

FABRICATION AND TESTING OF GEOPOLYMER BASED EMI SHIELDING MATERIAL FOR AUTOMOTIVE APPLICATION

Submitted in partial fulfilment of the requirements for the award of Bachelor of
Engineering degree in Automobile Engineering

By

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**DEPARTMENT OF AUTOMOBILE ENGINEERING
SCHOOL OF MECHANICAL ENGINEERING**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

**Accredited with Grade "A" by NAAC | 12B Status by UGC | Approved by AICTE
JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI – 600 199**

March – 2021



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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of BH. JASHWANTH VARMA (37860005), D. R. SAI KRISHNA SANJAY (37860028) who carried out the project entitled "FABRICATION AND TESTING OF GEOPOLYMER BASED EMI SHIELDING MATERIAL FOR AUTOMOTIVE APPLICATION" under my supervision from December 2020 to March 2021.

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DECLARATION

I, BH. JASHWANTH VARMA hereby declare that the Project Report entitled “FABRICATION AND TESTING OF GEOPOLYMER BASED EMI SHIELDING MATERIAL FOR AUTOMOTIVE APPLICATION” done by me under the guidance of Dr. V. K. BUPESH RAJA, M.E., Ph.D., at Sathyabama Institute of Science and Technology is submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering degree in Automobile Engineering.

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SIGNATURE OF THE CANDIDATE

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ABSTRACT

The massive rise in utilization and sensitivity of electronic devices across a wide range of commercial, industrial, military and consumer sectors has caused a rapid rise in a electronic pollution which is known as electromagnetic radiation or electromagnetic interference (EMI) which can interfere with the functions of an electronic device and cause the device to malfunction. Therefore the need for an EMI shielding material is in high demand. The growing number of electronic components in a modern day vehicle drives the need to study the application of EMI shielding material. EMI shielding reduces electromagnetic interference among the electronic components, thus avoiding system malfunction and even failure. A geopolymer based EMI shielding material is a cost effective and eco-friendly solution. This research work shall deal with the fabrication of the geopolymer and testing its structural, mechanical and EMI shielding properties. The results that shall be obtained in this study shall elucidate the scope in application of geopolymers as an EMI shielding material. Geopolymers offer a cheaper and eco-friendly alternative to currently available plastic based EMI shielding materials available in the market.

Geopolymers are lightweight materials with good compression strength and can withstand heavy impact loads. They are an alternate to ordinary Portland cements. The geopolymer can be manufactured with various proportions of fly ash, steel slag and river sand. Fly ash and steel slag act as the cementing materials, while river sand is the fine aggregate in the mixture. Graphite powder is added to the geopolymer mortar as the conductive material to help in increasing the EMI shielding effectiveness of the geopolymer. The geopolymer samples were fabricated with varying proportions of graphite powder and the EMI shielding effectiveness of these samples were tested.

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LIST OF SYMBOLS AND ABBREVIATIONS

%	Percentage
Si	Silicon
Al	Aluminium
AAFA	Alkali Activation of Fly Ash
OPC	Ordinary Portland Cement
°C	Degree Celsius
EMI	Electromagnetic Interferences

EMI SE	EMI Shielding Effectiveness
m ³	Cubic Metre
Kg/m ³	Kilograms per cubic metre
gm	Grams
CO ₂	Carbon dioxide
SiO ₄	Silicon-Oxygen tetrahedron
AlO ₄	Aluminium-Oxygen tetrahedron
F	Fahrenheit
PCC	Portland cement concrete
NaOH	Sodium Hydroxide
Na ₂ SiO ₃	Sodium Silicate
F.A.	Fine aggregate
SiO ₂	Silicon dioxide
pH	Potential of hydrogen
wt. %	Weight percentage
dB	Decibels
M	Mega Hertz
GBFS	Ground granulated furnace slag
GHz	Giga Hertz
HCFA	High carbon fly ash
LCFA	Low carbon fly ash
M	Moles
CLSM	Controlled low strength material

Kg	Kilogram
SEM	Scanning electron microscope
EDAX	Energy dispersive X-ray spectroscopy
μm	Micrometre

CHAPTER 1

INTRODUCTION

1.1 GEOPOLYMER

Geopolymer technology can possibly decrease greenhouse gas emissions by 80% in light of the fact that high temperature calcination isn't needed. It additionally displays ceramic kind of properties with great protection from fire at extreme temperature. Also geopolymer are indistinct to the semi- crystalline likeness of certain zeolite like materials along with properties like high heat and corrosion resistance and high strength materials. Materials that utilize lesser nature resources require less energy and emit less carbon dioxide, are described as green materials.

An alkailine may be utilized to react with silicone and the aluminium in the materials, which may be a natural mineral or an industrial by-product like fly ash to produce binder material. This process is known as alkali activation of the fly ash (AAFA), this is a physical- chemical process where solid material in the form of powder is mixed together with concentrated alkali solution at certain proportions to form a paste that can be moulded and stored.

The physical behaviour of a geopolymer is similar to that of Ordinary Portland Cement (OPC). Geopolymers have better compression strength, heat resistance, fire resistance, and corrosion resistance compared to ordinary cement. Geopolymers also exhibit a certain level of resistance to non-ionizing radiations, such as electromagnetic waves (EM waves). In this study, we briefly investigate this property of the geopolymer to validate the EMI shielding effectiveness of the geopolymer. We enhance EMI SE (shielding effectiveness) of geopolymer by introducing conductive material into the matrix in the form of graphite powder.

Volume of the geopolymer samples is designated as 0.000172 m^3 (cubic metres). The geopolymer mortar consists of the raw materials: fly ash, steel slag, fine aggregate (river sand), sodium hydroxide, sodium silicate and graphite powder in varying quantities. The data provided below refers to the quantities required to

prepare one geopolymer sample. These quantities are calculated as per the standard quantities of cementing material, fine aggregate and binding material per 1 kg/m³ of geopolymer.

Table 1.1 Geopolymer Mortar Composition

Fly Ash	68 gm.
Steel Slag	28 gm.
Fine Aggregate (F.A) / River Sand	190 gm.
Sodium Hydroxide (NaOH)	20 gm.
Sodium Silicate (Na ₂ SiO ₃)	40 gm.
Graphite powder	0 gm./ 18 gm./ 34 gm./ 60 gm.



Fig: 1.1: Geopolymer Sample

1.1.1 Characteristics of Geopolymer samples

As the greenhouse gases levels are on the rise in the climate, and the temperature of the climate builds, living organisms of the planet experience change. The main ozone harming substance is carbon dioxide (CO_2). The concrete industry is distinguished as perhaps the main consumers of carbon-based powers. Concrete creation produces 5–8% of the world's CO discharges. For the arrangement of certain issues, inorganic polymer concrete has been proposed. As they give the possibility to exceptionally huge (on the request for 80%) CO_2 reductions while offering almost similar performance in numerous sectors.

When an aluminosilicate solid form reacts with concentrated, aqueous alkali hydroxide and a silicate solution, it generates synthetic alkali aluminosilicate material referred at “geopolymer”. They also widely known as inorganic polymers. Polymerization process occurs when aluminosilicates are made to dissolve and SiO_4 and AlO_4 units are released in the solution. During this reaction, water slowly splits out and the tetrahedral units get linked alternatively to the polymeric precursors due to sharing of oxygen atoms between the tetrahedral units hence forming an amorphous geopolymer.

The geopolymers may showcase a wide range of properties and characteristics. This depends on raw materials selected and the processing conditions, including

high compressive resistance, low shrinkage, time for setting, resistance against acids, resistance to fire and low thermal conductivity.

1.2 MATERIALS

1.2.1 Fly Ash

Fly ash is naturally occurring material that is obtained from the process combustion of coal. It is mineral which almost similar to volcanic ash. During the combustion of coal in a power generation plants, temperatures may reach almost approximately 28000 F. These minerals occur naturally by combustion of coal include bottom ash as well as fly ash.

Presently, about 20 million metric tons of fly ash is utilized every year for various applications. A few engineering based applications also include Portland Cement Concrete (PCC), road base stabilization, grouts, structural fills and as asphalt filler.



Fig: 1.2: Fly Ash

1.2.1.1 Characteristics of Fly Ash

Fly ash usage, primarily in concretes, offers many benefits for the environment. which include, concrete road's life span is increased and structures are also enhanced by improving the durability of concrete, there is also reduction in energy usage and emission of greenhouse gases and other harmful air emissions when fly ash is used, the amount of coal combustion products that are supposed to be disposed of in landfills is reduced, and leads to conservation of other natural resources and materials.

1.2.1.2 Physical Characteristics of Fly Ash

The fly ash is a fine-grained material that is mainly composed of spherical and glass-like particles. A few ashes are found to also contain irregular or angular particles. Fly ash is a pulverized fuel ash that is obtained from fuel gases using a process such as cyclone-separation or electrostatic precipitation.

1.2.1.3 Chemical composition of Fly Ash

The chemical composition of fly ash is dependent on the sources of the coal used and also on various operating parameters of the boilers. Hence, the quality of it varies from one source to other and also within the source as well. Fly ash has good cement like properties but it takes long curing time when compared to cement.

In the Geopolymer, fly ash acts as a binder material whereas the alkaline solution acts as the activator. Both fly ash and the alkaline activator undergo the process of geopolymerization to produce an aluminosilicate gel.

1.2.2 Steel Slag

The steel slag by-product is obtained from steel manufacturing, is obtained at the time of separation of molten steel from other impurities present in the steel-making furnace. Steel slag occurs in the form of a molten melt and it is a complex solution made up of silicates and also oxides which solidify upon cooling.

Most of the furnace slag is either recycled for use aggregate, excess steel slag obtained from other operations (raker, ladle, clean out, or pit slag) is usually sent for disposal at the landfills. Steel slag can usually be obtained from slag processors who collect the slag from various steel-making facilities.

Steel slag that is destined to be used as an aggregate must be stockpiled outdoors for several months in order to expose the material to moisture through natural precipitation or by spraying water. The purpose of such storage is to allow potential destructive hydration and its associated expansion to take place prior to use of the material in aggregate applications. There are many variations in the amount of time required for adequate exposure to the elements. Up to 18 months may be required to hydrate these expansive oxides.



Fig: 1.3: Steel slag

1.2.2.1 Properties of Steel Slag

- Aggregates of steel slag are highly angular in shape and have a rough surface texture. They also have high bulk specific gravity and moderate water absorption property (less than 3%).
- Steel slag chemical composition is usually expressed in terms of simple oxides which are calculated from elemental analysis which is determined by x-ray

fluorescence method.

- Steel slag is mildly alkaline in nature, with a pH level usually in the range of 8 to 10. However, the pH of the leachate obtained from steel slag can sometimes exceed 11, a level that can be corrosive to aluminium or galvanized steel pipes which are placed in direct contact with slag.
- Processed steel slag has favourable mechanical properties required for aggregate usage; these include good abrasion resistance, good soundness characteristics, and also high bearing strength.
- Steel slag aggregates have high heat capacity due to which they have been observed to retain heat considerably longer than conventional natural aggregates. This heat retention property of steel slag aggregates can be advantageous in the process of hot mix asphalt repair work in cold weather.

1.2.3 River Sand

Sand is naturally occurring material in granular form. It is composed of finely divided rocks and mineral particles. It is characterized by size, being finer than gravel but coarser than silt. Sand can also be referred to a textural class of soil or soil type which contains more than 85% of mass sand-sized particles. The sand composition greatly varies, depending on the local rock sources and other conditions, but most common constituent of sand in inland continental areas and non- tropical coastal regions is silica (silicon dioxide, or SiO_2), usually occurring in form of quartz.

Second most common type of sand is calcium carbonate, for example, aragonite, which been mostly created, over past billion years, by numerous forms of life, like coral and shellfish. For example, it is the most common form of sand found in areas where coral reefs have been dominating the ecosystem for millions of years. Sand is a non-renewable natural resource over human time scales and is in high demand in recent times.



Fig: 1.4: River Sand

1.2.4 Sodium Hydroxide

Sodium hydroxide (NaOH) is a highly caustic substance which can be utilized to neutralize acids and prepare sodium salts. Sodium hydroxide is in the form of a white crystalline odourless solid at room temperatures. It absorbs moisture from the atmosphere. When dissolved in water or when neutralized by an acid it liberates heat. This heat may be sufficient to ignite combustible materials. Sodium hydroxide is very corrosive in nature. It is generally used as a solid or as a solution with 50% concentration. Other common names of sodium hydroxide include lye and caustic soda. Sodium hydroxide is used in manufacture of soaps, rayon, paper, explosives, dyestuffs, and petroleum products. Sodium hydroxide is also used in processing of cotton fabrics, laundering and bleaching, cleaning metals and in processing, in oxide coating, electroplating, and also electrolytic extraction. It is most commonly present in commercial drain cleaners and oven cleaners.

1.2.4.1 Properties of Sodium Hydroxide

The NaOH modules determines the physical properties of sodium hydroxide (caustic soda) solutions in a temperature range of 20°C to 100°C with concentrations from 0 to 50 wt. % NaOH. Sodium hydroxide is used in preparing

geopolymer samples as a part of our first phase of the experiment, normally we see addition of water in case of Portland cement, but in geopolymer, we use sodium hydroxide and sodium silicate solution and we make a mixture by using sand. The NaOH - Na₂SO₃ solution is taken at 1:2 ratio in the current study.



Fig: 1.5: Sodium Hydroxide Pellets

1.2.5 Sodium Silicate

Sodium silicate, commonly referred to as "water glass" or "liquid glass", is popular due to a wide range of commercial and industrial applications. It is mostly composed of oxygen-silicon polymer backbone accommodating water in the molecular matrix pores. Sodium silicate products are usually manufactured as solids or thick liquids, depending on the usage requirement. For example, water glass acts as a sealant material in metal components. Even though, sodium silicate manufacturing industry is mature, research is still being carried out currently for newer applications, because of its heat conductive properties. Sodium silicate is a versatile, inorganic chemical made by a combination of sand and soda ash (sodium carbonate) in various ratios at high temperatures. The process yields a variety of products, each with unique chemistry that is useful in many industrial and commercial applications.



Fig: 1.6: Sodium Silicate

1.2.5.1 Properties of Sodium Silicate

Sodium silicates have a wide range of useful properties not shared by any other alkaline salts. This uniqueness, combined with their low cost, results in their application in a wide range of industries.

Sodium silicates are utilized in industries as adhesives, detergents, ingredients in cleaning compounds, cement, binders, and also unique coatings, as well as coagulant aids, anti-corrosives, zeolites, etc. The different properties and functional characteristics of silicates can be used to effectively and economically solve various problems arising in different industrial and chemical processes. Silicates which are more siliceous (i.e., with a ratio of 2.8 to 3.2) are utilized as adhesives or binders, due to their higher composition of silica polymer. These materials remove the amounts of water, which are then converted from a liquid to solid. The advantages of sodium silicate adhesives are their ability to expand; and a controllable index adjustment across broad ranges; the formation of a rigid layer that is a strong, permanent seal resistant to tearing and mild resistance to heat and water.

In our study, we used only air curing to cure the geopolymer samples. The curing period is 28 days. We have observed that as the curing time is directly proportional

to the compression strength of samples. i.e., as curing time is increased, compression strength also increases. For each composition, three samples were made.

1.2.6 Graphite Powder

Graphite is in the form of a crystalline carbon material and also the most stable form allotrope of carbon under standard conditions. It is also the only non-metallic conductor of electricity. The atoms are arranged in a hexagonal shape in graphite and it occurs naturally in this form. Graphite has a wide range of applications in various industrial and commercial sectors. Graphite can also be referred to as “black lead” or “plumbago”. Graphite powders are used as mould release lubricants, powder metallurgy release agent, filler materials for various composites, plastics and rubbers; to prepare conductive dry moulds and conductive liquids.

Synthetic graphite powders are manufactured by using petroleum coke, pitch coke, natural graphite and carbon black. These raw materials are ground into fine powders by ball mills and the resulting powder is conditioned, baked at very high temperatures and compressed into moulds. The resultant material heat treated at extremely high temperatures excluding oxygen. This process is called graphitization, where amorphous carbon precursor is converted into crystalline graphite.



Fig: 1.7: Graphite Powder

1.2.6.1 Properties of Graphite Powder

Graphite has the unique ability of absorbing fast moving particles. This property along with graphite being the only non-metallic electrical conductor makes it an excellent electromagnetic radiation absorbent. Extensive research has been conducted on electromagnetic radiation absorption properties of graphite and it is proven to be able to absorb both ionizing and non-ionizing radiations.

In this study graphite powder is introduced into the geopolymer matrix in the form of a conductive filler to enhance its EMI shielding effectiveness. Graphite has been introduced to the geopolymer matrix at various proportions: 0 wt. %, 4.9 wt. %, 8.9 wt. % and 14.6 wt. % of the geopolymer.

CHAPTER 2

LITERATURE SURVEY

Pablo Moreno-Torres [ETAL] have reviewed the various sources and effects of EMI radiation on passengers in electric vehicles. They have discussed the effects of short-term and long-term exposure of passengers to EMI radiations originating from various components in an electric vehicle and the main sources of these magnetic fields and their properties. This review also discusses the various guidelines and standards in place to limit the exposure to such radiations.

S. Geetha [ETAL] have extensively reviewed the various methods and materials employed in shielding EMI radiations and measuring their effectiveness. Most commonly used methods to measure the EMI shielding effectiveness of a material are: (i) Open Field / Free Space Method, (ii) Shielded Box Method, (iii) Coaxial Transmission Line Method, (iv) Vector Network Analysis. The study compares the shielding effectiveness of metal based composites, plastic composites, a combination of both, and carbon filler materials in blocking EMI radiations. However it is also highlighted that, Carbon based shielding materials suffer from limited mechanical flexibility and metal based shielding materials are affected by heavy weight, corrosion and difficulty in tuning their shielding efficiencies.

Hongtao Guan [ETAL] have investigated the progress and prospective future of EMI shielding / Absorption properties of Cement-based materials. Cement based materials are readily available and have good environmental adaptability. The EMI shielding effectiveness of these materials can be enhanced by introducing a conductive filler material. Effectiveness of various metal fillers and carbon fillers have been discussed in this paper. It is to be noted that a sample with 30.0 vol% Graphite powder, a specimen with about 3 mm thickness can give a shielding effectiveness of 10–40 dB in the frequency range 200–1600 MHz.

Dimuthu Wanasinghe [ETAL] have conducted a study on the effect of varying proportions of cement to water ratio, fly ash, slag on the EMI shielding effectiveness of the mortar. The primary additives of the mortar are fly ash (FA) and ground granulated blast furnace slag (GBFS). EMI shielding tests were carried out within 30 MHz to 1.5 GHz frequency range as per ASTM D4935 – 18. Maximum EMI shielding values of 3.38 dB and 5.06 dB were obtained at a frequency of 1.5 GHz, when the FA content was 1.8 with a W/C ratio of 0.4 and GGBFS content of 1.2 with a W/C ratio of 0.4, respectively.

S. Lim [ETAL] have fabricated a controlled low strength material (CLSM) which has conductive properties. The matrix of this CLSM consists of Fly ash, Slag, Sand, Cement. Here two types of fly ash were utilized in different samples, namely high carbon fly ash (HCFA) and low carbon fly ash (LCFA). Copper slag was added as conductive filler. The effect of substitution of a fine aggregate (i.e. sand) with copper slag on the flow consistency of the CLSM was found to be negligible. Various experiments, including flow consistency test, bulk density measurement, compression test, and electrical conductivity measurement were conducted on the electrically conductive CLSM.

V. K. Sachdev [ETAL] have studied the EMI shielding effectiveness of Graphite dispersed in a matrix of acrylonitrile butadiene styrene (ABS) composite. The samples were prepared using compression moulding method, where graphite was taken at varying proportions of 0%, 5%, 10%, 15% and 20% of the total weight. Electrical conductivity and EMI shielding effectiveness of the samples were tested and compared. A maximum of 60dB EMI SE (Shielding Effectiveness) was achieved at 15% wt. of graphite.

Jingyao Cao [ETAL] Studied the EMI shielding effectiveness of Graphite as both an admixture and as a coating on cement. Graphite particles of size 0.7-0.8 μm

were used to prepare a colloidal solution with 22 wt. % graphite. The admixture proved to be a good enhancement to the EMI shielding effectiveness of the cement paste with 22 dB at 1 GHz frequency. Graphite in the form of a coating of 0.3 mm thickness, exhibited a shielding effectiveness of 11dB.

Rashida Mohamed Hamidi [ETAL] studied the effect of NaOH concentration on the geopolymerization process of a fly ash based geopolymer. The influence of NaOH concentration in the range of 4 M to 18 M was studied. The surface morphology and mechanical properties of the geopolymer were analysed. Based on the results, it was determined that the optimum NaOH concentration was 12 M where the geopolymer exhibited excellent mechanical properties.

CHAPTER 3

AIM AND SCOPE

3.1 AIM

The aim of this project is to fabricate an EMI shielding material by utilizing readily available and eco-friendly industrial by-products. The idea behind this project is to reuse the industrial waste products such as fly ash and steel slag and river sand which are eco-friendly as well. This geopolymer has good EMI shielding effectiveness and offers an eco-friendly alternative to currently available plastic based materials in the market.

3.2 SCOPE

- To fabricate a geopolymer that can be effectively utilized for shielding against electromagnetic interferences in a vehicle.
- To offer a better and eco-friendly alternative to currently available non bio-degradable EMI shielding materials.
- To offer a cheaper product by utilizing low cost and readily available industrial by-products that are eco-friendly as well.

CHAPTER 4

METHODOLOGY AND EXPERIMENTAL SET-UP

4.1 WORK MATERIALS

The data represented below clearly signifies the work materials that were used for the process. The main work materials utilized in the process were fly ash, steel slag and river sand for making geopolymer samples.

4.2 COLLECTION OF MATERIALS

Initially fly ash was gathered along with sodium hydroxide, sodium silicate and graphite powder. Fly ash was kept under sunlight for half a day in order to dry it. Sodium silicate and sodium hydroxide was normally brought at a quantity of 2kg sodium hydroxide and 5kg of sodium silicate. Steel slag was converted into fine powder by ball milling.

- Fly Ash
- Steel Slag
- River Sand
- Sodium Hydroxide
- Sodium Silicate
- Graphite Powder

4.3 PROCESS

The process was divided into 5 phases:

1. Readyng the geopolymer moulds.

2. Preparing the geopolymer mortar.
3. Pouring the geopolymer into the moulds.
4. De-moulding the geopolymer from the moulds after partially drying.
5. Curing stage.

The following tables list out the various quantities of materials used to make the geopolymer samples with varying proportions. The below quantities of various samples are obtained at the specified 14 molar concentration of solution.

Table 4.1: Composition of Geopolymer Sample 1

Fly Ash	68 gm.
Steel Slag	28 gm.
River Sand	190 gm.
NaOH	20 gm.
Na ₂ SiO ₃	40 gm.
Graphite Powder	0 gm.

Table 4.2: Composition of Geopolymer Sample 2

Fly Ash	68 gm.
Steel Slag	28 gm.
River Sand	190 gm.
NaOH	20 gm.
Na ₂ SiO ₃	40 gm.
Graphite Powder	18 gm.

Table 4.3: Composition of Geopolymer Sample 3

Fly Ash	68 gm.
Steel Slag	28 gm.
River Sand	190 gm.
NaOH	20 gm.
Na ₂ SiO ₃	40 gm.
Graphite Powder	34 gm.

Table 4.4: Composition of Geopolymer Sample 4

Fly Ash	68 gm.
Steel Slag	28 gm.
River Sand	190 gm.
NaOH	20 gm.
Na ₂ SiO ₃	40 gm.
Graphite Powder	60 gm.

4.3.1 Process Layout



Fig: 4.1: NaOH Solution



Fig: 4.2: Sodium Silicate



Fig: 4.3: Fly Ash



Fig: 4.4: River Sand



Fig: 4.5: Steel Slag



Fig: 4.6: Graphite Powder



Fig: 4.7: Dry Ingredients Mix



Fig: 4.8: Geopolymer Mortar

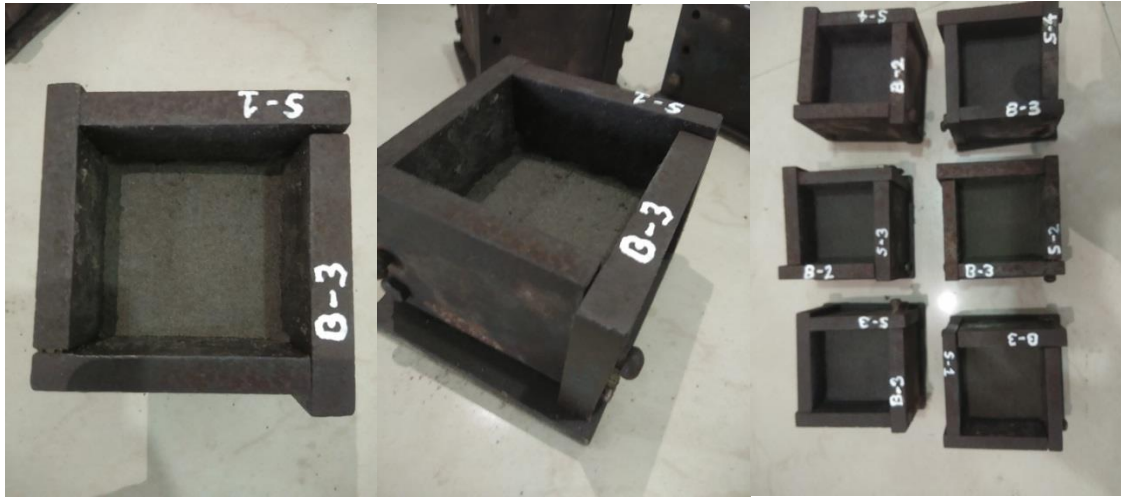


Fig: 4.9: Setting the Geopolymer into Mould

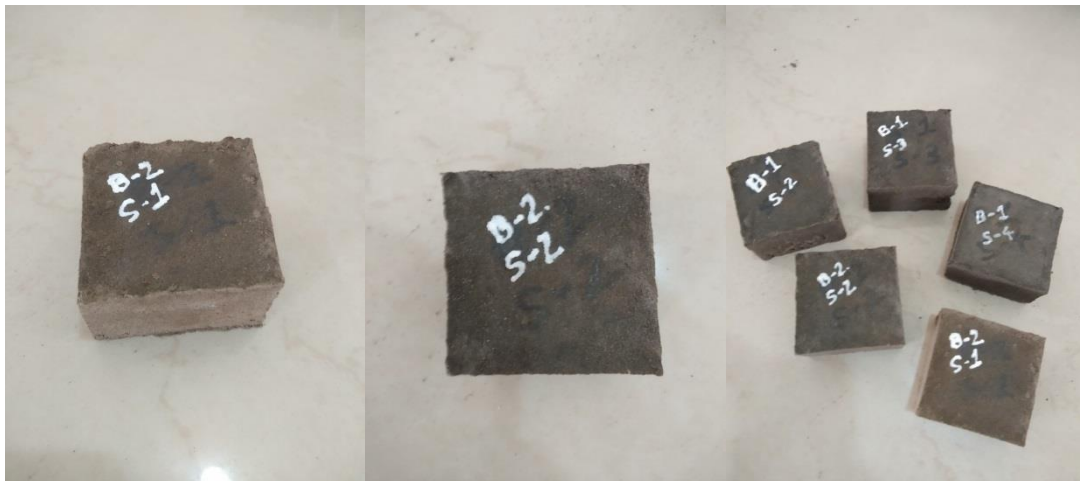


Fig: 4.10: De-moulding the Geopolymer

4.3.2 Experimental Procedure

- The geopolymer moulds are readied and cleaned using a cloth dipped in oil.
- The raw materials required for the geopolymer, i.e., fly ash, steel slag, fine aggregate (river sand), graphite powder, sodium hydroxide and sodium silicate are taken into separate containers and kept aside.
- Fly ash is taken at 1:3 ratios with river sand. All the dry materials, i.e., fly ash, steel slag, river sand and graphite powder are mixed evenly as per the appropriate proportions and kept aside.

- Now we have to prepare a solution of sodium hydroxide. We need to prepare a solution of 8 M. We take 100 ml of water and add the NaOH pellets as per the quantity calculated by molarity formula. The solution must be prepared in a glass container, as it is an exothermic reaction. The prepared solution must be set aside for at least 1 hour.
- After 1 hour, a solution of NaOH – Na₂SO₃ is prepared at a ratio of 1:3.
- Now, both the powdered mixture and liquid solution are mixed together evenly to make the geopolymer mortar. The solution is poured gradually with one hand, while mixing the paste with the other.
- The geopolymer mortar is poured into the mould and pressure is applied to avoid any air cavities in the sample.
- After a short period of time, the geopolymer is de-moulded and set aside for curing for 28 days.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 SEM ANALYSIS WITH EDAX DATA

5.1.1 Fly Ash

5.1.1.1 Fly Ash SEM Analysis

View000

jeol 1/1

Title	: IMG1
Instrument	: JCM-6000PLUS
Volt	: 15.00 kV
Mag.	: x 50
Date	: 2021/03/09
Pixel	: 512 x 384

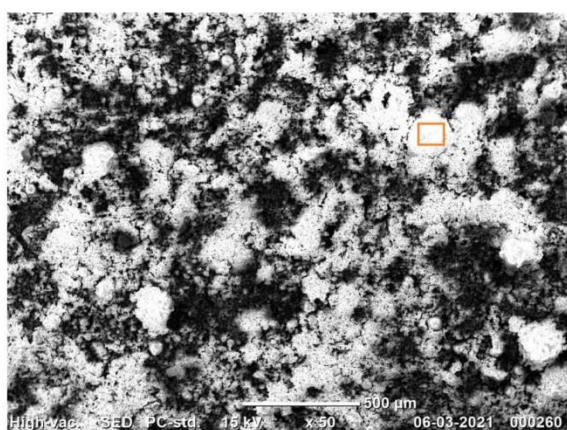


Fig: 5.1: Fly ash SEM image (500μm)

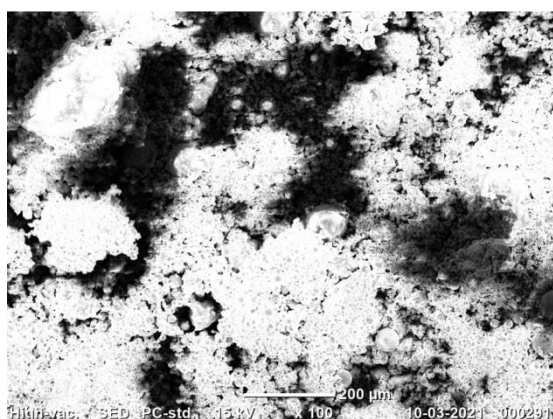


Fig: 5.2: Fly ash SEM image (200μm)

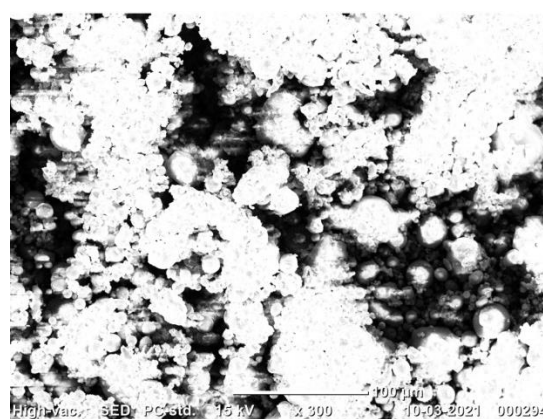


Fig: 5.3: Fly ash SEM image (100μm)

5.1.1.2 Fly Ash EDAX Data

Table 5.1: Fly Ash EDAX Data

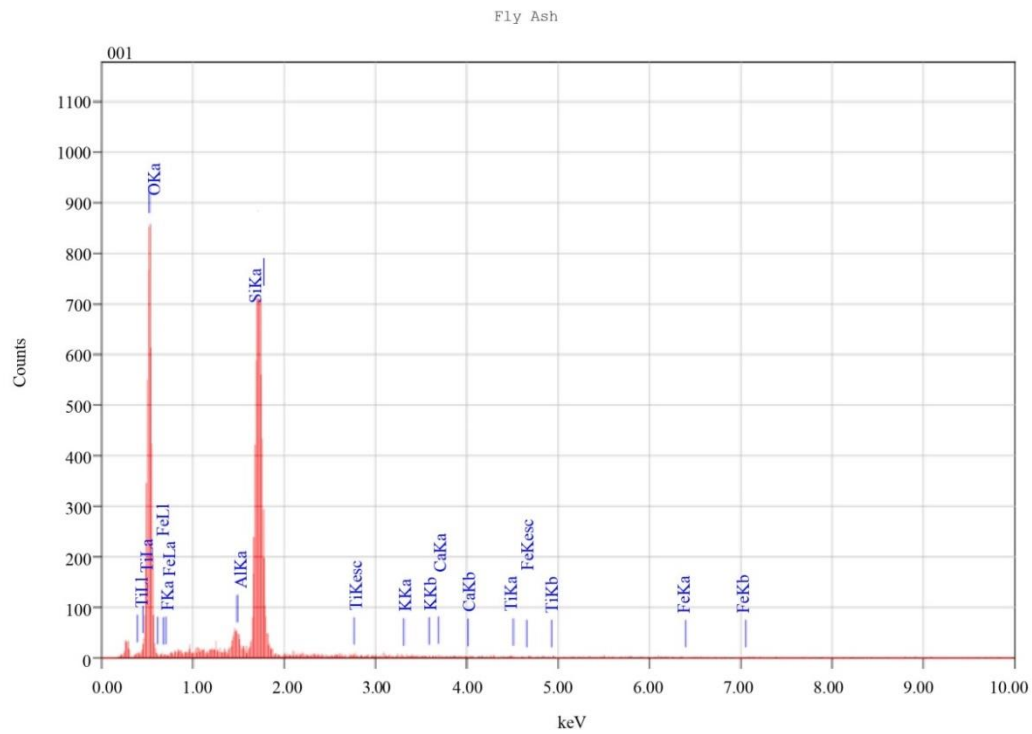


Table 5.2: Fly Ash Composition

Element	Mass (%)
OK	57.1
FK	1.28
AlK	15.73
SiK	24.21
KK	0.32
CaK	0.23
TiK	0.69
FeK	0.44

Acquisition Parameter
Instrument : JCM-6000PLUS
Acc. Voltage : 15.0 kV
Probe Current: 7.47500 nA
PHA mode : T3
Real Time : 50.51 sec
Live Time : 50.00 sec
Dead Time : 1 %
Counting Rate: 263 cps
Energy Range : 0 - 20 keV

5.1.2 Graphite Powder

5.1.2.1 Graphite Powder SEM Analysis

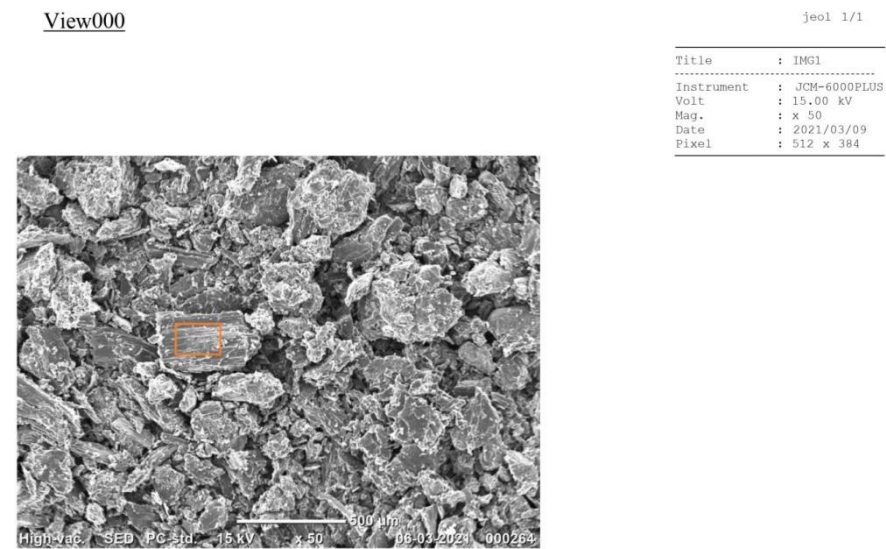


Fig: 5.4: Graphite Powder SEM image (500µm)

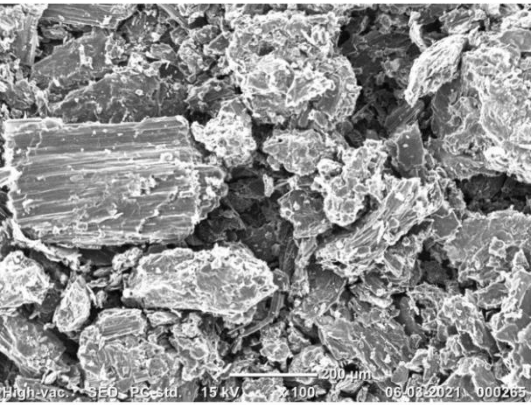


Fig: 5.5: Graphite Powder SEM image
(200µm)

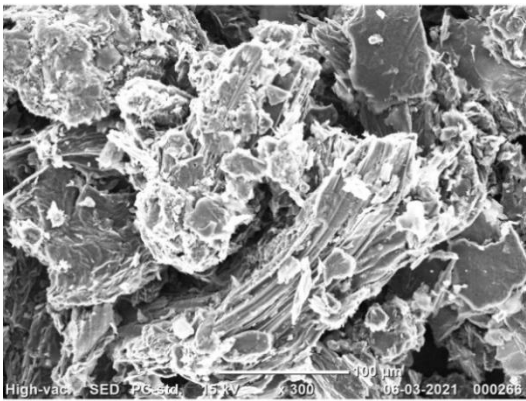


Fig: 5.6: Graphite Powder SEM image
(100µm)

5.1.2.2 Graphite Powder EDAX Data

Table 5.3: Graphite Powder EDAX Data

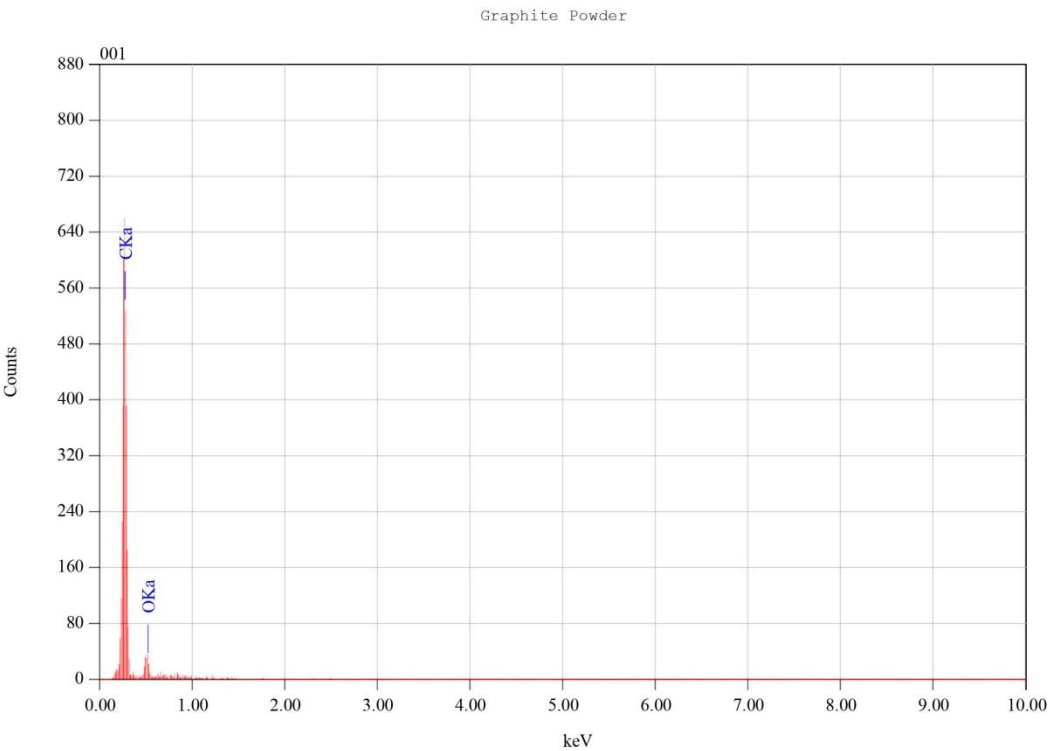


Table 5.4: Graphite Powder Composition

Element	Mass (%)
OK	14.30
CK	85.70

Acquisition Parameter
Instrument : JCM-6000PLUS
Acc. Voltage : 15.0 kV
Probe Current: 7.47500 nA
PHA mode : T3
Real Time : 50.51 sec
Live Time : 50.00 sec
Dead Time : 1 %
Counting Rate: 263 cps
Energy Range : 0 - 20 keV

5.1.3 River Sand

5.1.3.1 River Sand SEM Analysis



Fig. 5.7: River Sand SEM image (500µm)

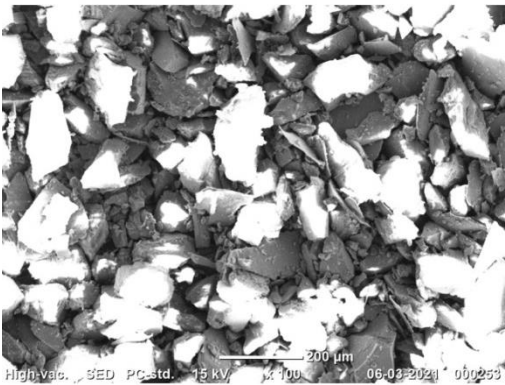


Fig. 5.8: River Sand SEM image
(200µm)

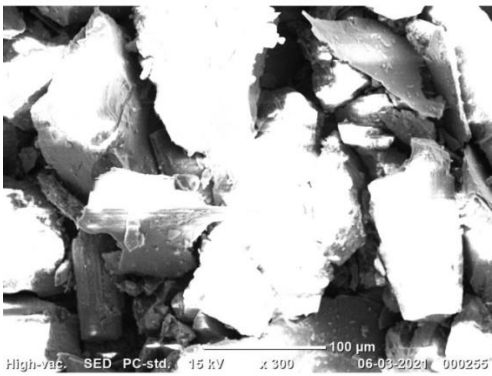


Fig. 5.9: River Sand SEM image
(100µm)

5.1.3.2 River Sand EDAX Data

Table 5.5: River Sand EDAX Data

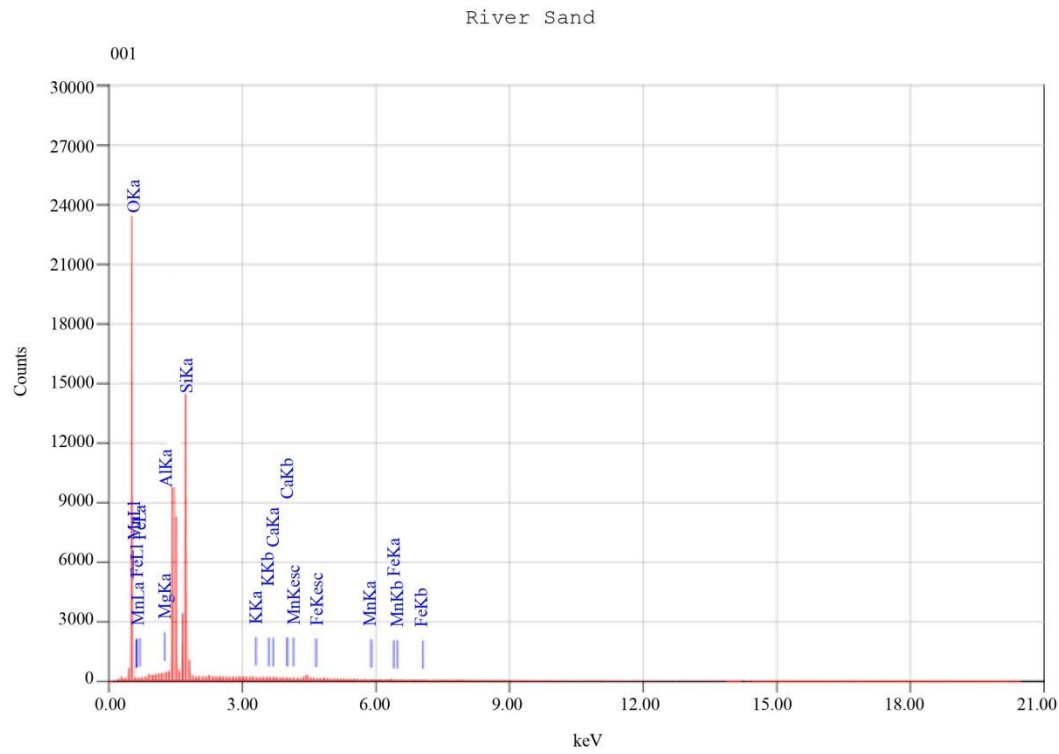


Table 5.6: River Sand Composition

Element	Mass (%)
OK	57.61
MgK	0.44
AlK	5.40
SiK	33.40
KK	0.50
CaK	0.35
FeK	2.30

Acquisition Parameter
Instrument : JCM-6000PLUS
Acc. Voltage : 15.0 kV
Probe Current: 7.47500 nA
PHA mode : T3
Real Time : 50.51 sec
Live Time : 50.00 sec
Dead Time : 1 %
Counting Rate: 263 cps
Energy Range : 0 - 20 keV

5.1.4 Steel Slag

5.1.4.1 Steel Slag SEM Analysis



Fig: 5.10: Steel Slag SEM Image (500µm)

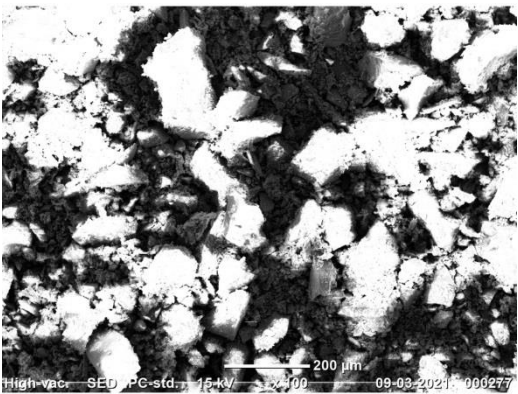


Fig: 5.11: Steel Slag SEM image
(200µm)

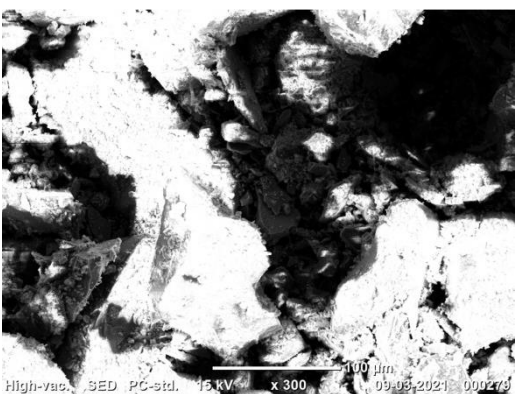


Fig: 5.12: Steel Slag SEM image
(100µm)

5.1.4.2 Steel Slag EDAX Data

Table 5.7: Steel Slag EDAX Data

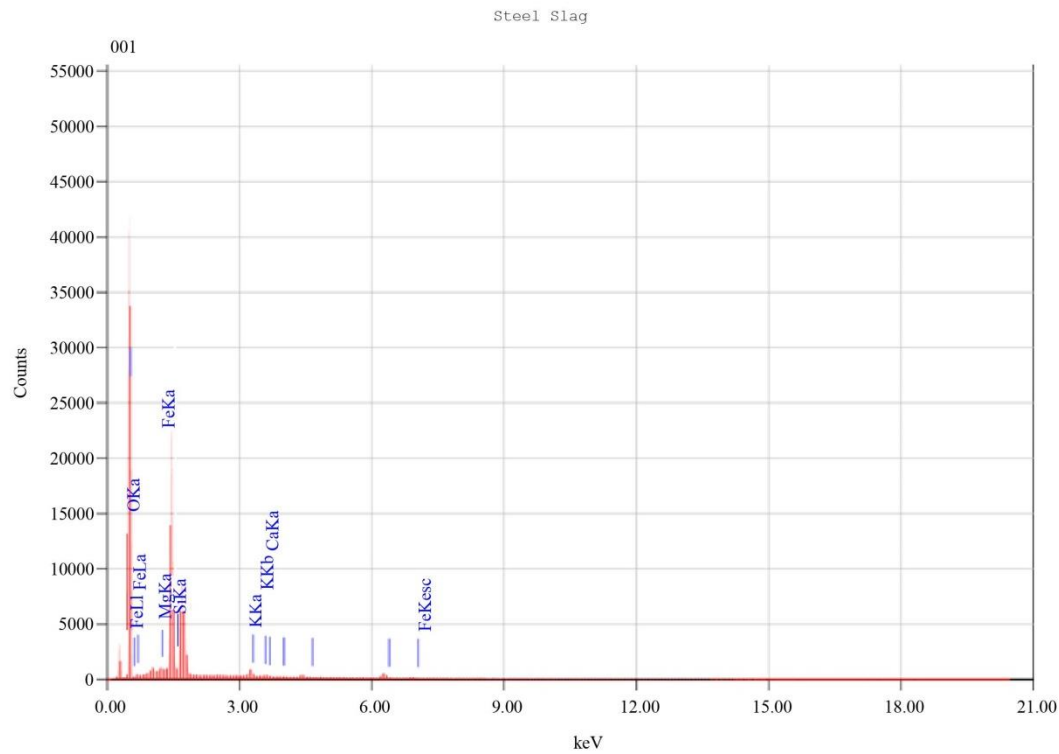


Table 5.8: Steel Slag Composition

Element	Mass (%)
OK	54.40
MgK	0.22
AlK	0.34
SiK	13.21
KK	0.28
CaK	1.20
MnK	0.22
FeK	30.13

Acquisition Parameter
Instrument : JCM-6000PLUS
Acc. Voltage : 15.0 kV
Probe Current: 7.47500 nA
PHA mode : T3
Real Time : 50.51 sec
Live Time : 50.00 sec
Dead Time : 1 %
Counting Rate: 263 cps
Energy Range : 0 - 20 keV

The SEM analysis with EDAX data of the materials used in the geopolymer help us understand the structural properties such as size and texture of the particles and also chemical properties of the materials. It helps us understand how the materials might contribute to the structural and mechanical properties of the samples and add up to the strength of the material by bonding with each other.

5.2 COMPRESSION TEST

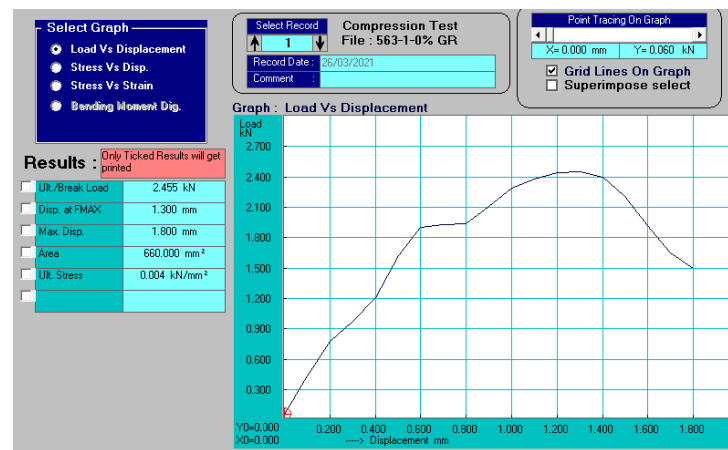


Fig: 5.13: Compression test of Sample 1 (28 days curing period)

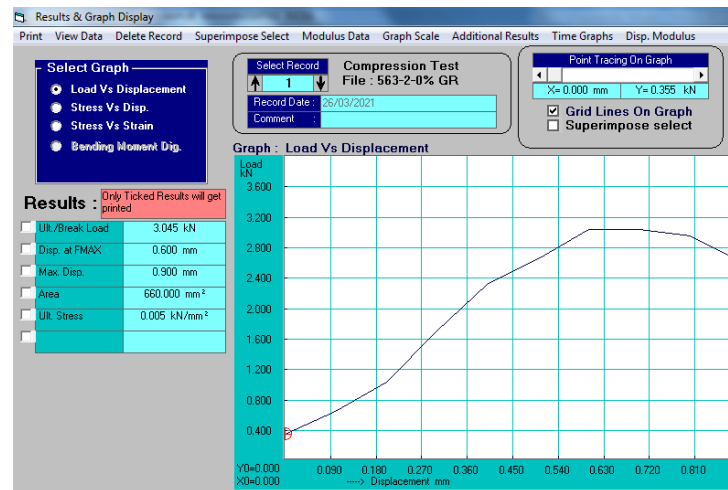


Fig: 5.14: Compression test of Sample 1 (14 days curing period)

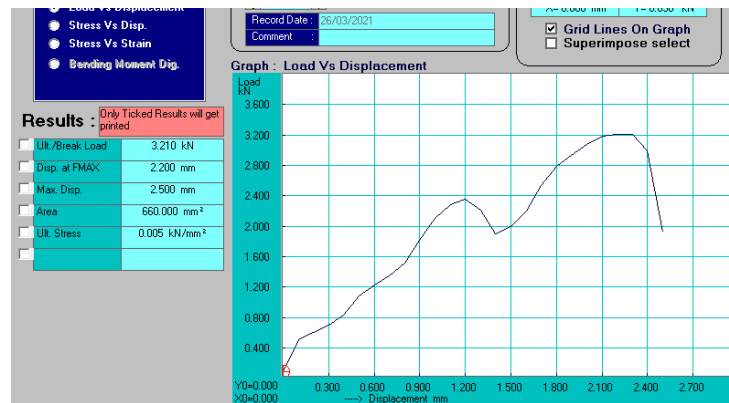


Fig: 5.15: Compression test of Sample 2 (28 days curing period)

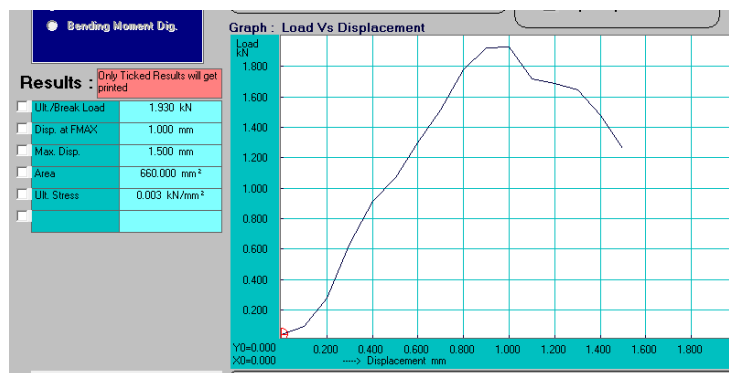


Fig: 5.16: Compression test of Sample 2 (14 days curing period)

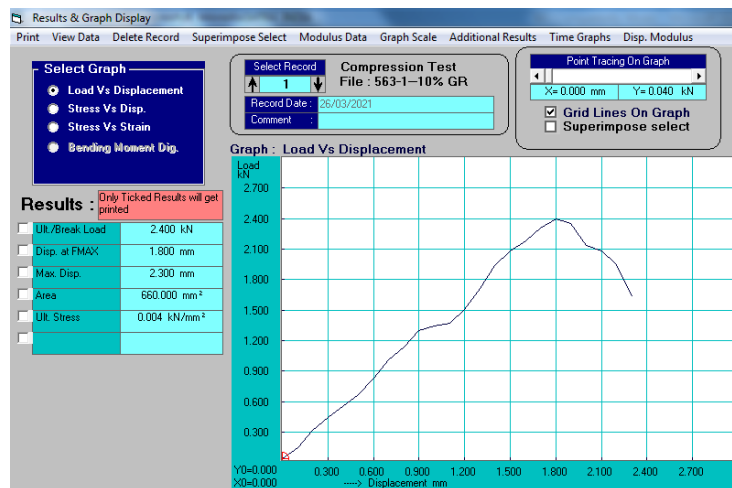


Fig: 5.17: Compression test of Sample 3 (28 days curing period)

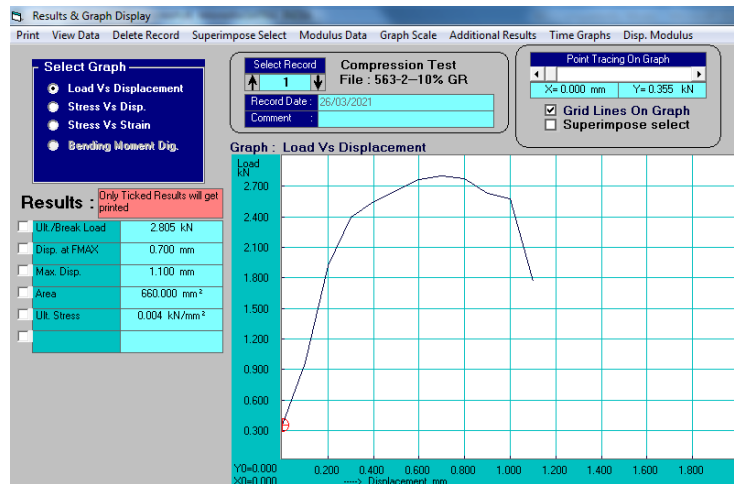


Fig. 5.18: Compression test of Sample 3 (14 days curing period)

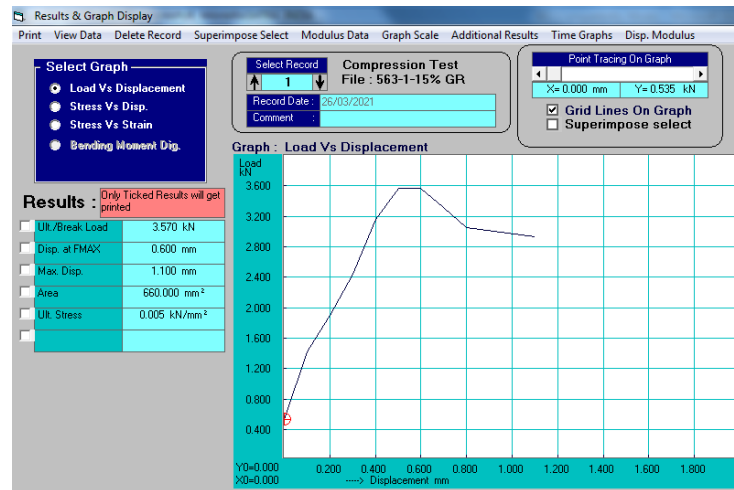


Fig. 5.19: Compression test of Sample 4 (28 days curing period)



Fig. 5.20: Compression test of Sample 4 (14 days curing period)

Table 5.9: Compression test data comparison

	Break Loads			
Curing Period	Sample 1	Sample 2	Sample 3	Sample 4
14 Days	2.455 kN	1.930 kN	2.806 kN	3.050 kN
28 Days	3.045 kN	3.210 kN	2.400 kN	3.570 kN

The compression strengths of the samples after 28 days curing period are found to be slightly higher than that of samples with a curing period 14 days. The compression resistance of the samples have also been observed to increase slightly with the increase of graphite percentage. However, Sample 1 (0% graphite) has been observed to have compression resistance slightly similar to Sample 3 (10% graphite). Highest compression resistance was observed in Sample 4 (15% graphite) with a curing period of 28 days.



Fig: 5.21: Compression test experimental set-up

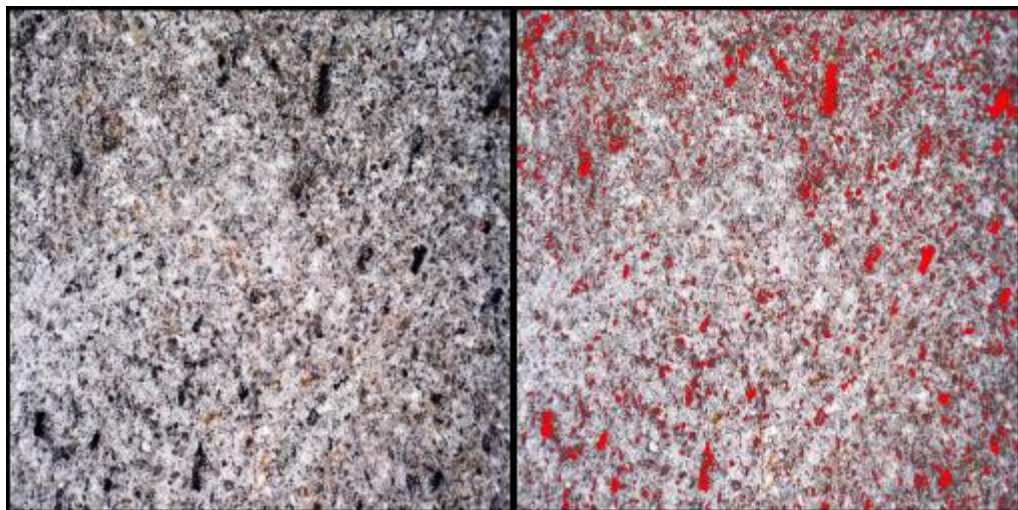
5.3 HARDNESS TEST

Table 5.10: Hardness testing data

No. of Samples	Test 1	Test 2	Test 3	Mean	Total Hardness by deviation formula
Sample 1 (0% graphite)	76.5 N/mm ²	77.1 N/mm ²	79.8 N/mm ²	77.8 N/mm ²	1.75
Sample 2 (4.9% graphite)	81.5 N/mm ²	83.7 N/mm ²	82.7 N/mm ²	82.6 N/mm ²	1.21
Sample 3 (8.9% graphite)	89.1 N/mm ²	87.9 N/mm ²	89.8 N/mm ²	88.93 N/mm ²	0.96
Sample 4 (14.6% graphite)	92.8 N/mm ²	95.1 N/mm ²	94.6 N/mm ²	94.16 N/mm ²	1.29

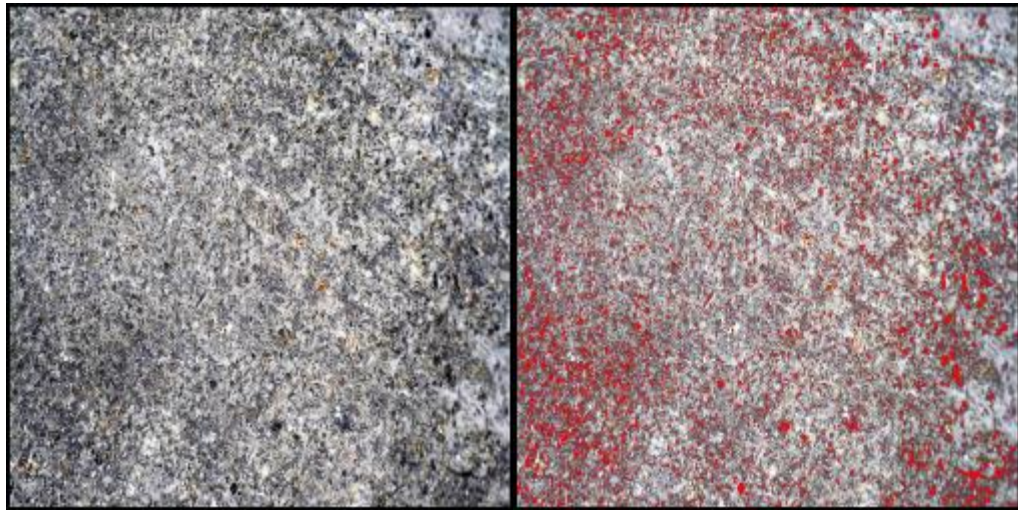
Hardness testing data shows that the hardness of the sample increases as the graphite content in the samples increases.

5.4 POROSITY TEST



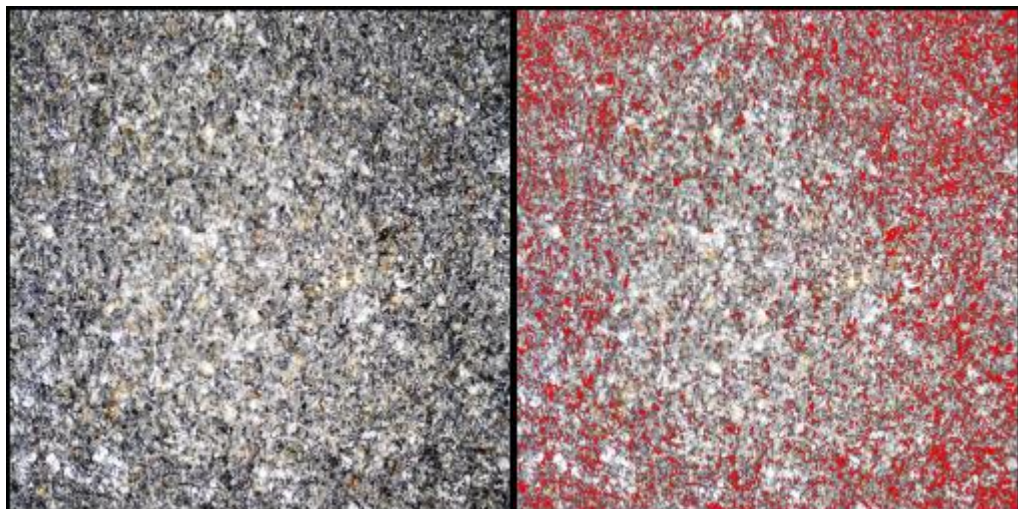
S.No.	NAME	AREA	AREA PERCENTAGE
1	Phase 1	11514.757 Micron Sqr	7.772

Fig: 5.22: Porosity Test of Sample 1



S.No.	NAME	AREA	AREA PERCENTAGE
1	Phase 1	13667.535 Micron Sqr	9.226

Fig: 5.23: Porosity Test of Sample 2



S.No.	NAME	AREA	AREA PERCENTAGE
1	Phase 1	20106.578 Micron Sqr	13.572

Fig: 5.24: Porosity Test of Sample 3

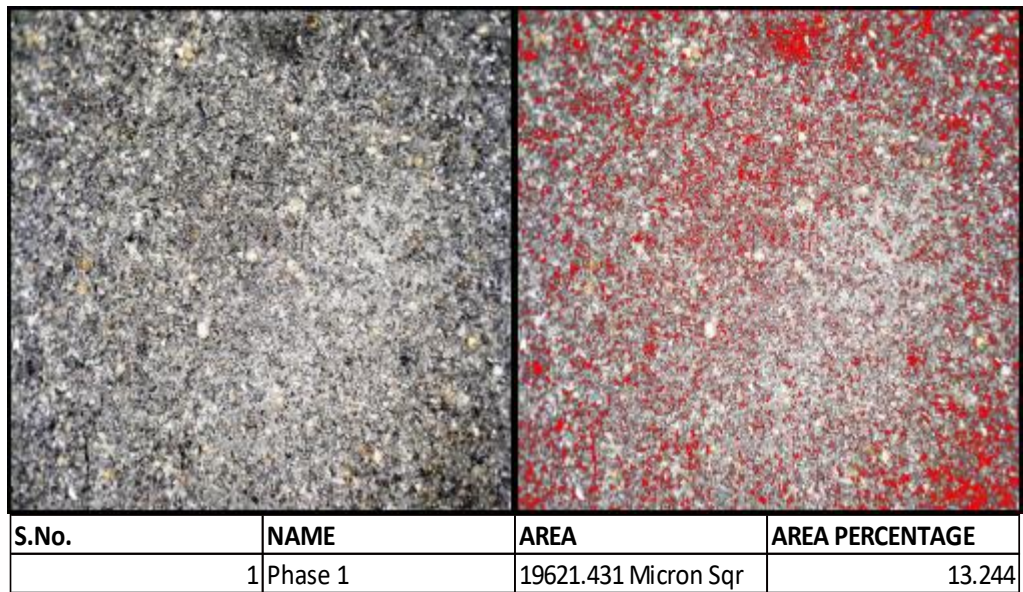


Fig: 5.25: Porosity Test of Sample 4

It can be observed that the porosity of the samples differs from samples 1 and 2 (0% and 4.9% graphite) to samples 3 and 4 (8.9% and 14.6% graphite), while samples 3 and 4 show similar porosity.

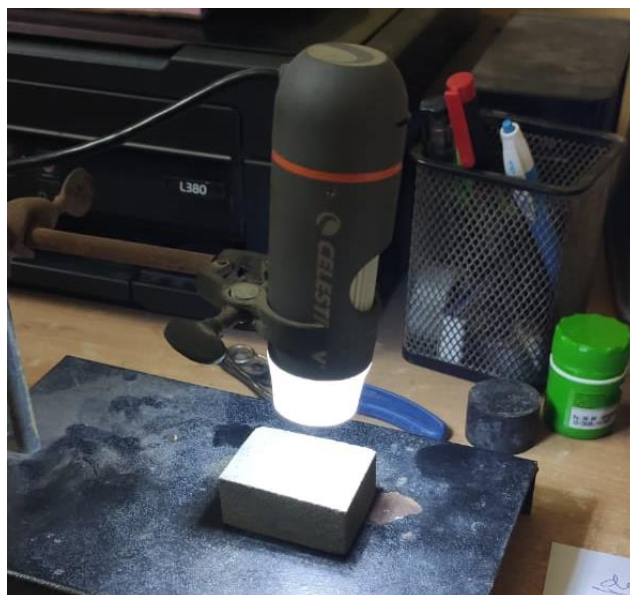


Fig: 5.26: Porosity test experimental set-up

5.5 DENSITY TEST

Formula: $\rho = \frac{m}{V}$

Where, ρ = Density

m = mass

V = volume

Table 5.11: Density test data

Sample I.D	Density g/cm ³
1	1.8004
2	1.862
3	1.712
4	1.765

As per the data, it can be observed that the density of the samples decrease slightly, with increase in graphite percentage in the sample. However, the change in densities is very minute. But sample 4 exhibits slightly higher density than sample 3.

5.6 WATER ABSORPTION TEST

Table 5.12: Water absorption test data

Sample I.D	Initial weight in g	Final weight in g	% Water absorption
1	51.852	54.73	5.25
2	47.511	50.37	5.67
3	53.705	57.481	6.56
4	57.706	62.009	6.93

As per the data it can be observed that the water absorption capacity of the samples steadily increases with the increase in graphite content in the sample.



Fig: 5.27: Water absorption test experimental set-up

5.7 EMI SHIELDING EFFECTIVENESS TEST

The EMI shielding effectiveness of the geopolymer was analysed using a vector network analysis. The EM waves reflected (S_{11}) by the geopolymer and the waves transmitted (S_{21}) through the geopolymer were analysed in the test for all the samples to determine the shielding effectiveness (SE).

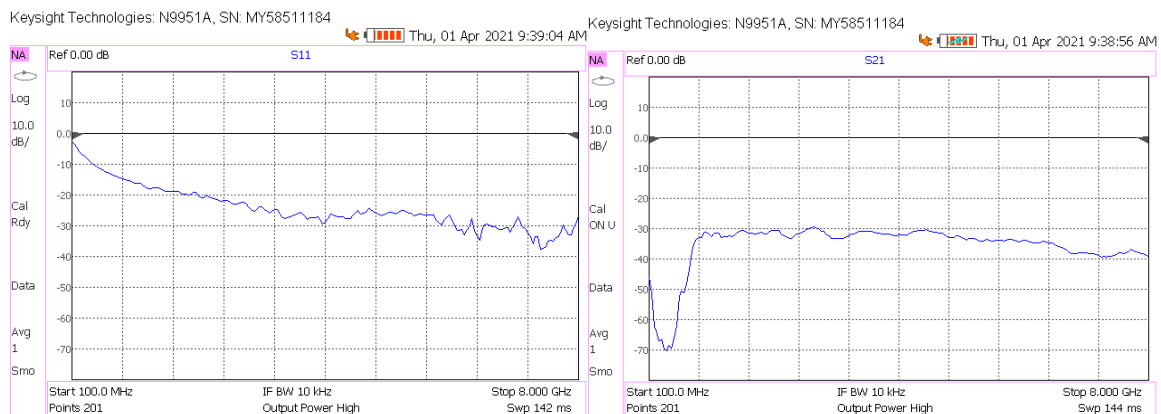
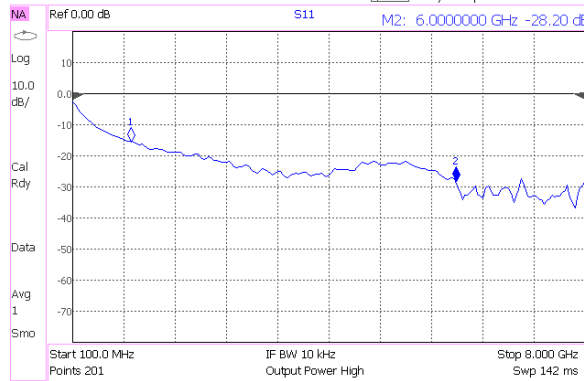
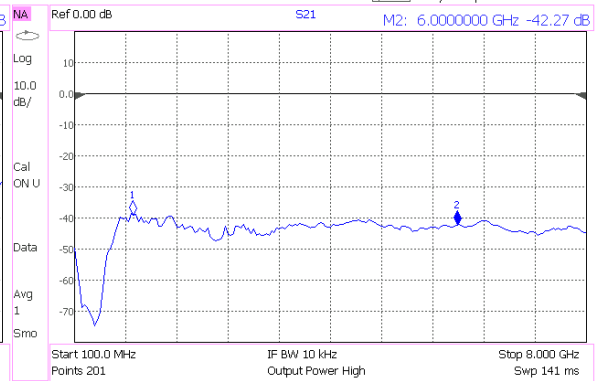
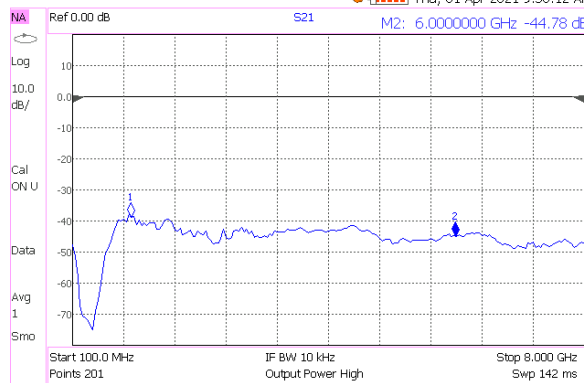
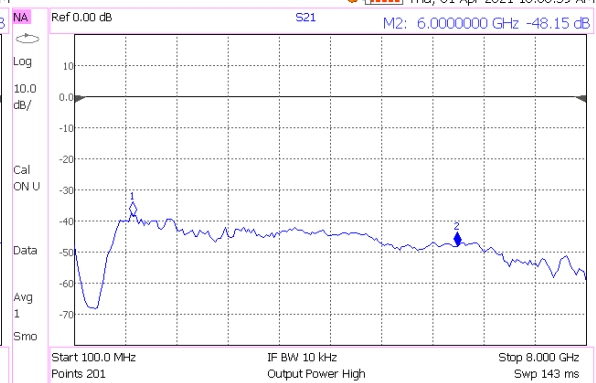
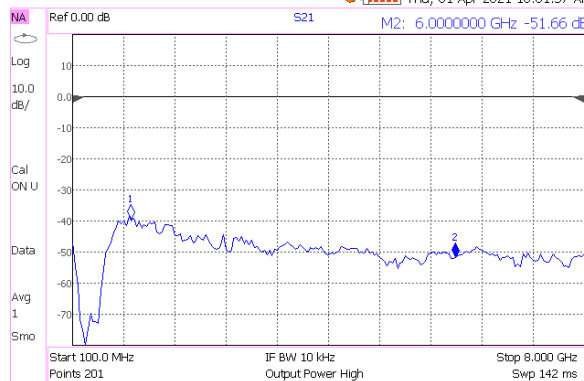


Fig: 5.28: S_{11} reading without sample

Fig: 5.29: S_{21} reading without sample

**Fig. 5.30: S₁₁ reading with Sample 1****Fig. 5.31: S₂₁ reading with Sample 1****Fig. 5.32: S₂₁ reading with Sample 2****Fig. 5.33: S₂₁ reading with Sample 3****Fig. 5.34: S₂₁ reading with Sample 4**

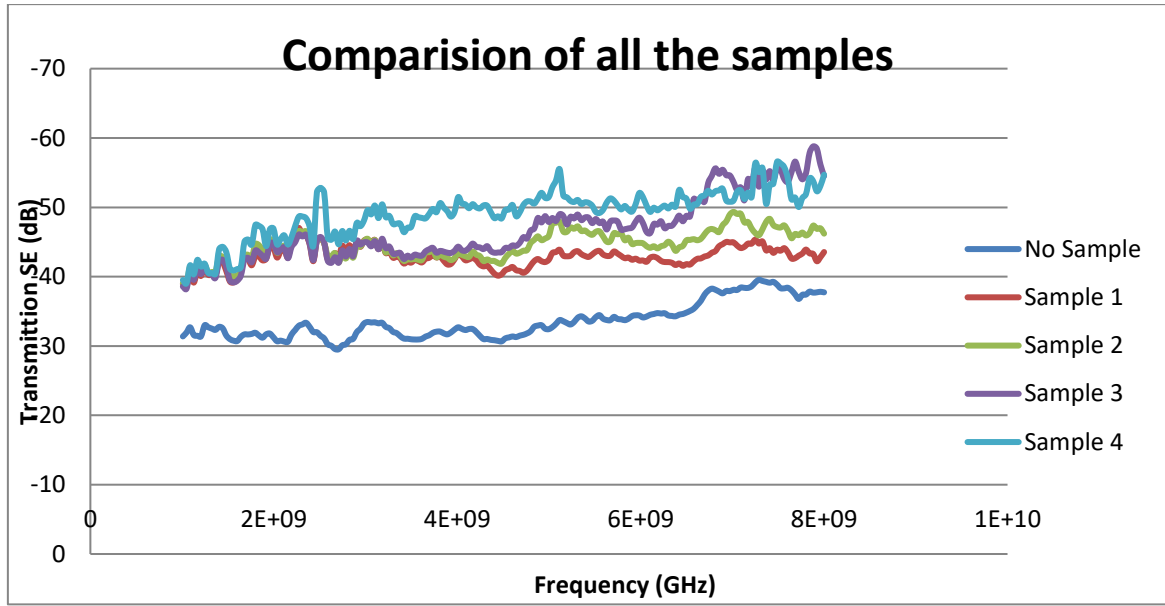


Fig: 5.35: Comparison of S_{21} data of all the samples

The above graph compares the S_{21} (Transmission shielding effectiveness) readings of all the samples with the reading without any samples. The S_{21} values were obtained at a wide range of frequency (0.1 GHz to 8 GHz). The highest differences in readings with and without samples were observed for sample 4. This is 25 dB at 6.85 GHz. The EMI shielding effectiveness is calculated using the following formula.

$$SE = -20 \log \frac{E_{transmitted}}{E_{incident}} \quad (1)$$

$$SE = SE_{AL} + SE_{RL} \quad (2)$$

$$SE_{RL} = 10 \log \left(1 - 10^{\frac{S_{11}}{10}} \right) \quad (3)$$

$$SE_{AL} = 10 \log \left(\frac{10^{\frac{S_{21}}{10}}}{1 - 10^{\frac{S_{11}}{10}}} \right) \quad (4)$$

In the above equations, by substituting the S_{21} and respective S_{11} values we can obtain the shielding effectiveness (SE). Hence, the maximum EMI SE of the geopolymer was calculated as 28 dB at 6.8 GHz when the geopolymer sample consists of 15% wt. Graphite powder.



Fig: 5.36: Experimental set-up for VNA

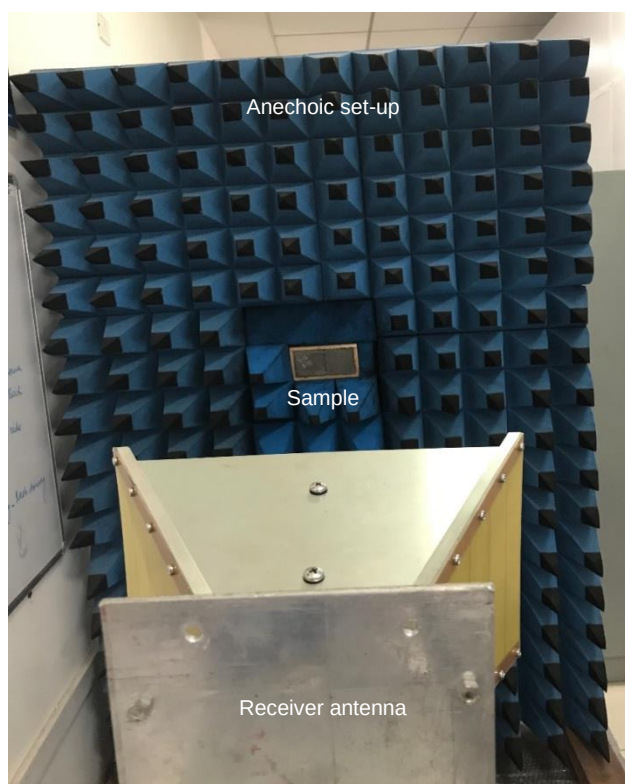


Fig: 5.37: Sample set-up



Fig: 5.38: Experimental Set-up

CHAPTER 6

CONCLUSION

The EMI shielding effectiveness of the geopolymer measured using a vector network analysis. The geopolymer sample with 15% graphite exhibits the highest EMI SE, 28 dB at 6.8 GHz frequency. SEM analysis with EDAX data was conducted to understand the properties of the materials and how they would contribute to the mechanical properties of the material. Various mechanical testing have been carried out to understand the capabilities of the material and how these properties are affected by varying graphite content in the geopolymer. These tests include:

1. Compression test
2. Hardness test
3. Density test
4. Porosity test
5. Water Absorption test

The geopolymer material is not only a cheap and eco-friendly alternative to the existing EMI shielding materials in the market but also a superior product altogether as it exhibits excellent EMI shielding effectiveness along with decent mechanical properties, which the other materials fail to do.

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