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Synthesis of Lightweight Geopolymer Concrete Containing Rubber Aggregates

A Thesis

Submitted to the Council of the College of Materials Engineering/University of Babylon in Partial Fulfillment of the Requirements for the Master Degree in Ceramic Engineering

By

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بسم الله الرحمن الرحيم

"ويسالونك عن الروح قل الروح

من امر ربي وما اوتيتم من العلم

الا قليلا"

صدق الله العلي العظيم

سورة الاسراء / الآية 85

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We certify that this thesis entitled **(Synthesis of Lightweight Geopolymer Concrete Containing Rubber Aggregates)**, which was prepared by "**Maytham Shnain Abedul-Hussain**", had been carried out under our supervision in the Department of Ceramics Engineering and Building Materials / College of Materials Engineering / University of Babylon in partial fulfillment of the requirements for the degree of Master in Ceramic Engineering.

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Dedication

To my family, friends, and anyone who inspired me.

Maytham 2023

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First of all, profusely all thanks be for **ALLAH** Lord of all creations who enabled me to achieve this work.

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Abstract

Geopolymer is a promising alterative of the ordinary Portland cement (OPC). The aim of the current study is to synthesize lightweight geopolymer concrete by using waste rubber materials as aggregate. Cheap and industrially available sodium silicate solution and sodium hydroxide were used to prepare the alkali activator solution, kaolin was used as a source of the solid part of the geopolymer paste. Waste rubber was used as partial replacement (5, 10, 15%) by volume of aggregate to produce of lightweight geopolymer concrete. To enhance the bond strength between crumb rubber and geopolymer paste, the crumb rubber was treated with Maliec Anhydride (MAn).

The effect of the heat treatment of the alkali solution, SiO_2/Al_2O_3 ratio, and amount of water were investigated, also, the impact of waste rubber on the mechanical properties (compressive strength, flexural strength, pull-off strength and damping ratio) and physical properties (density, water absorption and porosity) of lightweight geopolymer concrete were investigated.

This study showed that the heat treatment is important to achieve high compressive strength; a strength of 117.1 MPa was obtained using a ratio of SiO_2/Al_2O_3 of 3.6 and 8 ml of water for geopolymer paste. A compressive strength of 60.6 MPa and flexural strength of 6.076 MPa were obtained for a geopolymer concrete with 554.4 kg and 1293.6 kg fine and course aggregate respectively. Also, the experimental results showed that the strengths and density of lightweight geopolymer concrete were decreased with the increase of waste rubber content. In contrast, the damping property was increased with increasing rubber content.

It has been found that the surface treatment is an important factor that enhances the bonding strength of lightweight geopolymer concrete. The reduction in weight was about 100 kg per cubic meter for lightweight geopolymer concrete compared with the geopolymer concrete and 300 kg as compared with OPC concrete.

Moreover, it has been found that the cost of geopolymer concrete per unit at compressive strength, is nearly half of that for OPC concrete. In addition, the calculations showed that the geopolymer concrete has a superior environmental friendliness as compared with OPC concrete.

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List of Symbols

Symbols	Meaning
$	USA Dollar
µm	micrometer
C_I	The embodied CO_2 index
C_P	The cost per MPa for one cubic meter of binding materials
E	Elastic modulus
f_c	Strength (MPa) after 28 day.
G	Shear modulus
ƛ	Wave length
^{o}A	Angstrom
P_A	Apparent porosity
W_A	Water absorption
θ	Angle between the incident beam and the surface of the surface of the spacemen
ρ	Bulk density
υ	Poisons ratio
б	Compressive strength

List of Abbreviations

Abbreviation	Meaning
3D	Three dimension
AAM	Alkali-Activated materials
AAS	Alkali Activate Solution
AC	Activation concrete
ASTM	American society of testing and manufacturing
BPO	Benzoyl peroxide
CR	Crumb rubber
CSBR	Carboxylated styrene butadiene rubber
DTA	Differential Thermal Analysis
FA	Fly ash
FT-IR	Fourier transform-infrared
GC	Geopolymer concrete
GGFS	Ground granulated furnace slag
GP	Geopolymer
ICDD	International Center of Diffraction Data
IQS	Iraqi Stander
LGC	Lightweight geopolymer concrete
M	Molarity
MAn	Maleic anhydride
MK	Metakaolin calcined at 750 ˚C
MPa	Mega Pascal
NAC	Natural aggregate concrete
OPC	Ordinary Portland cement
OPCC	Portland cement concrete
PP	Potassium permanganate

PSA	Particle Size Analysis
PSC	Portland slag cement
RAC	Rubberized aggregate concrete
RC	Rubberized concrete
RGC	Rubberized geopolymer concrete
RG	Rubberized Geopolymer
rpm	Revolutions per minute
S/L	Solids/Liquid ratio
SBR	Syntheses butadiene rubber
SCA	Silane coupling agent
SEM	Scanning electron microscope
SH	Sodium Hydroxide
SS	Sodium Silicate
UFS	Ultrafine slag
V	Velocity
XRD	X-Ray Diffraction

CHAPTER ONE

INTRODUCTIO

Chapter One

Introduction

1.1 Overview

There is a noticeable and growing interest in reducing environment pollution regardless its kinds and causes. It is not a secret that the production of concrete, using ordinary Portland cement (OPC), and the destruction of the waste tyres are among the important issues in this regard.

Globally, the cement industry is one of the main sources of emission of harmful gases. In actuality, 2.5 tons of resources, involving fuel as well as other starting resources, are expended with each ton of ordinary Portland cement produced, producing over than 1 ton of Carbon dioxide. The building industry's constant need for OPC led to its huge production, which in turn increased (CO_2) emissions. It was assumed that using byproducts from the industrial sector as a solid substitute for OPC would help to alleviate these issues. These waste-based concretes exhibit enhanced mechanical efficiency and long life characteristics [**1].**

Moreover, concrete has another two drawbacks, these are the low damping for vibration and the low capacity to isolate sound. In civil infrastructure systems, structural vibration is a frequent but undesirable occurrence because it interferes with the capacity to manage the position of structural elements, maintain structural stability overall, be durable against fatigue, and reduce noise. Vibration may be brought on by a variety of dynamic stresses, including moving traffic, sound, wind, and earthquake. This is particularly relevant for concrete buildings in a public

substructure system, such as bridges. With regard to assessing the pliability and safety of middle- to great-distance bridges, vibration has grown to be a significant problem. According to the theory of viscoelasticity, which is valid for the majority of structures before substantial deformation occurs, it is possible to lessen the destructive mechanical vibration in concrete constructions by raising the damping ability and/or the stiffness of the concrete components. As a result, the damage modulus, which is the creation of these two numbers, may be used as a gauge for concrete's capacity to dampen vibrations [**2].**

Normal concrete has a relatively lowest damping ratio, while having strong compressive strength and durability. Hence, a sound insulation cover prepared of sound-proofing or robust resources must be included in the flooring structure to reduce floor impact noise. To allow for dissipation energy through interior friction, loss of heat, noiseless sound, and other sorts of dissipated energy, these sound-proofing or robust resources should have a great damping capacity. In contrast to regular concrete, soundproofing or resilient materials have lower compressive strength, stiffness, and durability. Hence, the creation of a novel form of concrete with a great damping capacity is required **[3].**

The proper disposal of wasted tyre rubber has emerged as a significant concern for the environment worldwide. Tyres are routinely disposed of, buried, or discarded all around the world, posing a very real hazard to the environment **[4].** Nearly a billion tyres are thought to reach the end of their useful lives each year, and more than half of them are simply disposed of in landfills or alongside other debris without being treated. Tyres that are no longer needed are disposed of in a variety of methods, including landfilling, burning, using as fuel, pyrolysis, producing carbon black, etc. Additionally, the air, water, and soil

contamination caused by stored tyres poses a number of concerns to human health, the environment, and the economy [**5].**

The framework of the research work is help to get rid of the problem of waste tyres, in addition to the desire of reducing the weight of the concrete and improve its damping properties, the idea of using waste tyres, in their various forms, in the manufacturing of concrete was appeared.

Chopped rubber, crumb rubber, and powder rubber are created using the highly automated grinding machine, and the separating is carried out in accordance with those results. Tyre disposal issues on land are instantly diminished when crumb rubber is incorporated into concrete or mortar**.** In several studies, the crumb is used in place of sand, which might be a different approach to minimize the expense of natural sand and its delivery, as well as the depletion of natural resources **[6].**

Also, recycling rubber has been used in the past to create interlocking bricks utilizing crumb rubber as fine aggregates in place of natural aggregate cementitious ingredients. Interlock bricks that met the hilly requirement yielded great promise, however crumb rubber incorporation had a negative impact on the strength qualities **[7].**

It has been concluded that tyre rubber and geopolymer can be used in mortar or lightweight concrete to help recycle existing resources, reduce the consumption of raw materials, and produce construction materials with improved properties**.** Waste tyre rubber is used as an aggregate in a new variety of cement concrete called rubberized concrete. In order to enhance the performance of the original multi-component concrete, a specific amount of flexible components are being added **[8].**

1.2 Scope of the Current Study

The current study is an attempt to solve the environmental issues concerning the waste tyres and OPC as well as the heavy weight of the concrete, and the low resistance to vibration. The study suggests preparing a composite material consist of metakaolin based geopolymer as a matrix and waste tyres as a filler. This approach was used in several previous studies, however, few of these studies paid attention to the interaction between the rubber and the geopolymer, this has been reflected on the mechanical strength of the composite. The current study utilizes the surface treatment of the rubber in order to enhance the interaction and, hence, reduce the reduction in the mechanical strength caused by rubber incorporation in the structure.

1.3 The Aim and Objectives of the Current Study

The current research aims to prepare geopolymer concrete that has the following characteristics:

1. Low cost.
2. High compressive strength.
3. Adequate flexural strength as compared with OPC.
4. Low porosity and density.
5. Adequate damping properties as compared with OPC.

In order to achieve that aim, the following actions have been taken:

1- The use of commercial grade starting materials and use a simple processing in order to reduce cost of the resulting materials.
2- Utilize the heat treatment for the activating solution, as well as the appropriate mixture, in order to obtain high mechanical strength.

3- Incorporation the waste tyres materials as a filler to reduce the density of the resulting material, and obtain damping properties.
4- The negative impact of the rubber on the mechanical strength was reduced via the surface treatment of the rubber with adequate coupling agent.

1.4 Structure of Thesis

There are five chapters in this thesis. An introduction to the topic, its importance, and the aim of the current work are presented in the first chapter. The second chapter focuses on updating certain theoretical ideas related to the study's and the overview of the literature's subject matter. The experimental techniques used to create the specimens and the testing equipment are covered in chapter three. The study's results are presented in chapter four along with a discussion of them. In chapter five, the conclusions that came from the current study and additional areas for future investigation were displayed.

CHAPER TWO

THEORETICAL ASPECTS AND LITRATURE REVIEW

Chapter Two

Theoretical Aspects and Literature Review

2.1 Introduction

This chapter is divided into two sections, the theoretical aspects related to the current work are described in the first section, while a review of the previous studies is provided in the second section.

2.2 Theoretical Aspects

2.2.1 Overview

Davidovits first used the term "geopolymer" for alumino-silicate polymers synthesized in an alkali solution about 50 years ago. Davidovits originally identified geopolymer as one of the green binders in the mid-1970s. Geopolymer is created by alkalizing appropriate alumino-silicate raw materials, including metakaolin, fly ash, and volcanic ash that include silicon and aluminum. Aluminate and silicate tetrahedral are created as a result of the process, and they can be combined to create tetrahedral structures connected by sharing oxygen [**9].**

Geopolymer can be described by the formula:

$$m_y\,[-(Si{-}O_2)_w{-}Al{-}O]_y.\ xH_2O \quad \text{.....(1)}$$

where m is an alkali component, the signifier "–" indicates incidence of a bond, w is 1, 2, or 3, y is level of polymerization and x is the hydration degree.

Poly (sialate) was proposed as the chemical name for geopolymer based on silico-aluminates. Silicon-oxo-aluminate is referred to as sialate.

Polysialate, which can be amorphous or semi-crystalline, is a chain or a ring polymer having Si^{4+} ion and Al^{3+} ion in IV-fold coordination with Oxygen. The 3D silico-aluminate frameworks, ranging from amorphous to semi-crystalline, were given the name "geopolymer", shown in Figure (2.1) of the following categories:

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 (sialate-multisiloxo) (Si/Al >>3) [**10].**

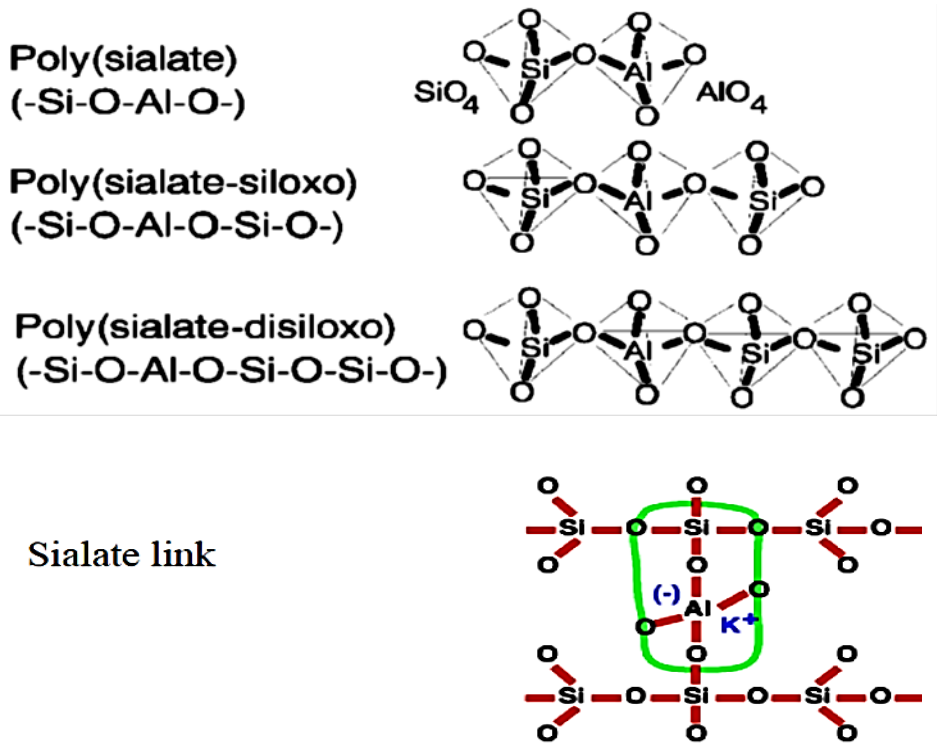


Figure (2.1) The Systems of Geopolymer Dependent on the Siloxo Number of Si − O Components [11]

Alkali activator and the supply of alumino-silicate are crucial components of the geopolymer materials. The chemical structure of the

raw material and alkali activators have been discovered to have a considerable impact on the mechanical properties of the geopolymer materials, regardless of the fact that the polymerization process of these materials remains unclear [**12].**

2.2.2 Geopolymer and Alkali-Activated Materials

Geopolymer must be distinguished from a category of binding material called alkali-activated materials (AAMs) . AAMs may be divided into three classes depending on the microstructure of the bindings there are:

1. High-calcium alkali activated materials.
2. Low-calcium alkali activated materials.
3. Hybrid alkaline cement.

The most typical primary material that used to produced high calcium AAM is ground granulated blast-furnace slag (GGBS). The gel of calcium silicate hydrate (C-A-S-H), is the major reaction result of this form of AAM, which is similar to the gel produced by hydrating OPC, but it has a low Ca/Si ratio. Though, low calcium Class F fly ash (contain CaO less than 10%) and metakaolin are the most common main ingredients used to production of low- calcium AAM. Alkaline alumino-silicate hydrate (N-A-S-H) gel in three dimensions is the primary reaction product of this class. It must be noticed that (C-A-S-H) and (N-A-S-H) must undergo further with polymerization process to produce geopolymer [**9].**

2.2.3 Materials for Making Rubberized Geopolymer Concrete

In addition to rubber, the materials which are used for making rubberized geopolymer are divided into two types; the Alumino-silicate precursor materials and the alkaline solution materials.

2.2.3.1 Alumino-Silicate Precursor Materials

Several starting materials were utilized in the preparation of geopolymer. In the early development stage, kaolinite was utilized in geopolymer synthesis widely [**13, 14, 15**]. Well along, the studies extended on other raw materials like calcined clays, waste materials that by-product from industrial (like waste glass [**16, 17**], slag [**18, 19**] and, fly ash [**20, 21, 22**], and several other artificial and natural silicoaluminates like zeolite [**23**].

2.2.3.1.1 Metakaolin (MK)

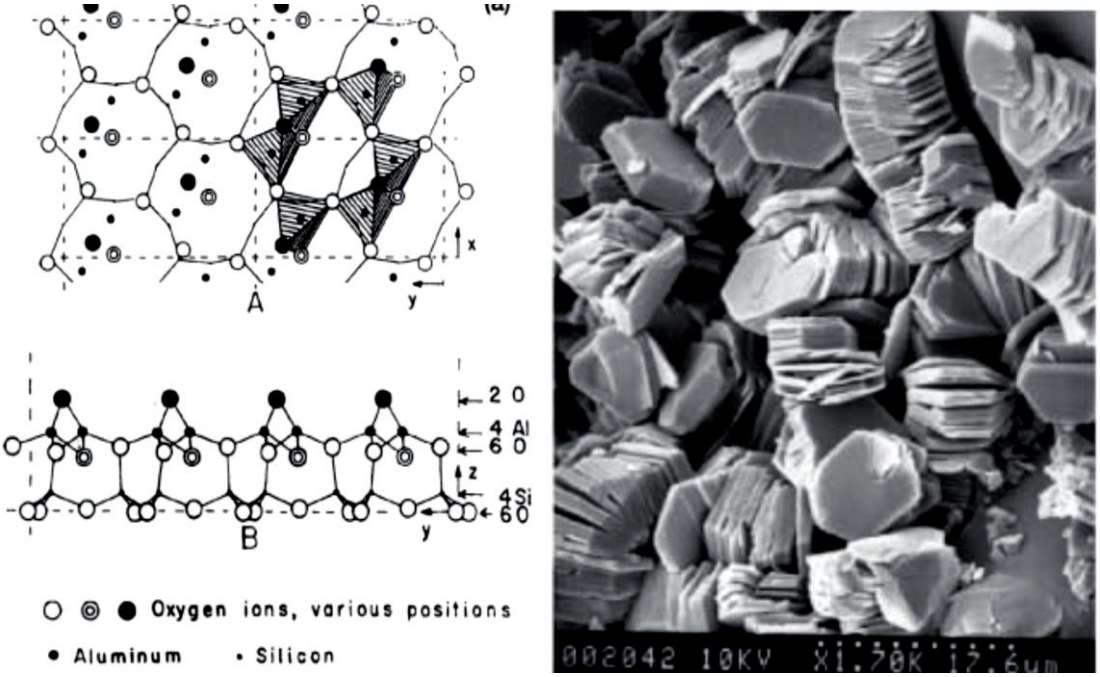
Metakaolin is the clay kaolin in a de-hydroxylated form that has alumina polyhedron sheet structures with aluminum ions that are 4, 5, and 6 coordinated. Porosity, high specific area, excellent absorbability, and strong coordinative bonding when stimulated, are just a few of the wonderful properties of metakaolin [**14**, **24, 25]**.

Dehydroxylation is the process by which kaolinite crystals break down into a somewhat amorphous structure. Following this modification, the sample's dimensions shrank less and the porosity increased. Weight loss and changes in mechanical and electrical characteristics were among the earliest signs of dehydroxylation.

According to the results of isothermal burning, dehydroxylation starts around 420°C. This reaction is described by the chemical equation:

$$Al_2O_3.2SiO_2.2H_2O \xrightarrow{600 - 800^oC} Al_2O_3.2SiO_2 + 2H_2O\ (g)$$

Figure (2.2) shows lattice and crystal of metakaolinite **[26]**.



(a) **(b)**

Figure (2.2) (a) Lattice of Metakaolinite (b) Metakaolinite Crystal [26]

2.2.3.1.2 Fly Ash (FA)

Thermal plants produce fly ash, which is a byproduct that contains hollow circular particles. Amorphous silicate structure with crystals such as hematite, mullite, and quartz can be found in fly ash particles. Due to the high temperatures in thermal plants, fly ash changes into fine crystals with significant concentrations of aluminate, silicate and iron oxide, providing an effective raw material for the geopolymerization process [**28]**.

Fly ash hardens when used as a raw material for geopolymer because it includes a lot of reactive silicone and aluminum, which causes polymerization with the alkali solution. The fly ash-based geopolymer researches focus on mixing, that modifies the molarity of the alkali solution without taking the fly ash's chemical components or appearance into account. Recent research has endeavored to determine the ratio of mixing by taking into account the fly ash's amorphous Si and Al concentrations, which can react with the alkali solution [**29].**

2.2.3.1.1 Ground Granulated Blast Furnace Slag (GGBFS)

It is possible to recycle silicon and aluminum from certain industrial waste materials for geopolymerization, for example mining wastes and ground granulated blast furnace slag (GGBFS) from the manufacturing of iron **[30].** Blast furnace slag pulverized into granulate form was one of the precursors used to prepare activating concrete. The specific gravity of GGBFS is 2890. According to a prior study, the amorphous phase predominated in the GGBFS. Contrary, FA contains crystalline phases such mullite, quartz, and hematite in addition to amorphous phases [**31**]**.**

Chemically speaking, GGBFS is composed mostly of calcium oxide, alumina, silica, magnesia, and a little proportion of ferric oxide. Due to the high silica and alumina concentration in GGBFS, it has the ability to be utilized as a raw material for geopolymer concrete. It is a pozzolanic material that is used to partially replace cement, which is also known as Portland Blast Furnace Cement (PBFC) or Portland slag cement (PSC) **[32].**

2.2.3.2 Alkalis Reactant

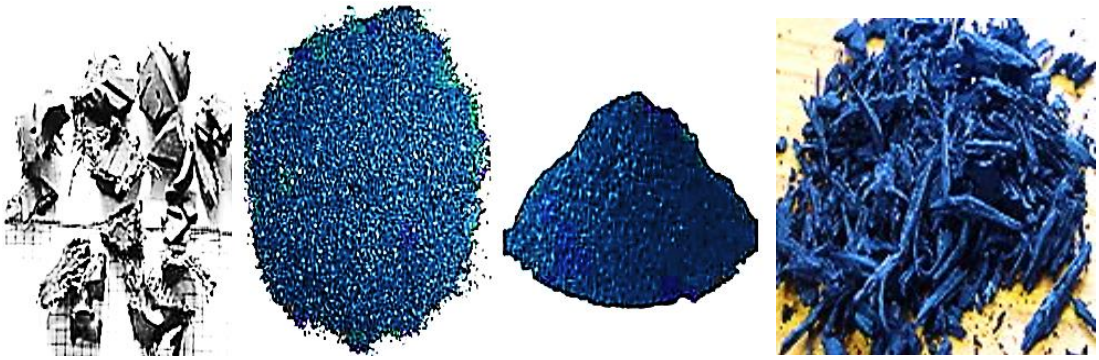
The majority of the documented geopolymers at this time are two-part combinations made from liquid alkali-activators and solid alumino-silicate minerals. The quantity, nature, and curing procedures of activators as well as the price and environmental friendliness of geopolymers are the main determinants. Solid NaOH, $Ca(OH)_2$, Na_2SiO_3, $Na_2SiO_35H_2O$, Na_2CO_3, $CaSO_4$, Na_2SO_4, $NaAlO_2$, and other compounds are often employed as activators. To attain the high strength, steam or increased temperature (40–80°C) cures are frequently required when Na_2CO_3 or Na_2SO_4 are used to activate the alumino - silicate precursors **[33].**

Alkaline solutions including sodium hydroxide, sodium silicate and potassium hydroxide are utilized in the activation process. Geopolymer paste is another name for the pozzolanic substance that has been alkali activated. Alkaline activates the silicate and aluminate found in geopolymer starting materials **[34].** A commercial sodium silicate liquid and sodium hydroxide are combined to create an alkali activating solution**.** The expected ratio of Na_2O to SiO_2 determines the concentration of Na_2SiO_3 **[35].**

Due to their low cost, materials based on sodium are typically employed to create alkaline liquids, whereas those based on potassium have a little higher cost but greater strength **[4].**

2.2.3.3 The Waste Tyre Rubber

According to particle size, the waste tyre rubber is divided into four types: chips rubber, powder rubber, crumb rubber, and fiber rubber, as shown in Figures (2.3) **[36].**



(a) (b) (c) (d)

Figure (2.3) Four Categories of Crumb Rubber (a) Chips, (b) Crumb, (c) Powder and (d) Fiber [36]

A chips rubber is pieces of rubber in large size about 20 mm and a specific gravity of about 1.1 **[37].**

The crumb rubber made from discarded automobile tyres has spherical particles that have dimensions, about 1- 4.75 mm **[38].** When comparison to natural aggregates, crumb rubber has a lower unit weight **[39].** Crumb rubber of automobile and truck scrap tyres with a specific gravity around 0.45 **[40].**

The tyre rubber is processed into rubber powdered by passing it through revolving corrugated metal cylinders. This takes the place of the fine aggregate. Rubber powdered is in 0 -1 mm size and has a specific gravity about 0.52 **[37].**

Rubber tyre fibers obtained from the mechanically grind machine of rubber tyre waste were used to partially replace the coarse aggregates. In terms of physical properties, the rubber tyre fibers used had a width of 2- 4 mm, a length of higher than 22 mm, a specific gravity about 1.09, and an aspect ratio of 8-10 **[41].**

2.2.4 Surface Treatment of Rubber

The surface of the rubber materials is sometimes subjected to a surface treatment before using them as a filler, the treatments can be divided in to two types:

2.2.4.1 Physical Treatment

Physical procedures are used to clean the surface of rubber particles to remove impurities that have adhered to the surface as well as plasticizing and softening agents like paraffin and stearic acid are applied. Rubber particles are commonly treated for 20 min period with saturated NaOH aqueous solution. After the treatment, the rubber particles are pulled out, and the fracture surface looks to be massive. The rubber-cement matrix interface shows discontinuity before the treatment, which suggests that there is inadequate adhesion between the two materials. On the other hand, after NaOH treatment, there is an adherent connection between the rubber particles and the matrix **[42, 43, 44].**

2.2.4.2 Chemical Treatment

Chemical techniques that compatible a rubber surface with a hydrophilic polar group are taken into consideration for rubber particle surface treatment **[45].** Rubber particles made of carboxylated styrene butadiene rubber (CSBR) or silane coupling agent (SCA) were used as aggregated in OPC concrete. Concrete with treated rubber always has greater compressive and flexural strengths than concrete with untreated rubber [**36].**

When potassium permanganate is used for the treatment of rubber, the C-H stretching bands essentially vanish. These alterations could point to the decomposition of polybutadiene, polyisoprene, and

other unsaturated rubber tyre components, in addition to a reduction in the concentration of minor components. Strong oxidation substance potassium permanganate (PP) causes the oxidation breakage of carbon-carbon double bonds **[45].** A cyclic manganate ester is created as an intermediary during the reaction with potassium permanganate; its breakdown with the breakage of the Mn-O bonds results in the addition of the hydroxyl groups. Additional intermediate oxidant can lead to chain scission **[46]** and the production of low molecular weight oxidizing material [**47].**

The CR surface characteristics, on the other hand, are significantly altered after treatment by an aqueous solution of 5% $KMnO_4$, which positively influences the change of compressive strength. The surface of rubber particles develops polar functional groups accordingly of oxidant reactions with potassium permanganate, and the rubber's surface energy rises. This enhances the hydrophilicity of CR by 2.2 times. The mass of water vapor adsorbed in this instance was used to determine the water absorption value, which improved from 1.5 to 3.3 weight percent. Additionally, these groups take part in interphase interactions during the geopolymerization process, creating strong hydrogen bonds between rubber and geopolymer that rise compressive strength by about 21% in comparison to spacemen mixtures from the control sequence (with not treated crumb rubber): from 12.8 MPa (geopolymer/not treated crumb rubber mixture) to 15.51 MPa at adding of 5 wt % $KMnO_4$ treated crumb rubber [**48].**

When the polymer chains are functionalized using maleic anhydride, cross-links are frequently formed due to grafting, which enhances the mechanical capabilities of polyolefins and blends made of them [**49, 50**]. The technique of altering rubber with maleic anhydride

was patented by **Farmer and Wheeler**. The rubber hydrocarbon's double bond is grafted with maleic anhydride. When an organic peroxide, such as dicumyl peroxide (DCP), is present, functionalization is often expedited. Maleic anhydride easily undergoes to reaction with polymeric double bonds and free radicals [**51, 52**].

2.2.5 Geopolymerization Reaction

Any process known as polymerization is one in which typically tiny particles, known as monomers, chemically combine to produce a great chainlike or network known as a polymer. In order to create an item with certain exceptional physical characteristics, such as versatility, high rigidity, or the ability to frame filaments that separate polymers from materials made out of littler and easier particles frequently, a significant number of monomer units are combined in a single polymer molecule. The process of polymerization involves reacting monomers to form polymer chains or 3D structures. Polymerization occurs in substance mixtures through a variety of reaction mechanisms which differ in complexity according to the practical groups that are introduced in the responsive component and their unavoidable steric effects [**27].**

Geopolymerization is what drives from the transformation of zeolitic-like source materials to alumino-silicate gels which later harden. Geopolymer are made when alumino-silicate oxides react chemically in an alkaline medium to generate polymeric Si– O– Al linkages. Poly (sialate), Poly (sialate-siloxo), Poly (sialate-disiloxo) [**53].**

The cross-linked SiO_4 and AlO_4-tetrahedral species that make up the geopolymer structure are balanced by the positive charges of the alkali ions (Na^+ and K^+) and the negative charge on Al^{3+} in IV-fold

coordination [**54]**. The geopolymerization reaction may be represented as seen in Figure (2.4)**.**

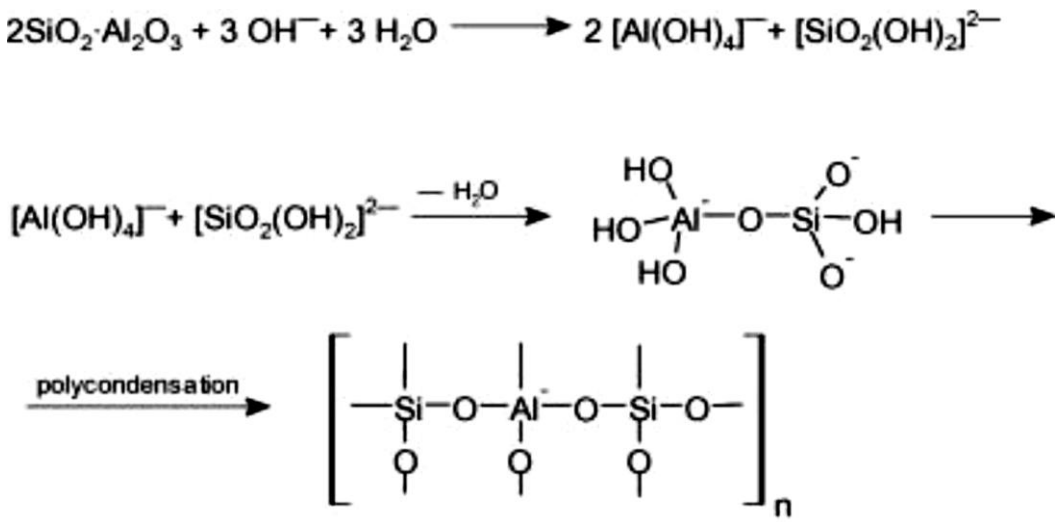


Figure (2.4) Geopolymerization Reaction [55]

The schematic diagrams of the three-dimension geopolymer structure have been drawn several times. Due to the disordered nature of the geopolymer and the challenge of accurately capturing a three-dimensional framework in two-dimension representation, this sort of effort will undoubtedly be challenging. **Davidovits'** geopolymer structure model uses poly (sialate-siloxo) monomers as the fundamental building blocks and MK as the raw material. This model made the assumption that the bulk polymer was comparable to organic polymers. However, the existence of water was not taken into consideration by this model. A novel model has been put out by **(Barbosa et al**.). The geopolymers are thought to be comparable to vitreous substances like alumino-silicate glass. Geopolymer and alumino-silicate glasses both have comparable three-dimensional structural arrangements, although the latter's structures are free from holes water. Figure (2.5) displays a model that serves as an example of the recommended structure [**56].**

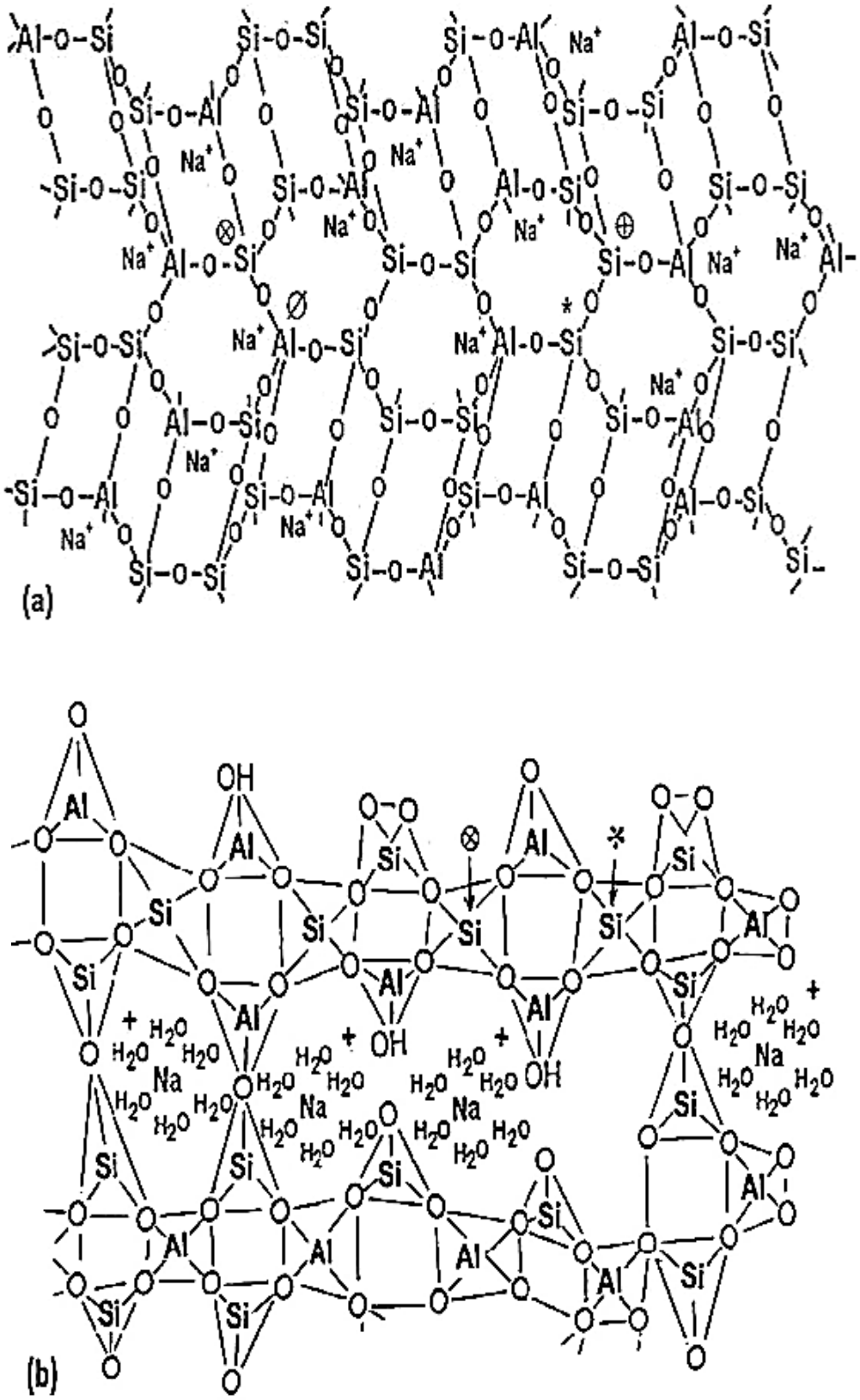


Figure (2.5) Structure of Geopolymer (a) Davidovits Model , (b) Barbosa Model [56]

2.2.6 Factors Effecting Geopolymerization

Particle size, initial liquid to solid content, the phases of reactive materials, metal silicate types, chemical composition, kinds of alumino-silicates, the concentration of alkali activator, curing systems, fillers or additive content, and the amount of H_2O all have an effect on the production of geopolymer.

2.2.6.1 Solids/Liquid (S/L) Ratio

The ratio of S/L is important because it controls how much liquid and solids are added to create a homogenous mixture, which directly impacts the finished product's ultimate strength, geopolymerization reaction, dissolution, and workability **[53, 54].**

2.2.6.2 Water Content

Water has an impact on the development, characteristics, and structure of geopolymer. It is a crucial geopolymer component, water serves as a dissolution medium, the transit of dissolved ions, oligomer hydrolysis, and oligomer polycondensation **[54]**. The role of water in the production of geopolymer is illustrated in Figure (2.6)**.**

Water also contributes to the superior flow ability of geopolymer mixtures. A sufficient amount of water facilitates mixing and acts as an ion transport mechanism **[57].** There is ongoing worry over the use of extra water in the geopolymer manufacturing process. According to one theory, adding more water reduces the system's alkalinity and transportations ions away from the reaction zone **[58].** Since this reaction is seen as a procedure for releasing water, more water may cause the geopolymerization to continue more slowly **[59].** Additionally, the amount of water in the geopolymer structure affects the open porosity and

density of the finished product. High open porosity resulted from a high water content **[60].**

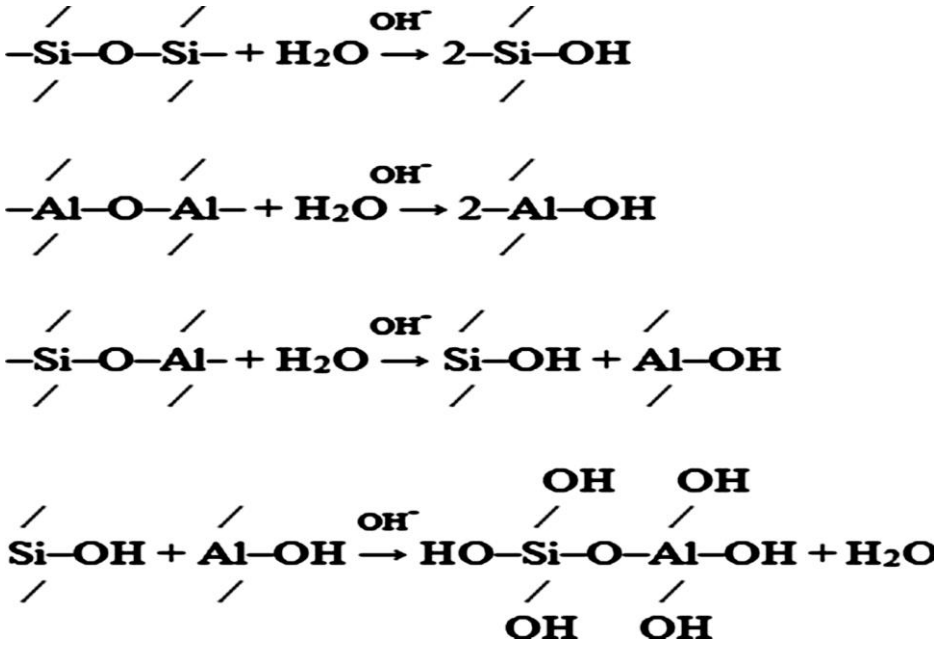


Figure (2.6) Role of Water in Geopolymerization [54]

Nevertheless, the amount of water needed depends on the qualities of the source materials used. Additionally, other mixing parameters including S/L ratio, alkali reactant proportions, and alkali concentration must be coupled with the amount of water in the geopolymer system **[61].**

2.2.6.3 The Treatment System

After conducting the mix, geopolymers are normally submitted to cure at room temperature or above. In general, a healing temperature of less than 100^{o}C is preferred. The majority of researchers agree with this information. For instance, Davidovits recommended a curing temperature range of 60°C to 95°C. Even though the strength increases as the curing temperature rises, if the temperature is high or the exposure time is more lengthy, the strength may actually decrease [**62].**

By speeding up the dissolution of alumina and silica from alumino-silicates and streamlining the geopolymer matrix hardening and polycondensation process, heat is effective for accelerating reactions**.** In other words, heating is necessary to start the geopolymerization process because it must be higher than the thermal reaction's activation **[63, 64]**.

2.2.6.4 pH of Liquid Phase

The alkaline solution's pH is the most crucial regulating element for compressive strength. If the pH of the solution is raised, the cement setting time is speed up. At higher pH levels, the geopolymer combination produced an extra fluid gel composition that is more workable and less viscous. At lower pH magnitudes, the mixture continues to behave as viscous cement. The prevalence of shorter chain oligomers and monomeric silicates that may be reacted with the soluble aluminum increased with an increase in pH magnitude. When the pH rises and existing calcium is reacted with, more increasing amounts of soluble aluminum are obtained [**65].**

2.2.6.5 The Alkali Concentration

Alkali content has a significant impact on the mechanical and physical characteristic of geopolymer. Alkali enhances the dissolution and solubility of alumino-silicates and also quickens the pace of geopolymerization [**66].** The pH scale determines the quantity of ions to help with the dissolving process and affects how much alkali is present in the solution. With an increase in alkali content, the reaction rate of heat evolution accelerates. The best alkalinity for the source materials' dissolution is suggested by a higher rate of heat evolution**.** Furthermore, the alkali concentration affects the workability of geopolymers. The

workability of the paste is related to setting rate, which is accelerated by an increase in alkali concentration **[54]**.

2.2.6.6 The Alkali Reactants Ratio

Geopolymers are made using an alkali silicate and alkali hydroxide solution mixture. The silicate works as a binder whereas hydroxide works as dissolvent. Increasing the reactant alkali percentage often results in stronger geopolymers. Increasing silicate content aids in the polymerization procedure, which results in a product with higher mechanical strength **[67].** The levels and geopolymerization reaction rate are determined by the alkali reactant proportions. Up to this point, a certain high proportion limits the paste's capacity to be worked and causes a subsequent loss of strength [**68].**

Various Na_2SiO_3/NaOH ratios between 0.24 and 2.2 were determined based on previous research. **Wang et al**. recommendation for metakaolin geopolymers with a 59 MPa ultimate compressive strength was for a Na_2SiO_3/NaOH ratio of 0.24 **[69]**. **Pelisser et al.** synthesized metakaolin geopolymers using a wider range of Na_2SiO_3/NaOH proportions (1, 1.6, and 2.2). At 1.6, the maximum strength (64 MPa at 7 days) was attained **[70]**.

The geopolymer matrix with the lowest fraction of 1 porosity yielded the lowest strength. This result for geopolymer relying on sediment of calcined clay was obtained by (**Poowancum and Horpibulsuk**). However, using sedimentary clay, the ideal fraction was determined to be 0.5 with a 27 MPa strength **[71].**

2.2.6.7 Molar Proportions of (H_2O, Na, Al, and Si)

The Na quantity in a geopolymer system is determined using liquid Na_2SiO_3 and NaOH solution. Liquid Na_2SiO_3 and alumino-silicates contribute to the amount of Si, but only alumino-silicates account for the amount of Al. Water is added to the combination during preparation along with liquid Na_2SiO_3, a solution of NaOH, and free water. In specific, changing mixing limits (for instance, Na_2SiO_3/NaOH ratio, NaOH concentration, and S/L ratio) result in different atomic or proportional amounts of oxide in the geopolymer structure **[70]**.

Nevertheless, the degree to which every component contributes to the geopolymerization reaction has been influenced by expressly on the reactivity of alumino-silicates, with time also determining how well their inclusion results in a stiff net. In conclusion, the quantities of Na, Al, and Si have a significant impact on the finale geopolymers' properties. Since different raw materials have different reactive phases and the ability of every component to bind in the system to create a stiff network, the majority of researchers find that, despite varying the initial mixture composition, the level of reaction will control the final features **[36].**

2.2.7 Applications of Lightweight Geopolymer Concrete

Rubberized concrete has excellent properties to normal concrete and can be employed in structural components. It can improve the ductility and energy absorption of structural components. The use of rubberized concrete can provide ductile behavior, which is crucial for structural components in seismic regions. Steel tubes filled with concrete to enhance the ductile behavior of the components while achieving an acceptable bearing capacity, concrete filled steel tubes components can be constructed with a rubberized concrete core. The steel tube's ability to

confine the rubberized concrete core can improve how the rubberized concrete filled steel tubes parts behave overall. Numerous studies investigated the use of rubberized concrete in mechanical constituents [**13].**

Further studies revealed that waste-derived concrete has great influence resistance and good ductility, making it suitable for use in structural components including railway lines, airport runways and bridges where the structural components are subject to significant effect and dynamic loads **[72].**

The rubberized concrete outperformed ordinary concrete in several ways, including being lighter in weight, more resistant to cracking, better under impact, anti-aging, low permeability, improved sound absorption, and outstanding thermal properties **[73, 74].** Given the excellent qualities mentioned, applying sound absorbers, foundation pads, and rubberized concrete for roadways and barriers that may experience severe dynamic impacts [**75, 76**]. Additionally, using recycled fibers rubber in building has financial benefits. With an array of good qualities, including higher mechanical characteristics, reduced creep, smaller shrinkage, and amazing resistance to chemicals like acid, greener, inorganic geopolymeric building composites are emerging as a very viable replacement for OPC-based systems today [**77, 78**].

2.3 Literature Review

This section is divided into three sub-sections, the first is regarding the studies that deal with preparation of geopolymer, the second and the third are concerning with the rubberized geopolymer concrete with and without the surface treatment of rubber respectively.

2.3.1 Geopolymer Literature Review

H.A. Abdel-Gawwad, et al., used a dry activator in one-mix geopolymer that might replace Portland cement. The dry alkali activator, involving of sodium carbonate Na_2CO_3, calcium hydroxide $Ca(OH)_2$, and pirssonite $Na_2Ca(CO_3)_2$. $2H_2O$ was created by dissolving sodium hydroxide NaOH in water and mixing it with calcium carbonate $CaCO_3$. The solution was then dried for 8 hours at 80°C. This broadens their marketability in terms of commerce. When water is added to the powdered geopolymer cement created by combining the dry alkaline activator with granulated blast-furnace slag, the geopolymerization process begins. It was investigated how the water cement ratio and NaOH / $CaCO_3$ ratio affected the physico-mechanical characteristics of slag paste. The findings shows that 4% and 5% from NaOH and $CaCO_3$, respectively, by the weight of slag, are the optimal percent of activator and $CaCO_3$ content, giving the highest physico-mechanical characteristics GBFS (70 MPa compressive strength and 9% water absorption) **[4].**

Saadet Gokce GOK, et al., produced activated concrete as an alternative to traditional concrete using geopolymeric materials. There was no cement used in this procedure. Alkaline liquids were used to activate pozzolanic materials, for example blast furnace slag and fly ash, and give them binding properties. Pozzolanic ingredients, aggregates, and alkaline activators were utilized to make geopolymer concrete. The mechanical characteristics of geopolymer concrete made with fly ash and blast furnace slag were examined. The 28-day compressive strengths were measured, and the impact of environmental factors on geopolymer concrete was investigated. It was discovered as a result that the amount of blast furnace slag increased (15% to 25%) led to increased compressive strength values (45.74 to 67 MPa) **[28].**

Bokyeong Lee, et al., studied the effect of changing silicon/aluminum ratio on the strength improvement characteristics of geopolymer mortar and paste containing 20% – 40% wt of sand. These ratios are determined using a mixture of the amorphous silicon and aluminum amounts in an alkaline activator fly ash and fly ash. The compressive strength of geopolymer paste is significantly influenced by the Si/Al ratio, according to experimental data. The geopolymer paste as well exhibited early high polymerization reactivity. Although the X-ray diffraction data could not directly corroborate a relationship between the geopolymer paste's polymerization reactivity and the strength development, scanning electron microscopy verified the change in polymerization reactivity brought on by the development of strength. After aging for 28 days, the compressive strengths of the geopolymer mortar with 20% – 40% wt of sand were result in 23.7–26.4 MPa, confirming the viability of employing geopolymer mortar as a building material **[29].**

Z. Zayer Hassan, **et al.**, studded the impact of several alkali activators (K and Na) on the mechanical properties of metakaolin-based geopolymers. Five variables were chosen as process parameters that are more likely to have an impact on the properties of the geopolymer. They include the quantity of Si, the kind and ratio of the alkaline reagents, the mixing time, and the water content. The impact of these factors on the compressive strengths, porosity, and density after 28 days of setting were observed. According to the study's findings, the formula ($0.8Na_2O.\ 0.2K_2O.\ 3.6SiO_2.\ Al_2O_3.\ xH_2O$) can be used to create a geopolymer paste with a high compressive strength of (107.2 MPa) when processing it under the right conditions. These conditions call for maintaining a 2.26 molar ratio between the alkali silicates and alkali hydroxides. The

findings showed that using an alkaline solution including Na-ions and K-ions significantly increases the compressive strength of the geopolymer when compared to using a solution alone containing Na-ions **[79].**

2.3.2 Rubberized Geopolymer Concrete without Surface Treatment of Rubber

Ahmad Azrem Azmi, et al., investigated the impact of varying crumb rubber percentages on the compressive strength of geopolymer concrete made from fly ash. The goal of this research was to create rubberized geopolymer concrete, which is durable, lightweight, and favorable to the environment. In order to substitute fine aggregates in geopolymer concrete, crumb rubber was employed. The percentages of crumb rubber substituted in the geopolymer concrete made with fly ash were 0%, 5%, 10%, 15%, and 20%. On 28 days, following the curing procedure, the samples' strengths were evaluated. The findings demonstrated that the compressive strength of concrete containing the crumb rubber is decreased overall the percentages of crumb rubber replacement from 65 MPa for GC to (48, 30, 20.6, 15.8 MPa) for RGC with the percentages of crumb rubber replacement of (5%, 10%, 15%, and 20%) respectively [**80].**

Ampol Wongsa, et al., presented the thermal and mechanical properties of a lightweight geopolymer mortar with fine aggregate manufactured entirely of recycled tyre crumb. Fly ash with a high calcium content that was activated with sodium silicate and sodium hydroxide solutions served as the geopolymer binder. Crumb rubber was used as a "complete" substitute for river sand in the geopolymer mortar to reduce its density and heat conductivity. The effects of the alkali activator to fly ash ratio, the concentration of the NaOH solution, the

Na_2SiO_3/NaOH ratio, and the curing temperature were investigated on the mechanical and thermal properties of geopolymers containing 100% crumb rubber. The results demonstrated that replacing river sand with crumb rubber significantly reduced the compressive strength of the geopolymer mortar from 36.44 to 2.69 MPa. However, the density and thermal conductivity of the geopolymer mortar containing 100% crumb rubber were typically lower 42% and 79%, respectively, than those of the control geopolymer mortar, the density decreased from (2009 to 1102 kg/m^3) and thermal conductivity from (1.284 to 0.237 W/m.K) [**57].**

Salmabanu Luhar, et al. studied the waste rubber tyre fibers as a partial substitution for fine aggregates. The experimental showed that using recycled rubber tyre fiber in substitution of sand is not only more affordable but also a more user and environmentally friendly way to create rubberized geopolymer concrete without sacrificing its sustainability. This study compared the properties of rubberized geopolymer concrete with that of OPC rubberized concrete in terms of strength like compressive strength, split tensile strength, flexural strength, modulus of elasticity, and pull off strength. The results of the comparison showed that rubberized geopolymer concrete has a compressive strength of 40 MPa, while it was 34 MPa for rubberized OPC concrete, flexural strength for RGC was 8.64 MPa, whereas it was 5.9 MPa for OPCC at 20% CR [**72**].

According to **Farhad Aslani, et al.**, rubberized geopolymer concrete was created by replacing 10% and 20% by volume of natural aggregate with crumb rubber aggregate, which contributes to further environmental contamination. This research discussed the behavior of produced GCs based on compressive strength, slump flow, density, flexural strength, and tensile strength at 28 days. Additionally, two

distinct CR sizes were introduced along with the best mix design determined by RGC mixes 2-5 and 5-10 mm. The compressive strength was reduced from 42.1 MPa of GC to 29.1 MPa for 20% rubber replacement of RGC. The results recommend that a geopolymer concrete mix typically results in higher splitting tensile strength than rubberized geopolymer concrete. The maximum splitting tensile strength (2.26 MPa at 28 days) was found for the control geopolymer concrete mix, whereas CR replacement produced a lower 28 days' tensile strength varying from 1.84–1.81 MPa, for RGC [**81].**

Aly Muhammed Aly et al. used pozzolanic materials (fly ash or silica fume) or cementitious materials (steel slag or blast furnace slag) that have been alkali activated. His research designed to ascertain the effects of various crumb rubber percentages as a partial substitute of coarse and fine aggregates by weight percentage (10, 20 and 30%) on the concrete strength (compressive, flexural and tensile strength) and influence resistance of slag-based geopolymer concrete using ground granulated blast furnace slag activated with sodium silicate and sodium hydroxide in place of cement. Since additional crumb rubber affects concrete, adding more than 20% crumb rubber to a mix results in a decrease in compressive strength from 37.4 to 28.3 MPa [**32]**.

Yuwadee Zaetang, et al. tried to sought to ascertain if tyre crumb rubber waste might be utilized as fine aggregate in fly ash-based geopolymer mortars. It was examined how substituting crumb rubber for river sand at ratios of 0, 25, 50, 75, and 100% by volume would affect the properties of the geopolymer mortar, such as workability, dry density, compressive strength, flexural strength, thermal conductivity, water absorption and porosity. The outcomes were contrasted with those of the mortars made using Portland cement. The test findings showed that a less

dense mortar matrix was produced with a greater crumb rubber percentage. The flexural strength of GPMs (4.4, 2.1, 1.7, 1.3, 1 MPa) with crumb rubber 0, 25, 50, 75, and 100% respectively. In comparison to PCMs, which had an average flexural to compressive strength ratio of 15%, GPMs had a 25% ratio. Additionally, the GPMs' superior insulating qualities over PCMs were evidenced by their decreased dry density of GPMs (1950, 1679, 1480, 1302, 1075 kg/m^3), and for PCMs of (2150, 1853, 1620, 1438, 1299 kg/m^3) [**82].**

Ahmad Azmi A., et al. intended to determine whether adding crumb rubber to geopolymer concrete made from fly ash will have any practical influence on the material's qualities. The binding component of geopolymer concrete uses fly ash rather than cement as an alternative. Compression test, density test and water absorption test were completed in the hardened condition for different percentages of replacement of the aggregate with crumb rubber, as 5, 10, 15, and 20%. After 28 days, compressive strength was tested. Loss of strength was noticed from 67 MPa for GC and (33, 25.5, 17, 10.2 MPa) when adding crumb rubber to geopolymer concrete with 5, 10, 15 and 20% replacement respectively [**83].**

Isam Mohamad, et al. conducted an experimental research establish the appropriateness of with chopped rubber as reinforcements in environmentally friendly and maintainable geopolymer concrete. Fly ash powder, fine aggregate, and superplasticizer were combined with a Na_2SiO_3/NaOH solution to create the geopolymer combination. Based on the quantity of recycled chopped tyre rubber (CTR), percentage replacement of fine aggregate was (0, 10, 20, and 30%) by volume with two maximum sizes (2 mm and 4 mm). At 28 days, the geopolymer hardened characteristics, including compressive strength, density, were

tested. Compressive strengths decreased by (18.6% and 26.7%) for (20% and 30%) CTR replacement and (21.2% and 37.1%) for (2 and 4 mm), respectively. Decreasing the ratio of 2 mm chips rubber to fine aggregate by 10, 20, and 30% results in drop in oven dry density of 4.6, 8.3, and 14.1%. The decreases climbed to 6.3, 12.9, and 17.8% as the maximum size of the chopped rubber was raised to 4 mm **[84].**

Suthari Bhavani, et al. used slag, fly ash, GGBS, and zeolite to prepared geopolymer. Sodium silicate and sodium hydroxide were used as alkali activator. Rubber chips were used in substitution of some of the natural coarse aggregate and powdered rubber was used in place of some of the natural fine aggregate. Fly ash has been replaced with 5% zeolite, natural coarse aggregate with 2.5% rubber chips, and natural fine aggregate with 5, 10, 15, and 20% by weight of rubber powder to create rubberized geopolymer concretes. The highest compressive strength was 70 MPa for rubberized geopolymer concrete prepared with untreated rubber and 71.5 MPa by using treated rubber. The minimum tensile strength was 4 MPa and maximum tensile strength was found to be 5.25 MPa. Maximum tensile strength was revealed by geopolymer concrete advanced by using 15% treated rubber [**37].**

Moghaddam C., et al. used dry curing at a temperature of 60^{o}C for geopolymer concrete that had greater than 20% of fly ash substituted with cement, 10% of the volume of fine grains worth of crumb rubber and steel fiber. The mechanical characteristics were examined in a sulfuric acid-contact environment after 28 days. The results revealed that the geopolymer concrete comprising crumb rubber and 1% fiber with 20% of fly ash substituted with cement had the highest compressive strength of 49 MPa and tensile strengths measuring of 4.7 MPa. The concrete containing 1% fiber and without cement exhibited the

maximum compressive strength, equivalent to 34 MPa, and shown the least decrease, similar to 26%, after being bare to acid for 90 days [**85].**

Salmabanu Luhar, et al. with the help of RGC made from fly ash and containing fibers from recycled rubber tyres, this research fulfilled the presentation estimation of durability studies on water permeability, acid resistance, drying shrinkage, and corrosion resistance. Comparisons between the results and their counterpart have revealed that rubberized geopolymer concrete performed better than rubberized OPC concrete in regards to all of the aforementioned metrics. The results showed that the geopolymer concrete has water penetration values of 31.2 mm at the minimum and 35.7 mm at the maximum. The minimum and maximum water penetration in OPC concrete are 38.03 mm and 42.8 mm, respectively. When compared to OPC concrete, geopolymer concrete has a lower amount of drying shrinkage. Due to its tiny pores and low drying shrink, it has low diffusiveness and a significantly lower drying shrinkage rate [**86].**

K. Arunkumar, et al. presented low calcium based geopolymer. Waste rubber was added as a fiber at different volume fractions of 0.5, 1, 1.5, and 2%. In all curing ages, the inclusion of fiber up to 1% increased the mechanical behaviors and setting qualities. At 90 days, the low calcium geopolymer mix's compressive strength, split tensile strength, flexural strength, and elastic modulus all increased by 4.36%, 6.25%, 3.64%, and 10.62%, respectively. Additionally, adding waste rubber fiber in excess of 1% causes all strength measures to decrease **[87].**

2.3.3 Rubberized Geopolymer Concrete with Surface Treatment of Rubber

When CR is added to geopolymer, the mechanical strength is reduced, which can be attributed to the rubber filler's low elastic modulus and the hydrophobic rubber particles' poor adherence to the water-based geopolymer. When a load is applied to the lightweight geopolymer concrete, a stress concentration zone develops in the area that is weaker surrounding the rubber aggregate, which causes fractures to form and the strength to diminish. A preparatory alteration of the CR surface to boost its reactivity may be the answer to this issue **[88].**

Liang He, et al. utilized the surface modification approach to add good polarity groups to the surface of rubber. The oxidation of rubber with $KMnO_4$ solution was followed by sulphonation with $NaHSO_3$ solution. The oxidation and sulphonation process significantly increased the interfacial adhesion strength between crumb rubber and cement paste by adding a lot of hydrophilic hydroxyl and sulfonate to the rubber and reducing the contact angle between the rubber surface and water. After the rubber surface was modified, the adhesion strength between the rubber and cement paste improved by 41.1% (from 0.170 to 0.239 MPa). The rubber surface treatment was also shown to be very beneficial in boosting the compressive strength and influence strength of rubber-cement concrete. Concrete that contains 4% modified rubber powder has a compressive strength (35.1 MPa) that is 48.7% greater than concrete that uses powdered rubber (23.6 MPa). It can be concluded that surface treating crumb rubber with $KMnO_4$ and $NaHSO_3$ solutions is an effective method for enhancing the mechanical characteristic of rubber-cement concrete **[89].**

Georgy Lazorenko, et al. compared the effects of different chemical and physical pre-treatments of crumb rubber with $(CH_3)_2CO$, NaOH, H_2SO_4 and $KMnO_4$ solutions, in addition to ultraviolet radiation. The best results have been observed when rubber is treated with a potassium permanganate aqueous solution; oxidative interactions with the solution result in the production of surface-active functional groups on the rubber. As a consequence, as indicated by the amount of water vapor adsorbed from 1.5% to 3.3% by weight, the hydrophilicity of CR particles rises by more than a factor of two. This creates a high adhesive force between the filler and the geopolymer matrix, which helps to modify the mechanical properties of the composites. In this case, the compressive strength was improved from 12.8 MPa for GP with untreated CR to 15.51 MPa by the addition of 5 wt.% potassium permanganates-treated CR **[90].**

2.3.4 Summary of Literature Review

Many of the studies reported in the literature, regarding the synthesis of geopolymer, utilized laboratory grade chemicals to prepare the activator solution to obtained good mechanical properties **[19, 94].** Also, the studies that utilized the industrial grade have obtained geopolymer with low mechanical properties **[28, 29],** and all of these studies didn't use any heat treatment of the alkali activator to enhance the compressive strength of geopolymer paste and concrete.

From the above literature review, it can be noticed that the compressive strength and flexural strength of lightweight geopolymer concrete are reduced when the replacement percentage of crumb rubber is increased. Very few researchers studied the treatment of the rubber surface to enhance the bonds between the crumb rubber and the geopolymer paste like **[89, 90]**. Moreover, in these studies the concrete

did not show a good bonding to the rubber, and hence, low mechanical strength.

In the current study, geopolymer paste prepared by using industrial grade to prepared alkali activator to reduce the cost of geopolymer, and utilization a heat treatment to the alkali activator to increased compressive strength of geopolymer, and utilization surface treatment of rubber to improve the bond strength to synthesis of lightweight geopolymer concrete with adequate mechanical and physical properties.

CHAPTER THREE

EXPERIMENTAL WORK

Chapter Three

Experimental Work

3.1 Introduction

This chapter describes the processes for synthesizing of geopolymer paste, geopolymer concrete, surface treatment of the rubber, and lightweight geopolymer concrete. Also, it defines the materials used, and a brief description of the characterization techniques is also given. Fig (3.1) illustrates the experimental work performed in the current work.

3.2 The Starting Materials

Kaolin, sodium hydroxide, sodium silicate, were used as starting materials to synthesis geopolymer paste. In addition, fine aggregate (sand and powder rubber), coarse aggregate (crashed aggregate and crumb rubber) were used to synthesis of lightweight geopolymer concrete. Maleic anhydride, benzoyl peroxide and potassium permanganate were used for the surface treatment of the rubber. The materials source, chemical formula , and pureness are shown in Table (3.1).

The calcination of local kaolin clay, from "Dwaikhla (Western Desert, Anbar, Iraq)", produced the metakaolin. The kaolin was heated to 750°C for 3 hr at 5°C/min in an air environment according to the result of DTA analysis reported by **Z. Zayer Hassan, et. al.** for kaolin **[79].** The symbol for the metakaolin utilized in this study will appear in the thesis as (MK). Crumb rubber and powder rubber were taken from Al-Diwaniyah company for tyres industry (Iraq).

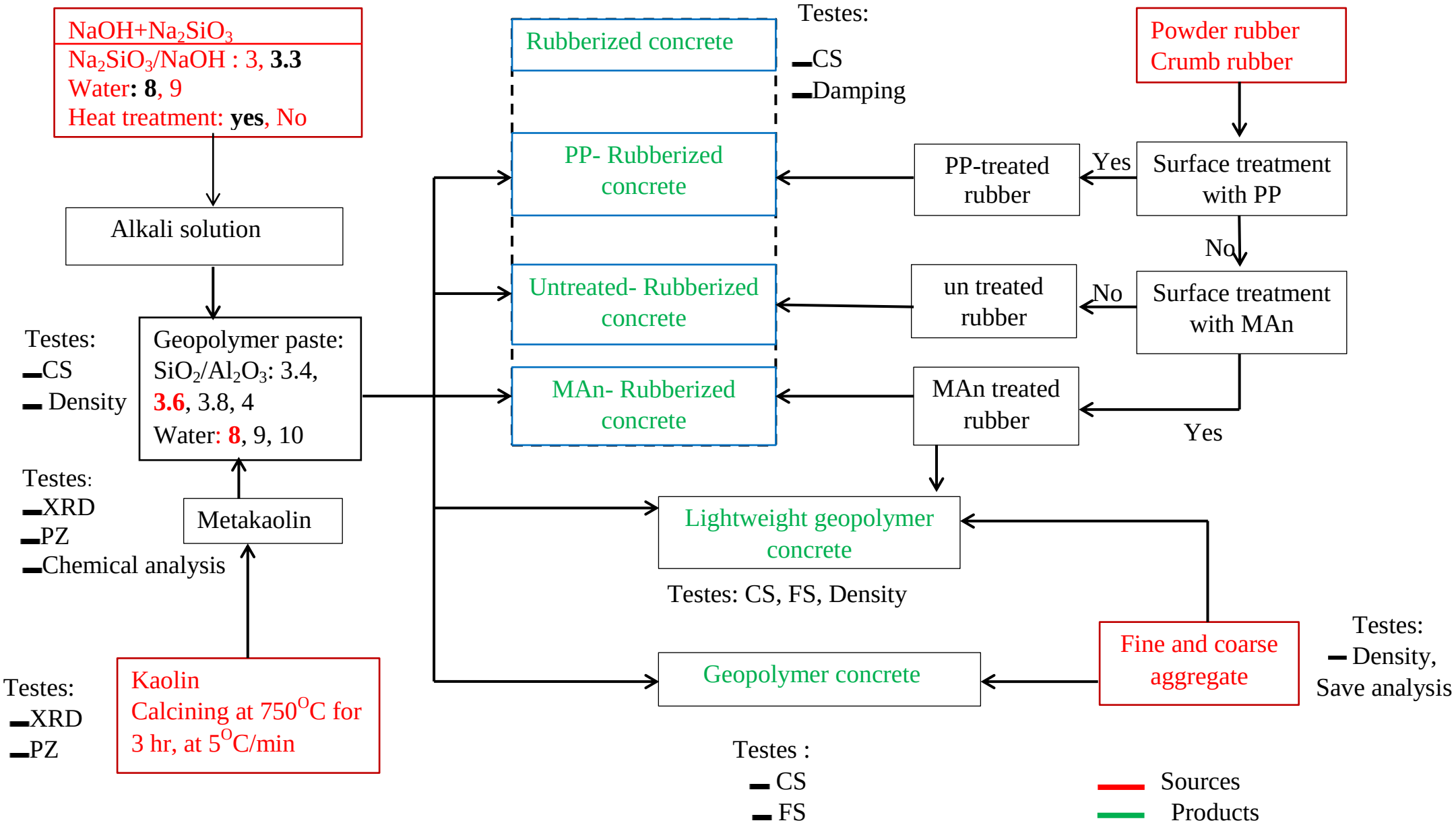


Figure (3.2) Flow Chart of the Experimental Work for Prepared: Geopolymer Paste , Concrete, and Lightweight Concrete

Table (3.1) Source, Chemical Formula, and Pureness of Starting Materials

Material Name	Chemical Formula	Pureness(%)	Supplier
Kaolin	$Al_2O_3.2SiO_2.2H_2O$	Industrial	Iraq
Sodium	NaOH	Industrial grade	ECHA, Finland
Sodium silicate	$Na_2SiO_3.5H_2O$	Industrial grade	UAE
Water	H_2O	Distilled water	Lab distillation
Maleic anhydride	$C_4H_2O_3$	95	Sigma-Aldrich, USA
Benzoyl peroxide	$(C_6H_5.CO)_2O_2$	98	CDH, India
Potassium permanganate	$KMnO_4$	99	India
Crumb rubber	-	-	Al- Diwaniyah company, Iraq
Fine, coarse aggregate	-	-	Iraq

3.3 Preparation of Geopolymer

The formula given below was used to describe the geopolymer composition

$$Al_2O_3.\ Na_2O.\ nSiO_2.\ xH_2O \quad \ldots\ldots\ldots\ldots \quad (3.1)$$

where; (n) signifies the number of SiO_2 moles and (x) signifies the number of moles of water. Four geopolymer formula were chosen to set the suitable moles (n) of SiO_2 in the geopolymer formula, the four formula are given in Table (3.2).

For each mix formula, the mixing time was set at 5 min, with a mechanical mixer operating at a fixed speed of (3000 rpm). Based on pervious study in the department of ceramic and building materials of

[79], that involving the optimization for the process parameter of geopolymer, these two parameters were selected. The values of (n) were designated based on a combination of primary experiments and previous studies **[28, 29]**.

The values of these parameters were determined using the following criteria:

1. The geopolymer paste need to be easy to mix.
2. Setting time shouldn't be either too short or too long as compared with the setting time of OPC.
3. There should be no macro-cracks in the resulting geopolymer body.

Table (3.2) The Geopolymer Formula Used

Batch no.	**Mix formula**
GP1	$Na_2O.\ Al_2O_3.\ 3.4\ SiO_2.\ xH_2O$
GP2	$Na_2O.\ Al_2O_3.\ 3.6\ SiO_2.\ xH_2O$
GP3	$Na_2O.\ Al_2O_3.\ 3.8\ SiO_2.\ xH_2O$
GP4	$Na_2O.\ Al_2O_3.\ 4\ SiO_2.\ xH_2O$

3.3.1 Preparation of Alkali Activator

The alkaline solution was prepared by dissolving the required quantity of sodium silicate solution and sodium hydroxide in water. Firstly sodium hydroxide was weighed and added to the required water. As the sodium hydroxide pellets were dissolved in water, heat was generated, so the liquid was cooled to room temperature before use. The sodium silicate solution was added to the solution. A desired amount of water was added to the solution to supply the geopolymer with the

required amount of water. Two batches of the alkali solution were designated, the first batch was prepared as described above, while, the second batch, which was prepared in the same way, was farther subjected to heat treatment that involved heating the solution at 85±2^{o}C for 20 min under stirring at 600 rpm, additional water was added to this batch to recompense the water mislaid due to evaporation. The alkali solution was then kept for 24 hr at ambient conditions before use.

3.3.2 Preparation of Geopolymer Paste

In order to obtain geopolymer paste with high compressive strength, to be used as a binder phase in the geopolymer concrete, the effect of the heat treatment of alkali activator solution on the compressive strength was investigated for geopolymer mixes with different Na_2SiO_3/NaOH ratio of 3 and 3.3 and different amount of water of 8 and 9 ml as showed in Table (3.3).

Table (3.3) The Geopolymer Mixes with and without Heat Treatment of Alkali Activator

Sample No.	Na_2SiO_3/ NaOH	Heat treatment	MK (gr)	Na_2SiO_3 (gr)	NaOH (gr)	H_2O (ml)
GN1	3	without	47.268	45.304	3.98	7.491
GN2	3	without	47.268	45.304	3.98	11.49
GN3	3.3	without	46.908	46.408	3.74	6.894
GN4	3.3	without	46.908	46.408	3.74	10.893
GH1	3	with	47.268	45.304	3.98	7.491
GH2	3	with	47.268	45.304	3.98	11.49
GH3	3.3	with	46.908	46.408	3.74	6.894
GH4	3.3	with	46.908	46.408	3.74	10.893

Once the role of the heat treatment in improving the compressive strength was confirmed through the compressive strength measurement, the alkali solution subjected to the heat treatment was used to prepared geopolymer paste with different SiO_2/Al_2O_3 ratio of 3.4, 3.6, 3.8 and 4 and different amount of water of 8, 9, and 10 ml in order to select the conditions that produced geopolymer with high compressive strength, the mixes are given in Table (3.4).

Table (3.4) The Geopolymer Mixes with Heat Treatment of Alkali Activator

Sample no.	SiO_2/Al_2O_3	MK (gr)	Na_2OSiO_3 (gr)	NaOH (gr)	H_2O (ml)
G1	3.4	48.156	42.512	4.66	9.02
G2	3.4	48.166	42.512	4.66	13.02
G3	3.4	48.166	42.512	4.66	17.02
G4	3.6	46.636	47.052	3.492	6.545
G5	3.6	46.636	47.052	3.492	10.545
G6	3.6	46.636	47.052	3.492	14.545
G7	3.8	45.204	51.312	2.396	4.241
G8	3.8	45.204	51.312	2.396	8.241
G9	3.8	45.204	51.312	2.396	12.241
G10	4	43.86	55.316	1.364	2.075
G11	4	43.86	55.316	1.364	6.075
G12	4	43.86	55.316	1.364	6.075

The geopolymer paste was prepared by adding the metakaolin powder to the activator solution under mechanical mixing at a speed of 3000 rpm for a total mixing time of 5 min. The geopolymer pastes were molded in plastic cylinder moulds with 2.1 cm of diameters and 4.2 cm of heights. The samples were kept at room temperature for 24 hr before demolding. Then, the samples were cured at room temperature for 28 days before testing. The samples of geopolymer cement paste after 24 hr of casting are shown in Figure (3.2).

Figure (3.2) Samples of Geopolymer Cement Paste after 24 hr of Casting

3.3.3 Rubber Surface Treatment

In this research two treatments were used to improve rubber surface with different materials to increase the bond strength between the rubber and geopolymer, these including the treatment with potassium permanganate (PP) and the treatment with maleic anhydride (MAn).

3.3.3.1 Treatment with Potassium Permanganate

As a reactive substance, 5% by weight of $KMnO_4$ solution was used to modify the crumb rubber surface. The treatment followed a standard protocol that can be comprised as the following **[90]:**

1- Immersion of the rubber in a 5% by weight solution of $KMnO_4$ to 30 min.

2- Rinsing the rubber-treated with deionized water six times.

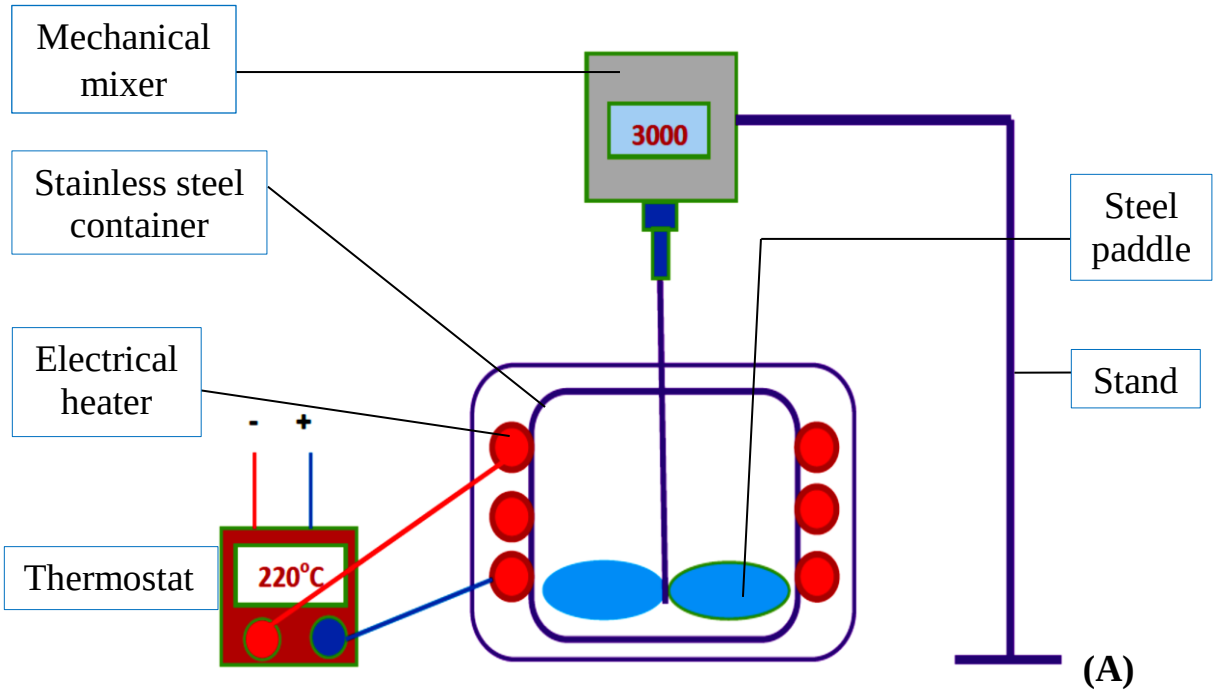
3- Drying the washed rubber for 72 hr at room temperature in a draft hood.

3.3.3.2 Treatment with Maleic Anhydride

The treatment was achieved in closed stainless steel mixer made by the researcher, the temperature was set at 220^{o}C and the treatment time was set to 80 min. Each 1 gm of powder or crumb rubber was well mixed with 0.1 gm of maleic anhydride (MAn) and 0.01 gm of the initiator benzoyl peroxide (BPO) as described by [**91].** The closed stainless steel mixer that was made is shown in Figure (3.3).

3.3.4 Preparation of Rubberized Geopolymer Concrete

The mix that yields a geopolymer with the highest compressive strength was used to prepared rubberized geopolymer concrete. RGC with 10% wt. of CR was prepared to investigate the bond strength between the geopolymer paste and the rubber surface using three types of rubber, these are rubber treated with maleic anhydride, rubber treated with potassium permanganate, and untreated rubber as shown in Table (3.5). Then the fresh rubberized geopolymer concrete casted in plastic moulds (2.1 cm of diameters and 4.2 cm of heights). The samples were kept at lab temperature (23 ± 2°C) for 24 hr and demolded. These specimens were then cured at an ambient temperature for 28 days before tested.



(A)

(B)

Figure (3.3) The Stainless Steel Mixer of Crumb Rubber,(A) Schematic Draw and (B) Photograph

Table (3.5) The Mix Design of Rubberized Geopolymer Concrete

Sample No.	Mk (gr)	Na_2OSiO_3 (gr)	NaOH (gr)	H_2O (ml)	Crumb rubber (gr)	Treatment
GM	46.636	47.052	3.492	6.545	12	Treated by MAn
GP	46.636	47.052	3.492	6.545	12	Treated by PP
GN	46.636	47.052	3.492	6.545	12	Un treated

3.3.5 Preparation of Geopolymer Concrete

The mix of the geopolymer that yields the highest compressive strength was used to prepared geopolymer concrete. Concrete was casted with different amount of fine and course aggregate, these amount are in accordance with the references that showed in the Table (3.6). The fine and course aggregate were added to the geopolymer paste and mixed for 15 min. The geopolymer concrete was casted in a steel moulds (70×70×70 mm) for compressive strength test and (70×70×280 mm) for flexural strength test, and cured at room temperature. Demolding took one day, and the concrete was kept at ambient temperature for 28 days before tested. Figure (3.4) shows the geopolymer concrete specimens for compression and flexural tests.

Table (3.6) The Mix Design of Geopolymer Concrete

Sample no.	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Geopolymer paste (kg/m^3)	Reference
GC1	554.4	1293.6	637	**[92]**
GC2	415	1146	745	**[93]**
GC3	675	1039	657	**[94]**

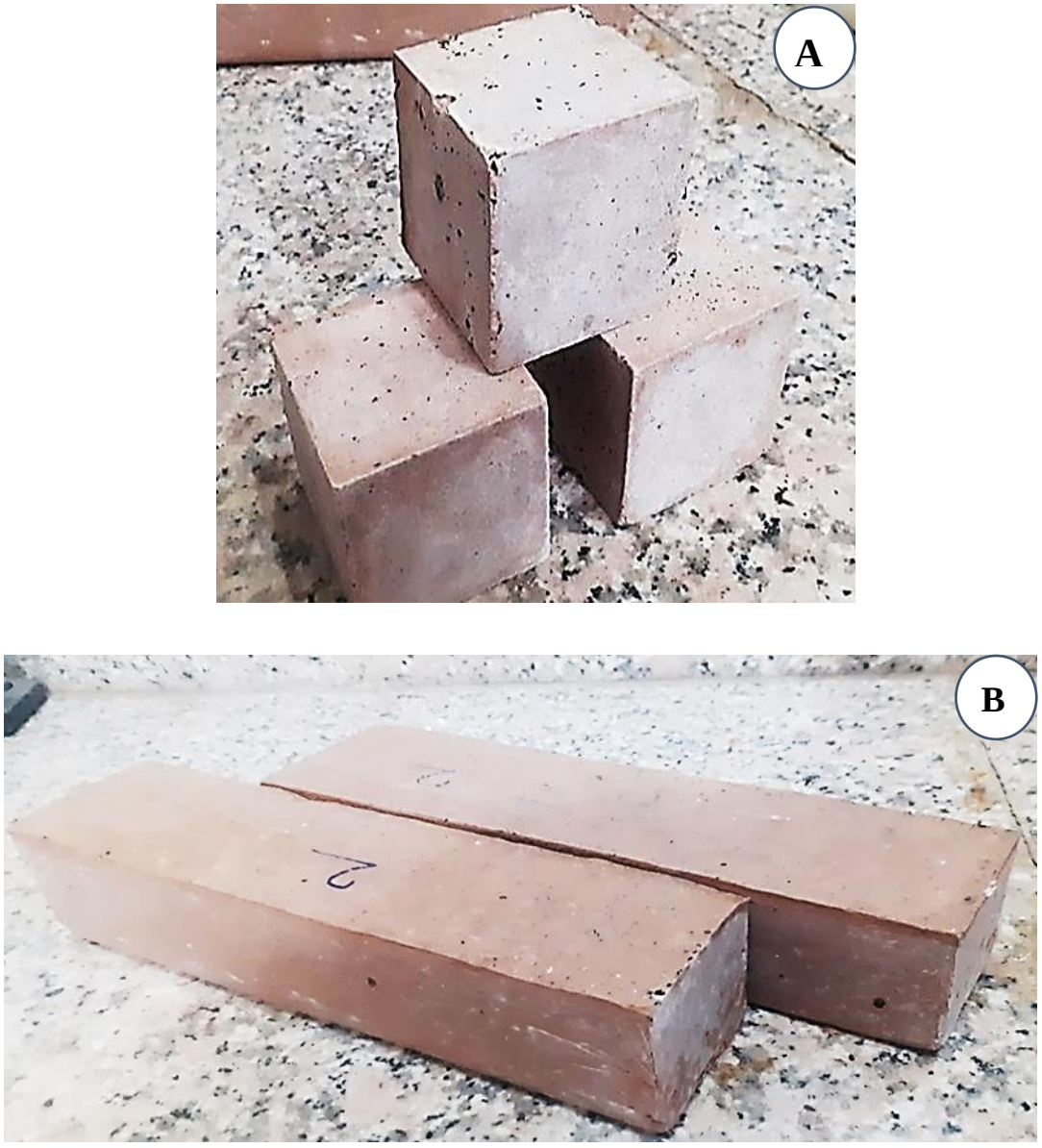


Figure (3.4) Specimens of Geopolymer Concrete for (A) Compression Test and (B) Flexural Test

3.3.6 Preparation of Lightweight Geopolymer Concrete

The mix of geopolymer concrete that yields the highest compressive strength and the rubber-treated that resulting in a highest bonding with the geopolymer were used to prepare the lightweight geopolymer concrete, where the crumb rubber and powder rubber, treated with MAn, partially replace in a ratio of (5%, 10%, 15%) by volume of the fine and coarse aggregate in the geopolymer concrete. The amount of

materials including the metakaolin (MK), Na_2SiO_3, NaOH, H_2O, fine aggregate (Fine A), coarse aggregate (Coarse A), crumb rubber (CR) and powder rubber (PR) are given in Table (3.7). The mixes were casted in a steel moulds (70×70×70 mm for compression test) and (70×70×280 mm for flexural test) and cured at ambient temperature, demolding took one day, and the concrete was kept at room temperature for 28 days before tested.

Table (3.7) Mix Design of Lightweight Geopolymer Concrete (kg/m^3)

Sample	MK (kg)	Na_2SiO_3 (kg)	NaOH (kg)	H_2O (ml)	Fine A (kg)	Coarse A (kg)	CR (kg)	PR (kg)	CR %	PR %
GBR0	286.3	288.8	21.4	40.1	554.4	1293.6	0	0	0	0
GBR1	286.3	288.8	21.4	40.1	526.6	1244.8	26.2	12.8	5	5
GBR2	286.3	288.8	21.4	40.1	526.6	1179.3	52.4	12.8	10	5
GBR3	286.3	288.8	21.4	40.1	526.6	1113.8	78.3	12.8	15	5
GBR4	286.3	288.8	21.4	40.1	498.9	1244.8	26.2	25.7	5	10
GBR5	286.3	288.8	21.4	40.1	498.9	1179.3	52.4	25.7	10	10
GBR6	286.3	288.8	21.4	40.1	498.9	1113.8	78.3	25.7	15	10
GBR7	286.3	288.8	21.4	40.1	471.2	1244.8	26.2	38.5	5	15
GBR8	286.3	288.8	21.4	40.1	471.2	1179.3	52.4	38.5	10	15
GBR9	286.3	288.8	21.4	40.1	471.2	1113.8	78.3	38.5	15	15

3.4 Characterization Techniques

3.4.1 X-Ray Diffraction (XRD)

The phase composition of the kaolin and metakaolin was defined by XRD analysis. The x-ray was generated by using high voltage

power (40 kv/30 mA), which fast-tracks electrons from a heated tungsten filament to strike a copper target. The resulted x-ray travels through a nickel filter and strikes the sample, which is moving in a circular motion at a speed of 5°/min. When the incident beam diffracts according to Bragg's law, diffraction occurs, as shown in equation (3.2) **[95]**.

$$n\lambda = 2d \sin\theta \quad \text{.....(3.2)}$$

where: (λ) is the incident wavelength ray (λ=1.5406 ^{o}A), (d) is the inter-planar distance (^{o}A), (n) is a positive integer, (θ) is the angle between the incident beam and the surface of the spacemen.

The x-ray diffracted from the specimen would be receiving by the rotating detector, which rotates at a speed of (2θ). Finally, diffraction data (the intensity of the diffracted ray and the values of diffraction angels) were obtained using a computer program. The tested specimens' d-spacing values were compared to the d-spacing standard data of ceramic materials provided by the International Center of Diffraction Data (ICDD). This test was carried out using an x-ray diffractometer (type: XRD 6000, manufactured by Shimadzu, Japan) available at the Department of Ceramics and Building Materials / Faculty of Materials Engineering / University of Babylon.

3.4.2 Chemical Analysis

The chemical composition analysis of kaolin was achieved using the method of wet chemical to know the weight fraction of components found in metakaolin powder. This investigation was conducted at the Iraqi Geological and Mining Survey Company.

3.4.3 Particle Size Analysis

A laser particle size analyzer was using to these test, was available at the Department of Ceramics and Building Materials / Faculty of Materials Engineering / University of Babylon. This test was run to measure the particle size distribution of kaolin and metakaolin powder. The basic laser diffraction standard was straight forward: The process of diffraction, or light scattering on particles, results in an angle behind the particle dependent on the intensity distribution. This angle contains a ring system with regions that are divided into dark and bright spots.

3.4.4 Sieve Analysis

This test has been done to determine the particle size distribution of fine and coarse aggregate. Sieve analysis test was conducted at the Department of Ceramics and Building Materials / Faculty of Materials Engineering / University of Babylon.

3.4.5 SO_3 Content

This test was performed on both fine and coarse aggregate used to prepare concrete specimens. This test was done to determine the amount of sulfite oxide in aggregate. **[96]**:

The SO_3 content was calculated by using the following equation :

$$SO_3\% = [(W_2 - W_1) * 34.3] / W \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.3)$$ **[96]**

where: W_1 is the weight of unfilled crucible, W_2 is the weight of the crucible after burning and W is the weight of the sample.

3.4.6 Density Measurement

3.4.6.1 Density of Fine Aggregate

This test was employed according to ASTM C128-12 [**97].** The specific gravity was calculated as follow:

$$\text{specific gravity} = A/(B + S\ C) \quad \ldots\ldots\ldots\ldots (3.4)$$ [**97]**

wherever A is the mass of specimen that dry in oven, B is the mass of the pycnometer when filled with water, S is the mass of the saturated surface-dry sample, and C is the mass of the pycnometer filled with specimen and water to the graduation mark. The test was conducted at the Department of Ceramics and Building Materials / Faculty of Materials Engineering / University of Babylon.

3.4.6.2 Relative Density (Specific Gravity) of Coarse Aggregate

This test was employed according to ASTM C127 [**98**] Relative density (specific gravity) was calculated by the formula:

$$RD = A/(B - C) \quad \ldots\ldots\ldots\ldots\ldots\ldots (3.5)$$ [**98**]

where, RD is the Relative density of course aggregate, A is the mass of the dry specimen in air, B is the mass of the saturated-surface dry specimen in air and C is the mass of the saturated specimen in water. The test was conducted at the Department of Ceramics and Building Materials / Faculty of Materials Engineering / University of Babylon.

3.4.6.3 Relative Density of Crumb Rubber

Employ a displacement strategy. A piece of rubber was weighed to determine how much water it displaces while submerged, then, the volume gain in a graduated cylinder or other graduated container

was measured. To guarantee that the rubber is completely submerged, it was might need a mesh, enabling adjustability for any weight that is attached to it as well as any quantifiable displacement caused by the rubber. However, if the material is made entirely of rubber, it should float in water and not require a submersion mesh. The density was calculated using the following equation:

$$D = M/V \quad \text{..... (3.6)}$$

where D is the rubber density, M is the measured mass of the rubber material and V is the volume of displaced liquid. The test was carried out at the Department of Ceramics and Building Materials / Faculty of Materials Engineering / University of Babylon.

3.4.6.4 Porosity, Density, and Water Absorption of the Prepared Specimens (Paste, Lightweight concrete)

The porosity, density, and water absorption of the prepared specimens were assessed using ASTM : C 642 – 06 **[99].**

1. All samples were dried at 150°C for 6 hr before being cooled to room temperature in desiccators. To within 0.001 g, the dry weight (D) was measured.

2. The samples were submerged in distillate water for 24 hr while the specimens were exposed to it. The suspended weight (S) of the samples was then determined to within 0.001 g.

3. The samples were softly rolled on a wet cotton cloth to remove any excess water from the surface after being identified as (M).

In order to calculate the mass after saturation (M) to within 0.001 g, the samples were directly weighted. The density was calculated using equation (3.7) as follows:

$$\rho = D / (M-S) \quad \text{……..……(3.7)} \quad \textbf{[99]}$$

where ρ is the bulk density.

To determine apparent porosity, multiply the volume of open pores by the sample's bulk volume. The following formula was used to determine the apparent porosity:

$$Ap = (M-D / M-S) \times 100 \quad \text{……..…(3.8)} \quad \textbf{[99]}$$

where Ap is the apparent porosity (%)

water absorption was calculated using the following equation:

$$WA (\%) = (M-D/ D) \times 100 \quad \text{……..(3.9)} \quad \textbf{[99]}$$

where WA is the water absorption (%).

3.4.7 Roughness Test of Rubber

The parts of car tyre are defer in the contants of materials, so the ruoghness was defer for every part. The roughness of surface was tested for every part of tyre after treatment it by (MAn and $KMnO_4$ (PP) and without treatment. The test was carried out using Surface Roughness Tester (HSR210) at the Department of Metallurgical Engineering / College of Materials Engineering/ University of Babylon. Table (3.8) showed the symbols of each part of tyre and its meaning.

Table (3.8) The Symbols of Each Part of Tyre and its Meaning

Symbol	Meaning
TMA	Tread treated by MAn
SMA	Side treated by MAn
TPP	Tread treated by PP
SPP	Side treated by PP
TNO	Tread untreated
SNO	Side untreated

3.4.8 Contact Angle Test

The contact angle was measured for rubber treated by MAn and untreated rubber in order to compare the effect of treatment by MAn on the wettability of the rubber. This test was performed using ***VINO*** Optical Contact Angle model: SL200KS. The contact angel test was conducted at the Department of Ceramics and Building Materials / Faculty of Materials Engineering / University of Babylon.

3.4.9 Compressive Strength Test

This test was carried out on geopolymer paste, geopolymer concrete, rubberized geopolymer concrete, and lightweight geopolymer concrete after 28 days. To ensure that the cylinders samples (2.1 mm diameter, 4.2 mm height) are leveled, the samples was smoothed with a polishing machine. Compression test was accepted according to BS:1881 part 116: 1989 **[100]**. This test was carried out at the Department of Ceramics and Building Materials / Faculty of Materials Engineering /

University of Babylon. The compression strength can be calculated using the following formula**.**

$$\text{бc} = P / A \quad \text{.....(3.10)} \quad \textbf{[100]}$$

where бc is compressive strength (MPa), P is load that used (kN) and A is sample area (mm^2).

3.4.10 Flexural Strength Test

At 28 days, geopolymer concrete and lightweight geopolymer concrete were underwent this test according to ASTM C239/239M **[101]** and available at the Department of Ceramics and Building Materials / Faculty of Materials Engineering / University of Babylon, by using Germany device (Universal-Werkstoffprufgerat, 50 kN) WP310 model, with load rate of 0.1 kN per min. The following formula was used to determine the flexural strength:

$$\text{Flexural strength } (N/mm^2) = [3PL / 2\,bd^2] \quad \text{.....(3.11)} \quad \textbf{[101]}$$

where P is the beam's failure load (N), L is the beam's span (mm), b is beam width (mm) and d is the specimen's depth (mm).

3.4.11 Damping Test

The rubberized geopolymer concrete, in addition to a sample of geopolymer used as control, were underwent the damping test, the rubberized geopolymer concrete contains crumb rubber at the volume percentage of (0, 5, 10, 15 %), the concrete was casted in glass moulds of (20×2.5×1.5 cm) and cured in the ambient condition for 28 days before testing. The test was consist that the prismatic sample was steadied in one end on the stand, vibration sensors was placed on a structure to recorded the vibration response of a structure due to a known excitation by either a

shaker system or an impulse hammer **[102].** This test was carried at the Department of Mechanical Engineering, College of Engineering, University of Babylon.

3.4.12 Pull-off Strength Test

Pull-off testing was done to evaluate the bonding between the crumb rubber and geopolymer paste. The pull-off load was measured as the amount of force needed to remove the rubber piece from the geopolymer surface. The pull-off load per unit area was used to compute the pull-off strength [**87]**.

This test was performed using Microcomputer Controlled Electronic Universal device with rate of 0.1 mm/s available at the Department of Polymers and the Chemical Industry, College of Materials Engineering, University of Babylon. Circler rubber pieces with diameter of 17 mm and high of 5 mm were prepared for this test. Some of rubber pieces was surface treated by Maliec anhydride and Potassium Permanganate, others rubber pieces were untreated. One day before the test, the rubber samples were adhered to 17 mm diameter steel discs using epoxy glue, while the other end of the rubber piece was adhered by geopolymer paste by casting geopolymer paste in cylinder mold of (17 mm diameter and 37 mm high) at the end 28 days. Figure (3.5) shows the sample before test. The rubber piece were choosing from different zones of the tyre including side of tyre and tread, according to symbols in Table (3.8).

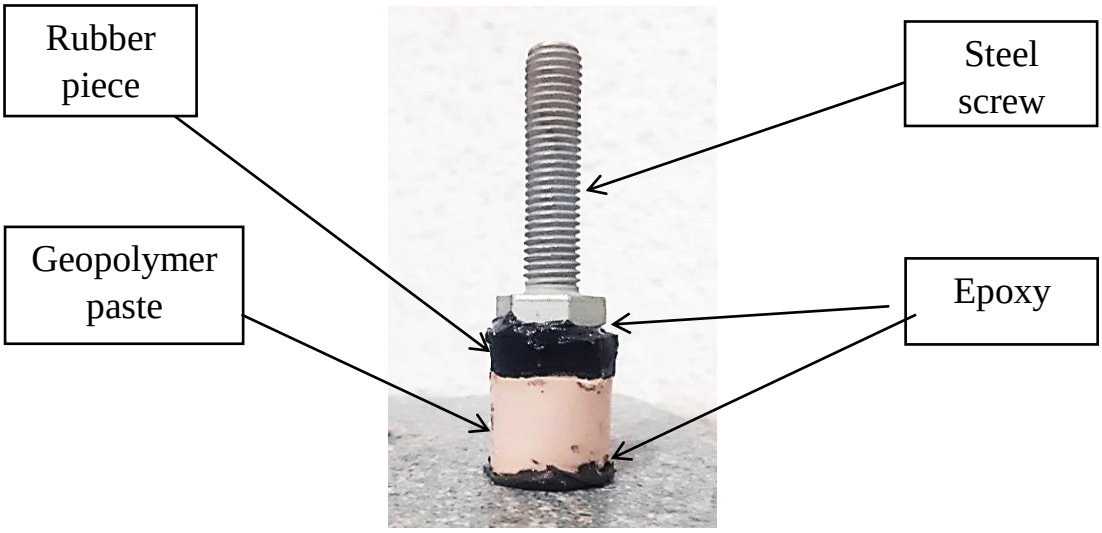


Figure (3.5) Sample of Pull-off Test

3.4.13 Microstructure Imaging

The scanning electron microscope (SEM) was used to observe the features of the microstructure of the lightweight geopolymer concrete, these features involved the pores shape, micro cracks, and the internal transition zone between the rubber and geopolymer paste. This test was carried out at the Department of Ceramic and Building Materials / Faculty of Materials Engineering / University of Babylon, by using TESCAN ***CE*** performance in nanospace, type VEG 3 SBU.

3.5 Cost and Embodied CO_2 Index Calculations

The cost of the materials is crucial to the broad use of practical building engineering. The cost of several raw commodities rose sharply during the previous years. An integrated measure comprising compressive strength is suggested as the subsequent equation, as reported in **[103]**, to assess the financial effectiveness of geopolymer concrete in this study.

$$C_P = Cost / f_c \quad \text{.....(3.16) [103]}$$

where C_P ($/m^3·MPa) is the cost per MPa for 1 m^3 of binding materials, ***Cost*** ($/m^3) is the total cost of 1 m^3 of paste and f_c is strength (MPa) after 28 day. The prices of the materials used to prepared the geopolymer concrete, as that of OPC, are given in Table (3.9) based on the price shown in Alibaba Group at 15/3/2023. The amount of the materials used to prepared one cubic meter of OPC concrete and geopolymer concrete are given in Table (3.10).

It is generally acknowledged that geopolymers emit far less CO_2 than Portland cement. The introduction of an embodied CO_2 index, which was developed for assessing the embodied environmental effect of self-compacting concrete, would allow for a quantitative analysis of the embodied environmental consequences of one-part geopolymer and OPC. The proposed phrase for this index is shown below.

$$C_I = \text{embodied } CO_2\text{- e} \,/\, f_c \quad \text{.....(3.17) } \textbf{[103]}$$

where C_I (kg/MPa·m^3) is the embodied CO_2 index, embodied CO_2-e (kg/m^3) is the total CO_2 emission of 1 m^3 of binding materials, and f_c is the compressive strength (MPa) after 28 day.

Table (3.9) The Prices of All Materials that used in the Production of Geopolymer Concrete and OPC Concrete ($/ton)

Material	Price
Metakaolin	95-150
Sodium silicate	100-200
Sodium hydroxide	600-800
OPC	85-125
Course aggregate	120-180
Fine aggregate	100-160

Table (3.10) Materials for One Cubic Meter of Geopolymer Concrete and Ordinary Portland Cement Concrete (kg/m^3)

Material	MK	Na_2SiO_3	NaOH	Coarse aggregate	Fine aggregate	OPC	H_2O
GPC	286.4	288.96	23.1	1293.6	554.4	0	40.19
OPCC	0	0	0	1200	800	300	150

CHARTER FOUR

RESULTS AND DESCUSSIONS

Chapter Four

Results and Discussions

4.1 Introduction

This chapter displays the results which were gained from the experimental works and their discussion. It includes the description of the impact of the heat treatment of alkali solution and the surface treatment for the rubber on the main characteristics of the lightweight geopolymer concrete. Moreover, it includes a comparison with the results obtained from many research work reported in the literature.

4.2 Kaolin and Metakaolin Results

4.2.1 Kaolin and Metakaolin XRD Analysis

The XRD pattern of kaolin powder is shown in Figure (4.1), the analysis of the pattern demonstrates that the powder has a crystalline structure depending on (ICCD=00-001-0527) of kaolinite and (ICCD=00-033-1161) of SiO_2 minerals.

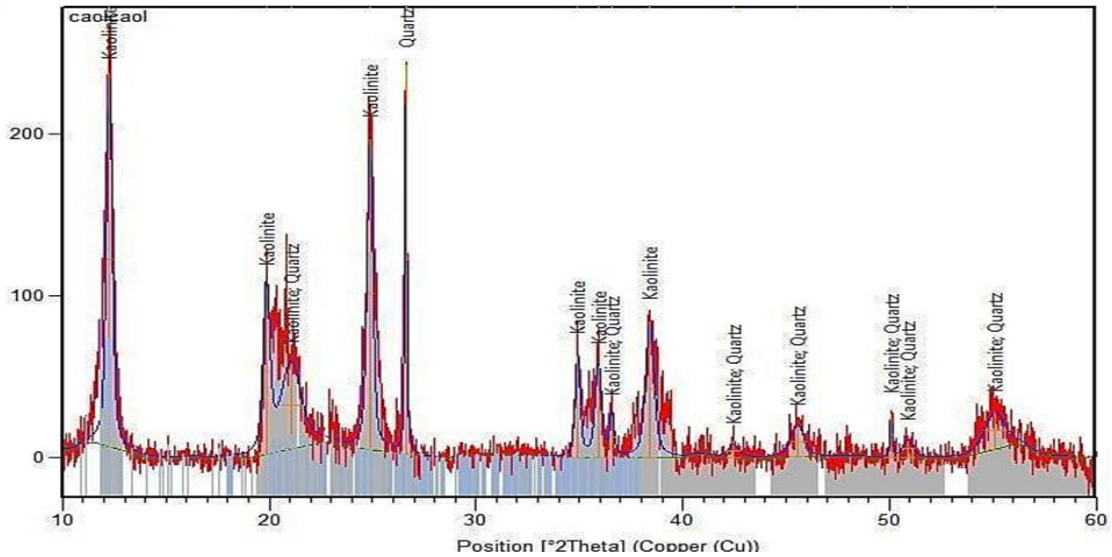


Figure (4.1) XRD Form of Kaolin

It is commonly known that metakaolin is produced when kaolin is heated to a moderate temperature. This was confirmed as shown in pattern in Figure (4.2), where the formula of metakaolin with an amorphous structure, containing free quartz, is confirmed.

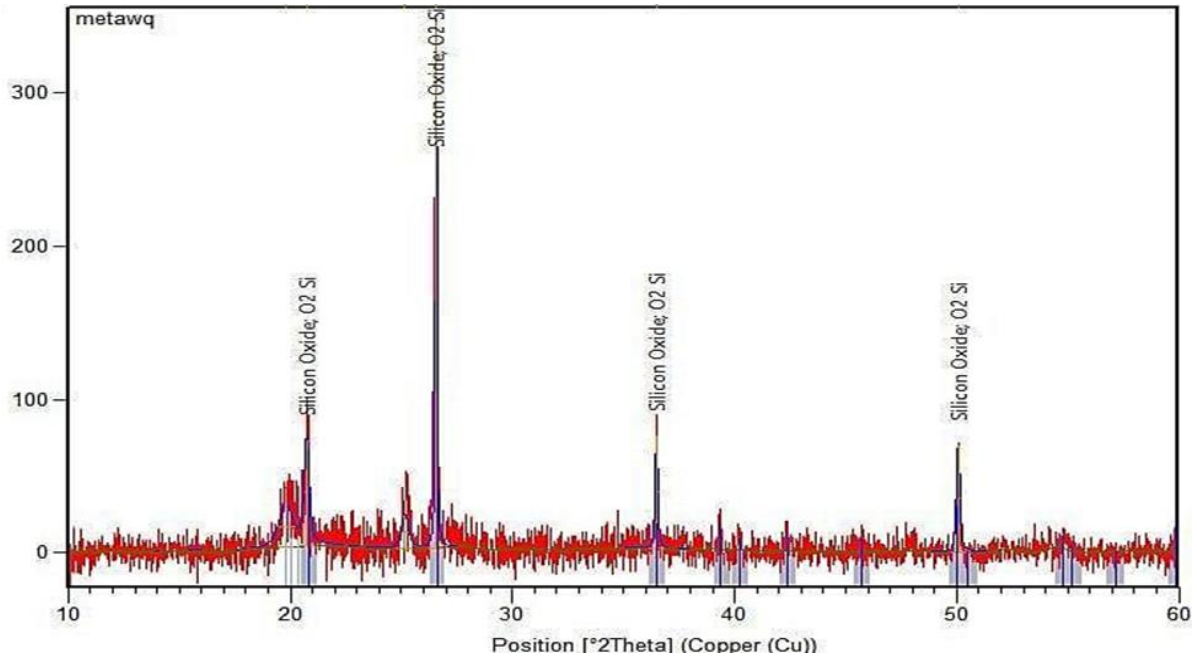


Figure (4.2) XRD Form of Metakaolin

4.2.2 Kaolin Chemical Analysis

The results of the kaolin wet chemical analysis are shown in Table (4.1).

Table (4.1) The Result of Kaolin Wet Chemical Analysis

Oxide	**SiO_2 %**	**Al_2O_3 %**	**Na_2O %**
Amount	52.64	34.90	1.84

As confirmed by the XRD result, regarding the existence of free quartz, the SiO_2 percent is higher than what is expected for kaolin. This result aids in calculating the approximate quantity of free quartz that

should be excluded when the composition of the geopolymer is computed. This is due to the fact that quartz is inert, that made quartz an inert element during the production of geopolymer. It can be observed that the quantity of SiO_2 in the clay is (52.64%) which is larger than that of the stoichiometric quantity in the kaolinite.

4.2.3 Kaolin and Metakaolin Particle Size Analysis

The particle size distribution of kaolin powder is shown in Figure (4.3) The results showed that the kaolin is made up mostly of microparticles smaller than 22 µm. The multimodal particle size distribution has a D50 of 3.6 µm. Figure (4.4) illustrates the metakaolin particle size distribution, it is well known that metakaolin, which is produced as a result of the breakdown of the kaolinite structure, has tiny particle size when compared with kaolin. However, as seen in Figure (4.4), the aggregation and agglomeration cause the creation of massive secondary particles of metakaolin with D50 of 12.86 µm.

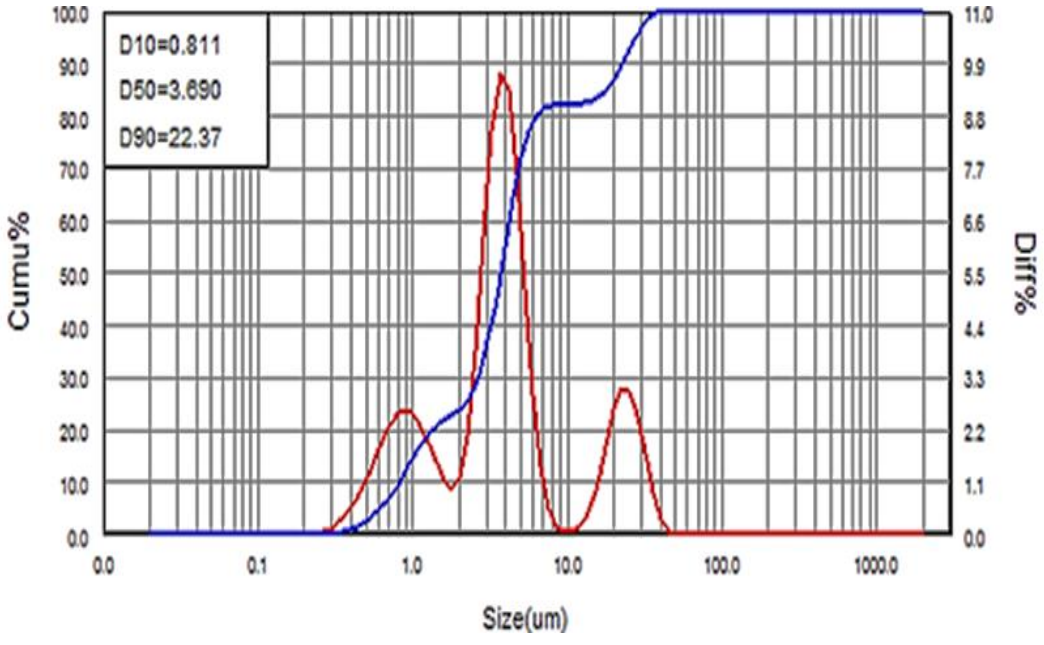


Figure (4.3) Particle Size Distribution of Kaolin Powder

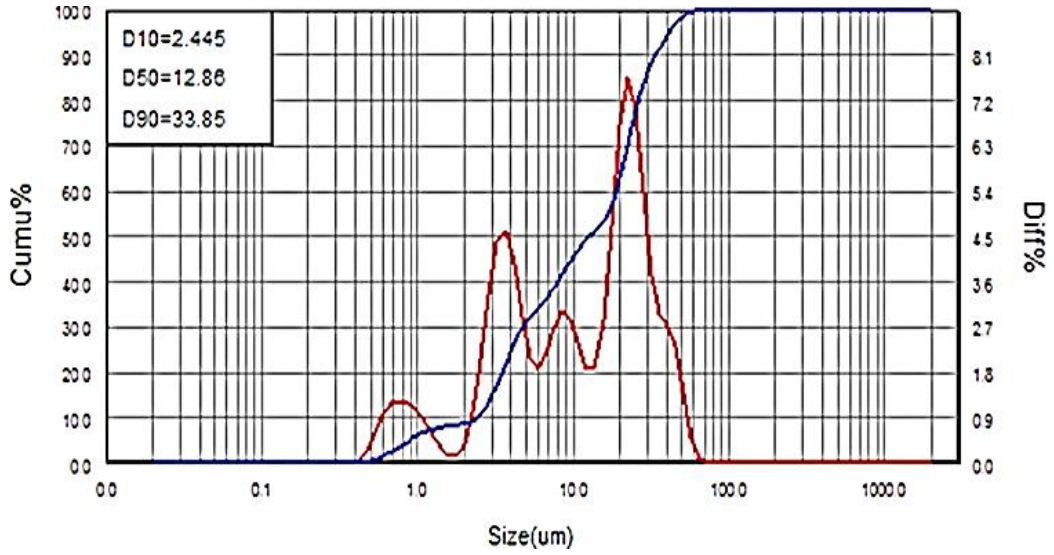


Figure (4.4) Particle Size Distribution of Metakaolin Powder

4.3 Result of Physical Test

4.3.1 Grading and SO_3 Content of the Aggregate

The result of SO_3 content showed that the fine and coarse aggregate has 0.04 % and 0.03 % of SO_3 respectively, this result is within the limits of the Iraqi Standard IQS 45-1984, zone 2 **[96].** Tables (4.2) and (4.3) show the results of grading test of coarse and fine aggregate, respectively, that used in geopolymer concrete. The coarse aggregate that was used in this study comprise all coarse aggregate that pass from sieve 10 mm and retained on sieve 5 mm.

Table (4.2) Mass Retained of Coarse Aggregate in Sieve Analysis

Sieve Size (mm)	Retained (g)	Retained (%)	Cumulative of retained(%)	Passing (%)	Limits of Iraqi Standard IQS 45-1984, Zone 2
20	0	0	0	100	95 - 100
10	200	40	40	60	30 - 60
5	250	50	90	10	0 -10
pan	50	10	100	0	

Table (4.3) Mass Retained of Fine Aggregate in Sieve Analysis

Sieve Size (mm)	Retained (g)	Retained (%)	Cumulative of retained	Passing (%)	Limits of Iraqi Standard IQS 45-1984, Zone 2
10	0	0	0	100	100
4.75	13.5	2.7	2.7	97	90-100
2.36	52	10.4	13.1	87	75-100
1.18	87	17.4	30.5	70	55-90
0.600	112	22.4	52.9	47	35-95
0.300	158	31.6	84.5	16	8-30
0.150	60.5	12.1	96.6	3	0-10
pan	17	3.4	100	0	

4.3.2 Specific Gravity of Aggregate and Rubber

Table (4.4) shows the specific gravity of fine, coarse aggregate and rubber, where the specific gravity of coarse and fine aggregate was about double the specific gravity of the crumb and powder rubber, respectively. This means that the volume of crumb and powder rubber is greater than the coarse and fine aggregate that have the same weight. Hence, the use of rubber is expected to produces a lightweight concrete.

Table (4.4) Specific Gravity of Aggregate and Rubber

Material	Fine aggregate	Course aggregate	Crumb rubber	Powder rubber
Specific gravity	2.6	2.5	1.1	1.2

4.3.3 Density, Porosity and Water Absorption Results

The results of density, porosity and water absorption of geopolymer paste after 28 days were shown in Table (4.5). It shows that the lower water absorption was 22.01% at 3.2 mole silica and 8 ml water, and the maximum porosity was 39.731% at 3.2 mole silica and 10 ml water. The low bulk density was 1318 kg/m^3 at 3.2 mole silica and 10 ml water. For all mixes the increase of water leads to higher porosity that leads to decrease of bulk density and increase of water absorption of geopolymer paste.

Table (4.5) Water Absorption, Porosity and Bulk Density Values of Geopolymer Paste after 28 Days

Batch Number	Water absorption%	Porosity%	Bulk density(kg/m^3)
G1	22.01	33.208	1508
G2	27.91	39.081	1400
G3	30.142	39.731	1318
G4	23.129	33.678	1456
G5	27.997	38.989	1392
G6	31.17	43.84	1338
G7	25.545	36.25	1419
G8	27.709	39.494	1425
G9	30.51	40.91	1394
G10	22.229	32.679	1470
G11	24.723	36.301	1468
G12	29.69	40.444	1362

The density, porosity and Water absorption of lightweight geopolymer concrete at 28 days is shown in Table (4.6). Figure (4.5) shows that the density of the lightweight geopolymer concrete decreases with increasing rubber percentage. Based on the results, the lightweight geopolymer concretes' unit weights varied from 2141 kg/m^3 for reference mix concrete to 2043 kg/m^3 for concrete have 15% replacement of rubber, where the reduction percentage of weight is 4.57%. As compared with the typical density for the OPCC, which has a density of (2400-2500 kg/m^3), it can be seen the lightweight geopolymer concrete achieved a reduction in the weight of a cubic meter up to (300 kg)**.** As shown in Figure (4.6), the porosity of lightweight geopolymer concrete was raised in all mixes for both fine and course aggregate, this is due to the trapped air in the rubber causes pore forming inside the concrete.

Table (4.6) Porosity, Density and Water absorption of Lightweight Geopolymer Concrete

Sample	Porosity (%)	Water absorption (%)	Bulk density (kg/m^3)
GBR0	9.57	4.47	2141
GBR1	7.13	4.65	2132
GBR2	8.12	4.87	2124
GBR3	9.78	5.02	2117
GBR4	7.87	5.12	2095
GBR5	8.91	5.23	2084
GBR6	10.67	5.36	2070
GBR7	8.32	5.39	2064
GBR8	9.65	5.53	2059
GBR9	11.2	5.76	2043

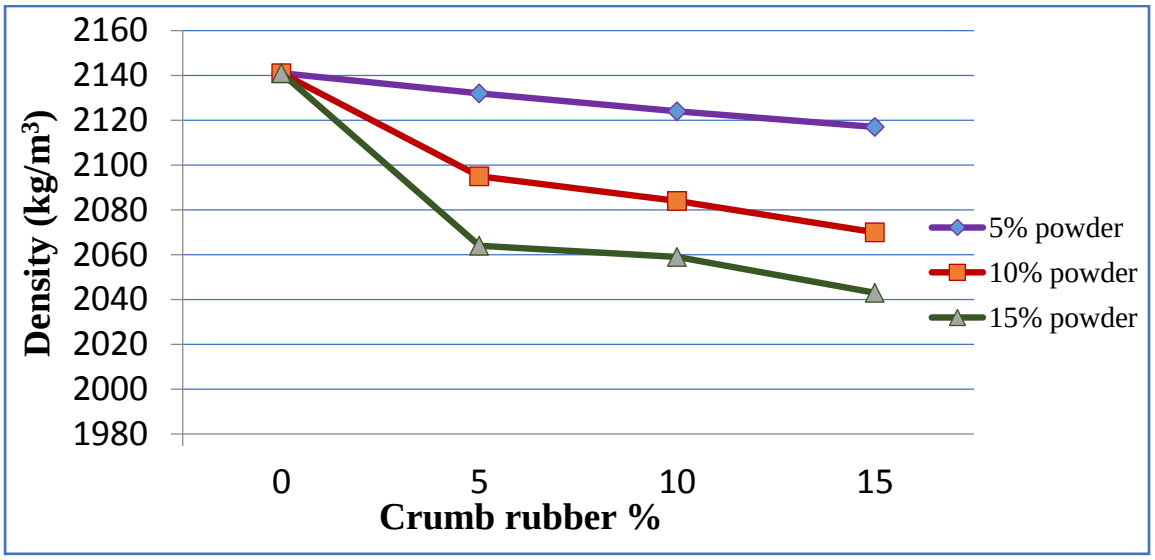


Figure (4.5) Density of Lightweight Geopolymer Concrete

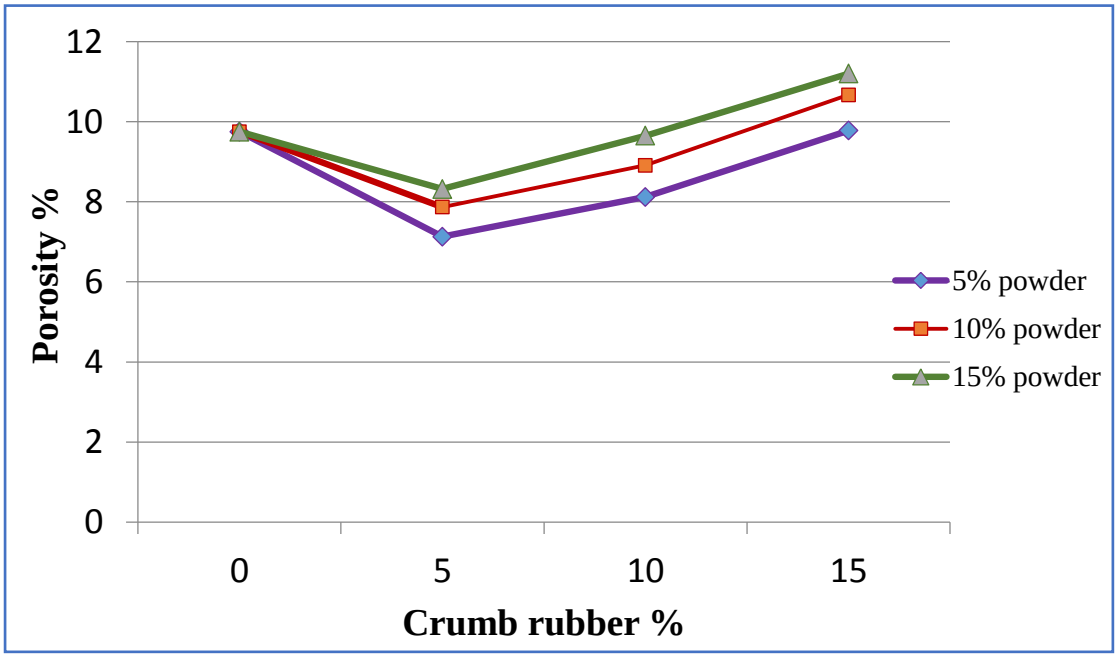


Figure (4.6) Porosity of Lightweight Geopolymer Concrete

4.4 Pull-off Strength Result

Table (4.7) shows the pull-of strength between the rubber surface and geopolymer paste surface. It can be noticed that the pull-off strength of treated rubber by MAn is more than double of that for untreated rubber, while the pull-off strength of treated rubber by PP

higher than for untreated rubber, but not higher than for treated rubber by MAn. This is because of the treated rubber by PP was created mechanical bond between the rubber and geopolymer, that was lower than chemical bond in the rubber treated by MAn. It can be noticed that the pull-off strength is differ for the different tyre zone in the same treatment of rubber, this is due to different composition of tyre zone.

Table (4.7) The Pull-off Strength of Treated and Untreated Rubber

Sample code	**Meaning**	**Pull-of strength** (MPa)
TMA	Tread treated by MAn	1.81
SMA	Side treated by MAn	1.69
TPP	Tread treated by PP	1.24
SPP	Side treated by PP	0.96
TNO	Untreated tread	0.87
SNO	Untreated side	0.77

Figure (4.7) shows the surface of frailer of the geopolymer sample after the pull-off test, it can be seen that a part of rubber is still on the geopolymer surface for the samples containing treated rubber with MAn, this indicates that the failure was occurred through the rubber indicating the good bond strength between the rubber surface and geopolymer.

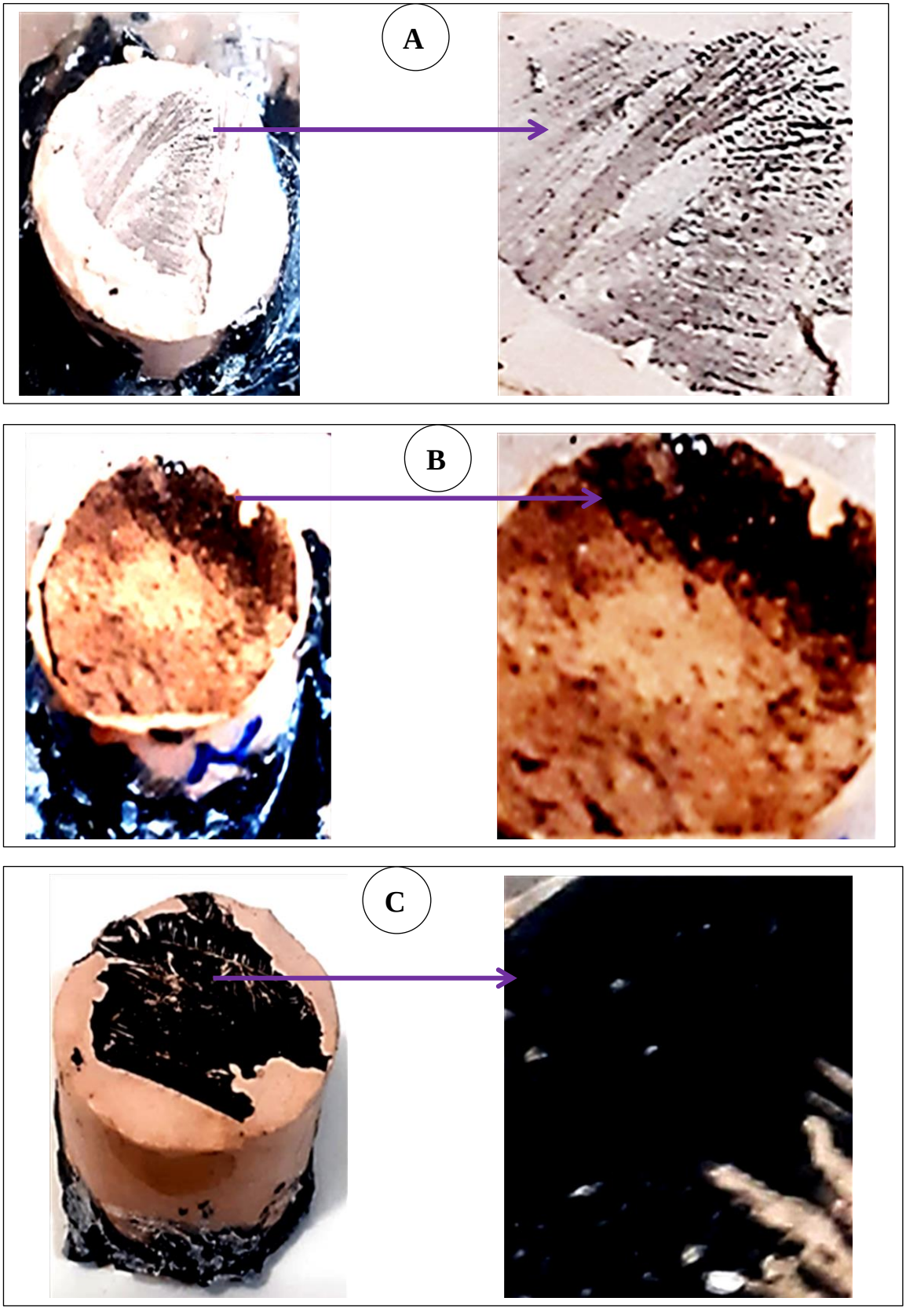


Figure (4.7) Surface of Failure after Pull-off Test, (A) without Treatment, (B) With Treatment by PP, (C) With Treatment by MAn

4.5 Roughness of Rubber Surface Result

Table (4.8) showed the roughness values of rubber surface of each parts of tyre after treated by (MAn and PP) and untreated one. It can be noticed that the roughness of rubber treated is higher than the untreated one, regardless the position in the tyre.

Table (4.8) The Roughness Values of Rubber Surface

Sample	Meaning	Roughness values (μm)
TMA	Tread treated by MAn	2.404
SMA	Side treated by MAn	1.136
TPP	Tread treated by PP	2.952
SPP	Side treated by PP	2.534
TNO	Untreated tread	2.302
SNO	Untreated side	1.021

Also, the treatment with PP increases the roughness more than the treatment by MAn, the roughness produces is very important to increase the bond strength between the rubber and geopolymer paste in term of physical and chemical bonding as it increases the surface area.

4.6 Contact Angle Test

Figure (4.8 A), shows the contact angle image of untreated rubber, the contact angle was 97^{o}, that means the surface of the untreated rubber is not well-wetted by water and rubber is a hydrophobic material and that it is not compatible with geopolymer paste, that affects the bond strength between rubber and geopolymer paste. In contrarily, Figure (4.8 B), shows the contact angle of rubber treated by Maliec anhydride, the

contact angle was 22°, that indicates that the surface of rubber is well-wetted by water and rubber becomes hydrophilic material, thus, it is more compatible with geopolymer paste, hence, this can enhance the bond strength between rubber and geopolymer paste.

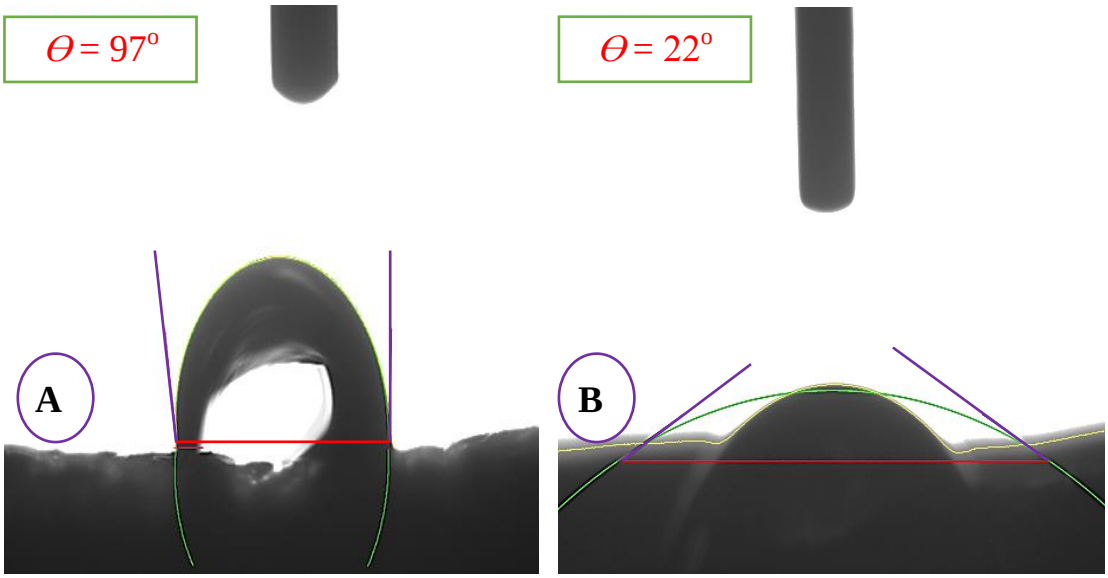


Figure (4.8) The Contact Angle of (A) Untreated Rubber and (B) Treated Rubber by MAn

4.7 Results of Mechanical Test

4.7.1 Compressive Strength

Table (4.9) shows the values of compressive strength of geopolymer paste samples prepared using alkali solution with and without heat treatment. It can be seen that the heat treatment for the alkali solution improves the compressive strength, this can be attributed to the breakdown of the sodium silicates chains, by the NaOH, during the heat treatment, resulting in more number of oligomers that building of the 3D network of geopolymer. It has been observed that the higher Na_2SiO_3/ NaOH ratio lead to higher compressive strength, this result is in agreement with that obtained by many researches work **[12, 88, 93].**

Table (4.9) Compressive Strength of Geopolymer Paste after 28 Days

Sample No.	Compressive strength (MPa)
GN1	41.228
GN2	36.622
GN3	31.633
GN4	43.871
GH1	59.23
GH2	65.75
GH3	80.56
GH4	74.26

Based on that, the heat treatment of alkali solution was used to prepared the geopolymer paste. Also, it is obvious that Na_2SiO_3/NaOH ratio of 3.3 is more better than 3 as it produces geopolymer paste with higher compressive strength, that is why the ratio was used to prepared the geopolymer paste for the lightweight geopolymer concrete. As expected, the lower water content is noticed to be in favor of the compressive strength.

Table (4.10) shows the compressive strength of geopolymer paste with heat treatment of alkali activator. It can be noticed that the compressive strength is high for the mixes that have low water amount, the increase of water leads to increase of porosity, see Table (4.5). Also, as the polymerization reaction is a condensation reaction, the presence of the access water enhances the breakdown reaction and, hence, decrease the strength. The highest obtained compressive strength of geopolymer

paste after 28 days is 117.1 MPa at the ratio of SiO_2/Al_2O_3 of 3.6 and 8 ml of water, this geopolymer was used as binder material to prepared the geopolymer concrete.

Table (4.10) Compressive Strength of Geopolymer Paste with Heat Treatment of Alkali Activator after 28 Days

Batch number	Compressive strength (MPa)
G1	95.8
G2	90.6
G3	90.7
G4	117.1
G5	89.15
G6	56.7
G7	97.3
G8	77.88
G9	75.34
G10	99.58
G11	62.4
G12	48.6

This value of the compressive strength is too higher as compared with that commonly reported for geopolymer, without any addition or reinforcement, as can be seen in Table (4.11). This result can be attributed to many reasons:

1. The effect of heat treatment of the alkali solution.
2. The use of low water content.

3. Curing at low temperature that enhance the exothermic geopolymerization reaction.
4. The use of appropriate geopolymer formulate and Na_2SiO_3/ NaOH ratio.

Table (4.11) Comparison of Compressive Strength of Geopolymer Paste after 28 Days with other Researches

Compressive strength (MP)	Reference
59.4	**[12]**
37.4	**[15]**
85	**[25]**
117.1	**Current study**

The compressive strength of geopolymer concretes are shown in the Table (4.12), the mix GC1 has a compressive strength of 60.6 MPa which is greater than the other mixes, this value indicates that the use of fine aggregate of (554.4 kg) and course aggregate of (1293.6 kg) is favorable as compared to the other mixes. Table (4.13) shows the compressive strength of current study compared with that reported in the literature for geopolymer concrete study.

Table (4.12) The Compressive Strength of Geopolymer Concretes

Batch No.	Compressive strength (MPa)
GC1	60.6
GC2	53.7
GC3	55.7

Table (4.13) Comparison of Compressive Strength Value of Geopolymer Concrete at 28 Days with other Studies

Compressive strength (MPa)	Reference
49	**[12]**
57	**[93]**
59	**[94]**
60.6	**Current study**

Figure (4.9) shows the cubic geopolymer concrete specimens after compression test, it can be seen that the fracture cracks path was through the coarse aggregates, that means that the strength of geopolymer paste and the bond strength between the geopolymer paste and aggregate is higher than the strength of course aggregate.

The Compressive Strength of rubberized geopolymer concrete for treated and untreated rubber are illustrated in Table (4.14), where the compressive strength of rubberized geopolymer concrete with rubber treated by melic anhydride (GM) was greater than the rubberized geopolymer concrete with rubber treated by potassium permanganate (GP) and rubberized geopolymer concrete that have untreated rubber (GN), this is because of the bond strength between the geopolymer paste surface and the higher surface area of the treated rubber surface was high as compared with those of untreated rubber. This result means that maleic anhydride is good coupling agent for rubber.

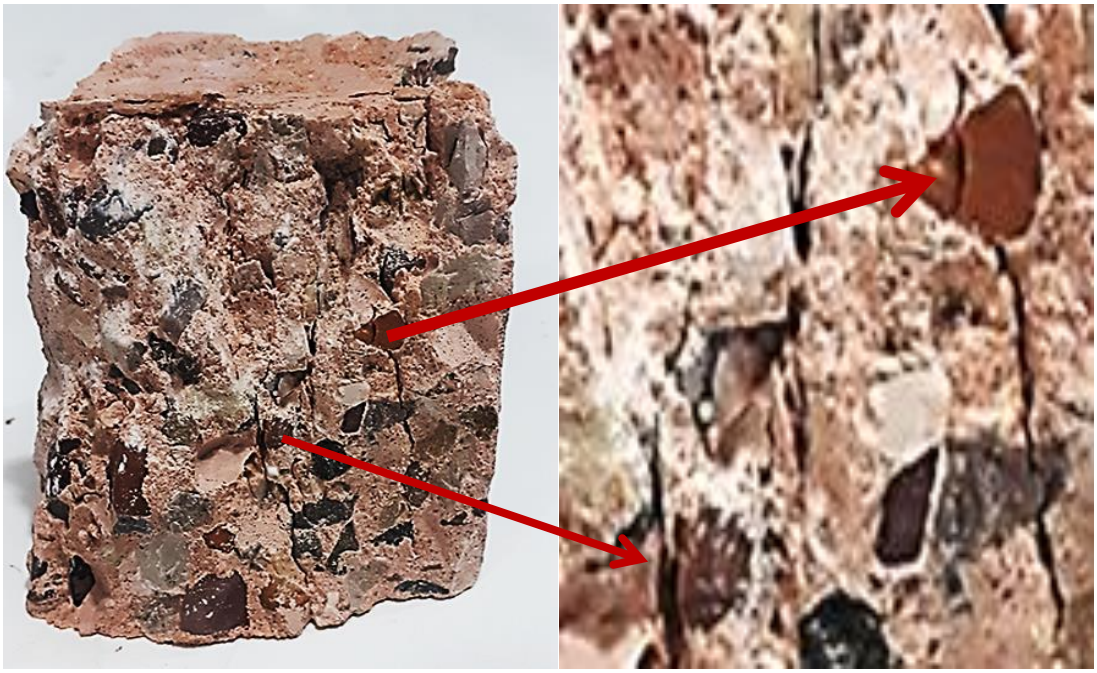


Figure (4.9)The Cubic Geopolymer Concrete Specimens after Compression Test

Table (4.14) Compressive Strength of Rubberized Geopolymer Concrete

Sample	Compressive strength (MPa)
GM	43.3
GP	34.0
GN	29.0

Table (4.15) and Figure (4.10) shows the compressive strength values of lightweight geopolymer concrete after 28 days, where the compressive strength was reduced when the percentage substitution of crumb rubber raises from 0 % to 15 % by volume of both coarse and fine aggregate. This is because the crumb rubber has lower strength than the aggregate and, may be, due to the trapped air that produce pores in the structure of the geopolymer. Also, all samples have compressive strength

higher than 25 MPa indicating that they are suitable for structural applications. The compressive strength of 15% fine rubber was higher than that of 10% fine rubber that have the same amount of course rubber, because of the fine rubber have higher surface area than the course rubber that lead to increase the bond strength in the lightweight geopolymer concrete**.**

Table (4.15) The Compressive Strength of Lightweight Geopolymer Concrete after 28 day

Batches	**Compressive strength (MPa)**
GBR0	60.6
GBR1	41.12
GBR2	35.8
GBR3	30
GBR4	29.2
GBR5	29
GBR6	27.7
GBR7	36.7
GBR8	29.5
GBR9	25.1

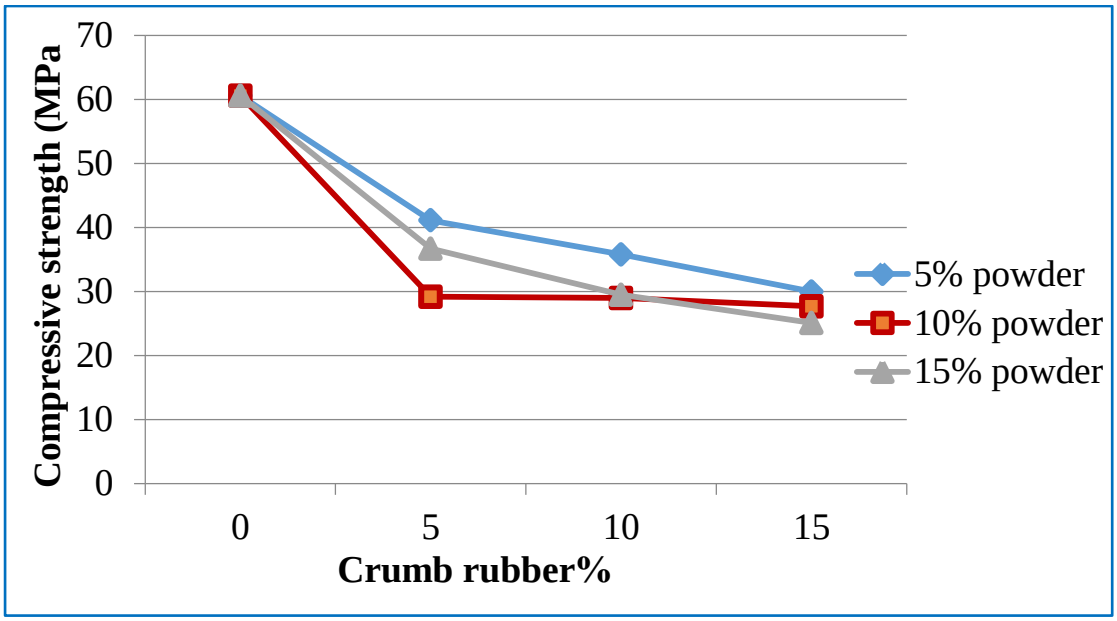


Figure (4.10) Compressive Strength of Lightweight Geopolymer Concrete

However, the values of compressive strength of lightweight geopolymer concrete are still good when compared with literature study at the same replacement percentage of crumb rubber as can be seen in Table (4.16).

Table (4.16) Compressive Strength of Lightweight Geopolymer Concrete with 15% CR after 28 Days Compared with other Studies

Compressive strength (MPa)	References
20.6	**[39]**
15	**[99]**
15.5	**[103]**
25.1	**Current study**

4.7.2 Flexural Strength

Flexural strength of lightweight geopolymer concrete reduced at the proportion replacement of crumb rubber was increased for both fine and coarse aggregate as shown in Table (4.17) and Figure (4.11), but it was increased at the percentage replacement of powder rubber was increased from 5 to 10%, indicating that the powder rubber improves the strength when compared with the crumb rubber. Table (4.18) shows the flexural strength of geopolymer concrete in current study compared with that obtained in other studies.

Table (4.17) Flexural Strength of Lightweight Geopolymer Concrete after 28 day

Batches	Flexural strength (MPa)
GBR0	6.076
GBR1	5.195
GBR2	4.842
GBR3	3.961
GBR4	5.402
GBR5	5.117
GBR6	4.515
GBR7	4.303
GBR8	4.138
GBR9	3.698

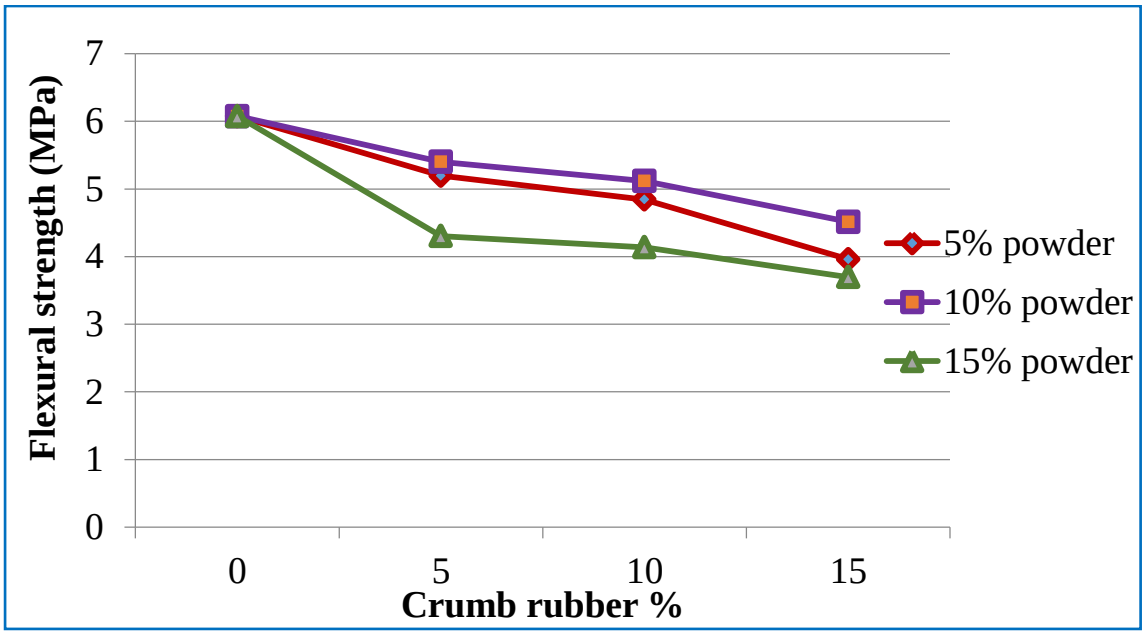


Figure (4.11) Flexural Strength of Lightweight Geopolymer Concrete

Table (4.18) Flexural Strength of Geopolymer Concrete Compared with that Calculated in other Studies

Flexural strength at 28-days (MPa)	Reference
5.54	**[7]**
3.7	**[81]**
2.5	**[104]**
6.07	**Current study**

4.7.3 Damping Ratio of Rubberized Geopolymer Concrete

Figure (4.12) shows the free vibration response of geopolymer concrete with and without CR. Table (4.19) shows the damping ratio of rubberized geopolymer concrete after 28 day, it demonstrates that adding CR has a significant benefit on raising the damping ratio of geopolymer

concrete. The improvement in damping ratio is more pronounced as CR content rises. The specimen which includes 15% by volume of CR has the damping ratio of rubberized geopolymer concrete of about 70% greatest than that to 0% CR of concrete after 28 days.

Table (4.19) Damping Ratio Results of Rubberized Geopolymer Concrete

Sample No.	Damping ratio %
D 0% CR	8.87
D 5% CR	11.4
D 10% CR	12.1
D 15% CR	14.8

This confirmed that the incorporation of CR is able to improve the ability of geopolymer to reduce vibration. The improvement in damping property in the case of geopolymer matrix reinforced with CR may be primarily attributable to two factors; one reason is that adding CR would inevitably introduce some interfaces into the geopolymer matrix. These interfaces have the ability to dissipate energy because they can move slightly and surfaces can slip slightly relative to one another during vibration. Another possibility is that geopolymer matrix might disperse energy with the aid of CR that are viscoelastic materials **[2].**

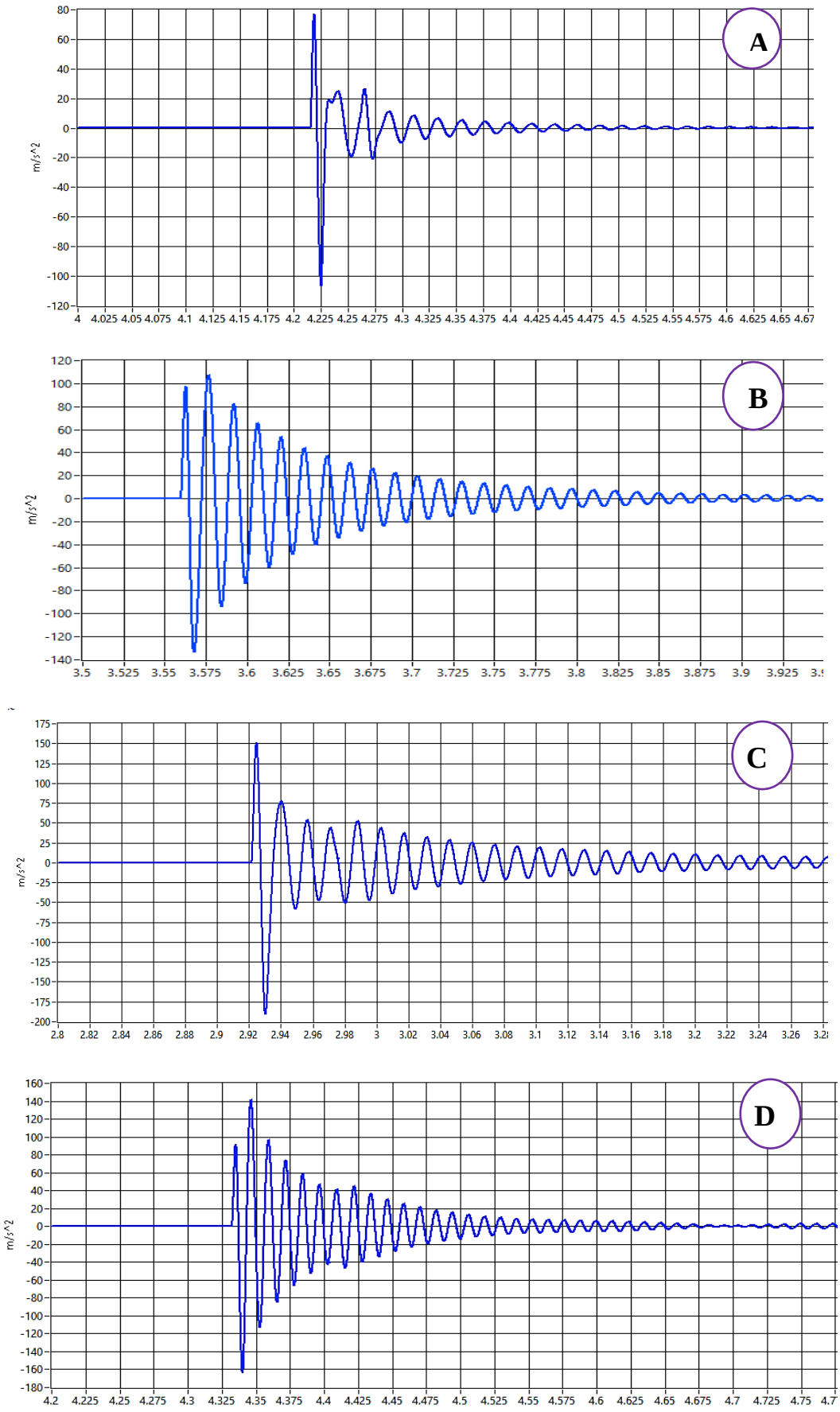


Figure (4.12) Free Vibration Responses of the Specimens, (A) 0% CR, (B) 5% CR, (C) 10% CR, (D) 15 CR

4.8 Microstructure of Lightweight Geopolymer Concrete

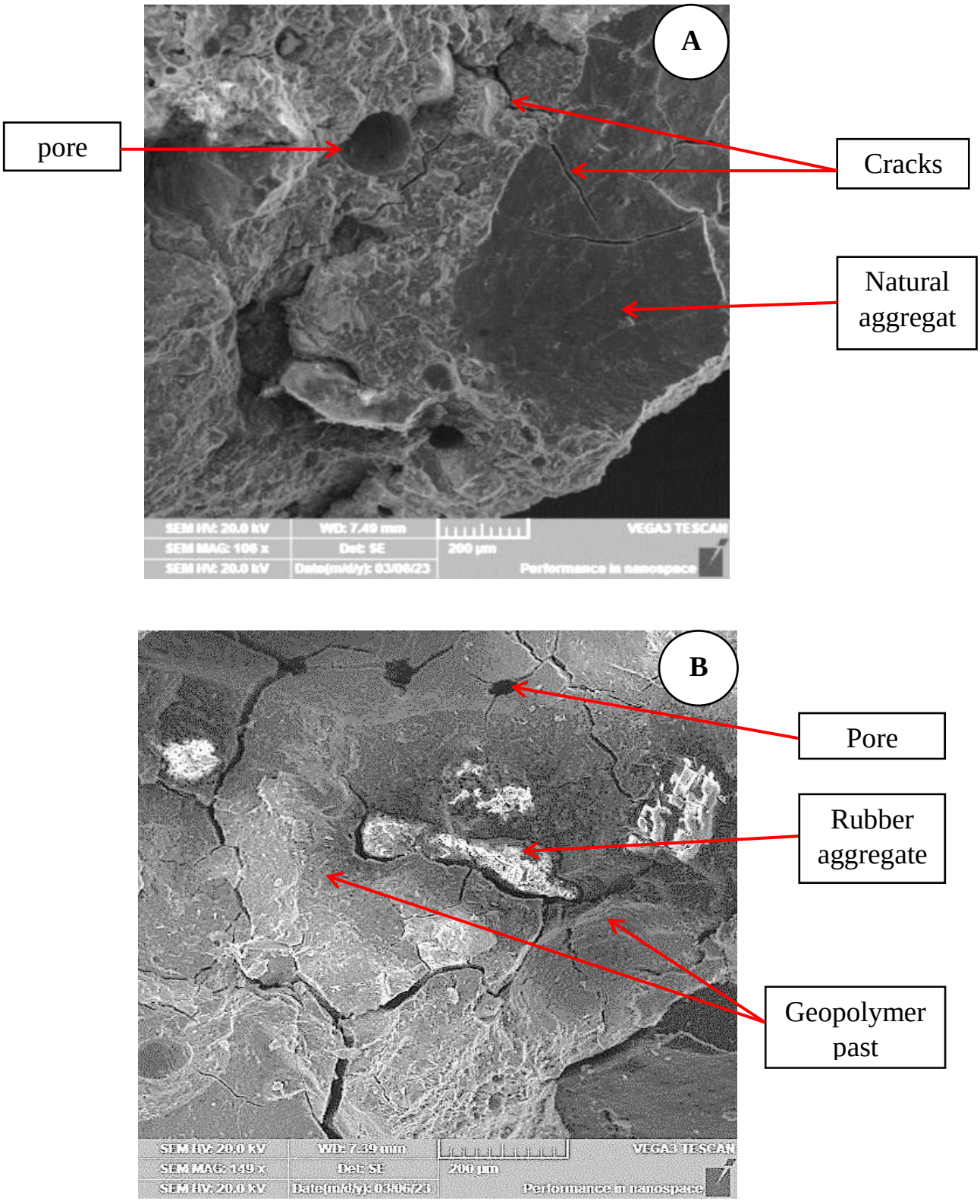
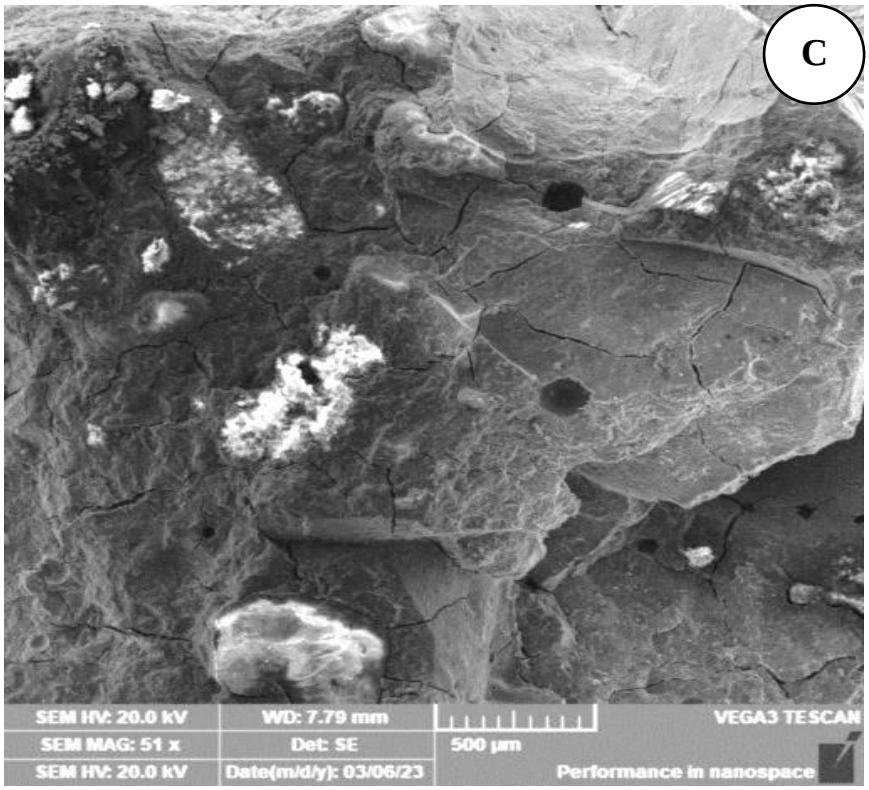


Figure (4.13) SEM Image of Lightweight Geopolymer Concrete after Fracture



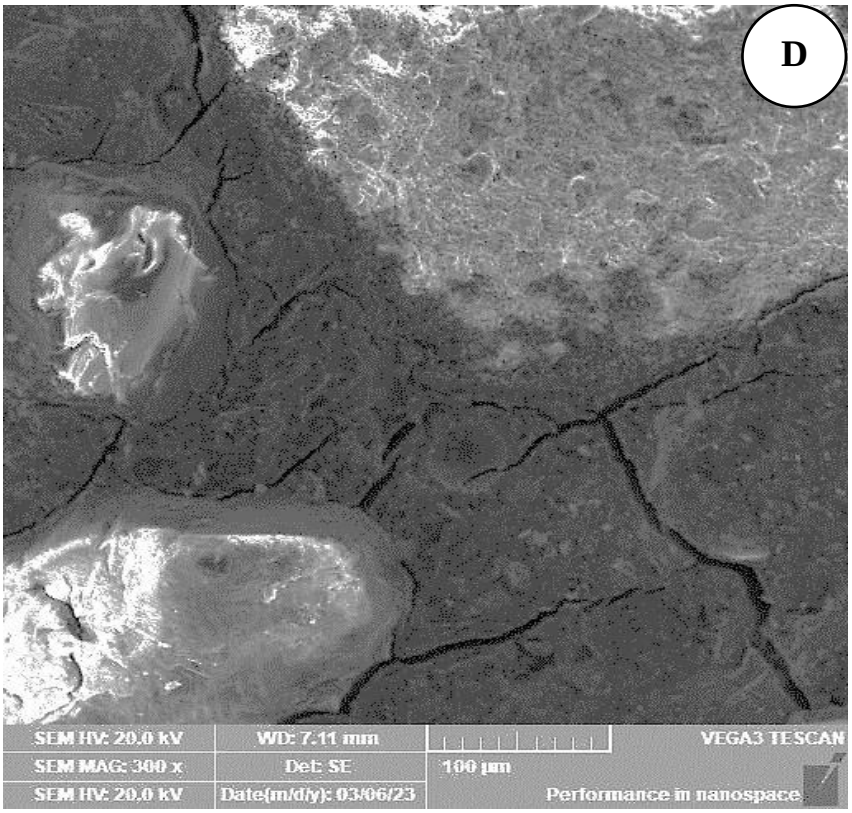


Figure (4.13) Continue

Figure (4.13) shows the SEM-images of lightweight geopolymer concrete after fracture, micro cracks and spherical voids, which can be qualified to air bubbles during the geopolymerization procedure, can be seen. These bubbles result to synthesis the total porosity, it is accentuated that the huge structure found helps confirm the amorphous characteristics of these geopolymers. From Figure (4.13) it can be noticed that the crack path was through the course aggregate, that indicates the strength of internal transition zone was greater than the strength of aggregate. The rubber particles work as branching of crack propagation and dissipated energy of crack.

4.9 Cost and Embodied CO_2 Index Calculations

From calculations of the C_P values of geopolymer concrete and ordinary Portland cement concrete, its equaled to 5.93 $\$/m^3 \cdot MPa$ and 10.3 $\$/m^3 \cdot MPa$, respectively, it is observed that the C_P value of ordinary Portland cement concrete is almost double that of geopolymer concrete. Although the cost of materials for production of geopolymer concrete is higher than that for the ordinary Portland cement concrete, these have been regarded the optimal cost for obtained high strength requirement for structural engineering.

The C_I value of geopolymer concrete of (5 $kg/MPa.m^3$) is lower than that for ordinary Portland cement concrete (20 $kg/MPa.m^3$), this indicate that the environmental friendliness of geopolymer concrete is superior to OPCC. Arbitrated from embodied environmental influence calculation, geopolymer is the most suitable for preparing cleaner concrete and more likely to recommend the wider application of geopolymer concrete.

CHAPTER FIVE

CONCLUSSIONS AND RECOMMENDATIONS

Chapter Five

Conclusions and Recommendations

5.1 Conclusions

In this study, industrial grade starting materials were used to synthesis geopolymer concrete, and recycle waste tyre rubber was used to synthesis of lightweight geopolymer concrete, the effect of heat treatment of the alkali solution on the properties of geopolymer paste and the impact of crumb rubber pre-treatment on the bond strength were investigated. The following conclusion can be driven:

1. The heat treatment of alkali activator is important to increase the compressive strength of geopolymer paste for a value as high as 117.1 MPa.
2. A geopolymer concrete with a high compressive strength of (60.6 MPa) and low density, compared with the ordinary Portland cement concrete, can be prepared without any additives when the alkali solution is subjected to heat treatment before use.
3. The increased of SiO_2/Al_2O_3 ratio and amount of water in the geopolymer paste lead to decrease of the compressive strength and density because of the increase of porosity.
4. The treatment of crumb rubber with MAn improves the bond strength between the rubber and geopolymer paste.
5. Geopolymer concrete with a compressive strength of 60.6 MPa and flexural strength of 6.07 MPa can be obtained via slitting the proper value of Na_2SiO_3/NaOH ratio, the AL_2O_3/Si_2 ratio, amount of water, and the fine and course aggregate.

6. Lightweight geopolymer concrete with adequate mechanical properties and cost can be produced using waste rubber materials with MAn-surface treatment.
7. The damping ratio of rubberized geopolymer concrete was enhanced (8.78 to 14.8%) with increasing replacement percentage of crumb rubber from (0 to 15%).
8. Although the cost of materials for production of geopolymer concrete is higher than that for the ordinary Portland cement concrete, the cost per strength of geopolymer concrete is lower than that for the ordinary Portland cement concrete.
9. The environmental friendliness of geopolymer concrete is superior to OPCC. Arbitrated from embodied environmental influence calculation, geopolymer is the most suitable for preparing cleaner concrete and more likely to recommend the wider application of geopolymer concrete.

5.2 Recommendations

1. Investigate the durability of lightweight geopolymer concrete (chemically resistance , sulphate attack and acid resistance).
2. Synthesis steel reinforcement geopolymer concrete and lightweight geopolymer concrete and investigate there properties.
3. Synthesis lightweight geopolymer concrete with fiber rubber.

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الخلاصة

يتوقع ان يغير الجيوبوليمر مستقبل السمنت البورتلاندي الاعتيادي. ان هدف هذه الدراسة هو تصنيع خرسانة جيوبوليمرية خفيفة الوزن باستعمال ركام المطاط . استعملت المواد الصناعية الرخيصة الثمن (سليكات الصوديوم المائية وهيدروكسيد الصوديوم) لتحضير محلول التنشيط القلوي، استعمل الكاؤلين كمصدر صلب لعجينة الجيوبوليمر. تم استعمال مفروم المطاط كاستبدال جزئي بنسبة حجمية (5%، 10%، 15%) من حجم الركام الطبيعي لإنتاج خرسانة جيوبوليمرية خفيفة الوزن، لتحسين مقاومة الربط بين المطاط وعجينة الجيوبوليمر، تم معاملة مفروم المطاط بمادة (مليكانهايدرايد).

تمت دراسة تأثير المعاملة الحرارية، نسبة السليكا الى الالومينا، وكمية الماء، وكذلك تم دراسة تأثير مفروم المطاط على الخواص الميكانيكية (مقاومة الانضغاط، مقاومة الانحناء، مقاومة الخلع و نسبة الاخماد) والخواص الفيزيائية (الكثافة، نسبة امتصاص الماء والمسامية) للخرسانة الجيوبوليمرية خفيفة الوزن.

بينت هذه الدراسة ان المعاملة الحرارية عامل مهم للحصول عل مقاومة انضغاط عالية، تم الحصول على مقاومة انضغاط (117 ميكا باسكال) للجيوبوليمر باستعمال نسبة سليكا الى الالومينا (3.6) وكمية ماء (8 مل). مقاومة انضغاط (60.6 ميكا باسكال) ومقاومة انحناء (6.076 ميكا باسكال) تم الحصول عليها لخرسانة الجيوبوليمر عند (554.4) كغم من الركام الناعم و(1293.6) كغم من الركام الخشن. نتائج التجربة اظهرت ان المقاومة والوزن للخرسانة الجيوبوليمرية الخفيفة الوزن تقل مع زيادة نسبة الإضافة من مفروم المطاط. وبالعكس فان نسبة الاخماد تزداد بزيادة محتوى المطاط في الخرسانة.

اظهرت المعاملة السطحية للمطاط تحسن كبير في زيادة قوة الربط بين المطاط وعجينة الجيوبوليمر. تم تسجيل نقصان بالوزن للخرسانة خفيفة الوزن بحولي (100) كغم للمتر المكعب الواحد عن الخرسانة الجيوبوليمر الاعتيادية و حوالي (300) كغم مقارنة مع خرسانة السمنت البورتلاندي الاعتيادي.

اخذت بنظر الاعتبار حسابات الكلفة للخرسانة الجيوبوليمرية، ووجدت ان كلفة الخرسانة الجيوبوليمرية لوحدة المقاومة تقريبا نصف قيمة الكلفة لخرسانة السمنت البورتلاندي، وان خرسانة الجيوبوليمر مادة صديقة للبيئة اكثر بكثير من خرسانة السمنت البورتلاندي الاعتيادي.

وزارة التعليم العالي والبحث العلمي
جامعة بابل
كلية هندسة المواد
قسم هندسة السيراميك ومواد البناء

تصنيع خرسانة جيوبوليمرية خفيفة الوزن حاوية على ركام المطاط

رسالة

مقدمة إلى كلية هندسة المواد / جامعة بابل كجزء من متطلبات نيل درجة الماجيستير في هندسة السيراميك

من قبل

ميثم شنين عبد الحسين النصري

بكالوريوس هندسة المواد 2001

دبلوم عالي هندسة السيراميك ومواد البناء 2018

بأشراف

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