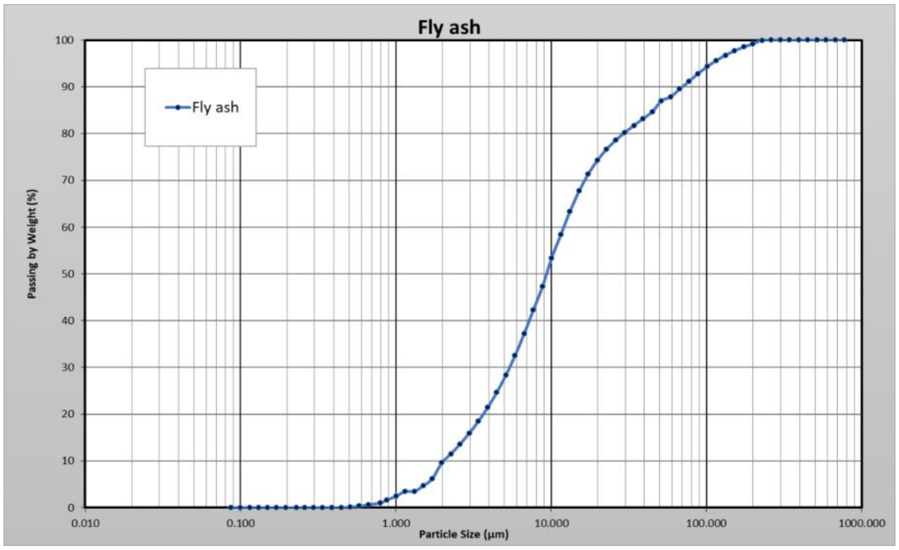


***Figure* 3.3:** particles size distribution of fly ash

### 3.2.1.2 Silica fume:

Silica fume is a byproduct of producing silicon metal or ferrosilicon alloys. One of the most beneficial uses for silica fume is in concrete. Because of its chemical and physical properties, it is a very reactive pozzolan. Concrete containing silica fume can have very high strength and can be very durable. Silica fume is available from suppliers of concrete admixtures and, when specified, is simply added during concrete production. Placing, finishing, and curing silica-fume concrete require special attention on the part of the concrete contractor.

Silica fume (SF) is a byproduct of the silicon and ferrosilicon industry. The reduction of high-purity quartz to silicon at temperatures up to 2000 °C produces SiO2 vapours, which oxidizes and condense in the low-temperature zone to tiny particles consisting of non-crystalline silica. By-products of the production of silicon metal and the ferrosilicon alloys having silicon contents of 75% or more contain 85–95% non-crystalline silica. The by-product of the production of ferrosilicon alloy having 50% silicon has much lower silica content and is less pozzolanic. Therefore, SiO2 content of the silica fume is related to the type of alloy being produced shows the schematic diagram of silica fume production.

Silica fume is also known as micro silica, condensed silica fume, volatilized silica or silica dust. Silica fume color is either premium white or grey.

## *Physical properties:*

More than 95% of silica fume particles are finer than 1 μm

## *Chemical composition:*

Silica fume has a very high content of amorphous silicon dioxide and consists of very fine spherical particles. Small amounts of iron, magnesium, and alkali oxides are also found.

## *Advantages of using silica fume*

-High early compressive strength.

-High tensile, flexural strength, and modulus of elasticity.

-Increased toughness.

-High bond strength.

-Enhanced durability.

-Very low permeability to chloride and water intrusion

Increased abrasion resistance.

-Superior resistance to chemical attack from chlorides, acids, nitrates and sulfates, etc.

-High electrical resistivity and low permeability.

## *Reaction mechanism of silica fume:*

Silica fume is a very reactive pozzolanic material because of its extreme fineness and very high amorphous silicon dioxide content. Mechanism of silica fume in concrete can be described basically under three ***roles:***
(i) pore-size refinement and matrix densification.
(ii) Reaction with free-lime.
(iii) Cement paste–aggregate interfacial refinement

**In concrete the characteristics of the transition zone between the aggregate particles and cement paste play a significant role in the**

## *Effect of silica fume on the workability of concrete*

Khayat and Aitkin (1993) reported that addition of 10% silica fume in a lean concrete (100 kg/m3) of cement reduced the water demand. In normal structure concrete, even with 5% silica fume addition, the water demand is increased to maintain constant slump. For producing very high strength and durable concrete, silica fume up to 10% is added as an admixture and use of superplasticizer to maintain specified slump is found necessary Porosity Igarashi et al. (2005) evaluated the capillary porosity and pore size distribution in high-strength concrete containing 10% silica fume at early ages. They concluded that silica-fume-containing concretes were found to have fewer coarse pores than the ordinary concretes, even at early ages of 12 and 24 h. The threshold diameter at which porosity starts to steeply increase with decreasing pore diameter was smaller in silica-fume-containing concretes than in ordinary concretes at 12 h. This smaller

***Figure 3.4*** silica fume

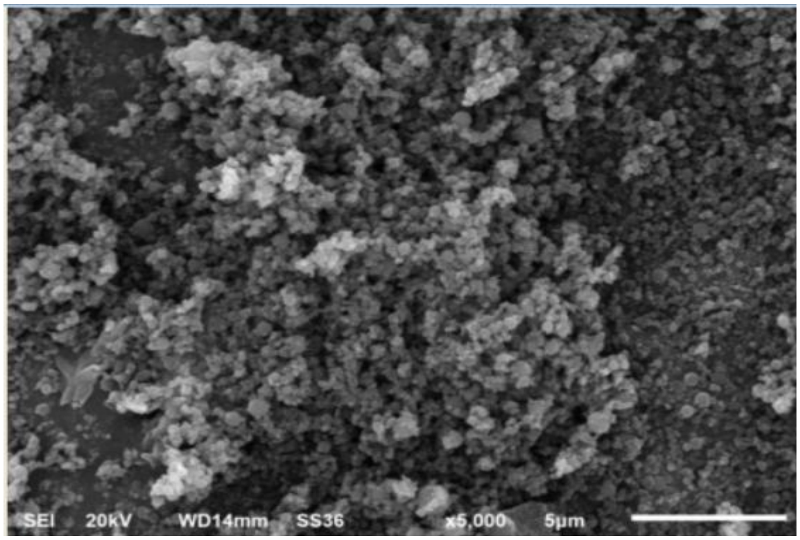


***Figure 3.5*****:** Micrograph showing silica fume particles.

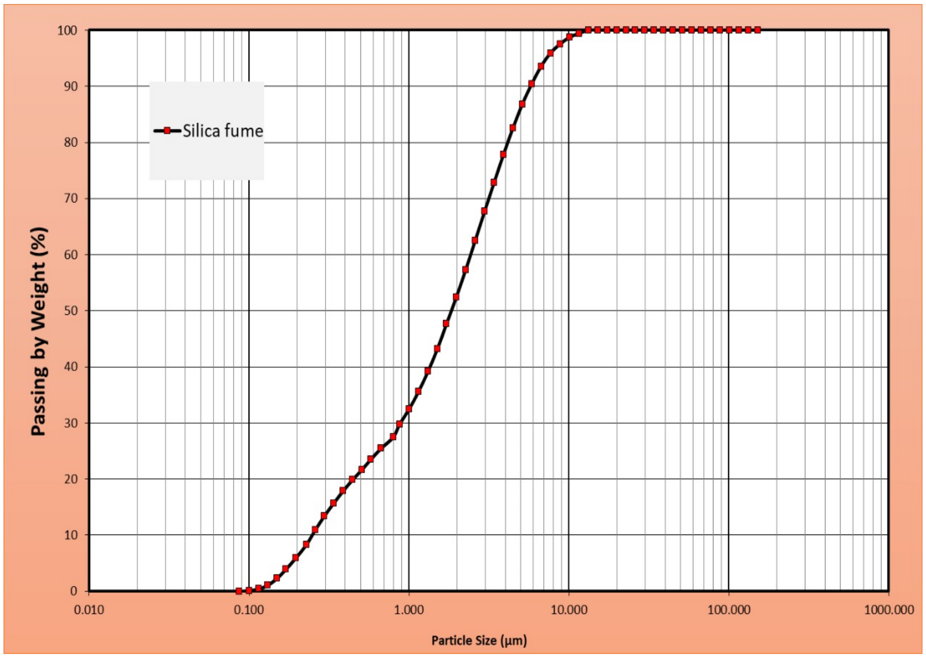


***Figure 3.6*****:** particles size distribution of silica fume

## *3.2.2 Alkaline solution:*

The Alkaline solution used is a combination of sodium hydroxide and sodium silicate.

### 3.2.2.1 Sodium hydroxide:

Pure sodium hydroxide is a colorless crystalline solid that melts at 318 °C (604 °F) without decomposition, and with a boiling point of 1,388 °C (2,530 °F). It is highly soluble in water, with a lower solubility in polar solvents such as ethanol and methanol. NaOH is insoluble in ether and other non-polar solvents. Similar to the hydration of sulfuric acid, dissolution of solid sodium hydroxide in water is a highly exothermic reaction where a large amount of heat is liberated, posing a threat to safety through the possibility of splashing. The resulting solution is usually colorless and odorless. As with other alkaline solutions, it feels slippery with skin contact due to the process of saponification that occurs between NaOH and natural skin oils.

***Figure** 3.7* sodium hydroxide

### 3.2.2.2 Sodium silicate:

Sodium silicate is an inorganic sodium salt which has silicate as the counterion. It is also called Sodium metasilicate or Waterglass. The chemical formula of Sodium silicate is $(Na_2O) \cdot SiO_2$.Sodium metasilicate is a flaked solid or powdered substance. It dissolves in water to produce alkaline solutions. It has a polymeric anion. In alkaline and neutral solutions it is stable whereas, in acidic solutions, the silicate ions will react with hydrogen ions and form silicic acids, which are likely to decompose into hydrated silicon on the dioxide gel. When further heated, it drives off the water and a hard translucent substance called silica gel is obtained.

***Figure 3.8***

### 3.2.3 Waste materials:

The waste materials used in this research are plastic (PET) and rubber.

#### 3.2.3.1 Plastic:

Plastics are a wide range of synthetic or semi-synthetic materials that use polymers as a main ingredient. Their plasticity makes it possible for plastics to be moulded, extruded or pressed into solid objects of various shapes. This adaptability, plus a wide range of other properties, such as being lightweight, durable, flexible, and inexpensive to produce, has led to its widespread use. Plastics typically are made through human industrial systems. Most modern plastics are derived from fossil fuel-based chemicals like natural gas or petroleum; however, recent industrial methods use variants made from renewable materials, such as corn or cotton derivatives. 9.2 billion ton of plastic are estimated to have been made between 1950 and 2017. More than half this plastic has been produced since 2004. In 2020, 400 million ton of plastic were produced. If global trends on plastic demand continue, it is estimated that by 2050 annual global plastic production will reach over 1,100 million ton.

***Figure* 3.9** plastic

### 3.2.3.2 Rubber:

Natural rubber is produced from plants and is classified as a polymer A chemical compound with large molecules made of many smaller molecules of the same kind. Some polymers exist naturally, and others are produced in laboratories and factories. A polymer is a chemical compound with large molecules made of many smaller molecules of the same kind. Some polymers exist naturally and others are produced in laboratories and factories. Natural rubber is one of the most important polymers for human society. Natural rubber is an essential raw material used in the creation of more than 40,000 products. It is used in medical devices, surgical gloves, aircraft and car tires, pacifiers, clothes, toys, etc. The properties of rubber include high strength and the capability to be stretched many times without breaking. Natural rubber compounds are exceptionally flexible, good electrical insulators, and are resistant to many corrosive substances.

***Figure 3.10*** rubber

### *3.2.4 Coarse aggregate:*

Clean dry angular gravel free from impurities was utilized in the mixture. Two types of gravel were used according to the sieve analysis test. The first category of the nominal maximum size is not more than 30 mm and not smaller than 20 mm, while the second category of nominal maximum size does not exceed 15 mm. Table 3.1 and Figure 3.11 show the results of the sieve analysis test.

| Sieve number (mm ) | Retained weight on every sieve(gm) | Cumulative retained weight (gm) | Cumulative Retained weight % | Passed weight % |
|---|---|---|---|---|
| **40** | **100** | **100** | **1.00** | **99.00** |
| **20** | **3500** | **3600** | **36** | **64** |
| **10** | **3200** | **6800** | **68** | **32** |
| **5** | **600** | **7400** | **74** | **24** |
| **2.36** | **700** | **8100** | **81** | **19** |
| **1.18** | **700** | **8800** | **88** | **12** |
| **0.6** | **300** | **9100** | **91** | **9** |
| **0.3** | **300** | **9400** | **94** | **6** |
| **0.15** | **300** | **9700** | **97** | **3** |
| **pan** | **300** | **10000** | **100** | **0** |

***Table 3.1*** Sieve analysis test results

***Figure*** 3.11

### *3.2.5 Fine aggregate:*

Fine aggregates used are natural sand particles from the land through the mining process, the fine aggregates consist of natural sand or any crushed stone particles that are ¼" or smaller.

Aggregates less than 4.75 mm in size are called fine aggregates.

***Figure*** 3.12

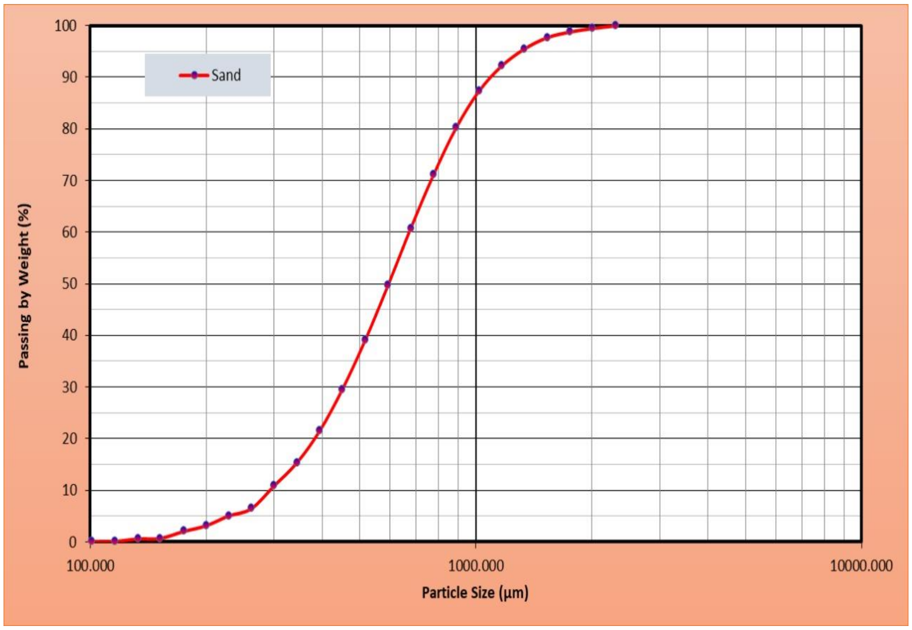


***Figure*** 3.13

### *3.2.6water:*

Water used for mixing in concrete should be free from oil, acids and alkali's, salts, sugars, organic materials, or any other substances that may be deleterious to concrete. Generally, it should be of potable quality. The pH value of water shall not be less than 7.

## *3.3 Bricks molds:*

The used mold in this experiment was from wood with a length of 26cm, 13cm width and 7cm height.

***Figure* 3.14**

### *3.4 Concrete mix:*

This concrete mixture was designed according to table3.2 to fill 1m$^3$.The concrete mixing was done mechanically by mixing materials in a dry condition for 3 minutes, then gradually adding Alkaline solution and continuing the mixing for another two minutes. Figures 3.15 and 3.16 show the components of the concrete mixture used in this study.

| ID | FLY ASH (KG) | SF (KG) | PLASTIC/RUBBER (KG) | SAND (KG) | DOLOMITE (KG) | WATER (L) | NAOH (KG) | SS (L) |
|---|---|---|---|---|---|---|---|---|
| **MG0** | 300 | 0 | 0 | 1050 | 700 | 78 | 40 | 170 |
| **MG1** | 272 | 28 | 105 | 945 | 700 | 78 | 40 | 170 |
| **MG2** | 244 | 56 | 210 | 840 | 700 | 78 | 40 | 170 |
| **MG3** | 300 | 0 | 0 | 1050 | 700 | 70 | 48 | 170 |
| **MG4** | 272 | 28 | 105 | 945 | 700 | 70 | 48 | 170 |
| **MG5** | 244 | 56 | 210 | 840 | 700 | 70 | 48 | 170 |
| **MGR1** | 244 | 56 | 210 | 840 | 700 | 78 | 40 | 170 |
| **MGR2** | 272 | 28 | 105 | 945 | 700 | 70 | 48 | 170 |
| **MGR3** | 244 | 56 | 210 | 840 | 700 | 70 | 48 | 170 |

***Table* 3.2**

***Figure* 3.15**

***Figure* 3.16**

### 3.4.1 MG0:

| Fly ash | SF | Plastic (PET) | Sand | Dolomite | Water | NaoH | SS |
|---|---|---|---|---|---|---|---|
| **2025g** | 0 | 0 | 7087.5 g | 4725 g | 562.5ml | 1147.5 ml | 1147.5ml |

**Table 3.3**

**Figure 3.17**

## 3.4.2 MG1:

| Fly ash | SF | Plastic (PET) | Sand | Dolomite | Water | NaoH | SS |
|---|---|---|---|---|---|---|---|
| **1836g** | 189 g | 708.75 g | 6378.75g | 4725 g | 562.5ml | 1147.5 ml | 1147.5 ml |

**Table 3.4**

**Figure 3.18**

### 3.4.3 MG2:

| **Fly ash** | **SF** | **Plastic (PET)** | **Sand** | **Dolomite** | **Water** | **NaoH** | **SS** |
|---|---|---|---|---|---|---|---|
| **1647g** | 378 g | 1417.75 g | 6378.75g | 4725 g | 562.5ml | 270g | 1147.5ml |

**Table 3.5**

**Figure 3.19**

### 3.4.3 MG3:

| Fly ash | SF | Plastic (PET) | Sand | Dolomite | Water | NaoH | SS |
|---|---|---|---|---|---|---|---|
| **2025g** | 0 | 0 | 7087.5 g | 4725 g | 472.5ml | 324ml | 1147.5 ml |

**Table 3.6**

**Figure 3.20**

### 3.4.4 MG4:

| **Fly ash** | **SF** | **Plastic (PET)** | **Sand** | **Dolomite** | **Water** | **NaoH** | **SS** |
|---|---|---|---|---|---|---|---|
| **1836g** | 189 g | 708.75 g | 6378.75g | 4725 g | 472.5ml | 324ml | 1147.5ml |

**Table 3.7**

**Figure 3.21**

## 3.4.5 MG5

| Fly ash | SF | Plastic (PET) | Sand | Dolomite | Water | NaoH | SS |
|---|---|---|---|---|---|---|---|
| **1647g** | 378 g | 1417.75 g | 6378.75g | 4725 g | 472.5ml | 324g | 1147.5ml |

**Table 3.8**

**Figure 3.22**

### 3.4.4 MGR1:

| **Fly ash** | **SF** | **Rubber** | **Sand** | **Dolomite** | **Water** | **NaoH** | **SS** |
|---|---|---|---|---|---|---|---|
| **1647g** | 378 g | 1417.75 g | 6378.75g | 4725 g | 562.5ml | 270g | 1147.5ml |

**Table 3.9**

**Figure 3.23**

## 3.4.5 MGR2:

| **Fly ash** | **SF** | **Rubber** | **Sand** | **Dolomite** | **Water** | **NaoH** | **SS** |
|---|---|---|---|---|---|---|---|
| **1836g** | 189 g | 708.75 g | 6378.75g | 4725 g | 472.5ml | 324ml | 1147.5ml |

**Table 3.10**

**Figure 3.24**

### 3.4.5 MGR3:

| **Fly ash** | **SF** | **Rubber** | **Sand** | **Dolomite** | **Water** | **NaoH** | **SS** |
|---|---|---|---|---|---|---|---|
| **1647g** | 378 g | 1417.75 g | 6378.75g | 4725 g | 472.5ml | 324g | 1147.5ml |

**Table 3.11**

**Figure 3.25**

## 3.5 Batching of concrete:

The concrete mixing was done by mixing materials according to their weights from the previous tables.

***Figure* 3.26 Sand**

***Figure* 3.27 dolomite**

*Figure* **3.28 plastic**

*Figure* **3.29 silica fume**

***Figure* 3.30 NaOH**

***Figure* 3.31 Sodium silicate**

***Figure* 3.32 Fly ash**

- Batching in a dry condition for 3 minutes figure 3.33

***Figure* 3.33**

- Adding Alkaline solution and continuing the mixing for another two minutes.

***Figure* 3.34**

## *3.6 Casting and compaction:*

Molds were prepared for placing the concrete mix. After mixing the concrete, it was poured into the molds and shaken to compact the concrete. As a figures.

***Figure* 3.35 placing the concrete.**

***Figure* 3.36 compaction the concrete**

***Figure* 3.37 shaking to compact the concrete.**

### 3.8 Compressive strength:

Compressive strength can be defined as the capacity of concrete to withstand loads before failure. Of the many tests applied to the concrete, the compressive strength test is the most important, as it gives an idea about the characteristics of the concrete. The compression strength machine was used for this test. Fig. 3.23 illustrates the machine used for this test. In this study, the compressive strength test of all the concrete mixes was performed on 250×120×60 $mm^3$.The reported compressive strength was the average of the three specimens tested. The compressive strength test was carried out according to **ECP 203-2018**, and **E.S.S 1658-1988 parts.**

**Figure 3.38**

### 3.9 Water Absorption:

Absorption (%) = (Ws-Wd)/Wd x 100 where:

Ws = Wet weight of samples.
Wd = oven-dry weight of samples.

The dimensions test of the geopolymer bricks was measured from the respective length, width and height of overall dimension of bricks and individual brick dimension. Test procedure was conducted on bricks which were selected randomly from bricks prepared for testing program in according to ECP 203-2018, and E.S.S 1658-1988 parts. saturated and dry weights (Ws and Wd) of concrete bricks saturated in water for 24 hrs. After that dried in an oven for 24 hrs at 115°C.

# *Chapter (4): Results and Discussion*

## *4.1 Introduction:*

This chapter shows the results of the experiments, including compressive strength , dry and wet densities, and water absorption.

A total of 3 bricks (25*12*6) cm were tested according to ECP 203-2018 and E.S.S 1658-1988.

## *4.2 Dry density: (plastic)*

### 4.2.1 First mixture:

- **MG0**

| Mix ID | Sample size | Dry weight | Dry density |
|---|---|---|---|
| **MG01** | 0.25x0.12x0.06<br>0.0018 m$^3$ | 3.77 kg | 2094.44 kg/m$^3$ |
| **MG02** | 0.25x0.12x0.06<br>0.0018 m$^3$ | 3.72 kg | 2066.67 kg/m$^3$ |
| **MG03** | 0.25x0.12x0.06<br>0.0018 m$^3$ | 3.70 kg | 2055.56 kg/m$^3$ |

### 4.2.2second mixture:

- **MG1**

| Mix ID | Sample size | Dry weight | Dry density |
|---|---|---|---|
| **MG11** | 0.25x0.12x0.06<br>0.0018 m$^3$ | 4.199 kg | 2332.77 kg/m$^3$ |
| **MG12** | 0.25x0.12x0.06<br>0.0018 m$^3$ | 4.101 kg | 2278.33 kg/m$^3$ |
| **MG13** | 0.25x0.12x0.06<br>0.0018 m$^3$ | 4.041 kg | 2245 kg/m$^3$ |

### 4.2.3 third mixture:

- **MG2**

| Mix ID | Sample size | Dry weight | Dry density |
|---|---|---|---|
| **MG2$_1$** | 0.25x0.12x0.06 | 3.981 kg | 2211.67 kg/$m^3$ |
| | 0.0018 $m^3$ | | |
| **MG2$_2$** | 0.25x0.12x0.06 | 3.982 kg | 2212.22 kg/$m^3$ |
| | 0.0018 $m^3$ | | |
| **MG2$_3$** | 0.25x0.12x0.06 | 4.078 kg | 2265.56 kg/$m^3$ |
| | 0.0018 $m^3$ | | |

**This chart shows the dry density of bricks with various ratios of plastic and Same molarity of NaOH 10 M.**

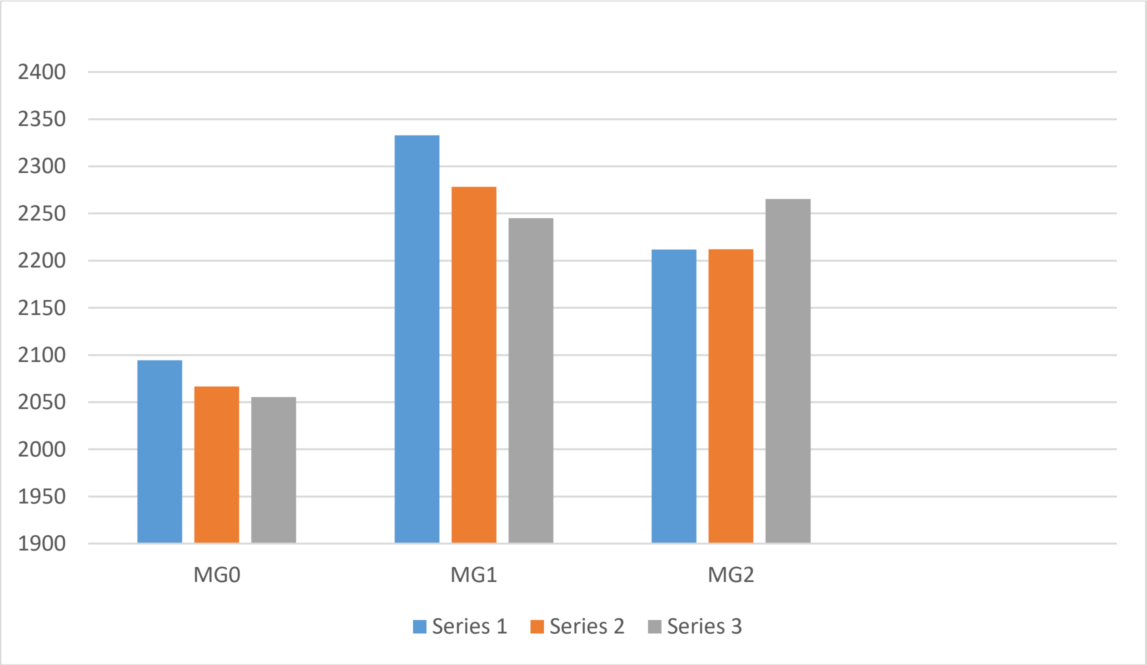


**Chart 4.1**

### 4.2.3 Fourth mixture:

- **MG3**

| Mix ID | Sample size | Dry weight | Dry density |
|---|---|---|---|
| **MG3$_1$** | 0.25x0.12x0.06<br>0.0018 m$^3$ | 4.582 kg | 2545.55 kg/m$^3$ |
| **MG3$_2$** | 0.25x0.12x0.06<br>0.0018 m$^3$ | 4.522 kg | 2512.22 kg/m$^3$ |
| **MG3$_3$** | 0.25x0.12x0.06<br>0.0018 m$^3$ | 4.542 kg | 2523.33 kg/m$^3$ |

### 4.2.4 Fifth mixture:

- **MG4**

| Mix ID | Sample size | Dry weight | Dry density |
|---|---|---|---|
| **MG4$_1$** | 0.25x0.12x0.06<br>0.0018 m$^3$ | 3.963kg | 2201.67 kg/m$^3$ |
| **MG4$_2$** | 0.25x0.12x0.06<br>0.0018 m$^3$ | 4.111kg | 2283.89 kg/m$^3$ |
| **MG4$_3$** | 0.25x0.12x0.06<br>0.0018 m$^3$ | 4.082 kg | 2267.78 kg/m$^3$ |

### 4.2.5 Sixth mixture:

- **MG5**

| Mix ID | Sample size | Dry weight | Dry density |
|---|---|---|---|
| **MG51** | 0.25x0.12x0.06<br>0.0018 $m^3$ | 4.037 kg | 2242.78 kg/$m^3$ |
| **MG52** | 0.25x0.12x0.06<br>0.0018 $m^3$ | 4.121 kg | 2289.44 kg/$m^3$ |
| **MG53** | 0.25x0.12x0.06<br>0.0018 $m^3$ | 4.193 kg | 2329.44 kg/$m^3$ |

**This chart shows the dry density of bricks with various ratios of plastic and Same molarity of NaOH 12 M.**

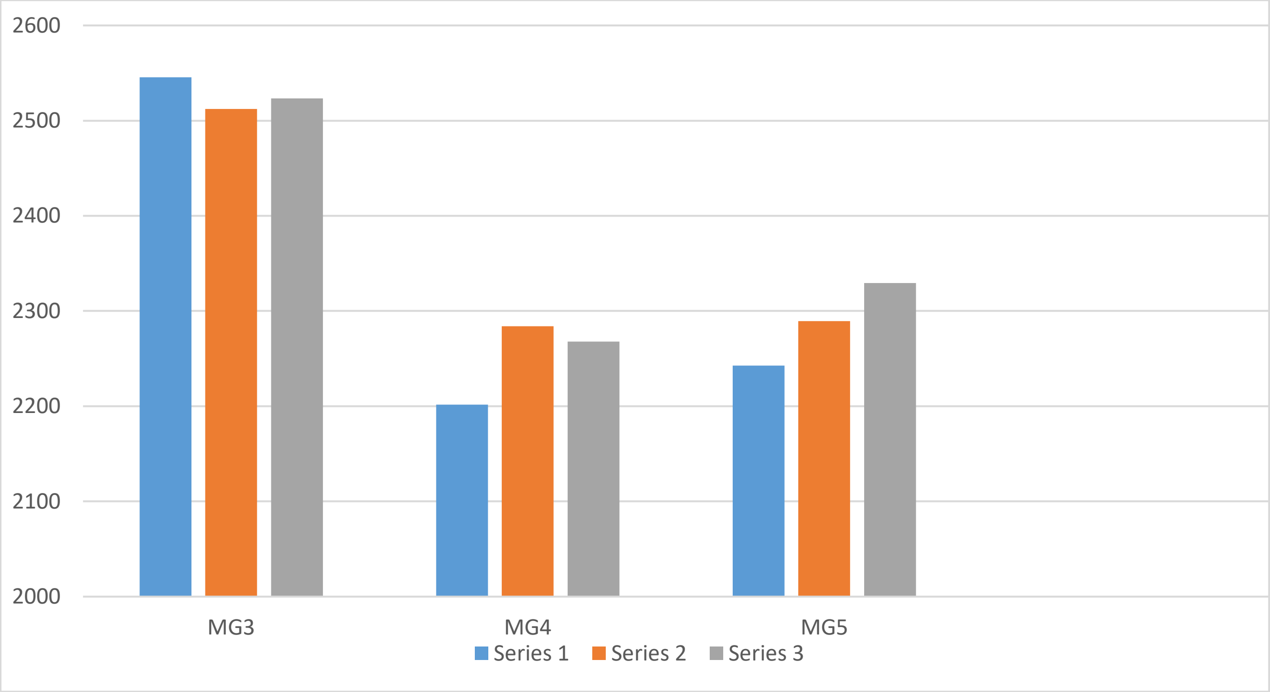


**Chart 4.2**

## *4.3 wet density:(plastic)*

### 4.3.1 First mixture:

- **MG0**

| Mix ID | Sample size | Wet weight | Wet density |
|---|---|---|---|
| **MG01** | 0.25x0.12x0.06 | 3.960 kg | 2200 kg/$m^3$ |
| | 0.0018 $m^3$ | | |
| **MG02** | 0.25x0.12x0.06 | 3.954 kg | 2196.67 kg/$m^3$ |
| | 0.0018 $m^3$ | | |
| **MG03** | 0.25x0.12x0.06 | 3.949 kg | 2193.89 kg/$m^3$ |
| | 0.0018 $m^3$ | | |

### 4.3.2second mixture:

- **MG1**

| Mix ID | Sample size | Wet weight | Wet density |
|---|---|---|---|
| **MG11** | 0.25x0.12x0.06 | 4.266 kg | 2370 kg/$m^3$ |
| | 0.0018 $m^3$ | | |
| **MG12** | 0.25x0.12x0.06 | 4.162 kg | 2312.2 kg/$m^3$ |
| | 0.0018 $m^3$ | | |
| **MG13** | 0.25x0.12x0.06 | 4.109 kg | 2282.78 kg/$m^3$ |
| | 0.0018 $m^3$ | | |

### 4.3.3 third mixture:

- **MG2**

| Mix ID | Sample size | Wet weight | Wet density |
|---|---|---|---|
| **MG21** | 0.25x0.12x0.06 | 4.000 kg | 2222.22 kg/$m^3$ |
| | 0.0018 $m^3$ | | |
| **MG22** | 0.25x0.12x0.06 | 4.005 kg | 2225 kg/$m^3$ |
| | 0.0018 $m^3$ | | |
| **MG23** | 0.25x0.12x0.06 | 4.102 kg | 2278.89 kg/$m^3$ |
| | 0.0018 $m^3$ | | |

**This chart shows the wet density of bricks with various ratios of plastic and Same molarity of NaOH 12 M.**

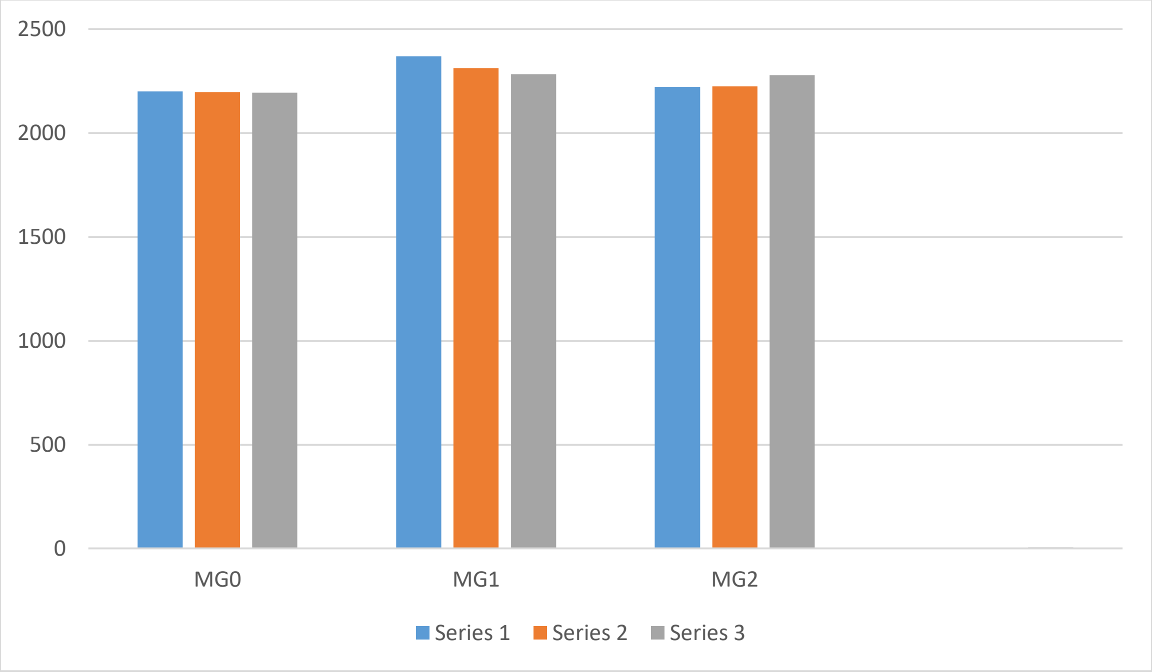


**Chart 4.3**

### 4.3.3 Fourth mixture:

- **MG3**

| Mix ID | Sample size | Wet weight | Wet density |
|---|---|---|---|
| **MG31** | 0.25x0.12x0.06 | 4.619kg | 2566.11 kg/m$^3$ |
| | 0.0018 m$^3$ | | |
| **MG32** | 0.25x0.12x0.06 | 4.560kg | 2533.33 kg/m$^3$ |
| | 0.0018 m$^3$ | | |
| **MG33** | 0.25x0.12x0.06 | 4.578kg | 2543.3 kg/m$^3$ |
| | 0.0018 m$^3$ | | |

### 4.3.4 Fifth mixture:

- **MG4**

| Mix ID | Sample size | Wet weight | Wet density |
|---|---|---|---|
| **MG41** | 0.25x0.12x0.06 | 3.987kg | 2215 kg/m$^3$ |
| | 0.0018 m$^3$ | | |
| **MG42** | 0.25x0.12x0.06 | 4.137kg | 2298.3 kg/m$^3$ |
| | 0.0018 m$^3$ | | |
| **MG43** | 0.25x0.12x0.06 | 4.106kg | 2281.1 kg/m$^3$ |
| | 0.0018 m$^3$ | | |

### 4.3.5 Sixth mixture:

- **MG5**

| Mix ID | Sample size | Wet weight | Wet density |
|---|---|---|---|
| **MG41** | 0.25x0.12x0.06<br>0.0018 $m^3$ | 4.072kg | 22262.22 kg/$m^3$ |
| **MG42** | 0.25x0.12x0.06<br>0.0018 $m^3$ | 4.158kg | 2310 kg/$m^3$ |
| **MG43** | 0.25x0.12x0.06<br>0.0018 $m^3$ | 4.228kg | 2348.89 kg/$m^3$ |

**This chart shows the wet density of bricks with various ratios of plastic and Same molarity of NaOH 12 M.**

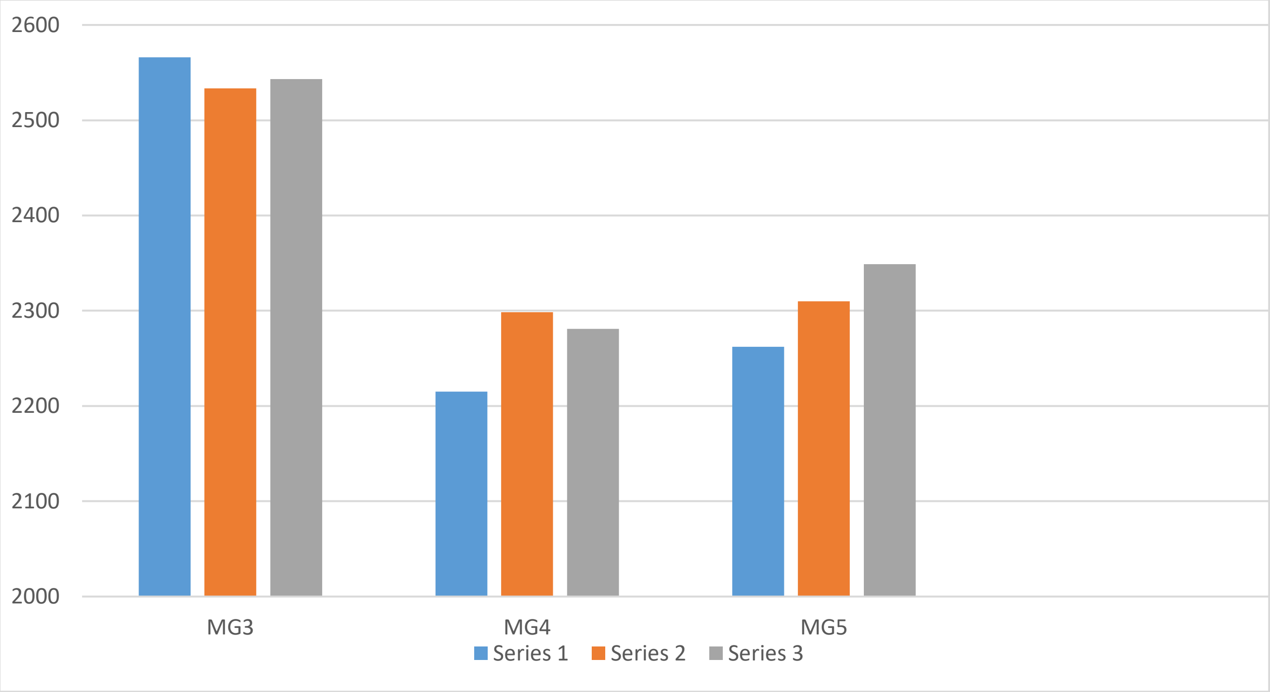


**Chart 4.4**

## *4.4 Dry density (rubber)*

### 4.4.1 First mixture:

- **MGR1**

| Mix ID | Sample size | Dry weight | Dry density |
|---|---|---|---|
| **MGR11** | 0.25x0.12x0.06<br>0.0018 $m^3$ | 3.910 kg | 2172.2 |
| **MGR12** | 0.25x0.12x0.06<br>0.0018 $m^3$ | 4.018 kg | 2232.2 |
| **MGR13** | 0.25x0.12x0.06<br>0.0018 $m^3$ | 4.060kg | 2255.56 |

### 4.4.2second mixture:

- **MGR2**

| Mix ID | Sample size | Dry weight | Dry density |
|---|---|---|---|
| **MGR21** | 0.25x0.12x0.06<br>0.0018 $m^3$ | 3.715kg | 2063.89 $kg/m^3$ |
| **MGR22** | 0.25x0.12x0.06<br>0.0018 $m^3$ | 3.730kg | 2072.2$kg/m^3$ |
| **MGR23** | 0.25x0.12x0.06<br>0.0018 $m^3$ | 3.801kg | 2111.67$kg/m^3$ |

### 4.4.3 third mixture:

- **MGR3**

| Mix ID | Sample size | Dry weight | Dry density |
|---|---|---|---|
| **MGR31** | 0.25x0.12x0.06<br>0.0018 $m^3$ | 3.870 kg | 2150 $kg/m^3$ |
| **MGR32** | 0.25x0.12x0.06<br>0.0018 $m^3$ | 3.890 kg | 2161.1 $kg/m^3$ |
| **MGR33** | 0.25x0.12x0.06<br>0.0018 $m^3$ | 3.867 kg | 2148.3 $kg/m^3$ |

**This chart shows the dry density of bricks with various ratios of rubber and molarity of NaOH .**

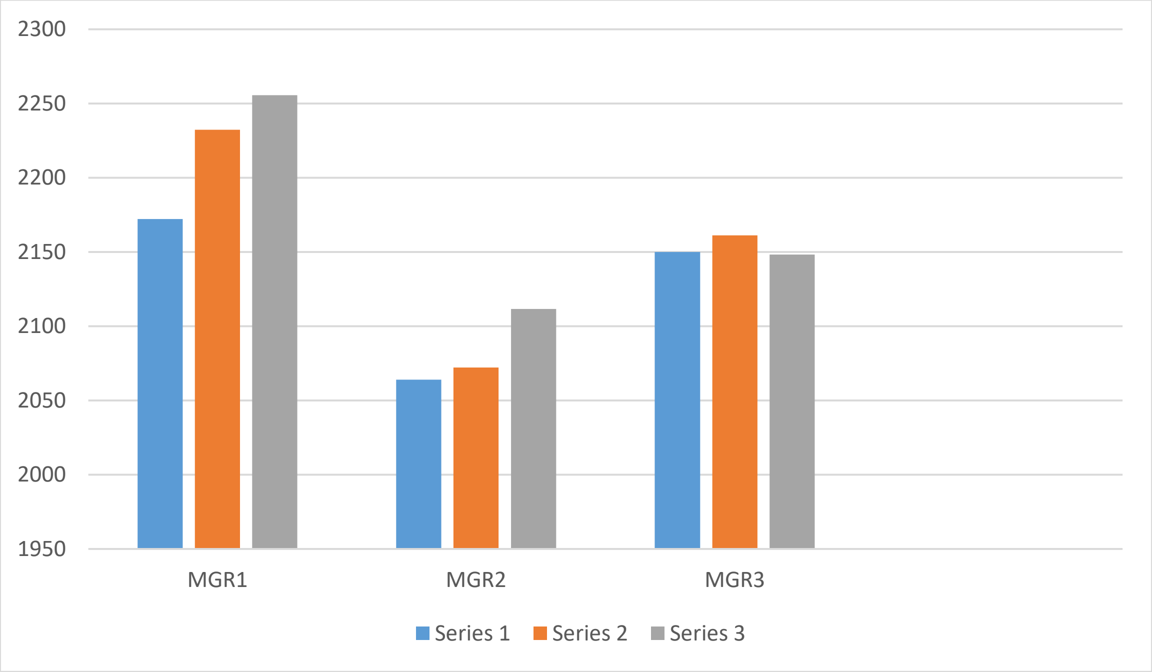


**Chart 4.5**

## *4.5 wet density:(Rubber)*

### 4.5.1 First mixture:

- **MGR1**

| Mix ID | Sample size | Wet weight | Wet density |
|---|---|---|---|
| **MGR1$_1$** | 0.25x0.12x0.06<br>0.0018 m$^3$ | 3.930 Kg | 2183.3 kg/m$^3$ |
| **MGR1$_2$** | 0.25x0.12x0.06<br>0.0018 m$^3$ | 4.042 kg | 2245.56 kg/m$^3$ |
| **MGR1$_3$** | 0.25x0.12x0.06<br>0.0018 m$^3$ | 4.082kg | 2267.78 kg/m$^3$ |

### 4.5.2second mixture:

- **MGR2**

| Mix ID | Sample size | Wet weight | Wet density |
|---|---|---|---|
| **MGR2$_1$** | 0.25x0.12x0.06<br>0.0018 m$^3$ | 3.735 kg | 2075 kg/m$^3$ |
| **MGR2$_2$** | 0.25x0.12x0.06<br>0.0018 m$^3$ | 3.750 kg | 2083.3 kg/m$^3$ |
| **MGR2$_3$** | 0.25x0.12x0.06<br>0.0018 m$^3$ | 3.822 kg | 2123.3 kg/m$^3$ |

### 4.5.3 third mixture:

- **MGR3**

| Mix ID | Sample size | Wet weight | Wet density |
|---|---|---|---|
| **MGR31** | 0.25x0.12x0.06<br>0.0018 $m^3$ | 3.880 kg | 2155.56 $kg/m^3$ |
| **MGR32** | 0.25x0.12x0.06<br>0.0018 $m^3$ | 3.900 kg | 2166.67 $kg/m^3$ |
| **MGR33** | 0.25x0.12x0.06<br>0.0018 $m^3$ | 3.878 kg | 2154.44 $kg/m^3$ |

**This chart shows the wet density of bricks with various ratios of rubber and molarity of NaOH.**

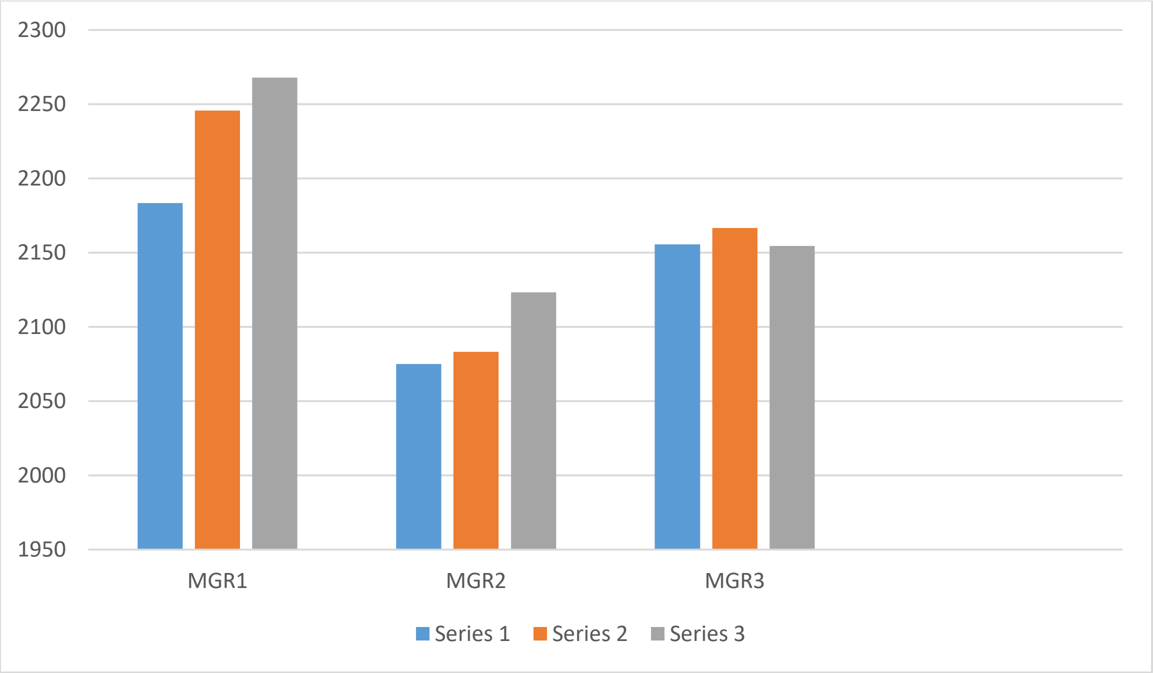


**Chart 4.6**

## *4.6 Compressive strength:*

### 4.6.1 first mixture

- **MG0**

| **Brick** | **weight (kg)** | **Load (kN)** | **Compressive Strength MPa** |
|---|---|---|---|
| **1** | 3.77 | 616 | 21 |
| **2** | 3.72 | 600 | 20 |
| **3** | 3.70 | 606 | 20.2 |

### 4.6.2 second mixture :

- **MG1**

| **Brick** | **weight (kg)** | **Load (kN)** | **Compressive Strength MPa** |
|---|---|---|---|
| **1** | 4.199 | 750 | 25 |
| **2** | 4.101 | 740 | 24.6 |
| **3** | 4.042 | 734 | 24.5 |

### 4.6.3 Third mixture :

- **MG2**

| **Brick** | **weight (kg)** | **Load (kN)** | **Compressive Strength MPa** |
|---|---|---|---|
| **1** | 3.981 | 420 | 14 |
| **2** | 3.982 | 408 | 13.6 |
| **3** | 4.078 | 414 | 13.8 |

**This chart shows the compressive strength of bricks with various ratios of plastic and Same molarity of NaOH 10M.**

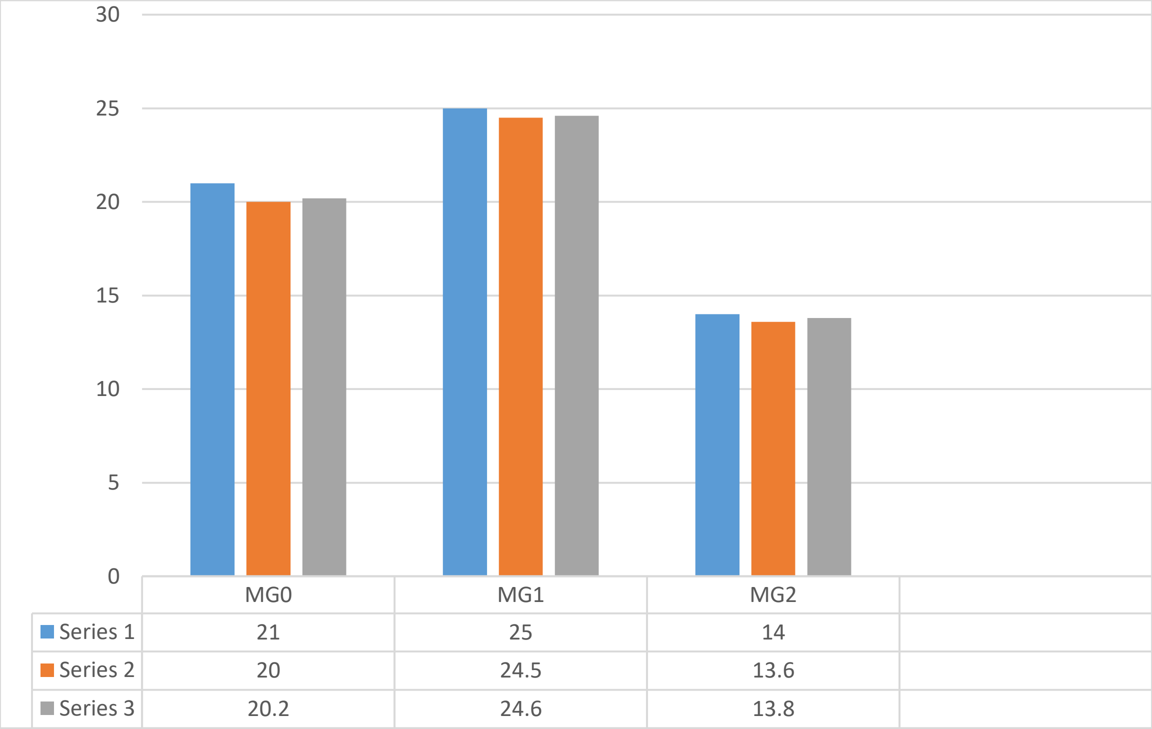


**Chart 4.7**

### 4.6.4 forth mixture:

- **MG3**

| Brick | weight (kg) | Load (kN) | Compressive Strength MPa |
|---|---|---|---|
| **1** | 4.582 | 468 | 15.6 |
| **2** | 4.522 | 462 | 15.4 |
| **3** | 4.542 | 450 | 15 |

### 4.6.5 fifth mixture :

- **MG4**

| Brick | weight (kg) | Load (kN) | Compressive Strength MPa |
|---|---|---|---|
| **1** | 3.963 | 449 | 14.9 |
| **2** | 4.111 | 468 | 15.6 |
| **3** | 4.082 | 461 | 15.3 |

### 4.6.6 sixth mixture

- **MG5**

| **Brick** | **weight (kg)** | **Load (kN)** | **Compressive Strength MPa** |
|---|---|---|---|
| **1** | 4.037 | 498.3 | 16.61 |
| **2** | 4.121 | 489 | 16.3 |
| **3** | 4.193 | 471 | 15.7 |

**This chart shows the compressive strength of bricks with various ratios of plastic and Same molarity of NaOH 12M.**

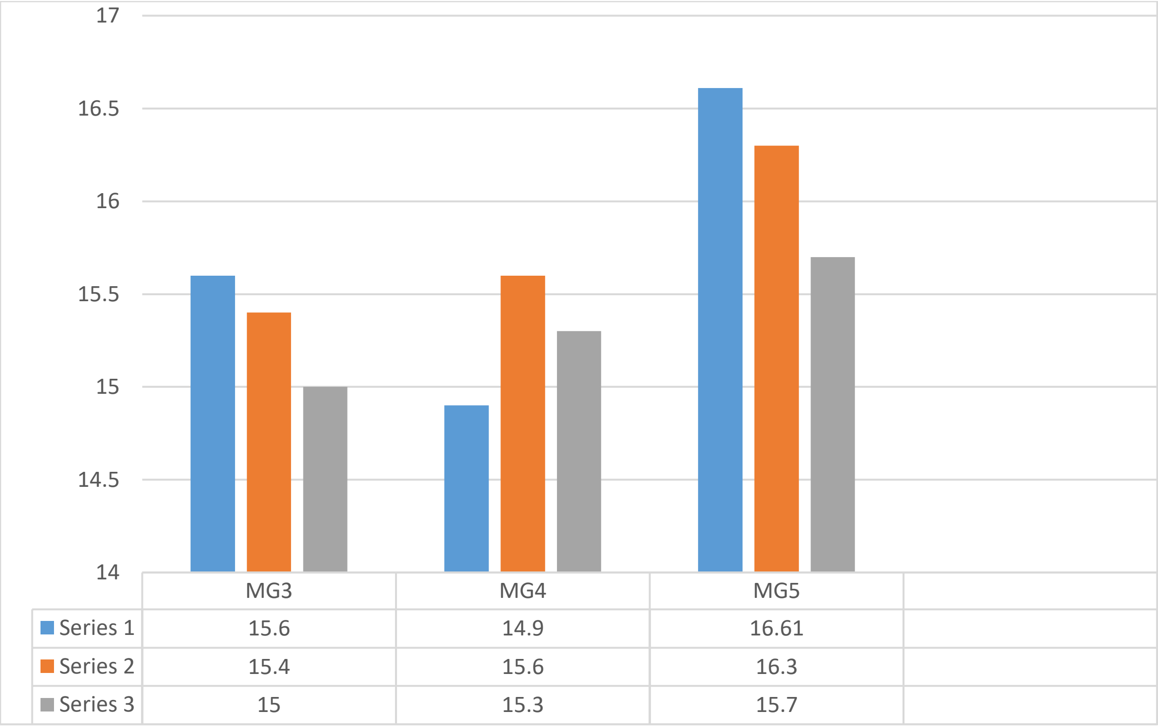


**Chart 4.8**

## *4.7 Compressive strength(Rubber):*

### 4.7.1 first mixture

- **MGR1**

| **Brick** | **weight (kg)** | **Load (kN)** | **Compressive Strength MPa** |
|---|---|---|---|
| **1** | 4.018 | 360 | 12 |
| **2** | 4.060 | 345 | 11.5 |
| **3** | 4.018 | 339 | 11.3 |

### 4.7.2 second mixture

- **MGR2**

| **Brick** | **weight (kg)** | **Load (kN)** | **Compressive Strength MPa** |
|---|---|---|---|
| **1** | 4.042 | 150 | 5 |
| **2** | 4 | 146 | 4.8 |
| **3** | 4.011 | 139 | 4.6 |

### 4.7.3 third mixture

- **MGR3**

| Brick | weight(kg) | Load (kN) | Compressive Strength MPa |
|---|---|---|---|
| **1** | 4.00 | 96 | 3.2 |
| **2** | 4.10 | 90 | 3 |
| **3** | 4.15 | 91 | 3.01 |

**This chart shows the compressive strength of bricks with various ratios of Rubber and NaOH molarity**

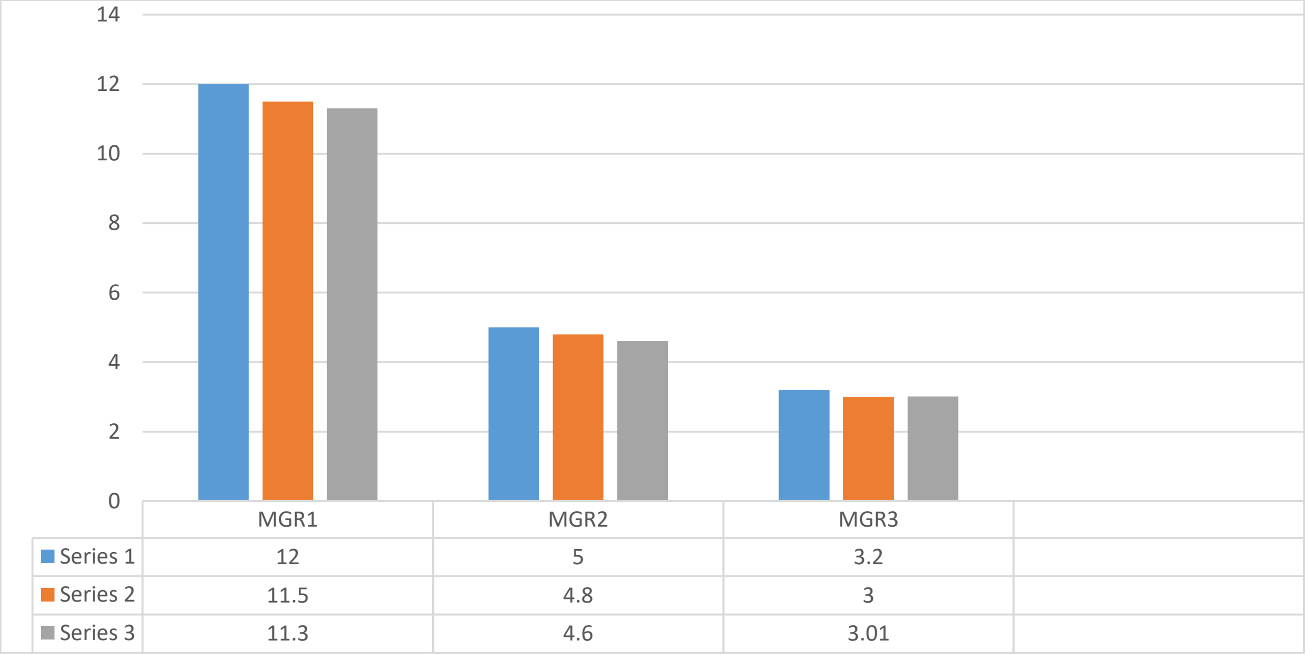


**Chart 4.9**

## *4.8 Water absorption:*

### 4.8.1 first mixture:

- **MG0**

| Brick | Dry weight | Wet weight | Water absorption |
|---|---|---|---|
| **1** | 3.77 kg | 3.89 kg | 3.12% |
| **2** | 3.72 kg | 3.87 kg | 4% |
| **3** | 3.70 kg | 3.83kg | 3.5% |

### 4.8.2 second mixture:

- **MG1**

| Brick | Dry weight | Wet weight | Water absorption |
|---|---|---|---|
| **1** | 4.199 kg | 4.266 kg | 1.6% |
| **2** | 4.041 kg | 4.109 kg | 1.5% |
| **3** | 4.101 kg | 4.162 kg | 1.7% |

### 4.8.3 third mixture

- **MG2**

| Brick | Dry weight | Wet weight | Water absorption |
|---|---|---|---|
| **1** | 3.981 kg | 4.000 kg | 0.5% |
| **2** | 4.078 kg | 4.102 kg | 0.6% |
| **3** | 3.982 kg | 4.005 kg | 0.8% |

**This chart shows the Water absorption of bricks with various ratios of plastic and Same molarity of NaOH 10 M**

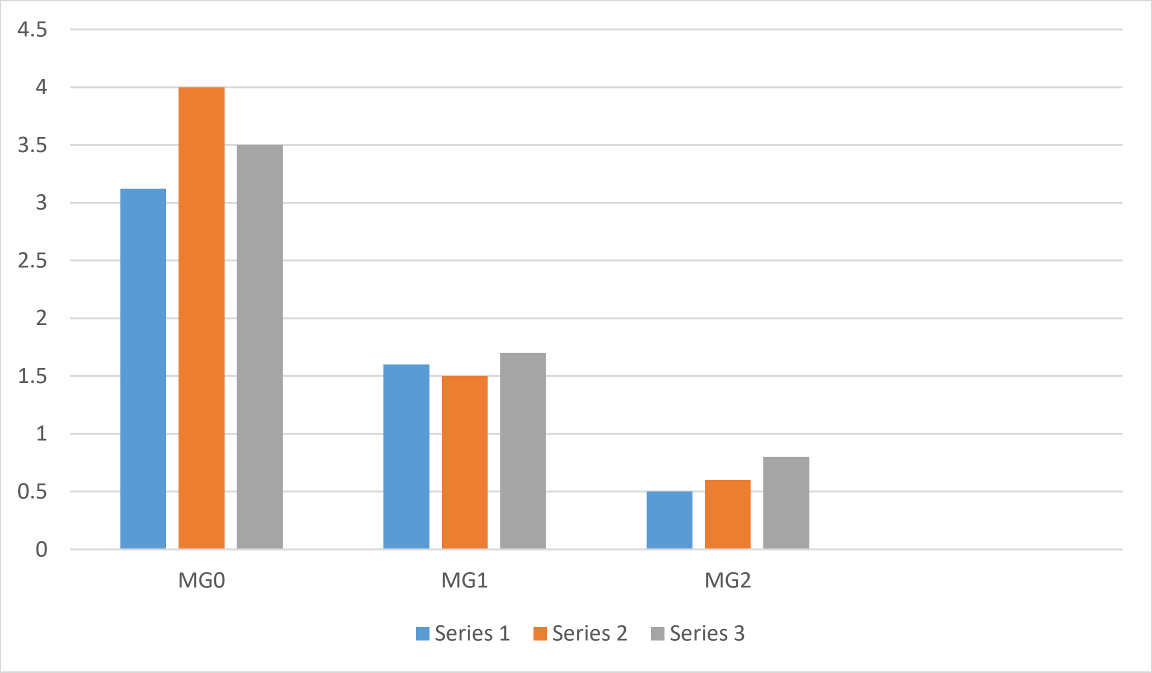


**Chart 4.10**

### 4.8.4 third mixture:

- **MG3**

| Brick | Dry weight | Wet weight | Water absorption |
|---|---|---|---|
| **1** | 4.582 kg | 4.619kg | 0.82% |
| **2** | 4.522 kg | 4.560kg | 0.85% |
| **3** | 4.542 kg | 4.578kg | 0.8% |

### 4.8.5 forth mixture

- **MG4**

| Brick | Dry weight | Wet weight | Water absorption |
|---|---|---|---|
| **1** | 3.963kg | 3.987kg | 0.62% |
| **2** | 4.111kg | 4.137kg | 0.65% |
| **3** | 4.082 kg | 4.106kg | 0.60% |

### 4.8.6 fifth mixture :

- **MG5**

| **Brick** | **Dry weight** | **Wet weight** | **Water absorption** |
|---|---|---|---|
| **1** | 4.037 kg | 4.072kg | 0.87% |
| **2** | 4.121 kg | 4.158kg | 0.9% |
| **3** | 4.193 kg | 4.228kg | 0.85% |

**This chart shows the Water absorption of bricks with various ratios of Rubber and Same molarity of NaOH 12 M**

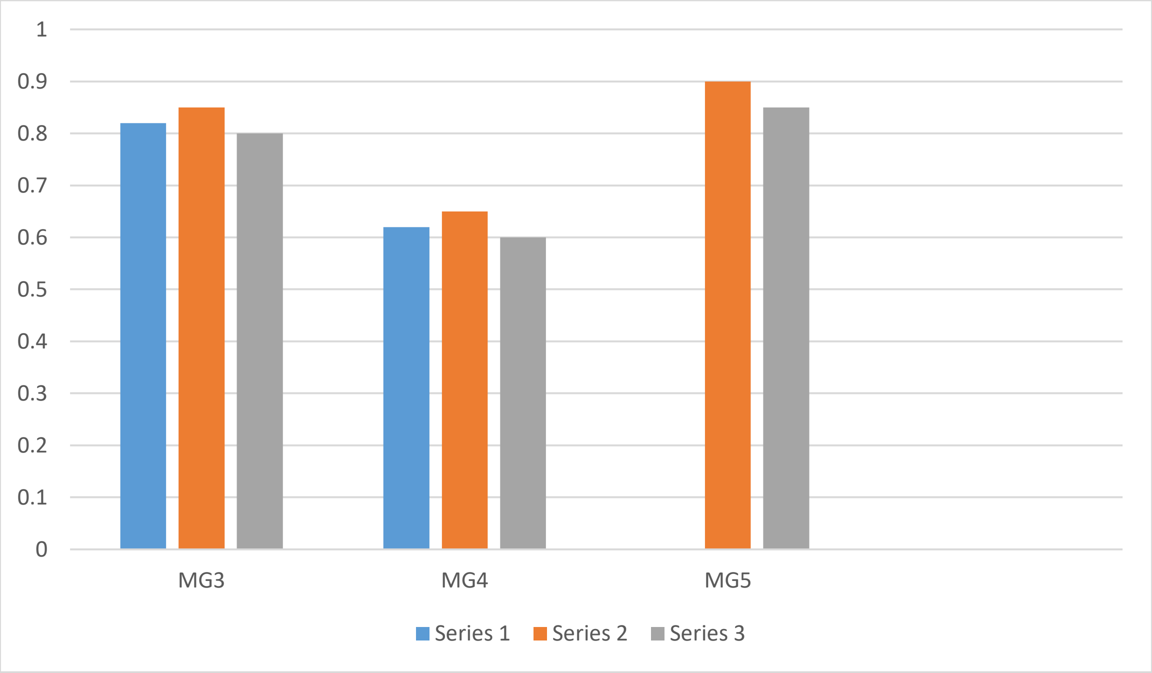


**Chart 4.11**

## *4.9 Water absorption: (Rubber)*

### 4.9.1 First mixture

- **MGR1**

| Brick | Dry weight | Wet weight | Water absorption |
|---|---|---|---|
| **1** | 3.910 kg | 3.930 Kg | 0.5% |
| **2** | 4.018 kg | 4.042 kg | 0.6% |
| **3** | 4.060kg | 4.082kg | 0.55% |

### 4.9.2 second mixture

- **MGR2**

| Brick | Dry weight | Wet weight | Water absorption |
|---|---|---|---|
| **1** | 3.715 | 3.735 kg | 0.53% |
| **2** | 3.730 | 3.750 kg | 0.55% |
| **3** | 3.801 | 3.822 kg | 0.57% |

### 4.9.3 third mixture :

- **MGR3**

| **Brick** | **Dry weight** | **Wet weight** | **Water absorption** |
|---|---|---|---|
| **1** | 3.870 kg | 3.880 kg | 0.25% |
| **2** | 3.890 kg | 3.900 kg | 0.27% |
| **3** | 3.867 kg | 3.878 kg | 0.3% |

**This chart shows the Water absorption of bricks with various ratios of Rubber and molarity of NaOH .**

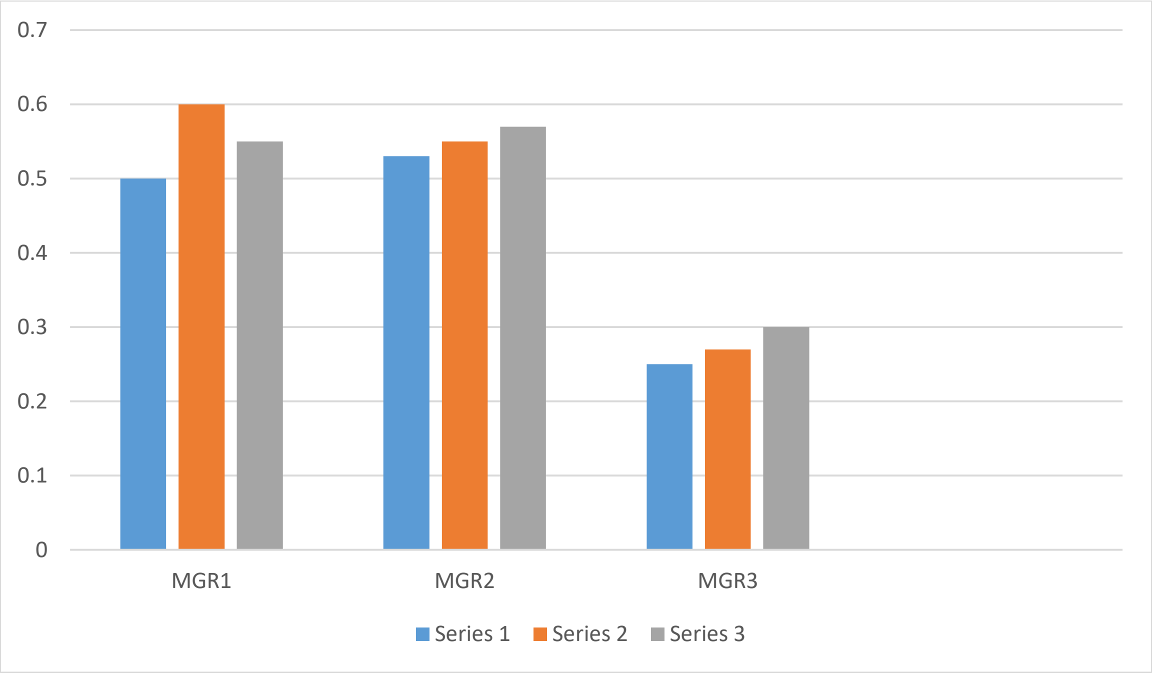


**Chart 4.12**

## *4.10 The relation between various ratios of plastic in compression strength*:

- **Various ratios of plastic with 10 NaOH molarity**

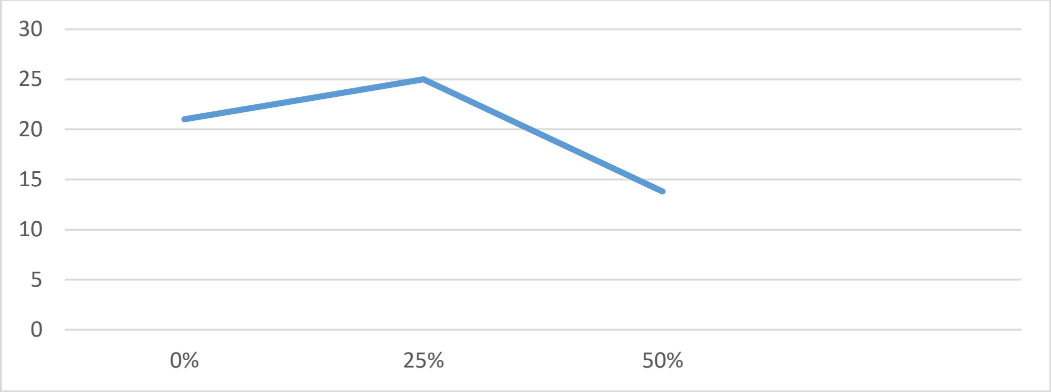


**Chart 4.12**

- **Various ratios of plastic with 12 NaOH molarity**

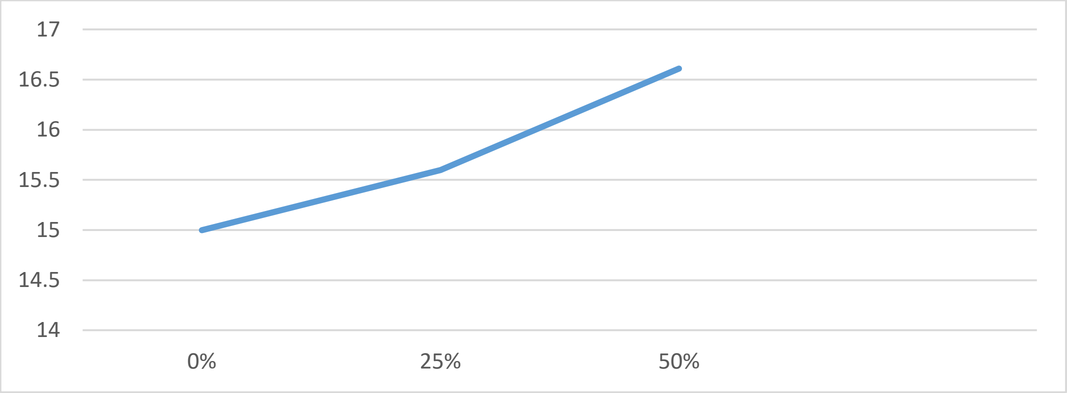


**Chart 4.13**

- **Various ratios of rubber with Various NaOH molarity**

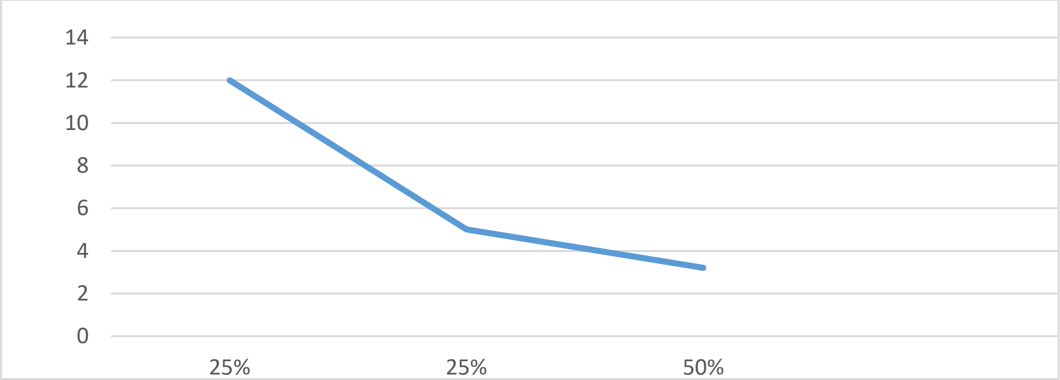


**Chart 4.14**

## *4.8 bricks after compressive strength test*:

**Figure 4.1**

**Figure 4.2**

## *5.1 Conclusion:*

The project dealt with the inclusion of plastic and rubber as waste material by replacement percentage of sand (fine aggregate), which is 0% 25% 50%, of fine aggregate (by Absolute volume) and a different molar of NaOH (10 M and 12M ) Each of the following was tested:

**-Compressive strength.**
**-Density ( Wet & Dry).**
**-Water absorption.**

Based on above results conclusions are drawn and discussions the following:

*The addition of plastic and rubber had a negative effect on the workability of Geopolymer concert.

*The mixtures were affected by the molarity of the alkaline activator solution, which increased the compressive strength of Geopolymer concrete under the influence of air curing.

*The compressive strength decreased by increasing the content of plastic and rubber up to 15%, and the density of concrete decreased by incorporating the rubber until the percentage decreased to 22%.

*The ability of Geopolymer concrete to absorb water decreased by inserting plastic and Rubber .

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## *Engineering standards*

* All the experimental work starting from design stage, followed by production stage ending with testing stage for the specimens examined in this project is conducted according to both the Egyptian code for design and construction of reinforced concrete structures, ECP 203-2018. Moreover, all egyptian standards in the field of construction products are nearly harmonized with the international, European, or foreign standards.