ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

MICROSTRUCTURAL, WATER PENETRATION AND MECHANICAL CHARACTERSTICS OF SCORIA IN CONCRETE

A Thesis in structural engineering

By Aklilu Shitu Gebremariam

write the submission Date

Addis Ababa

A Thesis

Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science

The undersigned have examined the thesis entitled '**Microstructural, Water Penetration and Mechanical Characterstics of Scoria in Concrete**' presented by **Aklilu Shitu**, a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

ESAYAS GEBREYOUHANNES (PhD)		
Advisor	Signature	Date
your Internal Examiners' Name		
Internal Examiner	Signature	Date
your External Examiners' Name		
External Examiner	Signature	Date
Dean of schools' Name		
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Aklilu Shitu

ABSTRACT

Concrete is a composite material of which 60-75% by volume is aggregates. Out of this volume, 30-40% is composed of fine aggregates. Fine aggregate is one of the predominant contents of concrete usually natural river sand is used as the fine aggregate. Currently, a shortage of river sand has become a problem for the construction industry in Ethiopia. Therefore, replacing this material with another available substituting material is a must.

The objective of this experimental study was to investigate the effect of using scoria as an alternative for fine aggregate in concrete. Detail experimental investigation has been carried out to understand the behavior of concrete when scoria replaces sand. Concrete mix design was prepared for C-25 classes of concrete using ACI mix design procedure. The fine aggregate was replaced by scoria at 35%, 50%, 70% and 100% by volume. The control mix without incorporation of scoria was prepared which was used as reference for comparison of test results with those specimens produced by partial replacement.

The research studied the chemical composition and chemical phases of scoria, microstructural analysis of sand and scoria and for the fresh and hardened concrete; workability, density, compressive strength, flexural strength, split tensile strength, ultrasonic pulse velocity test and water Penetration tests has been done for 7, 28 and 56 days of curing age.

The results are quite encouraging with these supplementary materials in the concrete. Based on the analysis with XRD and SEM it was identified that the main phases present on scoria sample are glassy form which is amorphous. And Considering the SEM analysis to determine the apparent porosity, in this paper only the effect of magnification is considered and the result obtained for apparent porosity on magnification 1000X for scoria sample is 41.427% and for sand 35.504%.

The slump of the concrete decreased through percentage replacement of sand with scoria and also the density of concrete decreased with the percentage replacement of sand with scoria. The water penetration of concrete decreased as compared to the control mix.

The investigation of this thesis has revealed that compressive strengths of concrete mixes with 35%, 50%, 70% and 100% sand with scoria replacement satisfy the ACI Specifications for Structural Concrete. The strengths achieved for the 28 days of curing age are 35.63, 35.58, 33.15 and 31.03MPa respectively and for the 56 days are 43.6, 38.61, 36.85 and 33.61 with this the optimum percentage 35% was selected. It is known that the concrete quality highly depends on the compressive strength therefore from the results of the ultrasonic test it is shown that the percentage substitution with 35% gives a higher pulse velocity that is in a good agreement with that of the compressive test result.

Even if there is a variation in flexural strength, the optimum is seen when sand replaces scoria with 50% with a value of 4.88MPa. And there is also a variation on the tensile strength of concrete and the maximum tensile strength attained is at a replacement of 50% scoria with a value 3.36 MPa which is higher than that of the control specimen so we can say that adding scoria in concrete will enhance the tensile strength of concrete to develop.

KEY WORDS: ULTRASONIC TEST, SCORIA, RIVER SAND, SEM ANALYSIS, XRD ANALYSIS

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LIST OF ABBREVIATIONS

ASTM	American Society of Testing Materials
ACI	American Concrete Institute
CES	Compulsory Ethiopian Standard
OPC	Ordinary Portland Cement
SEM	Scanning Electron Microscopy
XRD	X-ray Powder diffraction
SSD	Saturated Surface dry condition
PSD	Particle size distribution
PDF	Power diffraction file
FA	Fly ash
MPa	Mega Pascal
RC	Renforced concrete
UPV	Ultrasonic Pulse Velocity Test
PH	Power of hydrogen

LIST OF SYMBOLS

μm	Micrometer
σ	Stress
ρ	Density
υ	Poisson's ratio
E	Modulus of elasticity
K	Bulk modulus

CHEMICAL FORMULAS

SiO_2	Silicon di-oxide
Al_2O_3	Aluminum Oxide
Fe_2O_3	Iron Oxide
CaO	Calcium Oxide
MgO	Magnesium Oxide
Na_2O	Sodium Oxide
K_2O	Potassium Oxide
MnO	Manganese Oxide
P_20_5	Phosphorous Oxide
TiO_2	Titanium Oxide
H_2O	Water
LOI	Loss on Ignition
SO_3	Sulfur Trioxide
Cl^-	Chloride
$Na\ (Si_3Al)\ O_8$	Albite
$Ca\ (Mg, Fe, Al)\ (Si, Al)_2O_6$	Pyroxenes
$K(Si_3Al)\ O_8$	Orthoclase

CHAPTER 1 INTRODUCTION

1.1 General

Concrete has been an important construction unit in structures. It provides the building blocks that act as the main foundation, strength, and constitute to the overall quality of a building. Concrete can come in many forms, depending on the needs or requirements set by the type of building or structure that will be constructed. Typically, a concrete is made by mixing a part of cement with water, and mixed with aggregates. Concrete is one of the most versatile building materials. It can be cast to fit any structural shape from a cylindrical water storage tank to a rectangular beam or column in a high-rise building. The advantages of using concrete include high compressive strength, good fire resistance, high water resistance, low maintenance, and long service life. The disadvantages of using concrete include poor tensile strength, low strain of fracture and formwork requirement. The major disadvantage is that concrete develops micro cracks during curing. It is the rapid propagation of these micro cracks under applied stress that is responsible for the low tensile strength of the material. This weakness has been dealt with over many decades by using a system of reinforcing bars (rebars) to create reinforced concrete; so that concrete primarily resists compressive stresses and rebars resist tensile and shear stresses. Selection of aggregates used in concrete is important as aggregate makes up approximately 60 to 75% of the total volume of concrete. Not only do they contribute to the strength exhibited by concrete but also to its bulkiness, a property that enables the concrete to be placed.

The development in the construction industry all over the world is progressing. Attempts have also been made by various researchers to reduce the cost of concrete constituent and hence total construction cost by investigating and determining the usefulness of materials which could be classified as local materials. As a result of the increase in the cost of construction materials, especially cement, coarse aggregate, fine aggregate; there is the need to investigate the use of alternate building materials which are locally available [1]. The availability of scoria in large quantities, where sand is scarce and crushed stone is expensive, can have a significant reduction in cost in concrete construction.[2]

Green concrete is characterized by the application of industrial by-products or alternative materials for wise utilization of natural resources and to save energy besides minimizing environmental pollution [3]. In this changing time, scoria might just be one of solutions for the increase in cost of concrete production by replacing sand.

1.2 Statements of the problem

The construction industry is rapidly growing industry in Ethiopia and concrete is being widely used in construction of residential buildings, factories and multi-storied buildings. Due to this the demand of concrete in the construction industry is increasing. The increase in the demand for concrete production leads to the depletion of virgin concrete ingredients, which is a critical issue for all stakeholders of the construction industry for sustainable economic growth, particularly in developing countries. Therefore, there is a need to provide further attention to construction materials with regards to the economy, wise energy utilization, and environmental protection for sustainable development. Fine aggregate is one of the ingredients of concrete that needs to get considerable attention in the production of green concrete. Currently, a shortage of river sand has become a problem for the construction industry in Ethiopia. Therefore, replacing this material with another available substituting material is a must.

1.3 Objective

1.3.1 General Objective

The aim of this research is to study the possibility of using scoria as a partial replacement of sand in the production of concrete.

1.3.2 Specific Objective

- Research background information on the basic materials of scoria, cement and fine aggregate.
- Research the chemical, physical and microstructural properties of scoria and fine aggregate and determine the feasibility of replacing sand with scoria.
- Research the effects of combining scoria into the concrete mixture.
- Find the optimum replacement of fine aggregate by scoria to produce C-25 concrete.

1.4 Scope of the study

The scope of this research is limited to produce concrete with strength class of C-25 using scoria as a fine aggregate.

1.5 Methodology

This research involved laboratory test by preparing samples of concrete mixes containing varying amounts of scoria using a cube mold of size 150mmX150mmX150mm for the compressive strength test and water penetration test, 150mmX300mm size cylinder for the split tensile strength,100X200mm size cylinder for ultrasonic pulse velocity test and 100mmX100mmX500mm size beam for the flexural strength test. Prior to this, physical properties of scoria, fine aggregate and coarse aggregate were determined in the laboratory. In addition to this, chemical composition of scoria was also tested.

1.6 Limitations of the study

• Laboratory tests: is one of the essential methods that can't be easily available for necessary examinations of the study. There was one water penetration test equipment and few molds were available at the laboratory where the researcher was doing the test so that it could not be possible to do all tests at once because of this reason it takes months to complete the laboratory test.

• Time: this investigation requires a very deep study and vast time starting from the laboratory investigation to the final analysis stage for the required output to be obtained, but because of the pandemic disease (covid-19) occur here in Ethiopia recently, for a couple of days access for different services was not obtained so due to this reason the schedule of the work has been extended for months.

• Cost: is a very crucial component for choosing the method of investigation and research methods in every project. In this research, analysis is done according to a limited budget therefore a critical way of budget implementation is a must.

• Professional skill: this will be one of the defaults in this research techniques. At the beginning of laboratory investigation good workmanship was not obtained who know much about the water penetration test but later on it was handled.

1.7 Organization of the thesis

The thesis is organized in six main chapters along with appendixes included at the end of the thesis. The introduction chapter highlights the background problem, the objectives and scope of the study. Chapter two deals with previous works done on sand replacement with other substituting materials and with scoria. Chapter three briefly describes the materials used for experimentation and methods and procedures used in the research. Chapter four explains the mix proportion used in this research. Chapter five discusses the results of the experiments, followed by analysis and interpretation while the conclusions and recommendations of this thesis report are discussed under chapter six.

CHAPTER 2 LITRATURE REVIEW

2.1 Introduction

Concrete has been around for many centuries, the first known use of a material resembling concrete was by the Minoan civilization around 2000 BC. During the early stages of the Roman Empire around 300 BC, the Romans discovered that mixing a sandy volcanic ash with lime mortar created a hard water resistance substance which we now known as concrete. Concrete is the widely used building material in the world.

Concrete is a composite of various mineral phases (aggregates, cement, fly ash, micro silica, etc.) with significant porosity and water either filling pores or bound into hydrated mineral phases. The strength and durability of concrete comes from the development of a matrix of hydrated cement which binds these mineral phases together. The properties of concrete depend both on the overall arrangement and structure of the mineral matrix, and on the cementitious materials. River sand has been the most popular choice for the fine aggregate in concrete. The construction industry exploits sand mainly from stream beds, sandy marine sediments, and alluvial deposits but overuse of this material lead to environmental concerns, reduction of sources and an increase in price.[4]

With natural sand deposits the world over drying up, there is an acute need for a product that matches the properties of natural sand in concrete. In the last 15 years, it has become clear that the availability of good quality natural sand is decreasing. Crushed aggregate, bottom ash, foundry sand & various by-products are replacing natural sand and gravel in most countries.[5]

The quality of constituent materials used in the production of concrete plays a principal role in determining the physical as well as the strength properties of the resultant concrete. The properties of sand, specifically the gradation and fineness modulus of sand, are among the principal factors known to affect the performance of both fresh and hardened concrete. Impurities, such as organic matter, silt, and clay content, in the sand contribute to a reduction in the compressive strength of the concrete. [6] revealed that the compressive strength of hardened concrete decreases as the percentage of the silt and clay contents increases. Thus, assessing the quality of construction materials is very important to build strong, durable, and cost-effective structures for sustainable infrastructure development.[3]

2.2 Material used for concrete production

2.2.1 Aggregates

In a concrete mix, aggregates occupy between 60% to 80%. This high content of aggregates influences the properties of concrete both the fresh and hardened. Therefore, they must be well selected. Aggregate is classified as two different types, coarse and fine. Coarse aggregate is usually greater than 4.75 mm while fine aggregate is less than 4.75 mm. In this research only fine aggregate is discussed. The intense usage of both Coarse and Fine aggregate in civil engineering constructions raises concerns about the preservation of natural aggregates sources. [7] In addition, the process of extracting and processing the natural aggregate are the primary reasons of environmental concerns. In order to avoid these concerns and to protect the natural resources alternatives materials can be used as partially or fully replacement of aggregates in concrete production.

Sand is the most commonly material used as fine aggregate in concrete; it consists of small angular and rounded grains of silica.

2.2.1.1 Functions and requirements of fine aggregate (sand) used for construction purpose

- Functions of sand

1. Sand or fine Aggregate fills the empty existing voids in the Coarse Aggregate.

2. It helps in the reducing the potential of the concrete to shrink or crack.

3. It helps in hardening of cement as it allows the water to go through its voids.

- Requirements of Sand

1. Fine aggregate should consist of coarse angular sharp and hard grains.

2. It must be free from coatings of clay and silt.

3. It should not contain any organic matter.

4. It should be free from hygroscopic salt.

5. It should be strong and durable and chemical inert.

2.2.1.2 Environmental implication of Fine Aggregate (sand)

According to [8] In the past, river sand was considered as the only choice for the fine aggregate ingredient in concrete. However, excessive extraction of river sand causes the degradation of rivers. Instream mining lowers the stream bottom, which may lead to bank erosion. Depletion of sand in the streambed and along coastal areas causes the deepening of rivers and estuaries, and the enlargement of river mouths and coastal inlets. It may also lead to saline-water intrusion from the nearby sea. The effect of mining is compounded by the effect of sea level rise. Any volume of sand exported from streambeds and coastal areas is a loss to the system. Excessive instream sand mining is a threat to bridges, river banks and nearby structures. Sand mining also affects the adjoining groundwater system and the uses that local people make of the river.

Due to these issues, several environmental restrictions were put in place. This increases the shortage of natural fine aggregates and leads to search for alternate sources for its replacement.[8]

2.2.1.3 Properties of aggregates

1. Mechanical properties

It is not possible to relate the potential strength development of concrete to the properties of the aggregate, and indeed it is not possible to translate the aggregate properties into its concrete making properties.

a. Bond

Both shape and surface texture of aggregate influence considerably the strength of concrete, especially for high strength concrete; flexural strength is more affected than compressive strength. A rougher texture results in a greater adhesion or bond between the particles and the cement matrix. Likewise, the larger surface area of a more angular aggregate provides a greater bond. Generally, texture characteristics which permit no penetration of the surface of the particle by the paste are not conductive to good bond, and hence softer, porous and mineralogical heterogeneous particles result in a better bond.

The determination of the quality of bond is rather difficult and no accepted test exists. Generally, when bond is good, a crushed concrete specimen should contain some aggregate particles broken right through; in addition to the more numerous ones separated by the paste matrix. However, an excess of fractured particles suggests that the aggregate is too weak.

b. Strength

Clearly the compressive strength of concrete cannot significantly exceed that of the major part of the aggregate contained therein, although it is not easy to determine the crushing strength of the aggregate itself. A few weak particles can certainly be tolerated; after all, air voids can be viewed as aggregate particles of zero strength.

The required information about aggregate particles has to be obtained from indirect tests; crushing strength of prepared rock samples, crushing value of bulk aggregate, and performance of aggregate in concrete. Testes on prepared rock samples are little used, but we may note that a good average value of crushing strength of such samples is about 200MPa, although many excellent aggregates range in strength down to 80 MPa. It should be observed that the required aggregate strength is considerably higher than the normal range of concrete strength because the actual stress at points of contact of individual particles may be for in excess of the nominal applied compressive stress.

2. Physical properties

Several common physical properties of aggregate are relevant to the behavior of aggregate in concrete and to the properties of concrete made with the given aggregate.

a. Specific gravity

Since aggregate generally contains pores, both permeable and impermeable, the meaning of the term specific gravity has to be carefully defined, and there are indeed several types of this measure. According to [9], specific gravity is defined as the ratio of the density of a material to the density of distilled water at stated temperature; hence, specific gravity is dimensionless.

The absolute specific gravity and the particle density refers to the volume of the solid material excluding all pores, whilst the apparent specific gravity and the apparent particle density refers to the volume of solid material including the impermeable pores, but not the capillary ones. It is the apparent specific gravity or the apparent particle density which is normally required in concrete technology, the actual definition being the ratio of the mass of aggregate dried in an oven at 100 to 110 ˚c for 24 hrs. to the mass of water occupying a volume equal to that of the solid including the impermeable pores.

The bulk specific gravity (SSD) and the bulk particle density are most frequently and easily determined, and are necessary for calculations of yield of concrete or the quantity of aggregate required for given volume of concrete.

The majority of natural aggregates have an apparent specific gravity of between 2.6 and 2.7, whilst the values for light weight and artificial aggregates extend considerably from below to very much above this range. Since the actual value of specific gravity or particle density is not a measure of the quality of the aggregate, it should not be specified unless we are dealing with a material of a given petrological character when a variation in specific gravity or particle density would reflect a change in the porosity of the particles.

b. Bulk density

It is well-known that in the metric system the density of a material is numerically equal to the specific gravity although, of coarse, the latter is a ratio of while density is expressed in kilograms per liter. The absolute density refers to the volume of individual particles only, and of coarse it is not physically possible to pack these particles so that there are no voids between them, thus, when aggregate is to be batched by volume it is necessary to know the bulk density which is the actual mass that would fill a container of unit volume, and this density is used to convert quantities by volume. The bulk density depends on how densely the aggregate is packed and, consequently on the size distribution and shape of the particles.

Thus, the degree of compaction has to be specified. As mentioned earlier, the bulk density depends on the size distribution of the aggregate particles all of one size can be packed to a limited extent but smaller particles can be added in the voids between the larger ones thus increasing the bulk density, in fact the maximum bulk density of a mixture of fine and coarse aggregates is achieved when the mass of the fine aggregate is approximately 35 to 40 percent of the total mass of aggregate. Consequently, the minimum remaining volume of voids determines the minimum cement paste content and therefore, the minimum cement content; this latter is, of coarse, of economic importance.

c. Fineness Modulus

The fineness modulus (FM) of either fine or coarse aggregate according to [10] is calculated by adding the cumulative percentages by mass retained on each of a specified series of sieves and dividing the sum by 100. The specified sieves for determining FM are: 150 µm (No. 100), 300 µm (No. 50), 600 µm (No. 30), 1.18 mm (No. 16), 2.36 mm (No. 8), 4.75 mm (No. 4), 9.5 mm, 19.0 mm, 37.5 mm, 75 mm and 150 mm. FM is an index of the fineness of an aggregate. The higher the FM, the coarse the aggregate. Different aggregate grading may have the same FM. FM of fine aggregate is useful in estimating proportions of fine and coarse aggregates in concrete mixtures.

d. Absorption and Surface Moisture

The absorption and surface moisture of aggregates should be determined according to [11], [9], and [12] so that the total water content of the concrete can be controlled and correct batch weights determined. The internal structure of an aggregate particle is made up of solid matter and voids that may or may not contain water. Coarse and fine aggregate will generally have absorption levels (moisture contents at SSD) in the range of 0.2% to 4% and 0.2% to 2%, respectively. Free-water contents will usually range from 0.5% to 2% for coarse aggregate and 2% to 6% for fine aggregate. The maximum water content of drained coarse aggregate is usually less than that of fine aggregate. Most fine aggregates can maintain maximum drained moisture content of about 3% to 8% whereas coarse aggregates can maintain only about 1% to 6%.

Grading of Aggregates

Grading is the particle-size distribution of an aggregate as determined by a sieve analysis [13]. The aggregate particle size is determined by using wire mesh sieves with square openings. According to [14] the seven standard sieves for fine aggregate have openings ranging from 75µm to 9.5mm. The grading and grading limits are usually expressed as the percentage of material passing each sieve. There are several reasons for specifying grading limits and nominal maximum aggregate size; they affect relative aggregate proportions as well as cement and water requirements, workability, pump ability, economy, porosity, shrinkage, and durability of concrete. Variations in grading can seriously affect the uniformity of concrete from batch to batch. Very fine sands are often uneconomical; very coarse sands and coarse aggregate can produce harsh, unworkable mixtures. In general, aggregates that do not have a large deficiency or excess of any size and give a smooth grading curve will produce the most satisfactory results.[15]

Fine Aggregate Grading

Fine aggregates generally consist of natural sand or crushed stone with most particles smaller than 5 mm.

Coarse-Aggregate Grading

The coarse aggregate grading requirements of [14] permit a wide range in grading and a variety of grading sizes. The grading for a given maximum-size coarse aggregate can be varied over a moderate range without appreciable effect on cement and water requirement of a mixture if the proportion of fine aggregate to total aggregate produces concrete of good workability. Mixture proportions should be changed to produce workable concrete if wide variations occur in the coarse-aggregate grading. Since variations are difficult to anticipate, it is often more economical to maintain uniformity in manufacturing and handling coarse aggregate than to reduce variations in gradation. The maximum size of coarse aggregate used in concrete has a bearing on the economy of concrete. Usually, more water and cement are required for small-size aggregates than for large sizes, due to an increase in total aggregate surface area.

2.2.2 Cement

Portland cements are hydraulic cements composed primarily of hydraulic calcium silicates. Hydraulic cements set and harden by reacting chemically with water. During this reaction, called hydration, cement combines with water to form a stone like mass, called paste. When the paste (cement and water) is added to aggregates it acts as an adhesive and binds the aggregates together to from concrete, the world’s most versatile and most widely used construction material.

Portland cement is produced by pulverizing clinker which consists primarily of hydraulic calcium silicates. Clinker also contains some calcium aluminates and calcium alumino ferrites and one or more forms of calcium sulfate (gypsum) is interground with the clinker to make the finished product. Materials used in the manufacture of Portland cement must contain appropriate amounts of calcium, silica, alumina, and iron components. During manufacture, chemical analyses of all materials are made frequently to ensure uniformly high-quality cement.

2.2.3 Water

The quality of water is important because impurities in it may interfere with the setting of the cement, may adversely affect the strength of the concrete or cause staining of its surface and also may lead to corrosion of the reinforcement. For these reasons, the suitability of water for mixing and curing purposes should be considered. Water that is suitable for drinking and that has no pronounced taste or odor may be used. It is generally thought that the PH of the water should be between 6.0 and 8.0.

Salt water must not be used as mixing water, because chlorides and other salts in such water will attack the structure of the concrete and may lead to corrosion of pre stressing tendons.

2.3 Properties and proportions of concrete Constituents

Concrete is a mixture of cement, aggregate and water. An increase in the cement content in the mix and use of well graded aggregate increases the strength of concrete.

2.3.1 Properties of fresh concrete

When concrete is freshly produced, it is plastic in behavior and is often called plastic concrete. The requirements for fresh concrete include the time available for placing it into formwork and workability. Workability is often referred to as the ease with which a concrete can be transported, placed and consolidated without excessive bleeding or segregation.

In everyday practice, slump is the most common test for workability. The main purpose of this test is intended to detect the change in water content as indicated by a change in slump. Before the age of chemical admixtures, a higher slump is deemed to indicate higher water content and may result in lower strength due to the likely higher water/cement ratio.

The use of mechanical concrete mixers and the proper time of mixing both have favorable effects on strength of concrete. Also, the use of vibrators produces dense concrete with a minimum percentage of voids. A void ratio of 5% may reduce the concrete strength by 30%.

2.3.2 Properties of hardened concrete

Generally, the term concrete strength is taken to refer to the uniaxial compressive strength as measured by a compression test of a standard test cylinder or cube, because this test is used to monitor the concrete strength for quality control or acceptance purposes. For convenience, other strength parameters, such as tensile or bond strength, are expressed relative to the compressive strength.

a. Compressive Strength

Among the large number of factors affecting the compressive strength of concrete, the following are probably the most important for concretes used in structures. These are; water cement ratio, type of cement, supplementary cementitious material, aggregate type, mixing water, moisture condition during curing, temperature condition during curing, age of concrete, maturity of concrete and rate of loading.

The curing conditions exercise an important influence on the strength of concrete. Both moisture and temperature have a direct effect on the hydration of cement. The longer the period of moisture storage; the greater the strength of concrete.

- Age of Concrete

The strength of concrete increases appreciably with age, and hydration of cement continues for months. In practice the strength of concrete is determined from cylinders or cubes tested at the age of 7 days and 28 days. As a practical assumption concrete at 28 days is 1.5 times as strong as at 7 days. The range varies b/n 1.3 and 1.7. The British Code of Practice accepts concrete if the strength at 7 days is not less than two thirds of the required 28 days strength.

b. Tensile Strength of Concrete

The tensile strength of concrete falls between 8 and 15 percent of the compressive strength. The actual value is strongly affected by the type of test carried out to determine the tensile strength, the type of aggregate, the compressive strength of the concrete, and the presence of a compressive stress transverse to the tensile stress.

- Standard Tension Tests

Two types of tests are widely used. The first of these is the modulus of rupture or flexural test [16], in which a plain concrete beam, generally long, is loaded in flexure at the third points of a 450cm span until it fails due to cracking on the tension face. The flexural tensile strength or modulus of rupture, from a modulus-of-rupture test is calculated from Eq. 1, assuming a linear distribution of stress and strain:

$$Fr = \frac{PL}{bd^2} \tag{1}$$

Where; P= Load applied

d= overall depth of specimen

b= width of specimen

L= Length of specimen

The second common tensile test is the split cylinder test [17], in which a standard compression test cylinder is placed on its side and loaded in compression along a diameter. In a split-cylinder test, an element on the vertical diameter of the specimen is stressed in biaxial tension and compression. The stresses acting across the vertical diameter range from high transverse compressions at the top and bottom to a nearly uniform tension across the rest of the diameter. The splitting tensile strength, fct, from a split cylinder test is computed with Eq. 2 as shown below:

$$fct = \frac{2P}{(\pi l d)} \tag{2}$$

where; P= maximum applied load in the test l= length of the specimen

d= diameter of the specimen

The tensile strength of concrete is affected by the same factors that affect the compressive strength. In addition, the tensile strength of concrete made from crushed rock may be up to 20 percent greater than that from rounded gravels.

The tensile strength of concrete develops more quickly than the compressive strength. As a result, such things as shear strength and bond strength, which are strongly affected by the tensile strength of concrete, tend to develop more quickly than the compressive strength. At the same time, however, the tensile strength increases more slowly than would be suggested by the square root of the compressive strength at the age in question.

c. Relationship between Compressive and Tensile Strengths of Concrete

Although the tensile strength of concrete increases with an increase in the compressive strength, the ratio of the tensile strength to the compressive strength decreases as the compressive strength increases. Thus, tensile strength is approximately proportional to the square root of the compressive strength. The mean split cylinder strength, fct, from a large number of tests of concrete from various localities has been found to be as shown in Eq. 3:

$$fct = 0.53\sqrt{f'c} \tag{3}$$

similarly, the mean modulus of rupture fr, can be expressed as follows in Eq. 4:

$$fct = 0.69\sqrt{f'c} \tag{4}$$

where fct and f'c are all in MPa.

2.4 XRD analysis to determine the chemical composition of materials

X-ray diffraction (XRD) is one of the most prominent analytical methods used to characterize fine-grained, crystalline materials such as cement and other cementitious materials. It has a wide range of applications in phase identification, lattice parameters determination, crystal structure determination, and crystal structure refinement and quantitative phase analysis.

X-ray diffraction by a crystalline material results in a pattern composed of peaks at distinctive diffraction corners of variable intensities. The diffraction angle or position of the peaks is determined through the law of Bragg by the symmetry and size of unit cell crystalline material, whereas the intensities of the peaks are related to the nature and disposition of the atoms in the unit cell of the material [18].

XRD is used in qualitative phase identification. Qualitative phase analysis is done by comparing peaks in a measured XRD pattern to a database of peak patterns of predefined phases. The most commonly used general-purpose database is the powder diffraction file (PDF) published by the International Centre for Diffraction Data and using such kind of database along with chemical or categorical filters will minimize the number of possible patterns [18].

To retrieve information from XRD output, the following methods can be used [19].

- Basic XRD data analysis using High Score Plus
- Profile fitting and crystallite size determination
- Reitveld refinement. [20]

2.5 Water penetration test

Assessing performance related to penetration of water in concrete can be determined by using this test. Non steady water penetration of concretes made with OPC was carried out at 28 days and 56 days on cured 150 mm concrete cubes respectively to determine the water penetration depth in concrete.

2.5.1 Factors influencing concrete water penetration

There are three major factors that influence the water penetration of concrete:

1. Water to Cement ratio

Water to cement ratio influences concrete water penetration to a great extent. The higher the w/c ratio the greater the concrete water penetration. In this case, not only does sizable free water remain in concrete after completion of cement hydration but also particles of cement and aggregate would not be as compact as in the case of low water to cement ratio.

Consequently, it creates pores which are not filled with hydration product. Hence, concrete would be penetrable when free water leaves the pores due to evaporation or any other reason. [2]

2. Compaction of Concrete

When concrete is adequately compacted, air-voids and trapped bleed water in concrete are eliminated. As a result, pores and more importantly interconnected pores are avoided and eventually concrete water penetration is declined. Therefore, it is crucial to select and use proper and suitable compaction equipment during concrete placement and supervise the work to achieve the desired compaction. [2]

3. Curing of Concrete

It is obvious that curing of concrete substantially influences the water penetration of concrete. Sufficient curing allows proper cement hydration. Subsequently, pores in concrete would be filled with hydration product. [2]

4. Other Factors

There are other factors that affect concrete water penetration, but are not as influential as those discussed above. For example, age of concrete, cement properties, aggregate, use of admixtures, and loss of mixing water. Water penetration declines as the concrete age increases because pores would be filled by hydration product.

2.6 Scoria as sand substituting material

2.6.1 Scoria origin

Scoria is vesicular and dark colored igneous rock that have or have not contain any crystals. It is typically dark color, such as dark brown, black or purplish red. Most scoria is basaltic or andesitic in composition. The top of a lava flow is made up of a highly vesicular, rubbly material known as scoria. It has the appearance of vesicular lava. The formation of the rock when gases in the magma expand to form bubbles as lave reaches the surface. The bubbles are then retained as the lava solidifies. Scoria is common in areas of recent volcanism, such as the Canary Islands and the Italian volcanoes. It is relatively low density due to its vesicles, but it is not as light as pumice. Also differs from pumice in that it has larger vesicles with thicker walls. It has commercial use as a high-temperature insulating material. It also has applications in landscaping and drainage.

Scoria is usually heavier, darker and more crystalline than pumice. Scoria is abundant in various parts of the world including Ethiopia, Turkey, Papua New Guinea and Saudi Arabia. Scoria can be utilized in several industrial applications including the manufacturing of lightweight concrete, as a source of pozzolan to manufacture Portland-pozzolan cement additive, as a heat insulating materials, in addition to other uses such as low-cost fillers, filter materials, absorbents and other architectural applications. [21]

Scoria, which is a product of explosive volcanic eruptions, has been used for centuries in the world as a construction material. Different researchers have examined the use of scoria as a construction material in concrete production. scoria used as a coarse aggregate was found to be very useful in the production of lightweight concrete, with sufficient strength giving it the advantage of reducing the dead load in building structures. Scoria is also used as a lightweight aggregate with silica fume and fly ash mineral admixture in the production of lightweight structural concrete in which an outstanding performance was observed with regards to the strength to unit weight ratio. [3]

Improvements in the mechanical strength of mortar were also observed when using volcanic scoria as sand in the production of Portland cement mortar. Volcanic materials are comprehensively utilized in the production of blended cement due to their availability and properties. Volcanic materials are used as supplementary cementitious materials to produce environmentally friendly concrete. The use of scoria as a replacement of cement was investigated in the production of self-consolidating concrete, which was found to be economically and environmentally pleasant with the required strength and durability properties of concrete. [3]

The use of scoria as a replacement of cement in concrete production also improved the durability of the concrete by increasing its resistance to chloride penetration and giving longer periods of corrosion initiation. Scoria, as a cement additive in Portland cement, was found to be effective in improving the property of the cement paste, particularly in controlling the alkali–silica reaction. [3]

2.6.2 Scoria Composition

Scoria is a volcanic igneous rock. Also referred to as scoriaceous basalt, a term commonly used to indicate a basaltic pumice. It is commonly composed of approximately 50% silica and 10% calcium oxide with lesser contents of potash and soda. It is an extrusive igneous rock whose major minerals are plagioclase, pyroxene and olivine. Minor mineral contents may include apatite, biotite, hematite, hornblende, ilmenite, magnetite, and quartz. It has a relative hardness of 5-6.

2.6.3 Scoria Formation

When the Scoria explodes, it consists of an explosive in the volcano, the excess gases and ash from the volcano. These gases are dissolved in the magma under extreme pressure. The magma from the volcanic eruption enters the air in which the pressure is released, and the magma solidifies when the temperature falls from the surface mineral. When the magma solidifies, the gases in the melt are not released from the melt without solidification. These gases produce round or long pores. These pores were vesicles of rapidly emerging gas regions of melt solidification, otherwise gases would not be compressed.

The scoria from the explosion will be located near the mouth of the volcano and the heavy rock will fall down from the top of the volcano.

- Where is it located

Scoria can be found in regions where Earth's volcanic activity occurs. It is a ruthless rock filled with air bubbles ranging from black to dark red. The It is created as gas runs out of a volcano and the rock strikes around.

Scoria is gathered around the vents of a volcano. The cone-shaped hill formed by Scoria is called an ash cone. Scoria-producing volcanoes usually have short eruptions and are not very long. It is often used as a lightweight aggregate that is added to the landscape or to the concrete.

2.6.4 Scoria Uses

- It is often used in landscaping and drainage works. It is also commonly used in gas barbecue grills.
- It can be used for high-temperature insulation.
- It is used on oil well sites to limit mud issues with heavy truck traffic.
- It is also used as a traction aid on ice- and snow-covered roads.
- Pumice has a higher concentration of trapped bubbles allowing it to float, but thick walls of scoria make it heavy enough to sink.
- The production of lightweight aggregate is one of the main uses of scoria. It is crushed to the specific sizes and sold for a variety of uses.
- Using concrete with scoria weighs about 100 pounds per cubic foot, but with typical sand and gravel it would weigh about 150 pounds per cubic foot.
- The lighter scoria allows buildings to be constructed with less structural steel, and the air trapped in the scoria makes the concrete a better insulator resulting in lower heating and cooling costs.
- Crushed scoria is used for ground cover in landscape projects, as a substrate in hydroponic gardening, and as roofing granules.
- In addition, scoria may be used as rip-rap, drainage stone, or low-quality road metal. Small amounts of it can be used as sauna rock and as a heat sink in barbecue grills.
- There are also scoria substitutes such as a lightweight aggregate that is produced by heating shale in a rotating kiln under controlled conditions.

2.7 Related works

Here related papers done on sand replacement using different replacing materials will be discussed. Sand replacement is a well-known method used in concrete since recent times because of the depletion of natural sand resource in different countries around the world various researches has been made so far to know the best material which can replace sand by different researchers. Here some works of the researchers will be presented:

Quarry dust wastes are used as alternative construction materials for natural sand replacement in order to minimize the shortage of river sand in concrete production in some countries. For instance, quarry dust was used to replace the river sand in India to conserve the sustainable development of scarcely available natural sand. [3]

The use of copper slag as a replacement of fine aggregate in RC slender columns. The percentage of fine aggregate was replaced from 0%, 20%, 40%, 60%, 80%, 100% using copper slag was studied by [22]. Twenty columns of size 150 mm x150 mm x 2500 mm were tested under monotonic axial compression load until failure. Five cubes of size 100 mm x100 mm x100 mm, eight cylinders of size 150 mm x 300mm and five prisms of size 100 mm x 100 mm x 500 mm were cast and tested for each mixture to determine the compressive, tensile and flexural strengths of the concrete respectively. The results showed that the replacement up to 40% of fine aggregate with copper slag caused no major changes in concrete strength and further increasing the percentage reduced the concrete strength and column failure load and increased concrete slump, lateral deflections and vertical deflections of the column.

Concrete produced using scoria aggregates provides engineers and the construction industry with an alternative for conventional concrete because of its reduced self-weight. Depending on the importance of the structure, Light weight concrete can provide engineers with more design opportunities as the lighter concrete beams could potentially have greater spans in a structure [23]. Also, concrete produced using scoria aggregates can insulate heat five to seven times better than the concrete produced using conventional aggregate. The scoria is therefore, suitable as a thermal insulating material and has the potential to be utilized in manufacturing heat-insulating concrete and building blocks having strength and durability characteristics comparable to other lightweight aggregate [24].

The highest compressive strength obtained was 46MPa for 100% replacement of fine aggregate by Copper Slag and Ferrous Slag and the corresponding strength for control mix was 30MPa was reported by [25]. It has been observed that up to 80% replacement, copper slag and ferrous slag can be effectively used as replacement material for fine aggregate. The results showed that the compressive strength of copper slag and ferrous slag concrete increased when compared with control concrete (30.23MPa to 46.18MPa cured at 90 days), whereas the increased strength was more or less same for different percentage of copper slag &ferrous slag. The results showed that the split tensile strength of copper slag and ferrous slag concrete increased when compared with control concrete (6.10 MPa to 8.65 MPa cured at 90 days), whereas the strength increased was more or less same in different percentage of copper slag and ferrous slag in concrete.

Blended cement and lightweight concrete using scoria was studied by [24]. He reported that scoria concrete made with 50 to 100% scoria aggregate as replacement of coarse aggregate satisfies the criteria for semi-lightweight structural concrete. Scoria concrete made with 100% fine and coarse scoria aggregate also satisfies the criteria for lightweight structural concrete.

Sixty percent replacement of conventional aggregate with cinder by volume along with cement replaced by ten percent of silica fume by weight, yields the target mean strength of M20 concrete concluded by [26]. It is worth to be noted that there is a slight increase in strength and other properties due to extended curing periods and the unit weight of the cinder concrete is varying from 1980Kg/m^3 to 2000Kg/m^3 with different percentages of cinder. It is also noted that there is a decrease in density after extended curing periods.

The strength and sorptivity characteristics of concrete made with cinder-based lightweight aggregates was studied by [27]. Structural lightweight concrete is defined as concrete made with low- density aggregate having an air-dry density of not more than (1850 kg/m^3) and a 28-day compressive strength of more than (17.2 MPa). This paper presented the test results of very low- density structural lightweight concrete mixtures developed in the laboratory for the purpose of finding a suitable mixture for use on a historic building rehabilitation project. Mixture parameters included a specified compressive strength of 3000 psi at 28 days and an air-dry density approaching 70 lb/ft3. Various constituent materials, mixture proportions and curing methods were examined. The result of this research exemplifies the feasibility of achieving very low densities with structural concretes.

2.8 Conclusion

Recently, the increasing consumption of concrete by the construction industry has led to the rapid depletion of natural sand and good quality of sand is not readily available in most areas of Ethiopia. It must be transported a long distance or contractors use whatever sand is available, which might not meet the necessary standards. Therefore, it is necessary to find a locally abundant supply of natural material as a substitute. Hence, instead of producing aggregates and minerals from virgin sources, it is more than appropriate to use waste by-products from industries and locally abundant natural materials. Therefore, it is necessary to do research on materials which can replace sand for construction purpose which meets the necessary standard given on codes.

CHAPTER 3 MATERIALS AND METHODS

3.1 Introduction

This chapter presents the experimental program and the constituent materials used to investigate the potential usefulness of using scoria in the concrete mixes as fine aggregates.

In this experimental work, effects of scoria on different properties of concrete will be seen by adding different amounts to the concrete. Several parameters were considered in the test program such as the way of using scoria and the percentages of scoria in concrete mixes. This work presents the test procedure, details and equipment's used to assess concrete properties.

The laboratory investigation consisted of tests for both fresh and hardened concrete properties. Fresh concrete was tested for slump flow to ensure reasonable workability of concrete. The tests for hardened concrete included compression tests for strength, indirect tensile tests (split cylinder and flexural strength tests), durability tests (water penetration test) ultrasonic pulse velocity test.

The properties of different constituent materials used to produce concrete with scoria aggregates are also discussed such as moisture content, unit weight, specific gravity and the grain size distribution.

3.2 Materials

The materials were used in the test program include ordinary Portland cement, natural coarse aggregate, sand, water and scoria. Material properties were as follows:

- Cement

Ordinary Portland cement (OPC 42.5 R) was used throughout the investigation. The cement was obtained from local concrete manufacture and kept in dry location.

- Water

Tap water, potable without any salts or chemicals was used in all concrete mixtures and in the curing of specimens.

- Aggregates

Two main categories of aggregate were used, coarse and fine aggregates, according to [14] for aggregate classification.

Fine aggregate

➢ Sand

The fine aggregate was mainly washed to remove excess silt. Hence, the fine aggregate was washed to minimize its silt content below 3.0% (specified silt content) but the sand that was bought is already having a silt content below the specified value so washing is not necessary. Sand was tested for physical properties as shown in Table 3-1.

Figure 3-1: Sand sample used and determination of silt content for sand

Table 3-1: Physical properties of fine aggregate (sand)

No	Test description		Result found
1	Moisture content		4.1 %
2	Silt content		2.5%
3	Unit weight		1577.5 Kg/m^3
4	Absorption capacity		0.89%
5	Specific gravity	Bulk	2.437
		Apparent	2.582
		SSD	2.486

Results of sieving sand in Table 3-2, indicate that sand is well graded according to [14].

Table 3-2: Sieve analysis result of sand

Sieve Analysis test calculations & Particle Size Distribution Curve of sand

Sieve Number	Diameter (mm)	Soil Retained (kg)	Accumulative Retain (kg)	% Mass Retain	% Passing
3/8"	9.5	**0**	**0**	**0**	**100**
#4	4.75	0.01	0.01	2.0000	98.0000
#10	2.36	0.02	0.03	6.0000	94.0000
#20	1.18	0.05	0.08	16.0000	84.0000
#40	0.60	0.23	0.31	62.0000	38.0000
#60	0.30	0.165	0.475	95.0000	5.0000
#200	0.150	0.025	0.5	100.0000	0.0000
Pan		0	∑= 0.5	∑= 281	

Fineness modulus=281/100=2.81

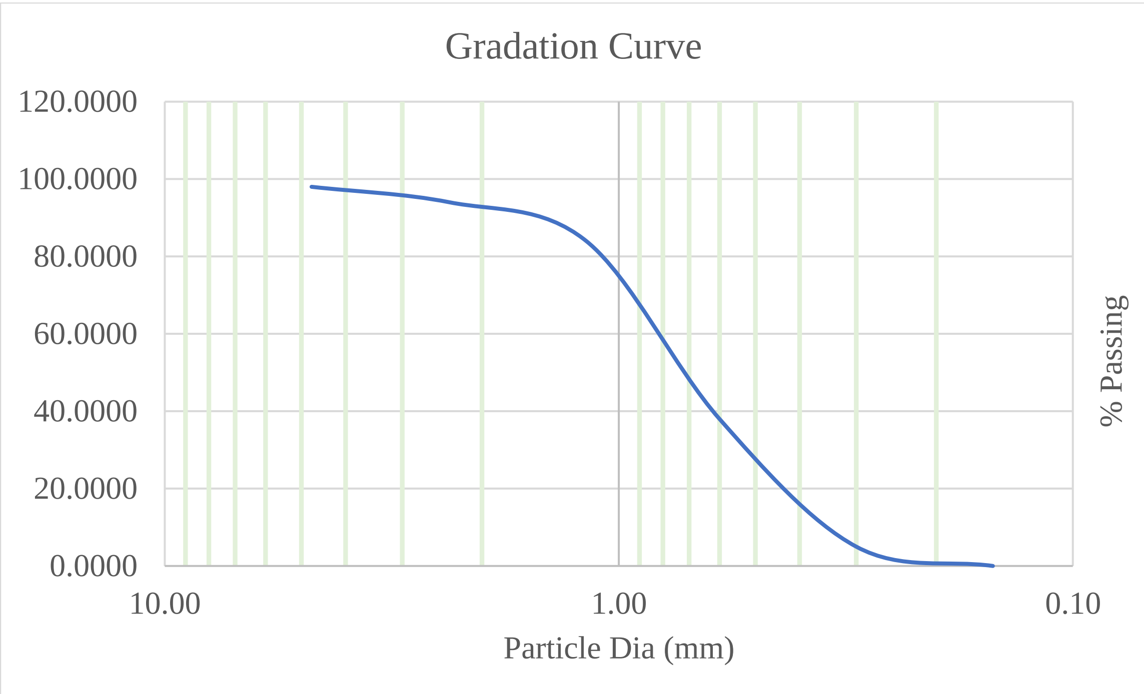


Figure 3-2: Gradation curve of fine aggregate

- Scoria

In this study, scoria fine aggregate was collected from tuludimtu area. Figure 3-3 illustrates samples of scoria after sieve. The same standard procedure like natural aggregate was applied to conduct the properties of scoria aggregates according to the ASTM specifications such as specific gravity, unit weight, absorption, and sieve analysis.

Figure 3-3: Samples of scoria

The experimental results of the scoria aggregate properties are presented in Table 3-3.

Table 3-3: physical properties of fine aggregate (scoria)

No	Test description		Result found
1	Moisture content		0.433%
2	Silt content		1.789%
3	Absorption capacity		0.80%
4	Unit weight		1240
5	Specific gravity	Bulk	2.192
		Apparent	2.359
		SSD	2.393

Grading and Sieve Analysis

The sieve analysis of scoria aggregate includes the determination of coarse and fine aggregate by using a series of sieves. As natural aggregate, [13] procedure was used to determine the sieve analysis of coarse and fine scoria aggregate. Table 3-4 and figure 3-4 show the sieve grading of the scoria aggregate.

Table 3-4: Sieve analysis result of scoria

Sieve Analysis test calculations & Particle Size Distribution Curve of scoria

Sieve Number	Diameter (mm)	Soil Retained (g)	Accumulative Retain (g)	% Mass Retain	% Passing
3/8"	9.5	**0**	**0**	**0**	**100**
#4	4.75	3.9	3.9	0.7800	99.2200
#10	2.36	115.3	119.2	23.8400	76.1600
#20	1.18	152	271.2	54.2400	45.7600
#40	0.60	93.1	364.3	72.8600	27.1400
#60	0.30	65.2	429.5	85.9000	14.1000
#200	0.150	47	476.5	95.3000	4.7000
Pan		23.5	500	∑= 332.92	

Fineness modulus=332.92 /100=3.33

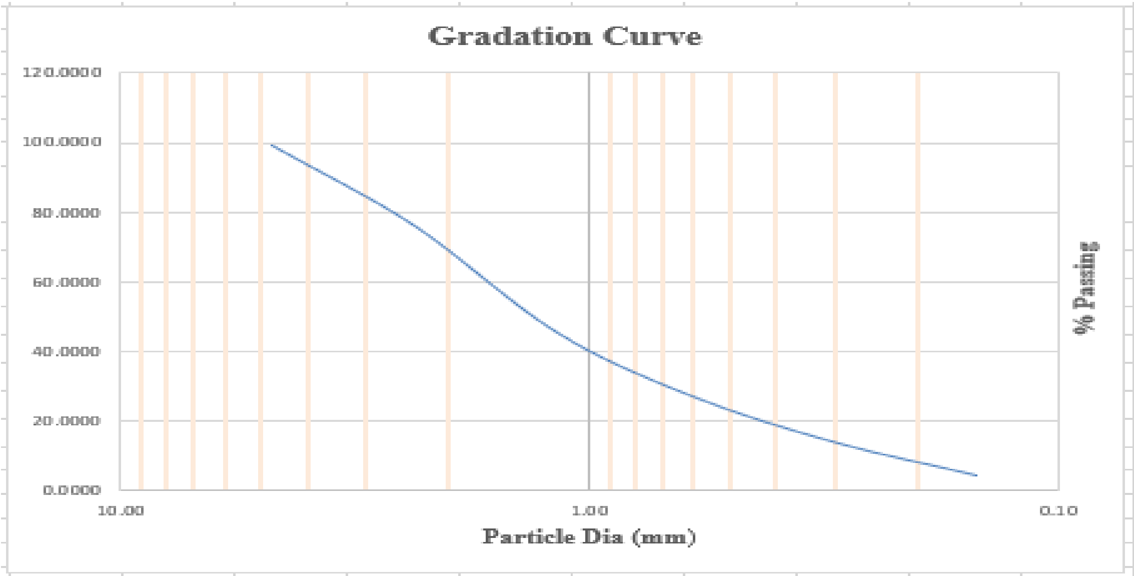


Figure 3-4: Grading curve of scoria

The chemical composition of scoria is determined in Ethiopia Geological Survey Geosciences Laboratory as shown in the Table 3-5.

Table 3-5: Chemical composition of scoria

Chemicals	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO
Composition (%)	53.44	9.81	11.16	10.44	4.28	3.00	1.20	0.12

P_2O_5	TiO_2	H_2O	LOI	SO_3	Cl^-
0.47	0.38	3.56	2.19	0.07	<0.10

XRD output

In this thesis paper XRD test is used to determine the chemical phases and crystalline size of scoria. To retrieve information from XRD output, the following methods can be used [19].

- Basic XRD Data Analysis using High Score Plus
- Profile Fitting and Crystallite Size Determination
- Rietveld Refinement.

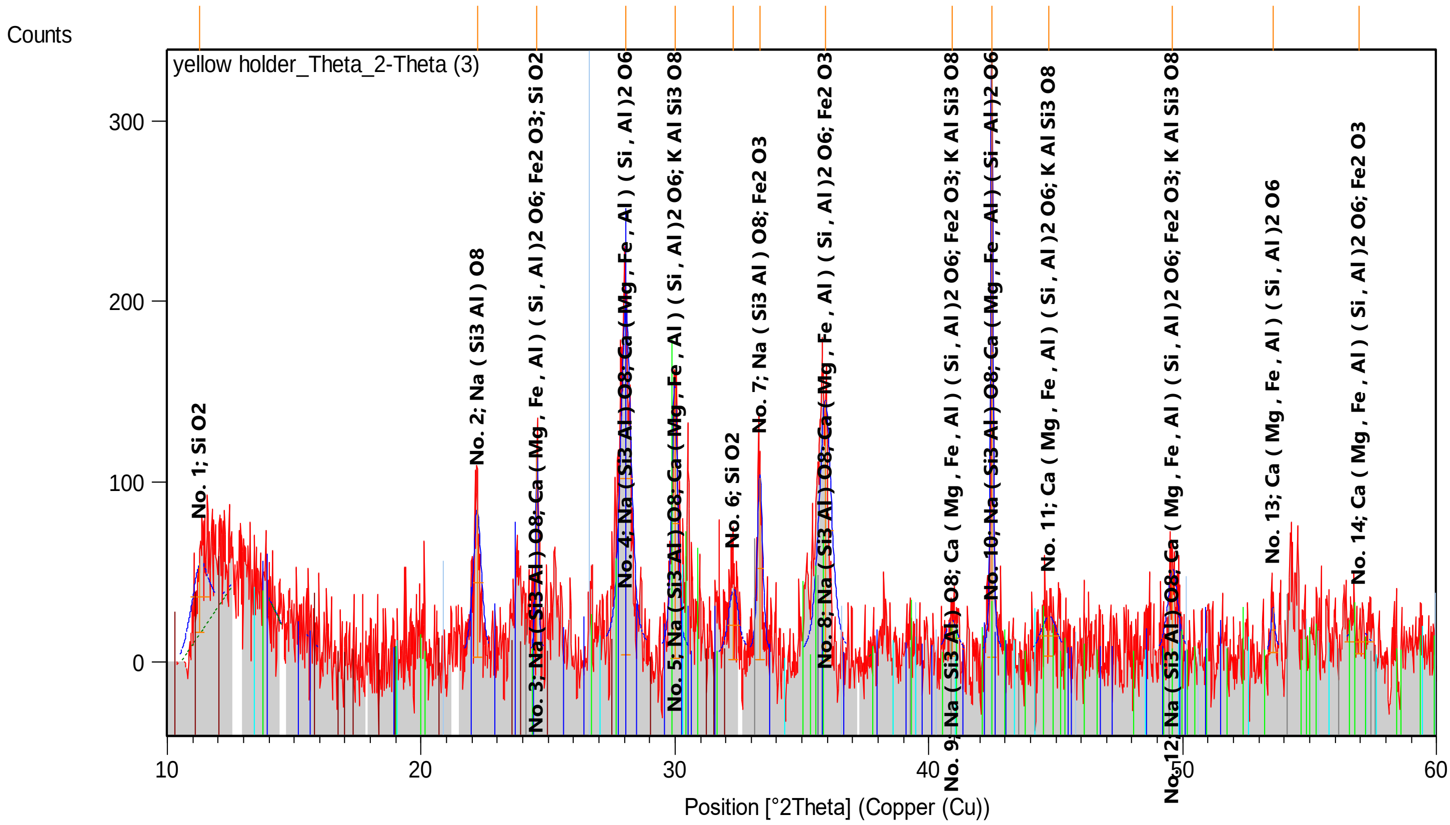


Figure 3-5:XRD pattern of scoria

Table 3-6: Chemical phases of scoria obtained from XRD analysis

Ref. Code	Score	Compound Name	mineral phase	Chemical Formula
00-010-0393	17	Sodium Aluminum Silicate	Albite	$Na (Si_3 Al) O_8$
00-038-0466	19	Calcium Magnesium Aluminum Iron Silicate	Pyroxenes	$Ca (Mg, Fe, Al) (Si, Al)_2 O_6$
00-033-0664	13	Iron Oxide	Hematite	$Fe_2 O_3$
00-045-0111	1	Silicon Oxide	Quartz	$Si O_2$
00-037-0362	2	Potassium Aluminum Silicate	Orthoclase	$K Al Si_3 O_8$

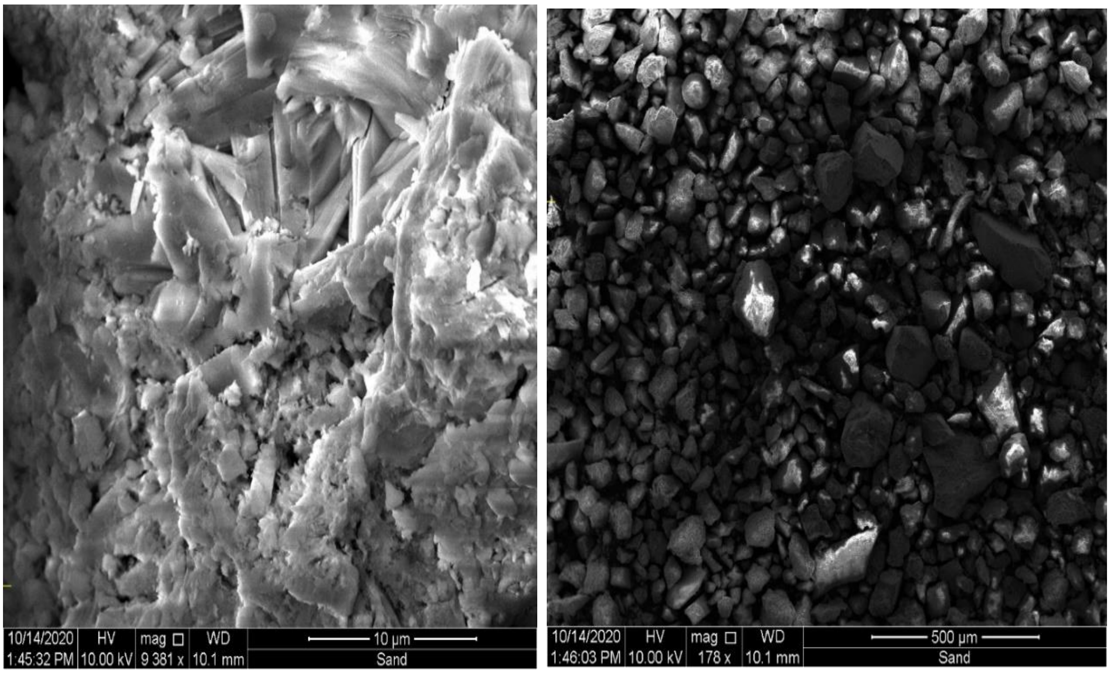
Micro structural investigation of scoria and sand samples

The type, amount, size, shape, and distribution of phases present in a solid constitute its microstructure. The gross elements of the microstructure of a material can readily be seen from a cross section of the material, whereas the finer elements are usually resolved with the help of a microscope. The term macrostructure is generally used for the gross microstructure visible to the human eye; the limit of resolution of the unaided human eye is approximately one-fifth of a millimeter (200 μm). The term microstructure is used for the microscopically magnified portion of a macrostructure. The magnification capability of modern electron microscopes is of the order of 105 times. Therefore, application of transmission and scanning electron microscopy techniques has made it possible to resolve the microstructure of materials to a fraction of one micrometer.

Microstructure studies have increasingly been used to improve understanding of the macroscopic behavior and physical properties of compacted and natural materials. In the past several decades, based on the SEM images, a large number of investigations have been done to assess porosity, permeability, strength, deformation and other hydro-mechanical properties as well as the distribution characteristics of particles and pores [28], [29], [30], [31]. It is a well-known fact that there is an inverse relationship between porosity and strength in solids. Strength resides in the solid part of a material; therefore, voids are detrimental to strength.

The microstructure of a material (such as sand, scoria, metals, polymers, ceramics or composites) can strongly influence physical properties such as strength, toughness, ductility, hardness, corrosion resistance, high/low temperature behavior or wear resistance. Microstructure analysis was performed to compare the microstructures of sand and scoria under the optical microscope to determine porosity, their particle size distribution and similarity in terms of morphology. Optical microscope was used to analyses the internal structure of the samples as well. The structure of sand and scoria used in the research is showed in Figure 3-6 and Figure 3-7. In the photo it can be noticed that the shape both sand and scoria is irregular.

Figure 3-6:Instrument used for SEM analysis



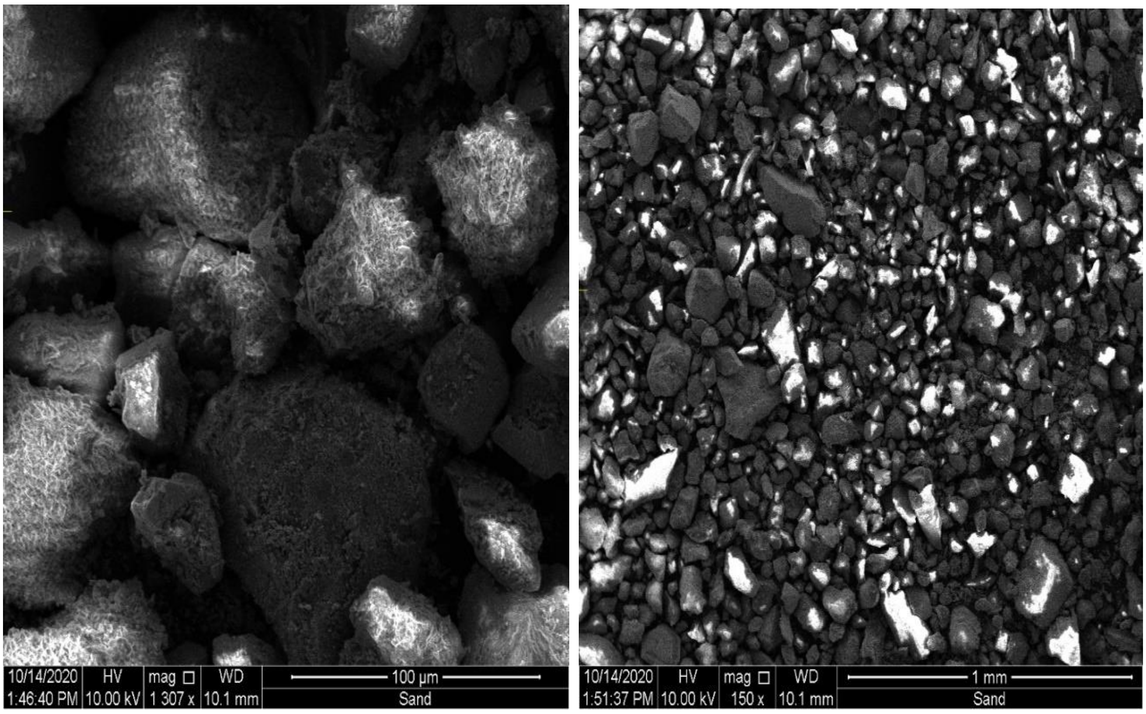
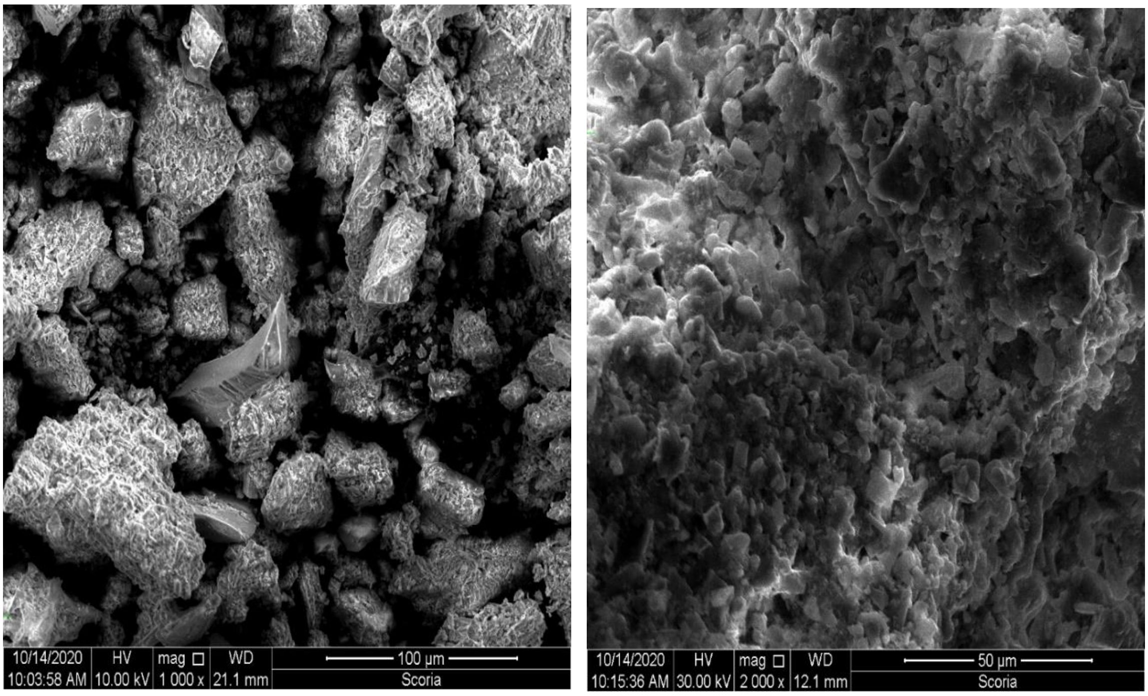


Figure 3-7:Microstructural characteristics of sand specimen



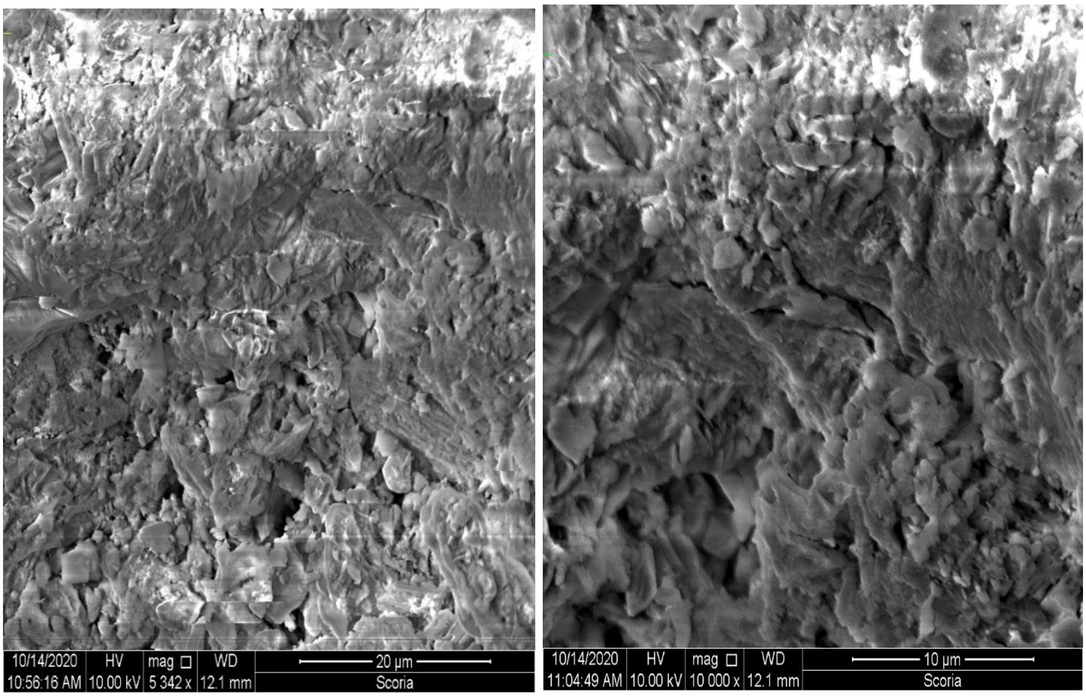


Figure 3-8:Microstructural characteristics of scoria specimen

Thin section of scoria samples indicates in Figure 3-8 that main phase is glassy form and phenocrystals of plagioclases in matrix show polysynthetic twin and minerals are classified as long rod-shaped. The scoria sample has irregular morphology, non-uniform plate shape and glassy form in SEM micrograph. Generally, it can be said that as seen in Figure 3-8, main phase is glassy form which is amorphous. The structure of the scoria is also checked with the XRD and ended up with the same conclusion. The XRD pattern Figure 3-5 shows that the sample has not a crystalline structure and broad reflection (peak) between 10° and 60° (2θ) which is confirmed the presence of amorphous quartz but some little crystalline mineral phases are also observed in the XRD pattern.

Analysis of SEM image

Analysis has been done to determine the microstructural characteristics such as the porosity of the scoria, average particle size (grain size) using ImageJ software and the interpretation result is shown below.

Table 3-7: Analysis result of SEM image scoria in 1000X magnification in µm

Slice	Count	Total Area	Average Size	%Area	porosity	Circ.	Solidity
Threshold	1589	43920.53	27.64	58.373	41.627	0.857	0.882

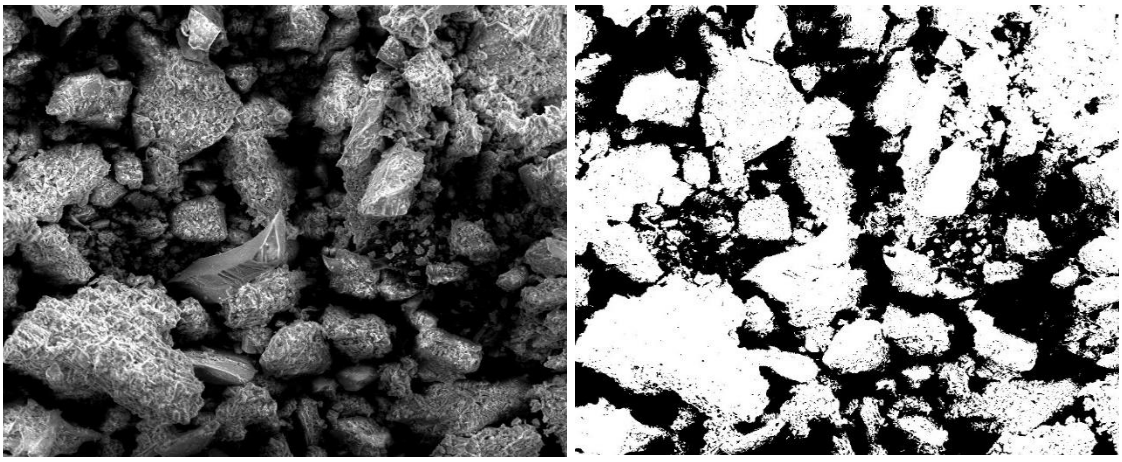


Figure 3-9:Duplicate image of scoria after scaling has done and image after thresholding for 1000X magnification

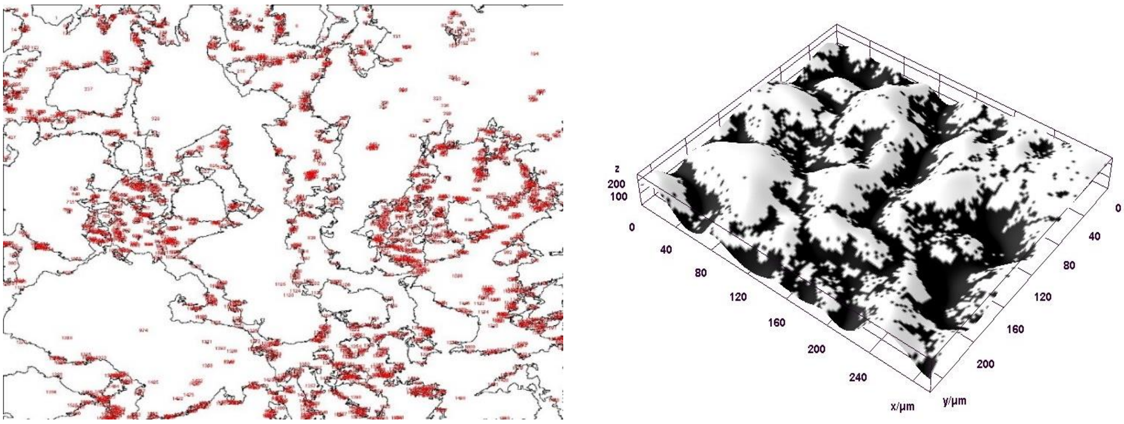


Figure 3-10:Analyzed particles and 3d image of scoria showing the distribution of pores for 1000X magnification

Table 3-8: Analysis result of SEM image scoria in 2000X magnification

Slice	Count	Total Area	Average Size	%Area	Porosity	Circ.	Solidity
Threshold	3852	611477	158.743	67.55	32.45	0.915	0.926

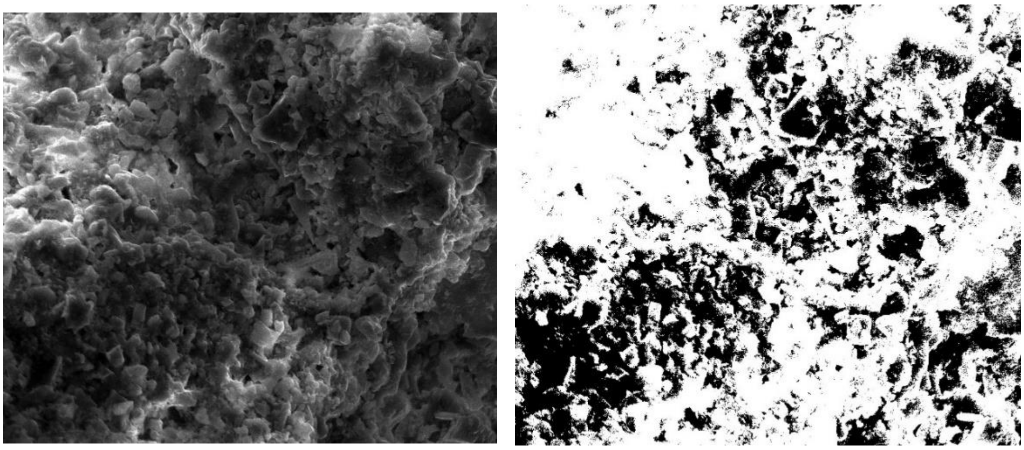


Figure 3-11:Duplicate image of scoria after scaling has done and image after thresholding for 2000X magnification

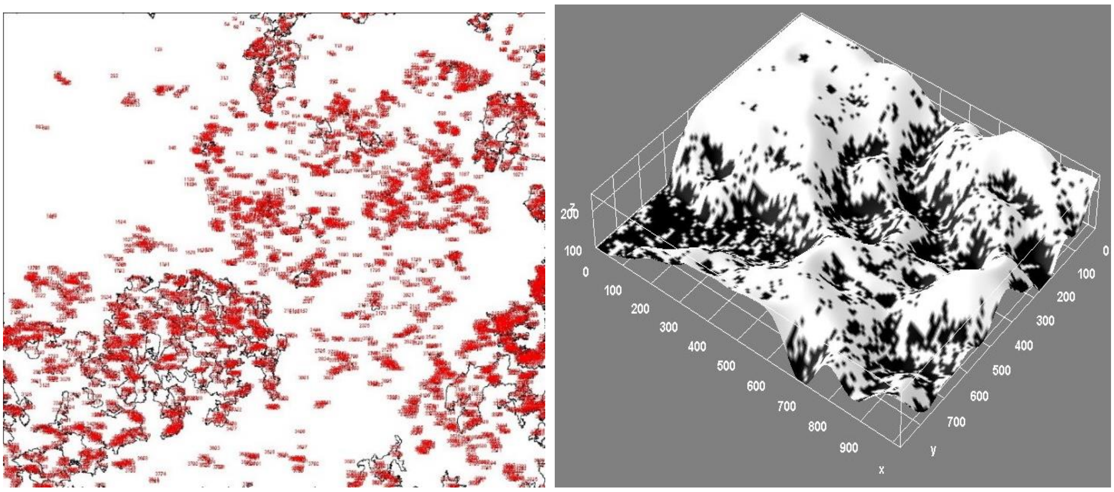


Figure 3-12:Analyzed particles and 3d image of scoria showing the distribution of pores for 2000X magnification

Table 3-9: Analysis result of SEM image scoria in 5342X magnification

Slice	Count	Total Area	Average Size	%Area	Porosity	Circ.	Solidity
Threshold	793	694711	876.054	76.919	23.081	0.867	0.892

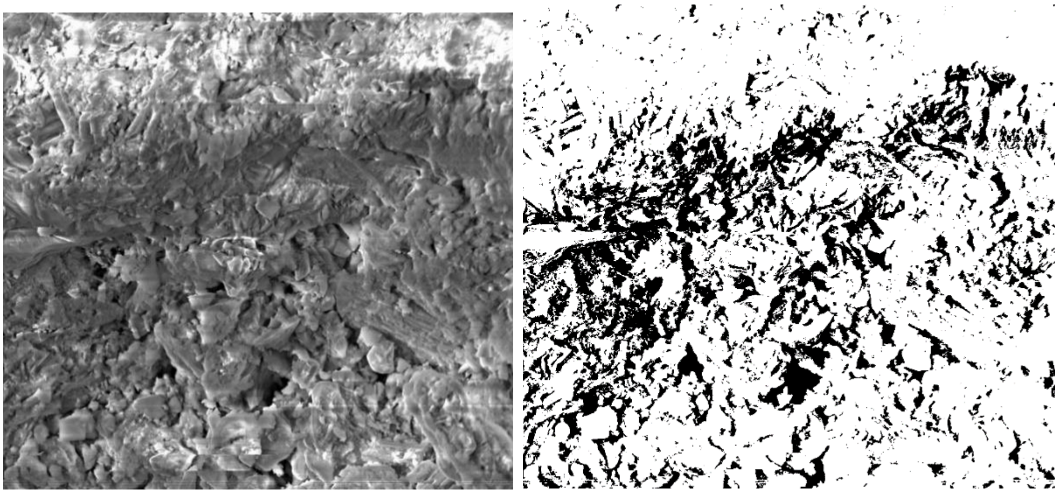


Figure 3-13: Duplicate image of scoria after scaling has done and image after thresholding for 5342X magnification

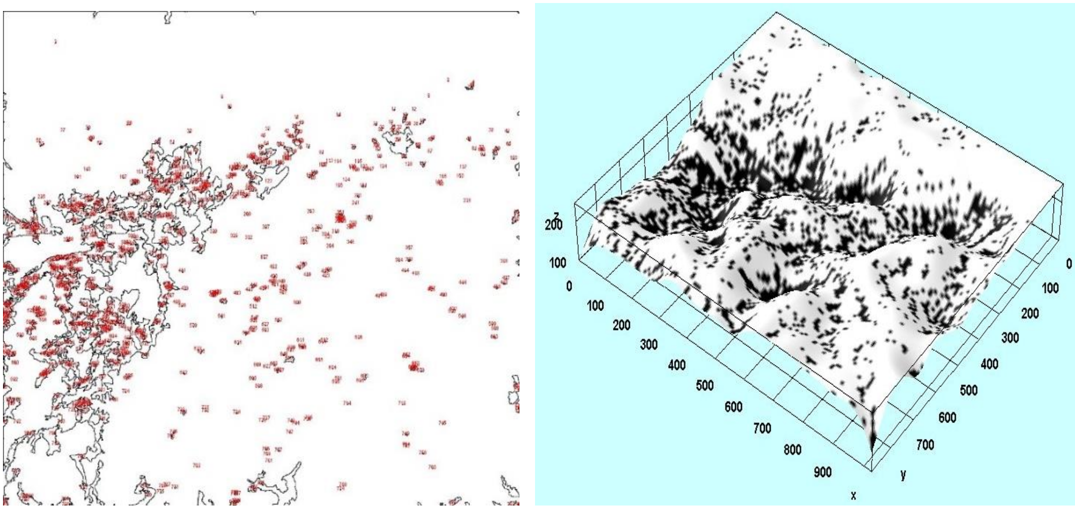


Figure 3-14: Analyzed particles and 3d image of scoria showing the distribution of pores for 5342X magnification

Table 3-10: Analysis result of SEM image scoria in 10000X magnification

Slice	Count	Total Area	Average Size	%Area	Porosity	Circ.	Solidity
Threshold	166	694.52	4.184	92.173	7.827	0.921	0.931

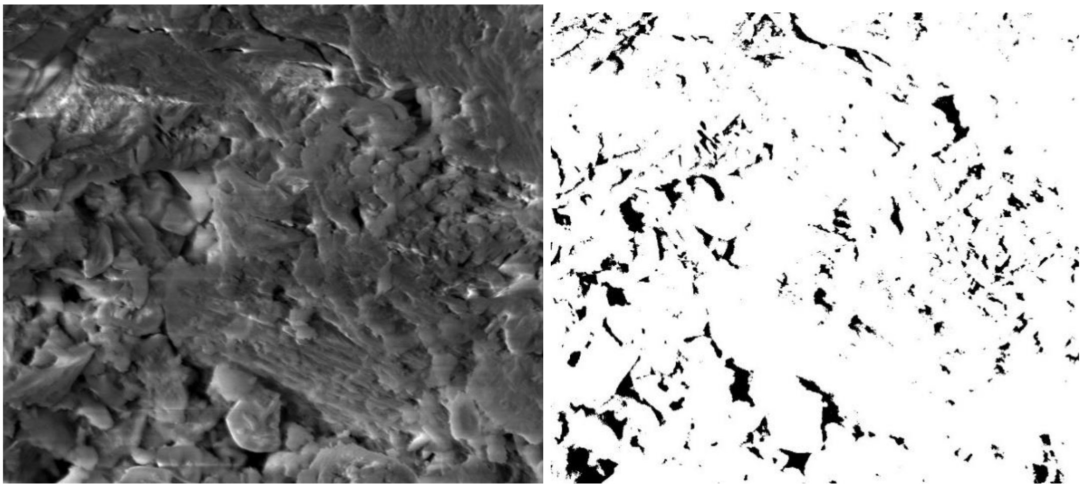


Figure 3-15: Duplicate image of scoria after scaling has done and image after thresholding for 10000X magnification

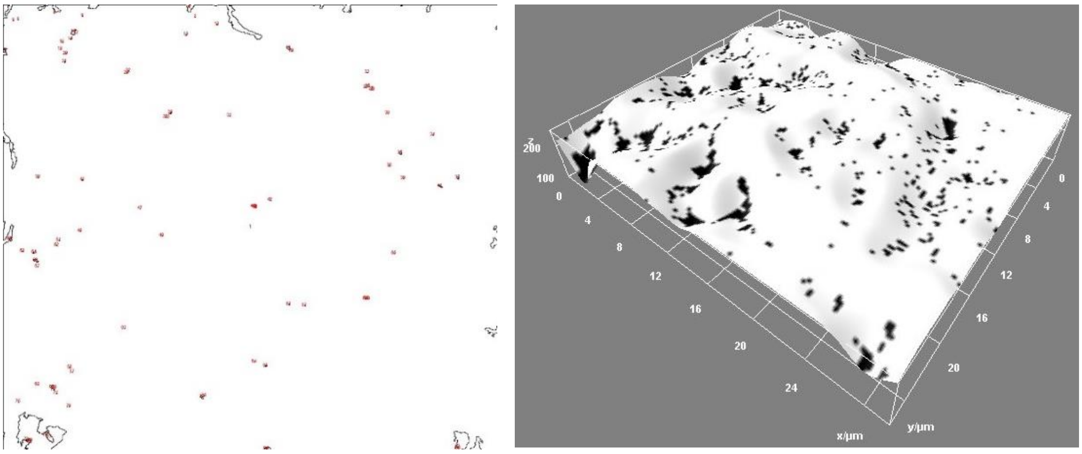


Figure 3-16: Analyzed particles and 3d image of scoria showing the distribution of pores for 1000X magnification

Table 3-11: Relation between porosity and sample magnification in SEM for scoria

Magnification	Apparent Porosity
1000	41.627
2000	32.45
5342	23.081
10000	7.827

It is therefore suggested that the magnification should be minimized for the sampled tested in this investigation to obtain accurate result for the determination of porosity of the material. This is because high magnification is usually related to small physical observation size. Some particles or pores would cover most of the image area and result only referred to microstructure information. As can be seen from the SEM images shown in Figure 3-15 at 10000 magnification, the image is mainly covered with particles. Generally, p decreases with increasing magnification.

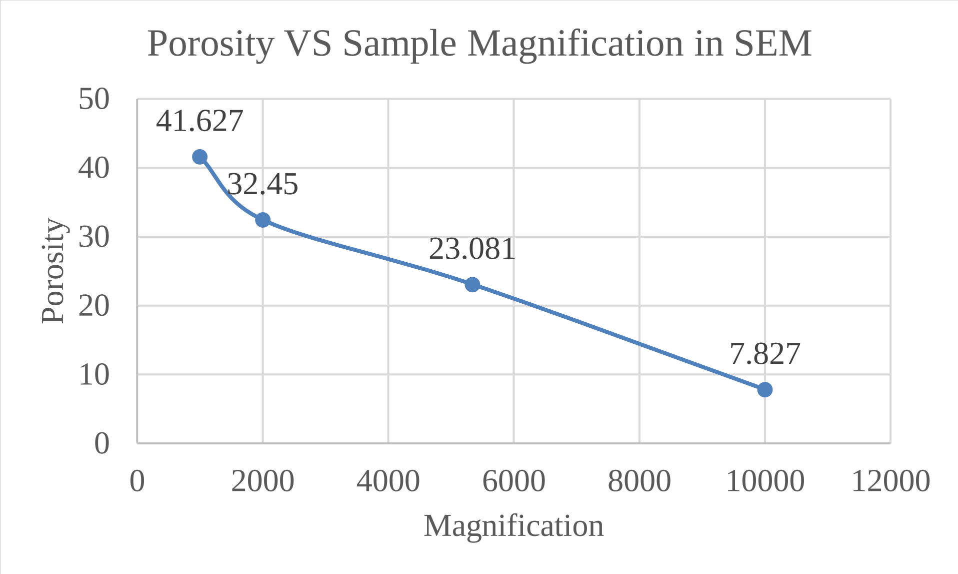


Figure 3-17: Relation between porosity and sample magnification for scoria

Table 3-12: Analysis result of SEM image sand in 150X magnification

Slice	Count	Total Area	Average Size	%Area	Porosity	Circ.	Solidity
Threshold	4687	2.015	4.30E-04	59.751	40.249	0.872	0.904

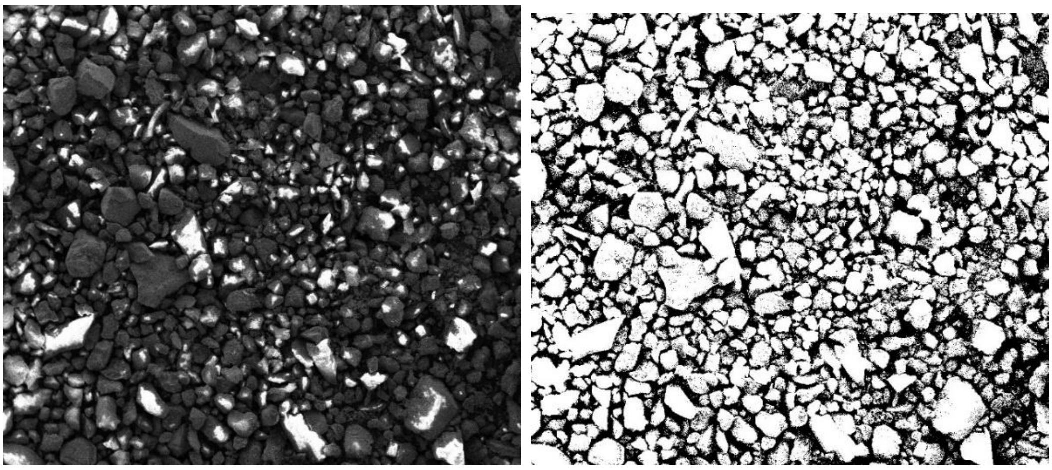


Figure 3-18: Duplicate image of sand after scaling has done and image after thresholding for 150X magnification

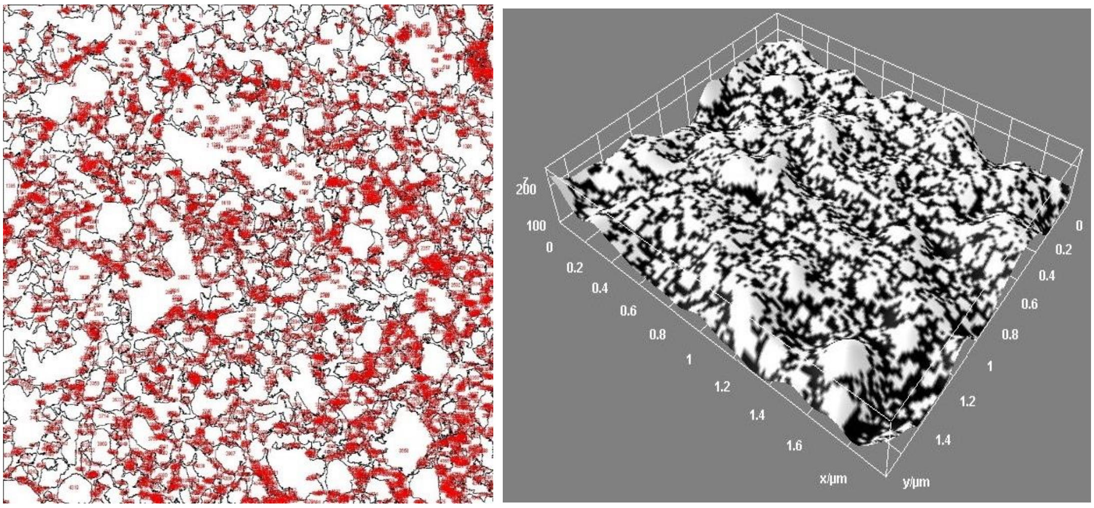


Figure 3-19: Analyzed particles and 3d image of sand showing the distribution of pores for 150X magnification

Table 3-13: Analysis result of SEM image sand in 178X magnification

Slice	Count	Total Area	Average Size	%Area	Porosity	Circ.	Solidity
Threshold	2824	1466420.09	519.271	61.718	38.282	0.871	0.908

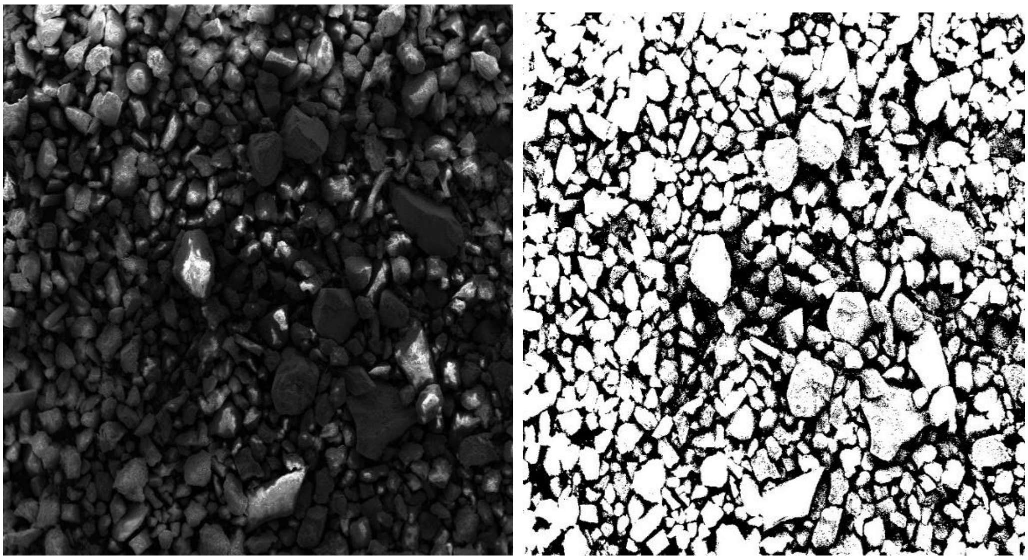
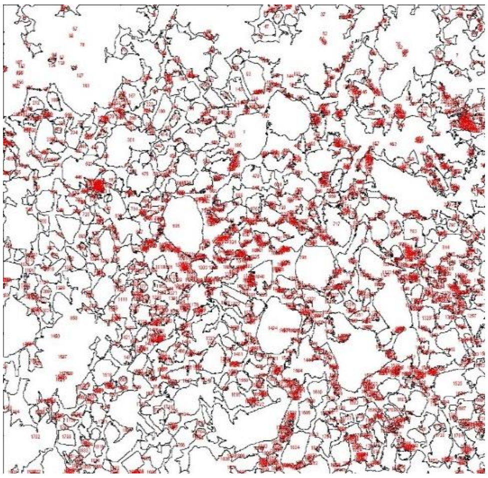


Figure 3-20: Duplicate image of sand after scaling has done and image after thresholding for 178X magnification



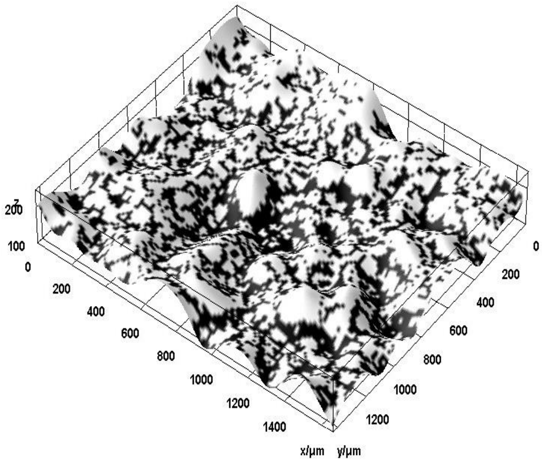
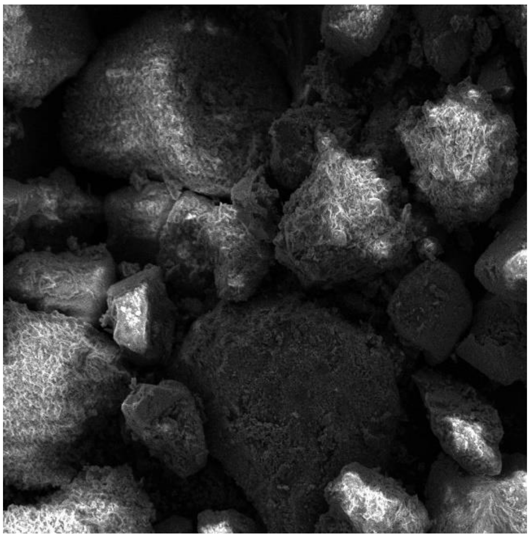


Figure 3-21: Analyzed particles and 3d image of sand showing the distribution of pores for 178X magnification

Table 3-14: Analysis result of SEM image sand in 1307X magnification

Slice	Count	Total Area	Average Size	%Area	Porosity	Circ.	Solidity
Threshold	3687	28586.22	7.753	64.496	35.504	0.901	0.911



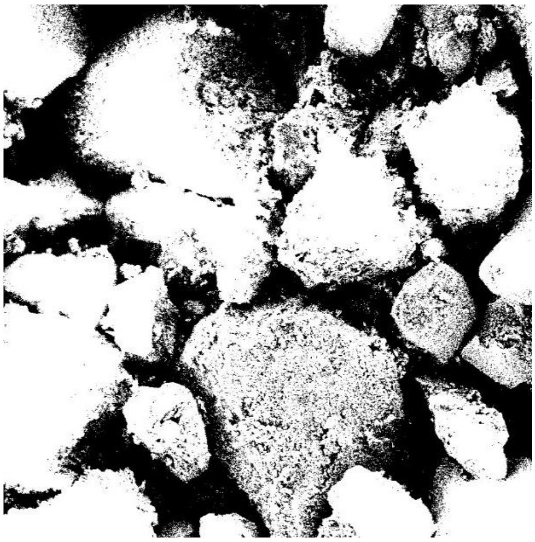


Figure 3-22: Duplicate image of sand after scaling has done and image after thresholding for 1307X magnification

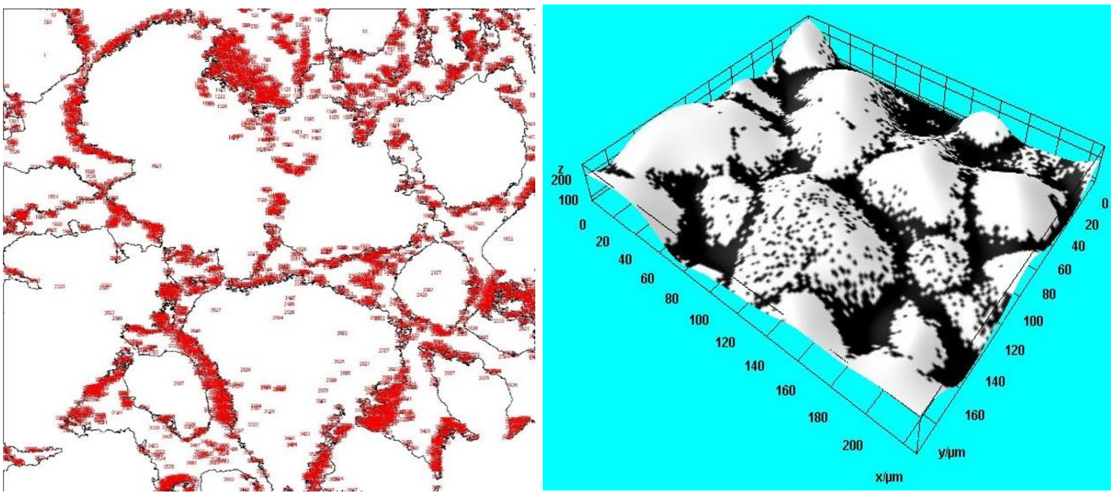


Figure 3-23: Analyzed particles and 3d image of sand showing the distribution of pores for 1307X magnification

Table 3-15: Analysis result of SEM image sand in 9381X magnification

Slice	Count	Total Area	Average Size	%Area	Porosity	Circ.	Solidity
Threshold	1661	682.806	0.411	82.491	17.509	0.92	0.929

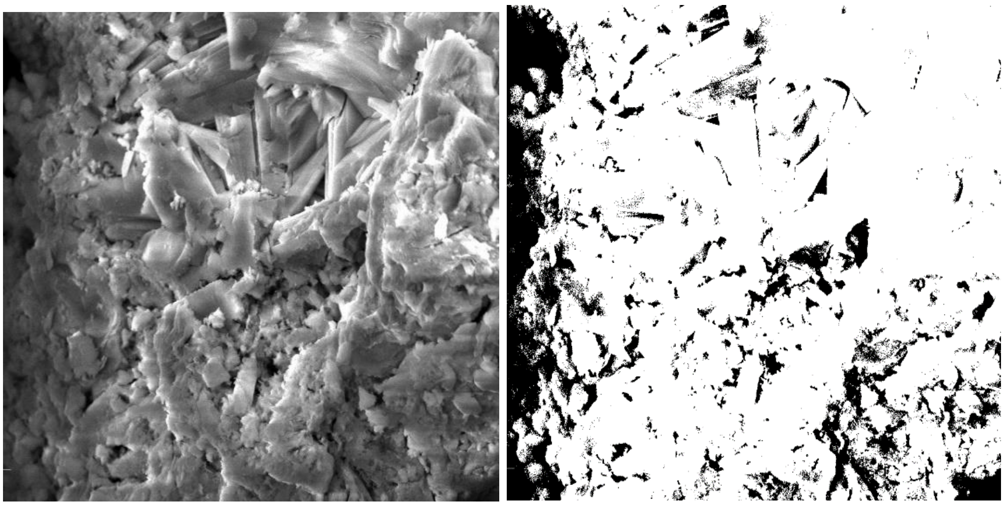
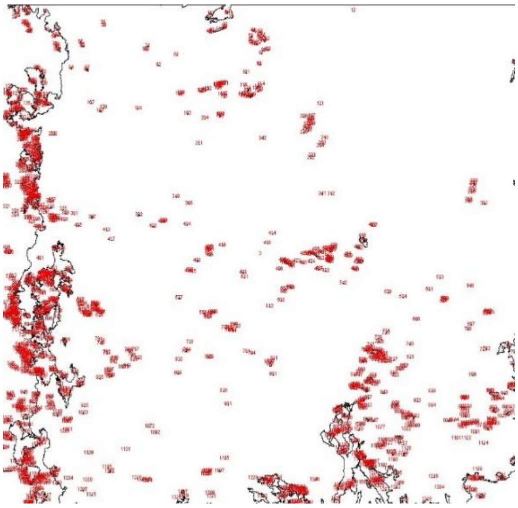


Figure 3-24: Duplicate image of sand after scaling has done and image after thresholding for 9381X magnification



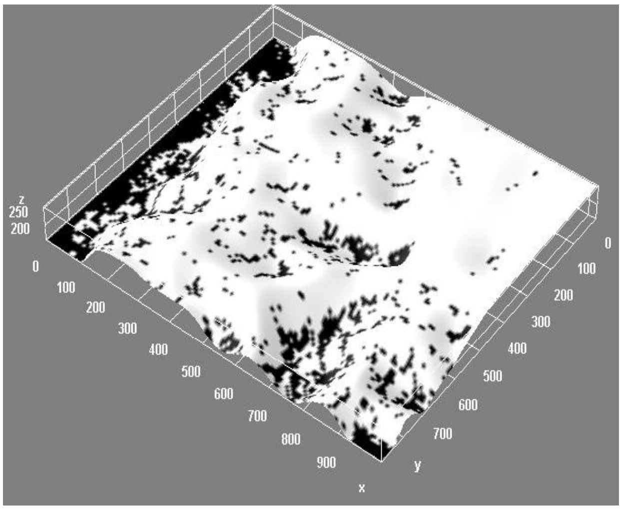


Figure 3-25: Analyzed particles and 3d image of sand showing the distribution of pores for 9381X magnification

Table 3-16: Relation between porosity and sample magnification in SEM for sand

Magnification	Apparent porosity
150	40.249
178	38.282
1307	35.504
9381	17.509

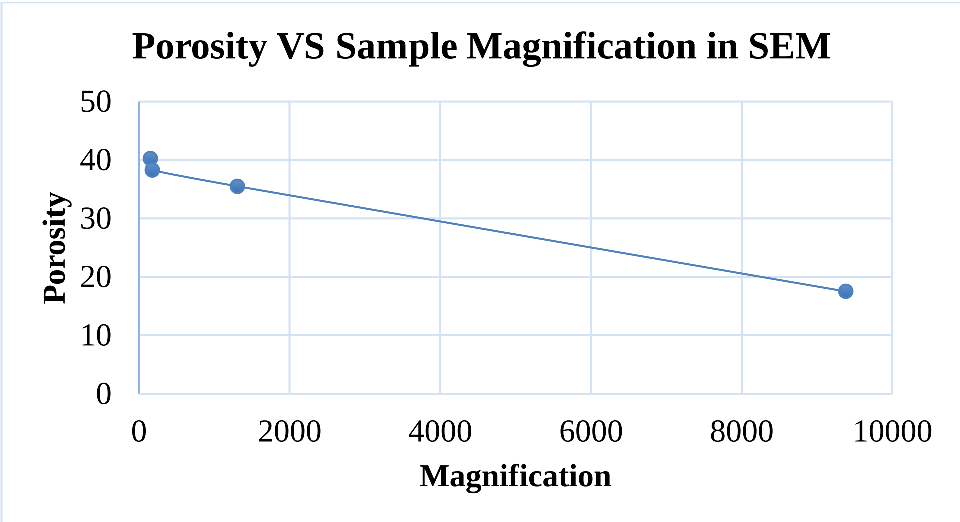


Figure 3-26: Relation between porosity and sample magnification for sand

- Coarse aggregate

Locally available crushed coarse aggregate was used in this study. The maximum nominal size of coarse aggregate is (25mm).

Figure 3-27: Coarse aggregate used for the concrete mix

Coarse Aggregate properties:

To prepare concrete mix we need to know the properties of aggregate which include specific gravity, unit weight, absorption, sieve analysis and moisture content.

- Specific Gravity

The determination of specific gravity of coarse aggregate was done according to [9]. The aggregate specific gravity is a dimensionless value used to determine the volume of aggregate in concrete mixes.

- Unit Weight (Bulk Density)

The unit weight or bulk density of aggregate is the weight of aggregate per unit volume. [9] procedure was used to determine aggregate unit weight.

- Absorption

Absorption of aggregate is the weight of water present in aggregate pores expressed as percentage of aggregate dry weight. [9] was used to determine coarse aggregate absorption.

- Moisture Content

The aggregate moisture content is the percentage of water present in a sample of aggregate either inside pores or in the surface. Moisture content of coarse and fine aggregate was done according to [12].

Table 3-17: Properties of coarse aggregate

No	Test description		Result found
1	Nominal size chosen		25 mm
2	Moisture content		0.832 %
3	Absorption capacity		1.712 %
4	Unit weight		1703.42 Kg/m^3
5	Specific gravity	Bulk	2.67
		Apparent	2.798
		SSD	2.716

Sieve Analysis

In this thesis sieve analysis was not done for coarse aggregate instead proportioning is done by choosing well graded aggregate so each diameter aggregate is measured to gain the right amount of aggregate in the concrete mix.

3.3 Mix Preparation

The main aim of this research is to perform an experimental study to investigate the possibility of substuting scoria as a fine aggregate in concrete. To carry out this study, all experimental programs are done at the Construction Material Laboratory in Addis Ababa Institute of technology. In this study, the mix proportions were prepared according to [32].

Five concrete mixes were prepared in this study with characteristic compressive strength C-25. One concrete mix contains only natural aggregate as reference and four concrete mixes contain scoria aggregate by replacing 35%, 50%, 70% and 100% in volume of natural aggregate by an equal volume of scoria aggregate.

Three samples for every concrete mix were prepared to be tested for compressive strength at 7, 28 and 56 days and All compression tests are done on 15cmX15cmX15cm concrete cubes a total of 75 cubes were used 45 cubes for the compressive strength test at different percentage of scoria and also 30 cubes are used for the water penetration test of the concrete at different percentage of scoria. Also, Three specimens for each percentage of replacement were prepared for Splitting tensile strength and the same number for flexural test, these specimens were tested at age 7, 28 and 56 days All splitting tensile strength tests are done on 15cmX30cm concrete cylinders a total of 45 cylinder molds were used for the split tensile strength test at different percentage of scoria and also all flexural strength tests are done on 10cmX10cmX50cm size molds a total of 45 beams were used for the flexural strength test at different percentage of scoria. Concrete containing scoria aggregate has to comply with the same requirements as concrete made with natural aggregate.

Table 3-18: Testing concrete specimen used for compression, tensile and flexural strengths

Percentage of sand replaced with scoria	Days for test and number of specimens used		
	7 day	28 day	56 day
0%	3	3	3
35%	3	3	3
50%	3	3	3
70%	3	3	3
100%	3	3	3

Table 3-19: Testing concrete cube specimen for the water penetration test

Percentage of sand replaced with scoria	Days for test and number of specimens used	
	28 day	56 day
0%	3	3
35%	3	3
50%	3	3
70%	3	3
100%	3	3

The mix operation of concrete for all samples was taken place in a mixer found in AaiT laboratory room. The coarse aggregate was added to the mixer first followed by cement and fine aggregate, then it was dry blended for about one minute. Two-thirds of water was added and the mixing was continued for an additional one minute. The remaining water is then added, and the total mixing time was three minutes. Slump tests of fresh concrete were done immediately after mixing to check workability. Finally, the concrete was placed in molds and vibrated for 30 seconds. After 24hrs the cast specimens were taken out of their molds and put in a water tank for curing until the test date.

Figure 3-28: Concrete mixer and mixing sample preparation

Figure 3-29: concrete mixing and placing in the mold

Figure 3-30: Concrete sample removed from the mold for curing

Mix design

Mix design is the process of finding the right proportions of coarse aggregate, fine aggregate, water and cement for a pre-required concrete strength. Although there are lots of papers and standards for determining mix design, the perfect mix design can only be mastered through repetition of trial mixes and following the correct path which results in a continuous error reduction, when compared with the anticipated result. [20]

3.4 Equipment and testing procedure

The laboratory work consists of fresh and hardened concrete tests. Fresh concrete tested for slump value. Hardened concrete tested for Compressive strength, Splitting tensile test, Flexural test, Ultrasonic pulse velocity test and Water penetration test.

3.4.1 Fresh concrete tests

- Slump Test

Slump test was conducted to assess the workability of fresh reference concrete and concrete containing scoria aggregate. The slump test was carried out according to [33]. For each mix in the experiment program, a sample of freshly mixed concrete is placed and compacted by rod in a frustum of cone mold. As shown in Figure 3-31, the slump value is equal to vertical distance between the original and displaced position of the center of the top surface of the concrete after raising a mold.

Figure 3-31: Slump test of the given concrete material

- Density

In this study, the density of concrete cube specimens is the theoretical density. The density is calculated by dividing the weight of each cube on the cube volume. The same cube specimens which used to determine compressive strength were used to determine the density in the same procedure.

3.4.2 Hardened concrete tests

- Compressive Strength Test

Forty-five cubic specimens of size 150mmX150mmX150mm were casted for conducting compressive strength test, three for each percentage (0%, 35%, 50%, 70% and 100%) of scoria aggregate. After 24 hours, cubes extracted from the mold and stored in water (curing phase) up to the time of test. Before testing, specimens were air dried for 10 to15 minutes.

The compressive strength test was based on [34] and was tested at the end of the 7, 28 and 56 days of curing. The compressive strength of any mix was taken as the average strength of three cubes.

The compressive strength of the specimen, σ (in MPa), is calculated by dividing the maximum load carried by the cube specimen during the test by the cross-sectional area of the specimen.

Figure 3-32: Machine and material setup for cubic compression test

- Splitting Cylinder Test

The splitting tensile strength of concrete specimens was measured based on [17] Standard test. forty-five cylindrical specimens of size 150 mm in diameter and in height 300 mm were cast. Three specimens for each percentage (0%, 35%, 50%, 70% and 100%) of scoria aggregate.

Figure 3-33: Testing set up for split tensile strength of concrete

- Flexural strength test

The flexural strengths of concrete specimens are determined by the use of simple beam (100mmX100mmX500mm) with three-point loading in accordance to [16] as shown in Figure 3-34. Forty-five beam specimens of size 100mmX100mmX500mm were casted.

Figure 3-34: Machine and material setup for flexural test

- Water penetration

For assessing performance related to penetration of water due to the replacement of scoria in different percentage in concrete production, non-steady water penetration test was conducted on 150mm cubes. Non steady water penetration of concretes made with OPC was carried out at 28 days and 56 days on cured 150 mm concrete cubes respectively. The steps followed for conducting water penetration test is shown as follows: -

The test samples were assembled in the permeability apparatus and 3 bar (0.3MPa) pressure was applied for the first 24 hours. then 5 bar (0.5MPa) water pressure was applied for the next 24 hours and the water pressure was increased to 7 bar (0.7MPa) for the third 24 hours to a total of 72 hours under pressure.

At the end of 72 hours, the concrete cubes were removed from the permeability rig and split in to two using tensile splitting machine. Upon visual examination, the portion of specimens into which water penetrated appears darker than the rest. Then the darker zone was marked and water penetration depth measurements were taken.

Figure 3-35: Machine and material setup for water penetration test

- Ultrasonic pulse velocity test

An ultrasonic pulse velocity (UPV) test is an in-situ, nondestructive test to check the quality of concrete. In this test, the strength and quality of concrete is assessed by measuring the velocity of an ultrasonic pulse passing through a concrete structure.[35]

This test is conducted by passing a pulse of ultrasonic through concrete to be tested and measuring the time taken by pulse to get through the structure. Higher velocities indicate good quality and continuity of the material, while slower velocities may indicate concrete with many cracks or voids.

The transducer, clock, oscillation circuit, and power source are assembled for use. After calibration to a standard sample of material with known properties, the transducers are placed on opposite sides of the material. Pulse velocity is measured by a simple formula:

$$\text{Pulse velocity} = \frac{width\ of\ structure}{time\ taken\ by\ the\ pulse\ to\ go\ through} \tag{5}$$

It is used to determine the integrity of structural concrete by measuring the speed and attenuation of an ultrasonic wave passing along a specific test path in the element being tested. The indirect application is primarily used for surface-opening crack depth measurements and determination of elastic modulus. The interpretation of pulse velocity test result can be stated in Table 3-21.[36]

The pulse velocity, V, of longitudinal stress waves in a concrete mass is related to its elastic properties and density according to the following relationship:

$$V = \sqrt{\frac{E(1-\mu)}{\rho(1+\mu)(1-2\mu)}} \tag{6}$$

where:

E = dynamic modulus of elasticity,

μ = dynamic Poisson's ratio, and

ρ = density

Table 3-20: Interpretation of pulse velocity

Pulse velocity	Concrete quality
3.5 – 4.0 km/s	Good to very good, slight porosity may exist
3.0 – 3.5 km/s	Satisfactory but loss of integrity is suspected
<3.0 km/s	Poor and los of integrity exist

CHAPTER 4 EXPERIMENTAL PROGRAM

4.1 Experiments

All concretes were mixed in the laboratory using the mixer shown in Figure 3-28. The coarse aggregate was added to the mixer first followed by cement and fine aggregate, then it was dry blended for about one minute. Two-thirds of water was added and the mixing was continued for an additional one minute. The remaining water is then added, and the total mixing time was three minutes. Slump tests of fresh concrete were done immediately after mixing to check workability and consistency. Finally, the concrete was placed in the given molds and vibrated for 30 seconds. After 24hrs the specimens were taken out of their molds and put in a water tank for curing until the test date.

The American Concrete Institute (ACI) method of the mix design method was used in designing the concrete mixes. The trial mix was prepared for a concrete grade of C-25 compressive strength. A maximum aggregate size of 25 mm was used in the experiment. A water to cement ratio of 0.498 was used based on the maximum aggregate size and the concrete grade. By considering the workability of the concrete in line with the aggregate size and strength of the concrete, the amount of water required was determined following the ACI mix design table. Accordingly, the amount of water required for the mix is 193 kg/m3. Based on the fineness modulus of the fine aggregate, the amount of the coarse aggregate was determined for the specified maximum aggregate size. The proportion of the concrete ingredients used in a unit cubic meter is indicated in Table 4-1, considering the associated physical properties of the materials. In this study, the fine aggregate used was a combination of scoria and sand. Replacement of scoria was made with a percentage of 0% (control), 35%, 50%, 70%, and 100% on a volume basis. The effects of the different levels of percentages were investigated on the workability of the concrete by measuring the slump height.

The amount of water, cement, and fine aggregate and coarse aggregate was proportioned as per [32]. The experiment is shown in the table below:

Table 4-1: Mix proportion used for the laboratory work

Sample name	Constituent	Water		Cement		Sand		Scoria		Coarse aggregate	
		By volume (m3)	By weight (kg)	By volume (m3)	By weight (kg)	By volume (m3)	By weight (kg)	By volume (m3)	By weight (kg)	By volume (m3)	By weight (kg)
Control	0% Scoria, 100% Sand	173.10	172.81	387.55	387.55	701.17	707.97	-	-	1149.07	1149.07
Sc-35	35% Scoria, 65% Sand	198.24	198.11	387.55	387.55	439.868	451.698	236.852	243.222	1149.07	1149.07
Sc-50	50% Scoria, 50% Sand	208.75	208.95	387.55	387.55	333.185	344.66	333.185	344.66	1149.07	1149.07
Sc-70	70% Scoria, 30% Sand	222.54	223.41	387.55	387.55	195.81	204.561	456.89	477.309	1149.07	1149.07
Sc-100	100% Scoria, 0% Sand	242.7	245.09	387.55	387.55	-	-	632.45	670.68	1149.07	1149.07

Mix-proportioning was done following the procedures given in [32], 2002 report.

Step 1- Selecting slump

Step 2- Choice of nominal maximum size of aggregate

Step 3- Estimation of mixing water (According to [32] table A1.5.3.3) which is based on selected nominal maximum aggregate size and slump.

Step 4- Selection of w/c (From [32] table A1.5.3.4 (a)) which is based on selected nominal maximum aggregate size and concrete grade.

Step 5- Calculation of cement content

Step 6- Estimation of coarse aggregate content (From [32] table A1.5.3.6) based on fineness modulus of fine aggregate and the selected nominal maximum aggregate size.

Step 7- Estimation of fine aggregate content.

CHAPTER 5 RESULT AND DISCUSSION

5.1 Introduction

In this section the test results on the performance of concrete made with partial replacement of sand with scoria are presented, analyzed and discussed.

5.2 Workability

In this study the slump was determined for each fresh concrete mix according to [33] standard test method for slump of cement concrete at the end of mixing and prior to casting. The results are reported to the nearest of 5 mm as shown in Table 5-1.

Table 5-1: Slump of concrete with percentage replacement

Code of the sample	Slump in mm
control	75
Sc-35	71
Sc-50	65
Sc-70	55
Sc-100	52

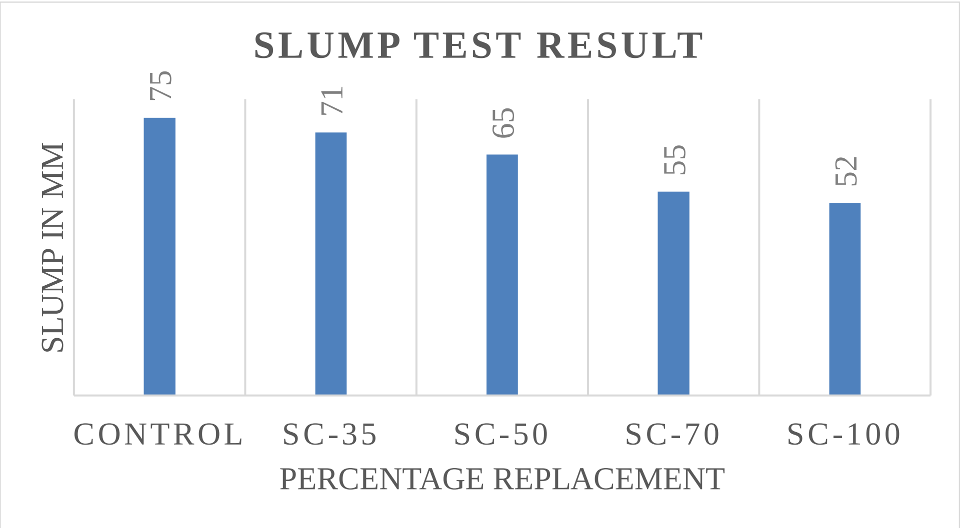


Figure 5-1: Slump test result for a given percentage of replacement of scoria

Result inconsistencies may arise from variations in characteristics and proportion of ingredients, variations in mixing, variations in placing and variations in mixing temperature and humidity (ACI Committee 2011). However, due to the same mixing time and speed, variations arising from mixing could be neglected and due to the usage of the same operator across all mixes variations in placing could also be neglected. Therefore, the inconsistencies occurred as a result of variations in characteristics of ingredients (Coarse aggregates, fine aggregates, and cement) and variations in mixing temperature and humidity. [20]

The test result of the slump height observed is indicated in Table 5-1. The test result of the experimental work shows that the workability of the fresh concrete slightly decreases as the amount of scoria replaced as fine aggregate increases. As the percentage of scoria increases, the fineness of the blended fine aggregate increases. The decrease in the workability of the concrete is supposed to be due to the relative coarseness of the fine aggregate as a result of the replacement of scoria with the higher fineness of modulus as compared to the river sand (3.32>2.81) and also due to the porosity of scoria as compared to river sand.

5.3 Density of concrete

At the end of the required curing days, 3 concrete cubes specimen were taken out for each mix from curing tank to measure the density of concrete before conducting compressive strength.

Table 5-2: Density of 150mm cubes concrete on 28 days

Code of specimen	Average density of the specimen (kg/m^3)
Control	2405.93
Sc-35	2350.22
Sc-50	2264.59
Sc-70	2208.89
Sc-100	2189.33

Table 5-3: Density of 150mm cubes concrete on 56 days

Code of specimen	Average density of the specimen (kg/m^3)
Control	2383.11
Sc-35	2335.70
Sc-50	2259.26
Sc-70	2197.33
Sc-100	2164.15

The density of the test sample at the age of the 28th and 56th day for the different levels or proportions of scoria replacement was determined, and the results are indicated in Table 5-2 and Table 5-3. It can be seen from the tables that the density of the concrete decreases as the percentage of scoria increases due to the lower unit weight of scoria. The reduction in the density of concrete helps to decrease the self-weight of the concrete in the determination of the design dead of the concrete structural member to have reduced concrete cross-sectional dimension supporting the structural member and thus saves the amount of concrete volume relatively.

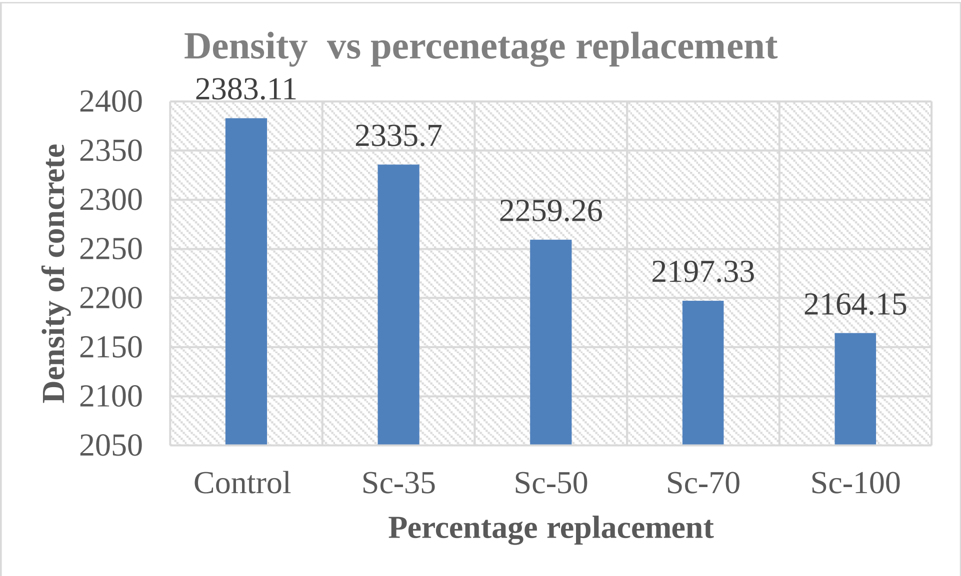


Figure 5-2: Density vs percentage replacement of scoria at 56 days of curing

5.4 Compressive strength of concrete

Tests for compressive strength of concrete made were carried out in this research after the cube samples were fully immersed in water for 7, 28 and 56 days. The mix design was prepared for C-25 according to [32]. The tests were performed on 150mm cubes. All of the 150mm cube strength test results obtained at 7, 28 & 56 days are reported in the Appendixes“. In this section mean cube compressive strength results and percentages which compare loss of strength compared to the control specimen due to partial replacements of sand with scoria are shown on Tables 5-4. Figures 5-4 demonstrate the relationship between compressive strength, curing age and replacement percentages for all concrete mixes.

The strength level of concrete will be considered satisfactory when the averages of all sets of three consecutive compressive strength test results molded and cured in accordance with the requirements of [37] equal or exceed fc' (specified strength); and no individual strength test falls below fc' by more than 3.5MPa when fc' is 35MPa or less, or by more than 0.1times fc' when fc' is more than 35 MPa.” For early day strength of moist cured concrete [38] gives a formula to calculate the expected compressive strength at specified dates.

$$f'cm(t) = f'c * (\frac{t}{4 + 0.85t}) \quad (7)$$

Where: - f’cm(t) - Expected mean strength at specified curing date t

f'c - Specified strength

According to Eq. 7 concretes made for this study are expected to attain 17.588 MPa at 7 days of curing. The compressive strength test result of the experiment shows that there is an increasing trend in the compressive strength at the curing ages of 7, 28, and 56 days with an increase in the amount of the scoria used as fine aggregate.

Figure 5-3: Samples of cube before test and after test

Table 5-4: Average cube compressive results of concrete

Sample code	7 days		28 days		56 days	
	Compressive strength (MPa)	Reduction in strength (%)	Compressive strength (MPa)	Reduction in strength (%)	Compressive strength (MPa)	Reduction in strength (%)
control	26.01	0	35.2	0	39.61	0
Sc-35	23.96	7.88	35.63	0	43.60	0
Sc-50	23.37	10.15	35.58	0	38.61	0
Sc-70	22.99	11.61	33.15	5.82	36.85	3.05
Sc-100	22.34	14.11	31.03	11.85	33.61	11.58

The enhancement in the properties of the concrete observed was due to the inherent physical properties of the scoria sample. The silt and clay content of scoria is smaller than the river sand. The decrease in the silt content of the blended concrete mixes helps the proper cement hydration processes to take place, favoring the compressive strength of the concrete to occur due to proper bondage between the aggregates. The blending of the finer river sand with the coarser scoria resulted in a well-graded particle size distribution, increasing the volume solid of the concrete and thereby increasing the strength of the concrete. The maximum compressive strength attained at a replacement of 35% of scoria. As the amount of scoria gets more and more, the amount of finer sand aggregates decreases, and thereby, the volume of solid decreases. Besides, the formation of the interaction of paste and aggregate also decreased due to the lowering of the filler or packing effect. As a result, the compressive strength of concrete declined beyond 35%. However, the compressive strength with 50%,70% and 100% replacement is still in a good agreement with that of the control sample due to the well-graded particle distribution of the blended fine aggregate as compared to that of the river sand. Generally, this experimental study shows that the scoria sample under consideration can replace the river sand up to 100% in order to produce concrete for the target mix design considered.

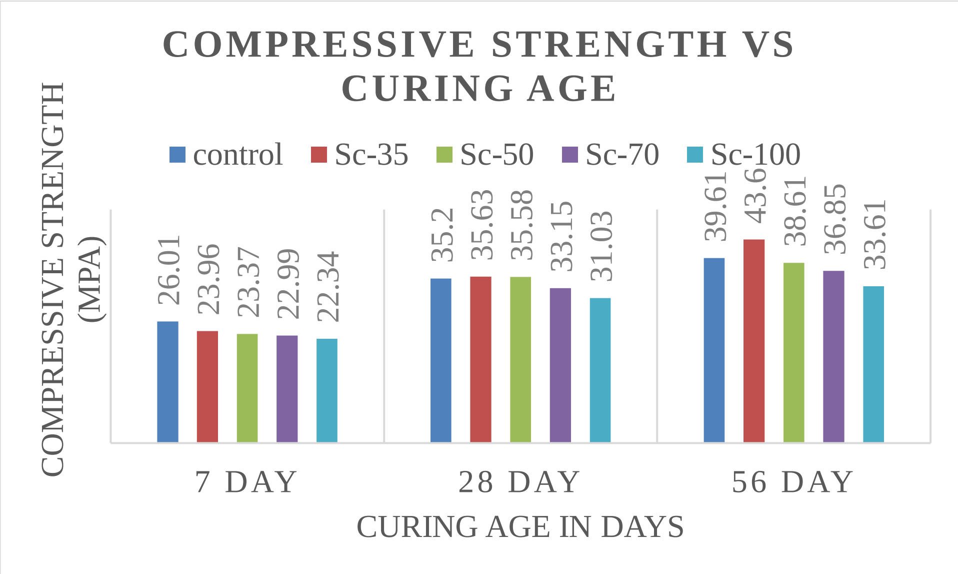


Figure 5-4: The relationship between compressive strength, curing age and replacement percentages

5.5 Flexural strength of concrete

Tests for Flexural strength of concrete made were carried out in this research after the flexural samples were fully immersed in water for 7, 28 and 56 days. The mix design was prepared for C-25 according to [32]. The tests were performed on 100X100X500mm beam samples. All of the flexural strength test results obtained at 7, 28 & 56 days are reported in the Appendixes‟. In this section mean flexural strength results and percentages which compare loss of strength due to partial replacements of sand with scoria are shown on Tables 5-5.

Figure 5-5: Samples of flexural specimen after the test

Table 5-5: Average flexural strength results of concrete

Sample code	7 days	28 days	56 days
	Flexural strength (MPa)	Flexural strength (MPa)	Flexural strength (MPa)
control	2.43	4.15	4.73
Sc-35	2.75	3.89	4.40
Sc-50	3.62	4.48	4.88
Sc-70	2.61	4	4.76
Sc-100	2.50	4.10	4.12

The flexural strength test result of the experiment shows that there is an increase in the flexural strength at the curing ages of 7, 28, and 56 days with an increase in the amount of the scoria used as fine aggregate. But with percentage replacement, there is a variation in flexural strength. The maximum flexural strength attained at a replacement of 50% of scoria with a value 4.88 MPa. Figures 5-6 demonstrate the relationship between flexural strength and replacement percentages for all concrete mixes.

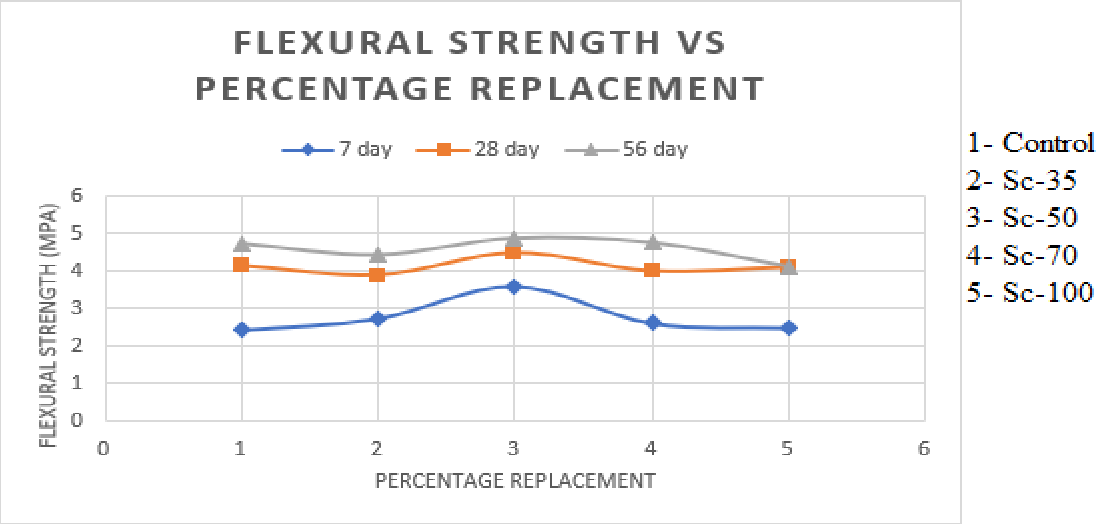


Figure 5-6: Relationship between flexural strength and replacement percentages

5.6 Split tensile strength of concrete

Tests for split tensile strength of concrete were carried out in this research after the cylindrical samples were fully immersed in water for 7, 28 and 56 days. The mix design was prepared for C-25 according to [32]. The tests were performed on 150X300mm cylindrical samples. All of the tensile strength test results obtained at 7, 28 & 56 days are reported in the Appendixes". In this section mean tensile strength results due to partial replacements of sand with scoria are shown on Tables 5-6.

Figure 5-7: Samples of cylindrical specimens before and after the test

Table 5-6: Average split tensile strength results of concrete

Sample code	7 days	28 days	56 days
	tensile strength (MPa)	tensile strength (MPa)	tensile strength (MPa)
control	2	2.86	3.02
Sc-35	1.94	2.77	2.80
Sc-50	2.55	3.24	3.36
Sc-70	2.14	2.49	2.76
Sc-100	1.75	1.87	2.01

The tensile strength test result of the experiment shows that a constant trend in the tensile strength at the curing ages of 7, 28, and 56 days with an increase in the amount of the scoria used as fine aggregate is not shown for some percentage replacements. But it can be decided from the above result that the maximum tensile strength attained is at a replacement of 50% of scoria with a value 3.36 MPa. Figures 5-7 demonstrate the relationship between tensile strength and replacement percentages for all concrete mixes.

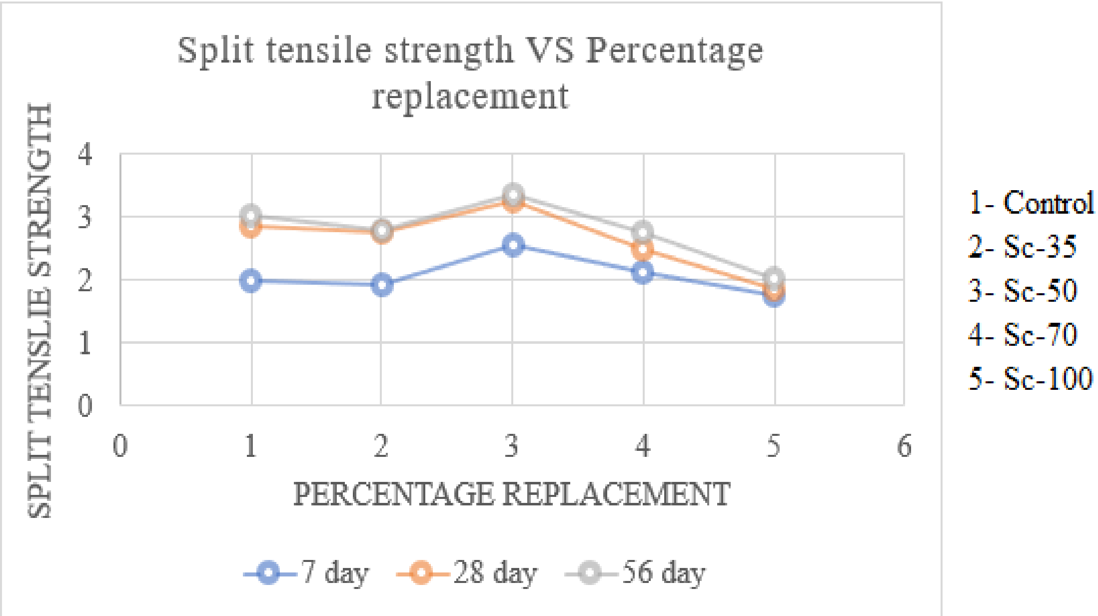


Figure 5-8: Relationship between tensile strength and replacement percentages

5.7 Water penetration test of concrete

For assessing changes related to durability due to replacing of sand with scoria in concrete production, non-steady state water permeability test was conducted. The maximum and average water penetration reading at 28 days and 56 days for concrete respectively are given in Table 5-7 and the changes in penetration through percentage replacement are demonstrated using graph as shown in Figure 5-10.



Figure 5-9: water penetration test of concrete cubes

According to [39], if water penetration depth in the concrete is less than 50mm the concrete is generally classified as impermeable; and if the penetration depth less than 30mm, it is classified as impermeable under aggressive conditions. Based on this, the concrete produced using scoria with all replacements of sand is found to be impermeable concrete.

Table 5-7: Water penetration of sample specimen at the age of 28 days

Sample code	Penetration depth (mm)
	Average
Control	34.67
Sc-35	20.83
Sc-50	33.83
Sc-70	40.33
Sc-100	44.36

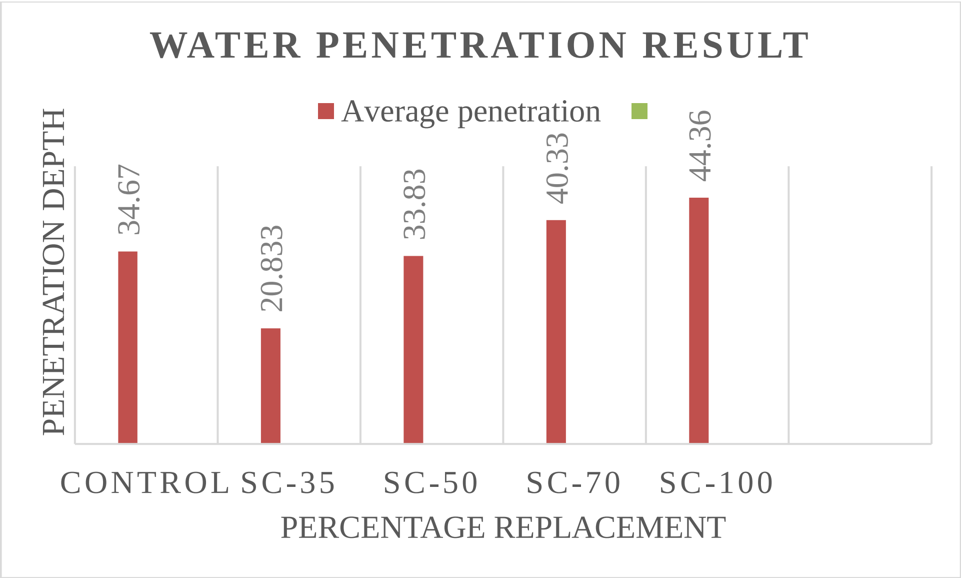


Figure 5-10: Changes in penetration through percentage replacement of scoria at 28 days of curing age

As shown in the Figure 5-10 the replacement of sand with scoria has significant effect on water permeability of concrete. So, as seen from the result best value for water penetration is obtained for the mix percentage of 35%. And the remaining replacement percentage was also in a good agreement with the recommended values.

Table 5-8: Water penetration of sample specimen at the age of 56 days

Sample code	Penetration depth (mm)
	Average
Control	34.02
Sc-35	20.14
Sc-50	32.89
Sc-70	40.33
Sc-100	43.98

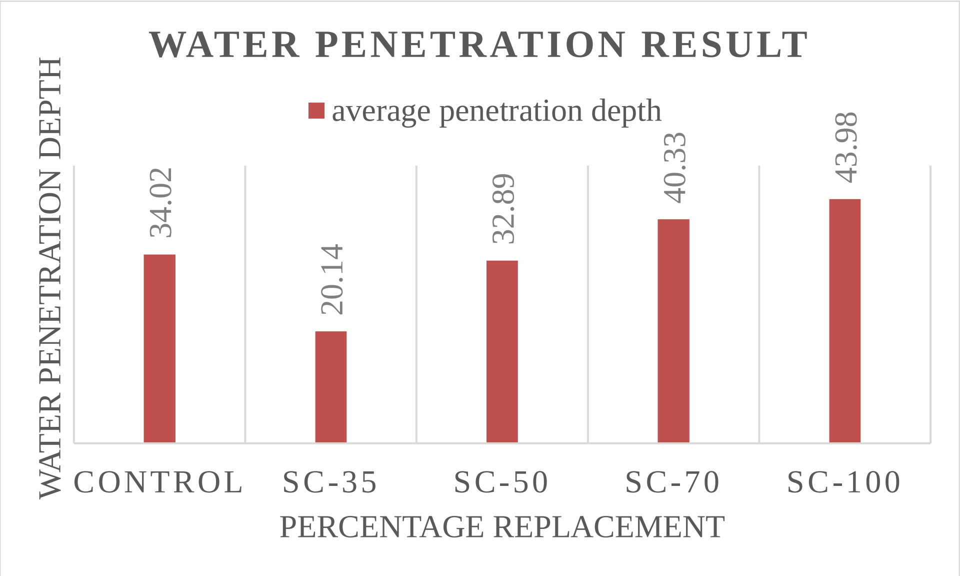


Figure 5-11: Changes in penetration through percentage replacement of scoria at 56 days of curing age

5.8 Ultrasonic pulse velocity test of concrete

The most available non-destructive test method which used for evaluating concrete properties is ultrasonic pulse velocity (UPV). UPV can be considering as the most useable method to obtain a total control of concrete structures. Velocities were measured by the direct transmission method. This test was carried out at 7, 28, 56 and above 90 days of curing as per [35] using a portable ultrasonic non-destructive digital indicating tester on 100x200mm cylindrical specimens as shown in Figure 5-13. This test based on the propagation of a high frequency sound wave which travels through the concrete. In this method an ultrasonic pulse is generated by a pulse generator and transmitted to the surface of concrete through the transmitter transducer. Three measurements were taken for each specimen by placing the transducers between the two opposite faces of the concrete cylinders. And before the test, the instrument must be calibrated according to the specification provided on the instrument.

Figure 5-12: Ultrasonic pulse velocity test equipment's

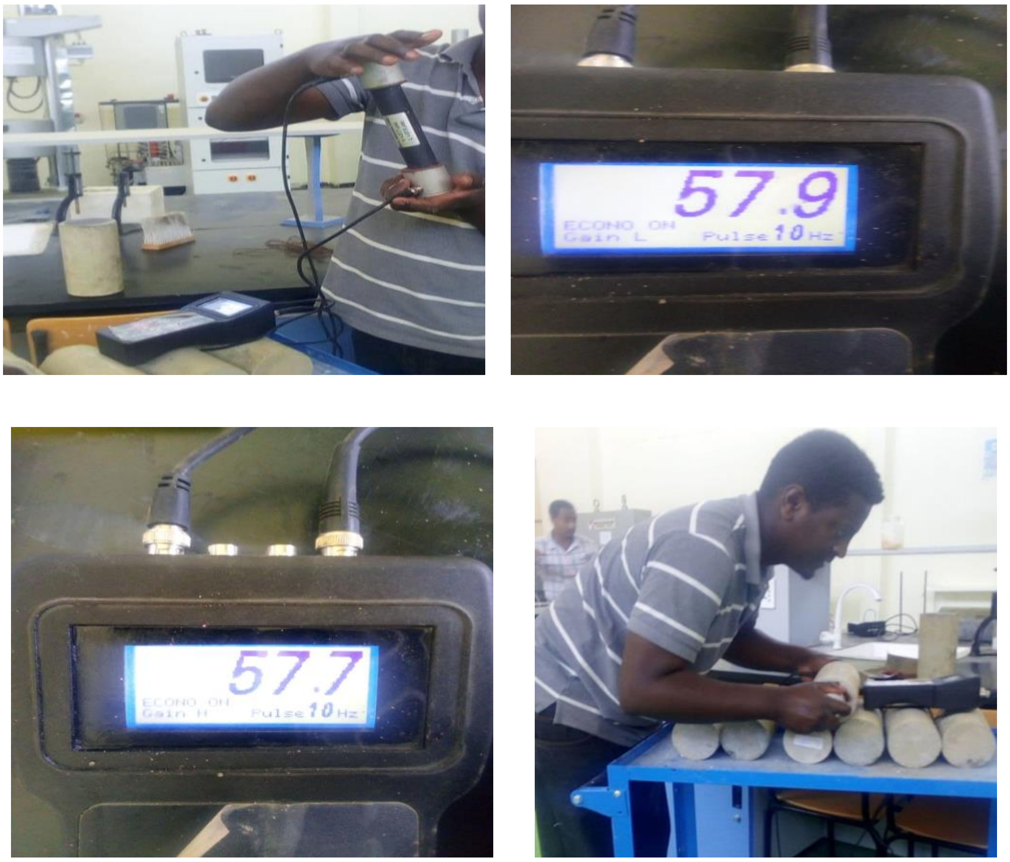


Figure 5-13: Calibrating the instrument and testing the concrete sample

Table 5-9: Average ultrasonic pulse velocity test results of concrete cylindrical specimen (100X200mm) at 7, 28 and 56 days of curing age

Sample code	7 days		28 days		56 days	
	Average ultrasonic pulse velocity(km/s)	Concrete quality (Grade)	Average ultrasonic pulse velocity (km/s)	Concrete quality (Grade)	Average ultrasonic pulse velocity (km/s)	Concrete quality (Grade)
control	4.13	Good	4.19	Good	4.2	Good
Sc-35	4.12	Good	4.25	Good	4.31	Good
Sc-50	4.08	Good	4.18	Good	4.28	Good
Sc-70	4.09	Good	4.16	Good	4.16	Good
Sc-100	4.07	Good	4.13	Good	4.11	Good

It is known that the concrete quality highly depends on the compressive strength of the concrete therefore from the results of the ultrasonic test it is shown that the percentage substitution with 35 % gives a higher pulse velocity that is in a good agreement with that of the compressive test result. So, we can say that the ultrasonic test can be used to estimate the quality of concrete.

Table 5-10: Results of ultrasonic test with compressive strength test

Sample code	7 days		28 days		56 days	
	Average ultrasonic pulse velocity(km/s)	Average compressive strength	Average ultrasonic pulse velocity (km/s)	Average compressive strength	Average ultrasonic pulse velocity (km/s)	Average compressive strength
control	4.13	26.01	4.19	35.2	4.25	39.61
Sc-35	4.12	23.96	4.25	35.63	4.33	43.6
Sc-50	4.08	23.37	4.18	35.58	4.31	38.61
Sc-70	4.09	22.99	4.16	33.15	4.2	36.85
Sc-100	4.07	22.34	4.13	31.03	4.15	33.61

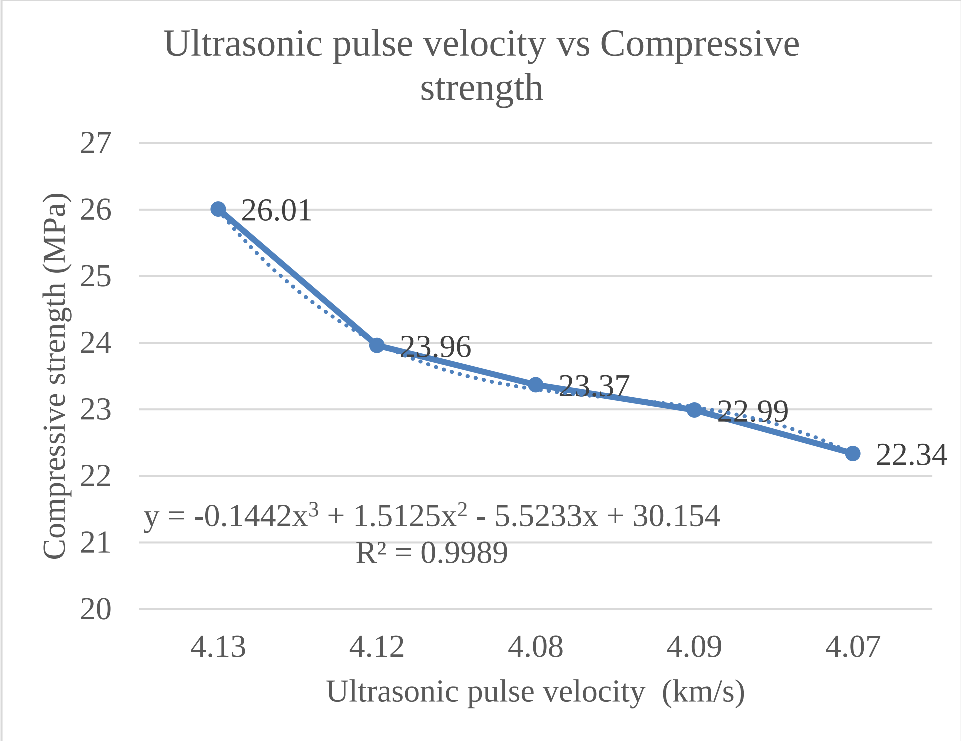


Figure 5-14: Ultrasonic pulse versus compressive strength test result for 7-day curing period

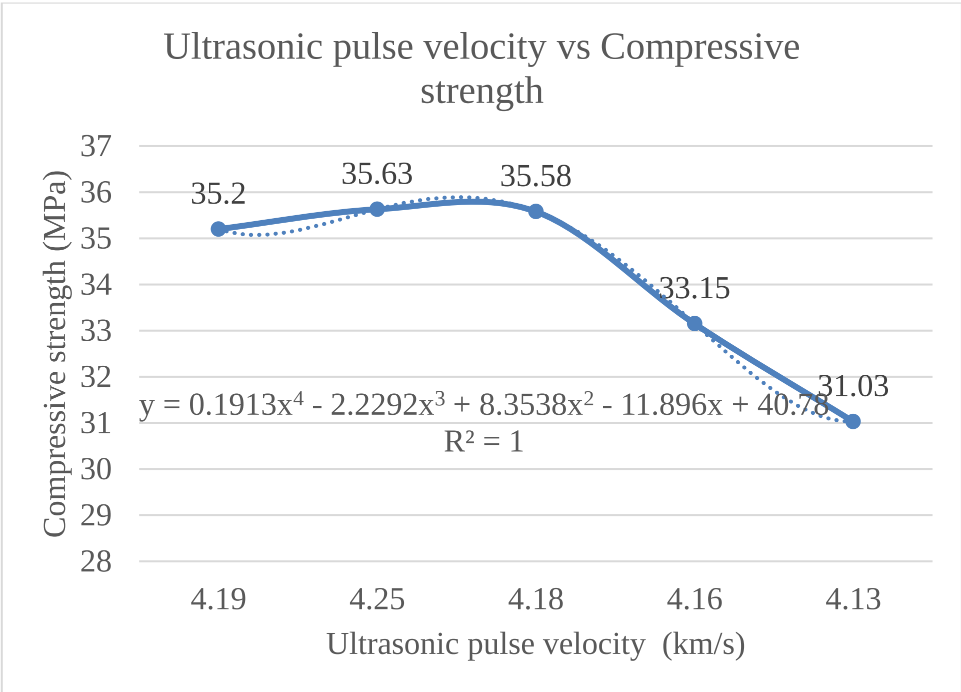


Figure 5-15: Ultrasonic pulse versus compressive strength test result for 28-day curing period

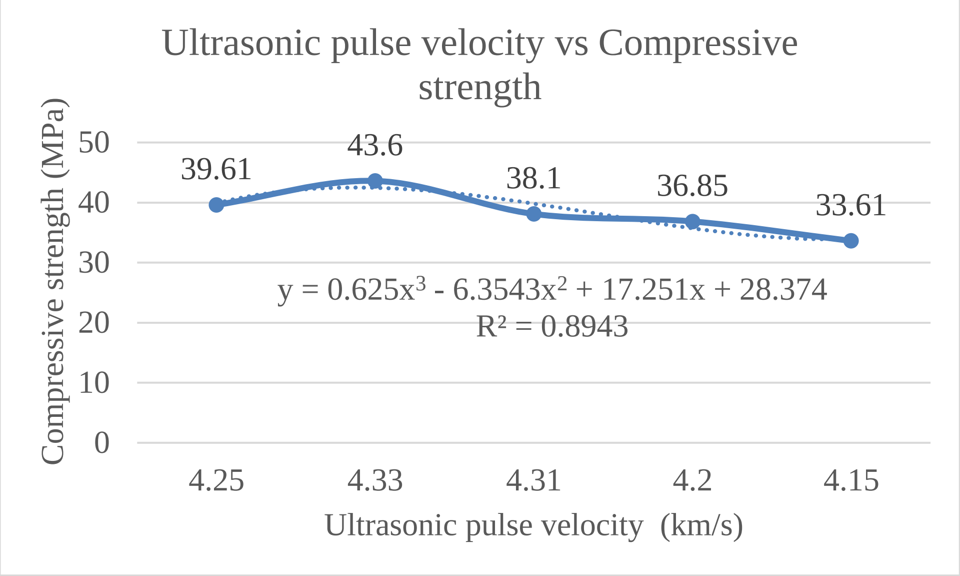


Figure 5-16: Ultrasonic pulse versus compressive strength test result for 56-day curing period

CHAPTER 6 CONCLUSIONS AND RECCOMENDATIONS

6.1 Conclusion

The study results can be inferred as follows: the assessment of the properties of scoria showed that scoria is appropriate for use in the production of concrete as a partial substitute of fine aggregate. Scoria was found to be of outstanding quality, especially compared to the river sand with regard to its silt content. As the ratio of scoria replacement increases due to its lower specific gravity, the density of the hardened concrete decreases and causes the concrete to have a comparatively decreased self-weight and thereby increases the strength to unit weight ratio or structural performance compared to the control sample. The following findings are drawn based on the empirical results of each experiment, in accordance with the objective of this study.

- Considering the chemical analysis

  An increase in fineness that exposes more surface area of the volcanic scoria may accelerate the early pozzolanic reactivity and [40] requires that for a material to be accepted as a natural pozzolan, the sum of SiO_2, Al_2O_3 and Fe_2O_3 should have a minimum value of 70% and as seen from the chemical tests for scoria done by Ethiopian geological survey geoscience laboratory test result SiO_2 have percentage of 53.44, Al_2O_3 have 9.81% and Fe_2O_3 11.16% adding them up it gives 74.41% which fulfills the astm designation to be classified as pozzolanic which helps the concrete by giving extraordinary strength.

  Additionally, increasing SO_3 content increases strength loss for mortar exposed to sodium sulfate solution. Drying shrinkage measurements indicate that increasing SO_3 beyond 3% increases the drying shrinkage for all cements. The most significant and common sources of chlorides are marine environments and from de-icing salts applied to road surfaces during cold weather (winter). Chlorides have little effect on hardened concrete but they increase the risk of reinforcement corrosion. corrosion of the reinforcement will be initiated when the chloride ion concentration at the steel reaches the so called ‘threshold level’. The subject of a safe level of chloride is somewhat controversial a fairly traditional view is that below 0.4% chloride by mass of cement represents a low corrosion risk, 0.4 to 1% a medium risk and above 1% a high risk. Considering this value and the chemical analysis of scoria which is <0.1 % which is below 0.4%, ranked with in the safe level of chloride.[41]

The loss on ignition of the raw material is roughly equivalent to the loss in mass that it will undergo in a kiln. Similarly, for minerals, the loss on ignition represents the actual material lost during smelting or refining in a furnace or smelter. The loss on ignition of the product indicates the extent to which the pyro processing was incomplete. And as seen from the test conducted by the Ethiopian geological survey, the loss on ignition is very low therefore it can be concluded that mass change will be very low during the concrete production process.

- Considering XRD and SEM analysis of scoria

Thin section of scoria sample is analyzed in XRD and SEM analysis and from the results of the analysis, the main phases are glassy forms and classified as long-rod shaped minerals as seen in SEM image magnified with 1000X magnification. Generally, it can be said that the main phases are glassy form which is amorphous. It is also checked with XRD output which shows a broad reflection peak which confirms the presence of amorphous quartz.

Considering the SEM analysis to determine the apparent porosity, in this paper only the effect of magnification is considered and it is concluded that high magnification is usually related to small physical observation size. Some particles or pores cover most of the image area. Better result is obtained on magnification 1000X and as seen from the 3d analyzed image, the pores are interconnected.

- Considering slump and density

As the amount of scoria increases the concrete becomes less workable. The decrease in the workability of the concrete is supposed to be due to the relative coarseness of the fine aggregate as a result of the replacement of scoria with the higher fineness modulus as compared to the river sand (3.32>2.81) and another is the higher porosity of scoria.

As the amount of scoria increase the density of the concrete decrease. The reason for this could be scoria is very light weight compared to sand as seen from the unit weight.

- Considering compressive strength test

There is an increase in the compressive strength of concrete with the curing age but there is a variation in compressive strength as the ratio of scoria to sand content is changed. Based on the compressive strength test results of the concrete mixes in this research, sand can be replaced by scoria with an optimum replacement of 35% to produce 25MPa cube compressive strength of concrete. However, the compressive strength with 50%,70% and 100% replacement is still in a good agreement with that of the control sample due to the well-graded particle distribution of the blended fine aggregate as compared to that of the river sand. Generally, this experimental study shows that the scoria sample under consideration can replace the river sand up to 100% in order to produce concrete for the target mix design considered. The decrease in the silt content of the blended concrete mixes helps the proper cement hydration processes to take place, favoring the compressive strength of the concrete to occur due to proper bondage between the aggregates.

- Considering flexural strength test

  It increases as the curing age increase from 7-56 days. As seen from the result there is a variation in flexural strength development as the percentage of scoria increase from 35-100%. Even if there is a variation in flexural strength, the optimum is seen when sand replaces scoria with 50% with a value of 4.88MPa.

- Considering split tensile strength

  There is also a variation on the tensile strength of concrete as the percentage of replacement was increased. Even though there is a variation on strength, the maximum tensile strength attained is at a replacement of 50% of scoria with a value 3.36 MPa which is higher than that of the control specimen so we can say that adding scoria in concrete will enhance the tensile strength of concrete to develop.

- Considering water penetration

  Based on the result, the concrete produced using scoria with all replacements of sand is found to be impermeable concrete. the replacement of sand with scoria has significant effect on water penetration of concrete. So, as seen from the result best value for water penetration is obtained for the mix percentage of 35%. And the remaining replacement percentage was also in a good agreement with the recommended values.

- Considering ultrasonic pulse velocity test

  The results show that there is a good correlation between strength and UPV. It is known that the concrete quality highly depends on the compressive strength of the concrete therefore from the results of the ultrasonic test it is shown that the percentage substitution with 35 % gives a higher pulse velocity that is in a good agreement with that of the compressive test result. It can be concluded that, by means of UPV, it is possible to contribute with the control of deterioration and concrete structures quality.

In general, as a fine aggregate and partial replacement of river sand, scoria is ideal for use in the manufacture of concrete. Its local availability supports its selection as an alternative building material. Compared to river sand across the central towns of Ethiopia, its availability at a shorter distance helps to save energy and expense and thus meets the green concrete development strategy.

6.2 Recommendation

Based on the experimental studies carried the following areas have been identified for future research.

- The present research work has focused mainly on concrete's strength properties and can be expanded to study other properties such as creep, shrinkage, fatigue, penetration of chloride, etc.
- It can also be further expanded with various supplementary materials for self-compacting concrete, high strength and high-performance concrete.
- On the blended aggregates, XRD and microscopy work should be performed, as it will help to demonstrate the effects of the blend on the original fine aggregate property and its pore structure.
- In this paper, only the effects of magnification on the SEM study are considered to describe both aggregates of sand and scoria. Other effects influencing the SEM study, such as window size effects, threshold effects and scanning location effects, require more studies.
- A relationship between the compressive strength and UPV has been evaluated in this study for a C-25 concrete with different curing ages. More testing can be done with different concrete grades and also with different curing ages to learn more about the relationship between the outcome of the UPV test and the concrete compressive strength.

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APPENDIX A

- Seven days compressive strength of concrete specimens prepared by partial replacement of sand with scoria.

	Sample code	No.	Dimensions (m)			Failure load (kN)	Area (m2)	Compressive strength (MPa)
Day 7	Control	1`	0.15	0.15	0.15	609.9	0.0225	27.11
		2	0.15	0.15	0.15	576.4	0.0225	25.62
		3	0.15	0.15	0.15	569.3	0.0225	25.3
		mean						26.01
	Sc-35	1	0.15	0.15	0.15	571.5	0.0225	25.4
		2	0.15	0.15	0.15	509.3	0.0225	22.63
		3	0.15	0.15	0.15	536.7	0.0225	23.85
		mean						23.96
	Sc-50	1	0.15	0.15	0.15	543.8	0.0225	24.17
		2	0.15	0.15	0.15	521.2	0.0225	23.16
		3	0.15	0.15	0.15	512.6	0.0225	22.78
		mean						23.37
	Sc-70	1	0.15	0.15	0.15	502.7	0.0225	22.34
		2	0.15	0.15	0.15	540.9	0.0225	24.04
		3	0.15	0.15	0.15	508.4	0.0225	22.59
		mean						22.99
	Sc-100	1	0.15	0.15	0.15	502.7	0.0225	22.34
		2	0.15	0.15	0.15	525.4	0.0225	23.35
		3	0.15	0.15	0.15	479.9	0.0225	21.33
		mean						22.34

➢ Twenty-eight days compressive strength of concrete specimens prepared by partial replacement of sand with scoria.

	Sample code	No.	Dimensions (m)			Failure load (kN)	Area (m2)	Compressive strength (MPa)
			L	W	H			
Day 28	Control	1	0.15	0.15	0.15	790.4	0.0225	35.13
		2	0.15	0.15	0.15	785.3	0.0225	34.9
		3	0.15	0.15	0.15	800.3	0.0225	35.57
		mean						35.2
	Sc-35	1	0.15	0.15	0.15	787.4	0.0225	34.99
		2	0.15	0.15	0.15	817.2	0.0225	36.32
		3	0.15	0.15	0.15	800.6	0.0225	35.58
		mean						35.63
	Sc-50	1	0.15	0.15	0.15	786.2	0.0225	34.94
		2	0.15	0.15	0.15	788.1	0.0225	35.03
		3	0.15	0.15	0.15	827.4	0.0225	36.77
		mean						35.58
	Sc-70	1	0.15	0.15	0.15	722.5	0.0225	32.11
		2	0.15	0.15	0.15	767	0.0225	34.09
		3	0.15	0.15	0.15	748.1	0.0225	33.25
		mean						33.15
	Sc-100	1	0.15	0.15	0.15	689.4	0.0225	30.64
		2	0.15	0.15	0.15	693.9	0.0225	30.84
		3	0.15	0.15	0.15	711.2	0.0225	31.61
		mean						31.03

- Fifty-six days compressive strength of concrete specimens prepared by partial replacement of sand with scoria.

	Sample code	No.	Dimensions (m)			Failure load (kN)	Area (m2)	Compressive strength (MPa)
			L	W	H			
Day 56	Control	1	0.15	0.15	0.15	906.5	0.0225	40.29
		2	0.15	0.15	0.15	891.2	0.0225	39.61
		3	0.15	0.15	0.15	876	0.0225	38.93
		mean						39.61
	Sc-35	1	0.15	0.15	0.15	958.5	0.0225	42.6
		2	0.15	0.15	0.15	995.3	0.0225	44.24
		3	0.15	0.15	0.15	989.1	0.0225	43.96
		mean						43.6
	Sc-50	1	0.15	0.15	0.15	885.4	0.0225	39.35
		2	0.15	0.15	0.15	883	0.0225	39.24
		3	0.15	0.15	0.15	838.2	0.0225	37.25
		mean						38.61
	Sc-70	1	0.15	0.15	0.15	824	0.0225	36.62
		2	0.15	0.15	0.15	834.5	0.0225	37.09
		3	0.15	0.15	0.15	828.9	0.0225	36.84
		mean						36.85
	Sc-100	1	0.15	0.15	0.15	743	0.0225	33.02
		2	0.15	0.15	0.15	758.8	0.0225	33.72
		3	0.15	0.15	0.15	767.2	0.0225	34.1
		mean						33.61

APPENDIX B

- Seven days flexural strength of concrete specimens prepared by partial replacement of sand with scoria.

	Sample code	No.	Dimensions (m)			Failure load (kN)	Location of fracture	Flexural strength (MPa)
Day 7	Control	1	0.5	0.1	0.1	5.7	M	2.565
		2	0.5	0.1	0.1	5	M	2.25
		3	0.5	0.1	0.1	5.5	M	2.475
		mean						2.43
	Sc-35	1	0.5	0.1	0.1	6.3	M	2.835
		2	0.5	0.1	0.1	6.2	M	2.79
		3	0.5	0.1	0.1	5.8	M	2.61
		mean						2.75
	Sc-50	1	0.5	0.1	0.1	8.3	143mm	3.735
		2	0.5	0.1	0.1	7.1	M	3.195
		3	0.5	0.1	0.1	8.7	M	3.915
		mean						3.62
	Sc-70	1	0.5	0.1	0.1	5.8	M	2.61
		2	0.5	0.1	0.1	5.9	139mm	2.655
		3	0.5	0.1	0.1	5.7	M	2.565
		mean						2.61
	Sc-100	1	0.5	0.1	0.1	5.47	M	2.46
		2	0.5	0.1	0.1	5.69	M	2.56
		3	0.5	0.1	0.1	5.51	M	2.48
		mean						2.5

- Twenty-eight days flexural strength of concrete specimens prepared by partial replacement of sand with scoria.

	Sample code	No.	Dimensions (m)			Failure load (kN)	Location of fracture	Flexural strength (MPa)
			L	W	H			
Day 28	Control	1	0.5	0.1	0.1	7.09	M	3.19
		2	0.5	0.1	0.1	9.49	M	4.27
		3	0.5	0.1	0.1	11.1	145mm	4.98
		mean						4.15
	Sc-35	1	0.5	0.1	0.1	8.3	143mm	3.97
		2	0.5	0.1	0.1	7.58	M	3.41
		3	0.5	0.1	0.1	9.51	M	4.28
		mean						3.89
	Sc-50	1	0.5	0.1	0.1	10	M	4.5
		2	0.5	0.1	0.1	9.24	M	4.16
		3	0.5	0.1	0.1	10.6	M	4.77
		mean						4.48
	Sc-70	1	0.5	0.1	0.1	8.87	M	3.99
		2	0.5	0.1	0.1	9.3	144	4.17
		3	0.5	0.1	0.1	8.56	M	3.85
		mean						4.00
	Sc-100	1	0.5	0.1	0.1	9.78	M	4.4
		2	0.5	0.1	0.1	8.64	M	3.89
		3	0.5	0.1	0.1	8.91	M	4.01
		mean						4.1

- Fifty-six days flexural strength of concrete specimens prepared by partial replacement of sand with scoria.

	Sample code	No.	Dimensions (m)			Failure load (kN)	Location of fracture	Flexural strength (MPa)
			L	W	H			
Day 56	Control	1	0.5	0.1	0.1	9.91	M	4.46
		2	0.5	0.1	0.1	10.9	141mm	4.88
		3	0.5	0.1	0.1	10.8	M	4.86
		mean						4.73
	Sc-35	1	0.5	0.1	0.1	9.51	M	4.28
		2	0.5	0.1	0.1	10.18	M	4.58
		3	0.5	0.1	0.1	9.64	M	4.34
		mean						4.40
	Sc-50	1	0.5	0.1	0.1	11.76	M	5.29
		2	0.5	0.1	0.1	10.8	M	4.86
		3	0.5	0.1	0.1	9.98	M	4.49
		mean						4.88
	Sc-70	1	0.5	0.1	0.1	9.78	M	4.4
		2	0.5	0.1	0.1	10.53	M	4.74
		3	0.5	0.1	0.1	11.4	145mm	5.13
		mean						4.76
	Sc-100	1	0.5	0.1	0.1	9.33	M	4.2
		2	0.5	0.1	0.1	9	149	4.05
		3	0.5	0.1	0.1	9.13	M	4.11
		mean						4.12

APPENDIX C

- Seven days split tensile strength of concrete specimens prepared by partial replacement of sand with scoria.

	Sample code	No.	Dimensions (m)		Failure load (kN)	πld	split tensile strength (MPa)
			D	H			
Day 7	Control	1	0.15	0.3	138.3	0.1414	1.96
		2	0.15	0.3	147.7	0.1414	2.07
		3	0.15	0.3	139.1	0.1414	1.95
		mean					1.99
	Sc-35	1	0.15	0.3	156.7	0.1414	2.22
		2	0.15	0.3	125.2	0.1414	1.77
		3	0.15	0.3	130.4	0.1414	1.84
		mean					1.94
	Sc-50	1	0.15	0.3	139.5	0.1414	1.97
		2	0.15	0.3	180.6	0.1414	2.55
		3	0.15	0.3	221.3	0.1414	3.13
		mean					2.55
	Sc-70	1	0.15	0.3	149.8	0.1414	2.12
		2	0.15	0.3	157.5	0.1414	2.23
		3	0.15	0.3	147.3	0.1414	2.08
		mean					2.14
	Sc-100	1	0.15	0.3	108.1	0.1414	1.53
		2	0.15	0.3	118.7	0.1414	1.68
		3	0.15	0.3	143.4	0.1414	2.03
		mean					1.75

- Twenty-eight days split tensile strength of concrete specimens prepared by partial replacement of sand with scoria.

	Sample code	No.	Dimensions (m)		Failure load (kN)	πld	split tensile strength (MPa)
			D	H			
Day 28	Control	1	0.15	0.3	233.2	0.1414	3.3
		2	0.15	0.3	212.6	0.1414	3.01
		3	0.15	0.3	160.2	0.1414	2.27
		mean					2.86
	Sc-35	1	0.15	0.3	144.1	0.1414	2.04
		2	0.15	0.3	226.5	0.1414	3.2
		3	0.15	0.3	217.7	0.1414	3.08
		mean					2.77
	Sc-50	1	0.15	0.3	244.2	0.1414	3.45
		2	0.15	0.3	218.3	0.1414	3.09
		3	0.15	0.3	225.2	0.1414	3.19
		mean					3.24
	Sc-70	1	0.15	0.3	154.6	0.1414	2.19
		2	0.15	0.3	185.2	0.1414	2.62
		3	0.15	0.3	187.9	0.1414	2.66
		mean					2.49
	Sc-100	1	0.15	0.3	116.5	0.1414	1.65
		2	0.15	0.3	126.8	0.1414	1.79
		3	0.15	0.3	152.7	0.1414	2.16
		mean					1.87

- Fifty-six days split tensile strength of concrete specimens prepared by partial replacement of sand with scoria.

	Sample code	No.	Dimensions (m)		Failure load (kN)	πld	split tensile strength (MPa)
			D	H			
Day 56	Control	1	0.15	0.3	181.4	0.1414	2.56
		2	0.15	0.3	226.8	0.1414	3.2
		3	0.15	0.3	232.2	0.1414	3.29
		mean					3.02
	Sc-35	1	0.15	0.3	217	0.1414	3.06
		2	0.15	0.3	221.5	0.1414	3.13
		3	0.15	0.3	155.5	0.1414	2.2
		mean					2.80
	Sc-50	1	0.15	0.3	253	0.1414	3.58
		2	0.15	0.3	226.8	0.1414	3.2
		3	0.15	0.3	232.2	0.1414	3.29
		mean					3.36
	Sc-70	1	0.15	0.3	183.2	0.1414	2.59
		2	0.15	0.3	159.2	0.1414	3.1
		3	0.15	0.3	188.2	0.1414	2.6
		mean					2.76
	Sc-100	1	0.15	0.3	132.89	0.1414	1.88
		2	0.15	0.3	138.54	0.1414	1.96
		3	0.15	0.3	155.51	0.1414	2.2
		mean					2.01

APPENDIX D

- Twenty-eight days water penetration of concrete specimens prepared by partial replacement of sand with scoria.

	Sample code	No.	Dimensions (m)			Area (m2)	Penetration depth (mm)
			L	W	H		
Day 28	Control	1	0.15	0.15	0.15	0.0225	32
		2	0.15	0.15	0.15	0.0225	34
		3	0.15	0.15	0.15	0.0225	38
		mean					34.67
	Sc-35	1	0.15	0.15	0.15	0.0225	21.5
		2	0.15	0.15	0.15	0.0225	22.5
		3	0.15	0.15	0.15	0.0225	18.5
		mean					20.83
	Sc-50	1	0.15	0.15	0.15	0.0225	34.5
		2	0.15	0.15	0.15	0.0225	35
		3	0.15	0.15	0.15	0.0225	32
		mean					33.83
	Sc-70	1	0.15	0.15	0.15	0.0225	40
		2	0.15	0.15	0.15	0.0225	37.5
		3	0.15	0.15	0.15	0.0225	43.5
		mean					40.33
	Sc-100	1	0.15	0.15	0.15	0.0225	44.8
		2	0.15	0.15	0.15	0.0225	42.6
		3	0.15	0.15	0.15	0.0225	45.68
		mean					44.36

- Fifty-six days water penetration of concrete specimens prepared by partial replacement of sand with scoria.

	Sample code	No.	Dimensions (m)			Area (m2)	Penetration depth (mm)
			L	W	H		
Day 56	Control	1	0.15	0.15	0.15	0.0225	35
		2	0.15	0.15	0.15	0.0225	33
		3	0.15	0.15	0.15	0.0225	34
		mean					34
	Sc-35	1	0.15	0.15	0.15	0.0225	22
		2	0.15	0.15	0.15	0.0225	21
		3	0.15	0.15	0.15	0.0225	17.4
		mean					20.13
	Sc-50	1	0.15	0.15	0.15	0.0225	33.97
		2	0.15	0.15	0.15	0.0225	31.5
		3	0.15	0.15	0.15	0.0225	33.2
		mean					32.89
	Sc-70	1	0.15	0.15	0.15	0.0225	39.49
		2	0.15	0.15	0.15	0.0225	41.5
		3	0.15	0.15	0.15	0.0225	40
		mean					40.33
	Sc-100	1	0.15	0.15	0.15	0.0225	42.5
		2	0.15	0.15	0.15	0.0225	43.9
		3	0.15	0.15	0.15	0.0225	45.54
		mean					43.98

APPENDIX E

- Seven days ultrasonic pulse velocity test of concrete specimens prepared by partial replacement of sand with scoria.

	Sample code	No.	Dimensions (m)		Travel time (μs)	Pulse velocity (km/s)
			D	H		
Day 7	Control	1	0.1	0.2	48.9	4.09
		2	0.1	0.2	48.5	4.12
		3	0.1	0.2	48	4.17
		mean				4.13
	Sc-35	1	0.1	0.2	48.5	4.12
		2	0.1	0.2	48.7	4.11
		3	0.1	0.2	48.4	4.13
		mean				4.12
	Sc-50	1	0.1	0.2	49.7	4.02
		2	0.1	0.2	48.5	4.12
		3	0.1	0.2	48.9	4.09
		mean				4.08
	Sc-70	1	0.1	0.2	49.7	4.02
		2	0.1	0.2	48.9	4.09
		3	0.1	0.2	48.2	4.15
		mean				4.09
	Sc-100	1	0.1	0.2	49.5	4.04
		2	0.1	0.2	49.2	4.07
		3	0.1	0.2	48.9	4.09
		mean				4.07

- Twenty-eight days ultrasonic pulse velocity test of concrete specimens prepared by partial replacement of sand with scoria.

	Sample code	No.	Dimensions (m)		Travel time (μs)	Pulse velocity (km/s)
			D	H		
Day 28	Control	1	0.1	0.2	47.85	4.18
		2	0.1	0.2	48.08	4.16
		3	0.1	0.2	47.28	4.23
		mean				4.19
	Sc-35	1	0.1	0.2	47.06	4.25
		2	0.1	0.2	47.39	4.22
		3	0.1	0.2	46.73	4.28
		mean				4.25
	Sc-50	1	0.1	0.2	47.96	4.17
		2	0.1	0.2	48.19	4.15
		3	0.1	0.2	47.39	4.22
		mean				4.18
	Sc-70	1	0.1	0.2	48.43	4.13
		2	0.1	0.2	47.85	4.18
		3	0.1	0.2	47.96	4.17
		mean				4.16
	Sc-100	1	0.1	0.2	48.54	4.12
		2	0.1	0.2	48.66	4.11
		3	0.1	0.2	48.08	4.16
		mean				4.13

- Fifty-six days ultrasonic pulse velocity test of concrete specimens prepared by partial replacement of sand with scoria.

	Sample code	No.	Dimensions (m)		Travel time (μs)	Pulse velocity (km/s)
			D	H		
Day 56	Control	1	0.1	0.2	46.95	4.26
		2	0.1	0.2	47.06	4.25
		3	0.1	0.2	47.17	4.24
		mean				4.25
	Sc-35	1	0.1	0.2	45.9	4.36
		2	0.1	0.2	46.2	4.33
		3	0.1	0.2	46.4	4.31
		mean				4.33
	Sc-50	1	0.1	0.2	46.62	4.29
		2	0.1	0.2	45.66	4.38
		3	0.1	0.2	46.84	4.27
		mean				4.31
	Sc-70	1	0.1	0.2	48.78	4.1
		2	0.1	0.2	47.62	4.2
		3	0.1	0.2	46.51	4.3
		mean				4.2
	Sc-100	1	0.1	0.2	48.19	4.15
		2	0.1	0.2	47.62	4.2
		3	0.1	0.2	48.78	4.1
		mean				4.15

APPENDIX F

- Chemical composition of scoria aggregate

	GEOLOGICAL SURVEY OF ETHIOPIA	Doc.Number: GLD/F5.10.2	Version No: 1
	GEOCHEMICAL LABORATORY DIRECTORATE		Page 1 of 1
Document Title:	Complete Silicate Analysis Report	Effective date:	May, 2017

Issue Date: -12/11/2020

Customer Name: -Aklilu Shitu

Request No:- GLD/RQ/257/20

Report No:- GLD/RN/742/20

Sample type:- Scoria(Red Ash)

Sample Preparation: - 200 Mesh

Date Submitted: - 08/10/2020

Number of Sample:- One (01)

Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides

Analytical Method: $LiBO_2$ FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI	SO_3	Cl^{-1}
AKSC	53.44	9.81	11.16	10.44	4.28	3.00	1.20	0.12	0.47	0.38	3.56	2.19	0.07	<0.10

Note: - This result represent only for the sample submitted to the laboratory.

Analysts
Lidet Endeshaw
Nigist Fikadu

Checked By
For Tizita Zemene Lidet

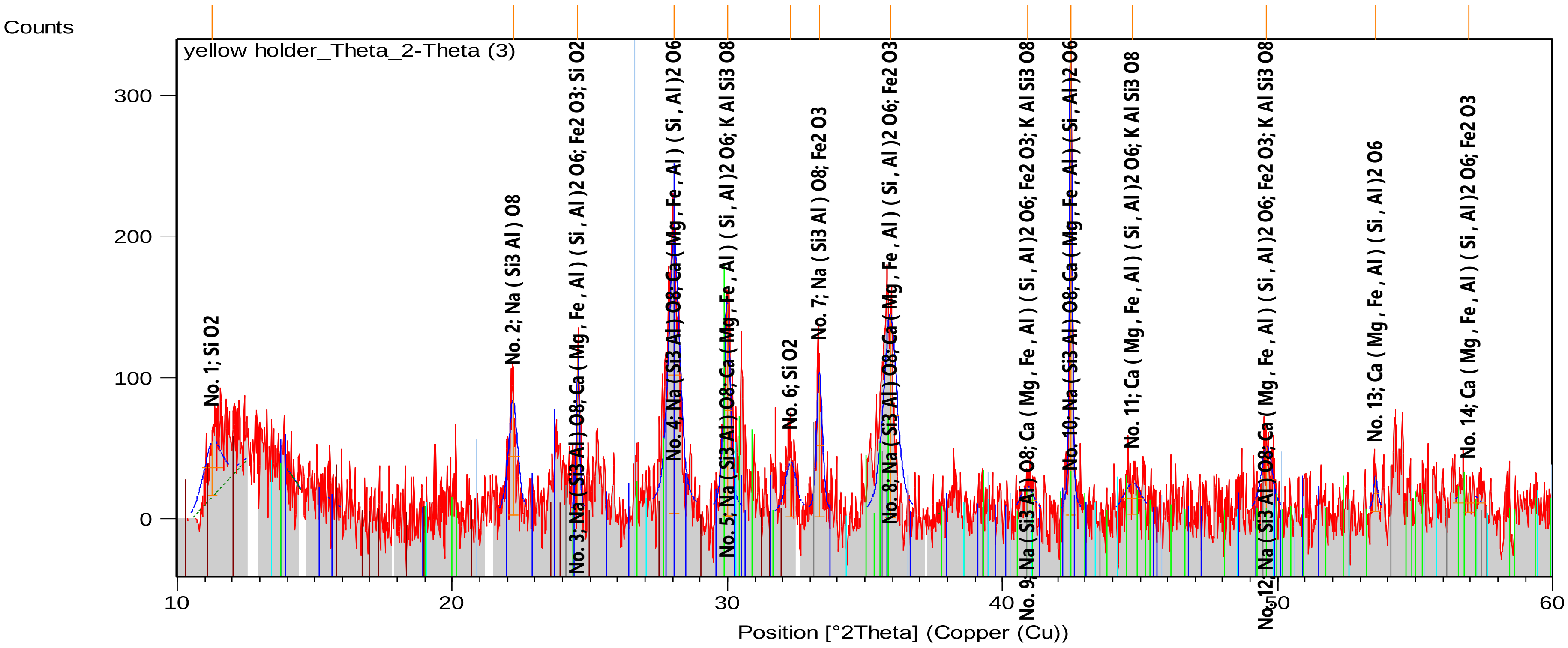
Approved By
Yohannes Getac

Quality Control
Gosa Haile

Geological Survey of Ethiopia Central Geological Laboratory

APPENDIX G

- XRD analysis results of scoria



- Result interpretation

Peak List:

Pos. [°2Th.]	Height [cts]	FWHM Left [°2Th.]	d-spacing [Å]	Rel. Int. [%]
11.286070	38.785380	0.768000	7.83378	11.51
22.205240	81.935520	0.384000	4.00016	24.32
24.562380	113.532000	0.120000	3.62136	33.70
28.058400	194.767300	0.480000	3.17759	57.81
29.985280	149.984000	0.288000	2.97763	44.52
32.300660	37.153680	0.480000	2.76928	11.03
33.345880	101.646100	0.240000	2.68483	30.17
35.917460	144.235600	0.576000	2.49828	42.81
40.898200	19.679630	0.576000	2.20479	5.84
42.479980	336.884400	0.120000	2.12628	100.00
44.706350	22.459450	0.768000	2.02543	6.67
49.599550	47.310710	0.480000	1.83646	14.04
53.547710	25.276150	0.192000	1.70999	7.50
56.929710	13.813580	1.152000	1.61617	4.10

- **Pattern List:**

Visible	Ref. Code	Score	Compound Name	Displacement [°2Th.]	Scale Factor	Chemical Formula
*	00-010-0393	17	Sodium Aluminum Silicate	0.000	0.729	Na (Si3 Al) O8
*	00-038-0466	19	Calcium Magnesium Aluminum Iron Silicate	0.000	0.522	Ca (Mg, Fe, Al) (Si, Al)2 O6
*	00-033-0664	13	Iron Oxide	0.000	0.200	Fe2 O3
*	00-045-0111	1	Silicon Oxide	0.000	0.284	Si O2
*	00-037-0362	2	Potassium Aluminum Silicate	0.000	0.155	K Al Si3 O8

APPENDIX H

- SEM analysis results of sand with 9381X magnification

	Area	Perim.	Circ.	Feret	FeretX	FeretY	FeretAngle	MinFeret	AR	Round	Solidity
1	0.135	3.73	0.122	0.819	9	0	177.879	0.485	1.578	0.634	0.509
50	9.18E-04	0.086	1	0.043	47	39	135	0.03	1	1	1
100	9.18E-04	0.086	1	0.043	494	65	135	0.03	1	1	1
150	0.002	0.129	1	0.068	56	137	153.435	0.03	2	0.5	1
200	0.002	0.129	1	0.068	81	159	153.435	0.03	2	0.5	1
250	0.011	0.703	0.28	0.221	14	187	164.055	0.144	1.522	0.657	0.48
300	9.18E-04	0.086	1	0.043	65	229	135	0.03	1	1	1
350	9.18E-04	0.086	1	0.043	68	262	135	0.03	1	1	1
400	9.18E-04	0.086	1	0.043	938	310	135	0.03	1	1	1
450	0.096	3.745	0.086	0.883	51	336	112.166	0.36	3.22	0.311	0.402
500	0.003	0.189	0.967	0.096	97	375	161.565	0.03	3	0.333	1
550	0.012	0.489	0.627	0.194	706	431	38.66	0.121	1.721	0.581	0.703
600	0.003	0.171	1	0.086	647	451	45	0.061	1.464	0.683	0.857
650	0.003	0.171	1	0.086	84	475	45	0.061	1.464	0.683	0.857
700	0.002	0.171	0.785	0.086	88	492	135	0.043	2.646	0.378	0.667
750	9.18E-04	0.086	1	0.043	67	518	135	0.03	1	1	1
800	9.18E-04	0.086	1	0.043	24	537	135	0.03	1	1	1
850	9.18E-04	0.086	1	0.043	167	550	135	0.03	1	1	1
901	9.18E-04	0.086	1	0.043	80	573	135	0.03	1	1	1
950	0.002	0.146	1	0.068	47	601	116.565	0.03	2	0.5	1

1000	9.18E-04	0.086	1	0.043	207	615	135	0.03	1	1	1
1050	0.002	0.171	0.785	0.086	752	628	45	0.043	2.646	0.378	0.667
1100	0.002	0.146	1	0.068	935	649	116.565	0.03	2	0.5	1
1150	9.18E-04	0.086	1	0.043	705	671	135	0.03	1	1	1
1200	9.18E-04	0.086	1	0.043	988	692	135	0.03	1	1	1
1250	9.18E-04	0.086	1	0.043	54	714	135	0.03	1	1	1
1300	9.18E-04	0.086	1	0.043	25	734	135	0.03	1	1	1
1350	0.002	0.146	1	0.068	129	752	116.565	0.03	2	0.5	1
1400	9.18E-04	0.086	1	0.043	798	778	135	0.03	1	1	1
1450	9.18E-04	0.086	1	0.043	40	806	135	0.03	1	1	1
1500	9.18E-04	0.086	1	0.043	91	829	135	0.03	1	1	1
1550	0.002	0.129	1	0.068	69	842	153.435	0.03	2	0.5	1
1600	0.002	0.146	1	0.068	925	854	116.565	0.03	2	0.5	1
1650	0.014	0.593	0.493	0.214	51	882	45	0.15	1.377	0.726	0.667
1651	9.18E-04	0.086	1	0.043	57	877	135	0.03	1	1	1
1652	9.18E-04	0.086	1	0.043	80	878	135	0.03	1	1	1
1653	0.002	0.146	1	0.068	664	878	116.565	0.03	2	0.5	1
1654	9.18E-04	0.086	1	0.043	748	878	135	0.03	1	1	1
1655	0.004	0.232	0.857	0.096	804	878	108.435	0.061	1.468	0.681	0.8
1656	9.18E-04	0.086	1	0.043	668	879	135	0.03	1	1	1
1657	0.003	0.171	1	0.086	354	882	45	0.061	1.464	0.683	0.857
1658	9.18E-04	0.086	1	0.043	357	880	135	0.03	1	1	1
1659	0.005	0.3	0.641	0.136	603	880	153.435	0.061	2.165	0.462	0.667
1660	9.18E-04	0.086	1	0.043	49	881	135	0.03	1	1	1
1661	0.003	0.189	0.967	0.096	608	881	161.565	0.03	3	0.333	1

- SEM analysis results of sand with 1307X magnification

	Area	Perim.	Circ.	Feret	FeretX	FeretY	FeretAngle	MinFeret	AR	Round	Solidity
1	985.235	227.49	0.239	42.93	9	160	53.189	35.479	1.115	0.897	0.882
100	0.049	0.627	1	0.314	913	13	135	0.222	1	1	1
200	0.049	0.627	1	0.314	410	25	135	0.222	1	1	1
300	0.049	0.627	1	0.314	900	44	135	0.222	1	1	1
400	0.246	2.325	0.572	0.941	886	60	45	0.627	1.553	0.644	0.714
500	0.049	0.627	1	0.314	581	68	135	0.222	1	1	1
600	0.098	1.254	0.785	0.627	463	83	45	0.314	2.646	0.378	0.667
700	0.049	0.627	1	0.314	178	95	135	0.222	1	1	1
800	0.246	2.769	0.403	0.8	638	108	123.69	0.665	1.172	0.853	0.625
900	0.295	2.325	0.686	1.109	397	123	53.13	0.595	2.166	0.462	0.706
1000	0.049	0.627	1	0.314	454	132	135	0.222	1	1	1
1100	0.049	0.627	1	0.314	716	146	135	0.222	1	1	1
1200	0.049	0.627	1	0.314	750	160	135	0.222	1	1	1
1300	0.049	0.627	1	0.314	735	174	135	0.222	1	1	1
1400	0.049	0.627	1	0.314	130	208	135	0.222	1	1	1
1500	0.393	2.325	0.914	0.992	743	245	116.565	0.665	1.372	0.729	0.8
1600	0.098	0.941	1	0.496	94	284	153.435	0.222	2	0.5	1
1700	0.049	0.627	1	0.314	809	347	135	0.222	1	1	1
1800	0.049	0.627	1	0.314	533	367	135	0.222	1	1	1
1900	0.049	0.627	1	0.314	104	395	135	0.222	1	1	1
2000	0.049	0.627	1	0.314	700	442	135	0.222	1	1	1
2100	1.967	11.755	0.179	3.089	628	475	21.038	1.845	1.992	0.502	0.503
2200	0.049	0.627	1	0.314	513	491	135	0.222	1	1	1

2300	0.098	0.941	1	0.496	935	506	153.435	0.222	2	0.5	1
2400	0.049	0.627	1	0.314	904	520	135	0.222	1	1	1
2500	0.344	3.396	0.375	1.402	923	550	71.565	0.631	2.804	0.357	0.56
2600	0.049	0.627	1	0.314	793	577	135	0.222	1	1	1
2700	0.049	0.627	1	0.314	258	610	135	0.222	1	1	1
2800	0.049	0.627	1	0.314	233	640	135	0.222	1	1	1
2900	0.049	0.627	1	0.314	204	684	135	0.222	1	1	1
3000	0.049	0.627	1	0.314	741	703	135	0.222	1	1	1
3100	0.049	0.627	1	0.314	423	730	135	0.222	1	1	1
3200	0.049	0.627	1	0.314	312	747	135	0.222	1	1	1
3300	0.098	0.941	1	0.496	693	758	153.435	0.222	2	0.5	1
3400	0.098	1.071	1	0.496	375	773	116.565	0.222	2	0.5	1
3500	0.049	0.627	1	0.314	378	810	135	0.222	1	1	1
3600	0.049	0.627	1	0.314	599	853	135	0.222	1	1	1
3650	0.148	1.568	0.754	0.8	321	868	33.69	0.397	2.702	0.37	0.667
3680	0.049	0.627	1	0.314	464	880	135	0.222	1	1	1
3681	0.049	0.627	1	0.314	494	880	135	0.222	1	1	1
3682	0.049	0.627	1	0.314	593	880	135	0.222	1	1	1
3683	0.049	0.627	1	0.314	304	881	135	0.222	1	1	1
3684	0.049	0.627	1	0.314	547	881	135	0.222	1	1	1
3685	0.098	0.941	1	0.496	603	881	153.435	0.222	2	0.5	1
3686	0.049	0.627	1	0.314	627	881	135	0.222	1	1	1
3687	0.049	0.627	1	0.314	671	881	135	0.222	1	1	1

- SEM analysis results of sand with 178X magnification

	Area	Perim.	Circ.	Feret	FeretX	FeretY	FeretAngle	MinFeret	AR	Round	Solidity
1	488857	31172.9	0.006	1805.65	0	0	156.639	782.547	2.662	0.376	0.403
100	653.7	128.904	0.494	39.033	921	81	106.928	27.6	1.341	0.746	0.832
200	2.636	4.592	1	2.296	764	136	135	1.624	1	1	1
300	5.272	6.888	1	3.63	117	176	153.435	1.624	2	0.5	1
400	2.636	4.592	1	2.296	850	202	135	1.624	1	1	1
500	2.636	4.592	1	2.296	662	219	135	1.624	1	1	1
600	2.636	4.592	1	2.296	661	242	135	1.624	1	1	1
700	2.636	4.592	1	2.296	485	284	135	1.624	1	1	1
800	8616.71	1026.74	0.103	227.162	579	353	173.434	84.347	3.206	0.312	0.579
900	2.636	4.592	1	2.296	761	349	135	1.624	1	1	1
1000	7984.1	805.272	0.155	148.205	685	372	114.6	100.482	1.739	0.575	0.714
1100	2.636	4.592	1	2.296	880	399	135	1.624	1	1	1
1200	2.636	4.592	1	2.296	493	427	135	1.624	1	1	1
1300	7.908	9.184	1	4.592	546	453	45	3.247	1.464	0.683	0.857
1400	15.815	17.974	0.615	7.261	369	466	153.435	4.871	1.844	0.542	0.667
1500	2.636	4.592	1	2.296	935	482	135	1.624	1	1	1
1600	2.636	4.592	1	2.296	320	501	135	1.624	1	1	1
1700	2.636	4.592	1	2.296	429	520	135	1.624	1	1	1
1800	5.272	9.184	0.785	4.592	956	536	45	2.296	2.646	0.378	0.667
2000	13.179	16.629	0.599	8.278	680	589	168.69	1.624	5	0.2	1
2100	2.636	4.592	1	2.296	325	633	135	1.624	1	1	1
2200	556.172	117.193	0.509	43.866	1021	669	92.121	24.353	1.403	0.713	0.851
2300	5.272	6.888	1	3.63	866	697	153.435	1.624	2	0.5	1

2400	2.636	4.592	1	2.296	896	731	135	1.624	1	1	1
2500	1088.62	219.89	0.283	56.801	714	768	149.036	37.214	1.421	0.704	0.71
2600	5.272	6.888	1	3.63	813	797	153.435	1.624	2	0.5	1
2700	2.636	4.592	1	2.296	983	840	135	1.624	1	1	1
2800	84.348	44.345	0.539	19.003	1018	882	70.017	6.494	2.985	0.335	0.853
2805	126.523	46.084	0.749	16.715	152	873	119.055	12.808	1.296	0.771	0.842
2806	2.636	4.592	1	2.296	622	873	135	1.624	1	1	1
2807	5.272	7.839	1	3.63	143	874	116.565	1.624	2	0.5	1
2808	2.636	4.592	1	2.296	156	874	135	1.624	1	1	1
2809	7.908	12.431	0.643	5.854	577	875	123.69	2.904	2.702	0.37	0.667
2810	2.636	4.592	1	2.296	533	877	135	1.624	1	1	1
2811	79.077	68.256	0.213	27.791	58	880	173.29	6.494	5.814	0.172	0.577
2812	5.272	6.888	1	3.63	72	878	153.435	1.624	2	0.5	1
2813	2.636	4.592	1	2.296	142	878	135	1.624	1	1	1
2814	52.718	40.147	0.411	15.402	232	882	18.435	6.494	2.64	0.379	0.727
2815	2.636	4.592	1	2.296	139	879	135	1.624	1	1	1
2816	5.272	7.839	1	3.63	280	880	116.565	1.624	2	0.5	1
2817	7.908	9.184	1	4.592	288	880	135	3.247	1.464	0.683	0.857
2818	10.544	12.431	0.857	5.854	1013	880	146.31	3.247	2	0.5	0.8
2819	2.636	4.592	1	2.296	23	881	135	1.624	1	1	1
2820	5.272	6.888	1	3.63	140	881	153.435	1.624	2	0.5	1
2821	2.636	4.592	1	2.296	275	881	135	1.624	1	1	1
2822	2.636	4.592	1	2.296	497	881	135	1.624	1	1	1
2823	13.179	16.629	0.599	8.278	503	881	168.69	1.624	5	0.2	1
2824	5.272	6.888	1	3.63	966	881	153.435	1.624	2	0.5	1

- SEM analysis results of sand with 150X magnification

	Area	Perim.	Circ.	Feret	FeretX	FeretY	FeretAngle	MinFeret	AR	Round	Solidity
1	3.74E-06	0.005	1	0.003	9	0	135	0.002	1	1	1
200	3.74E-06	0.005	1	0.003	870	48	135	0.002	1	1	1
400	3.74E-06	0.005	1	0.003	994	89	135	0.002	1	1	1
600	3.74E-06	0.005	1	0.003	986	124	135	0.002	1	1	1
800	7.48E-06	0.008	1	0.004	541	156	153.435	0.002	2	0.5	1
1000	3.74E-06	0.005	1	0.003	871	195	135	0.002	1	1	1
1200	2.62E-05	0.026	0.496	0.01	425	233	53.13	0.008	1.234	0.811	0.56
1400	1.31E-04	0.107	0.144	0.036	28	282	15.524	0.014	3.397	0.294	0.443
1600	3.74E-06	0.005	1	0.003	722	315	135	0.002	1	1	1
1800	3.74E-06	0.005	1	0.003	839	345	135	0.002	1	1	1
2000	3.74E-06	0.005	1	0.003	546	376	135	0.002	1	1	1
2200	3.74E-06	0.005	1	0.003	680	408	135	0.002	1	1	1
2400	3.74E-06	0.005	1	0.003	191	448	135	0.002	1	1	1
2600	3.74E-06	0.005	1	0.003	992	479	135	0.002	1	1	1
2800	3.74E-06	0.005	1	0.003	155	532	135	0.002	1	1	1
3000	3.74E-06	0.005	1	0.003	191	569	135	0.002	1	1	1
3200	3.74E-06	0.005	1	0.003	806	609	135	0.002	1	1	1
3400	3.74E-06	0.005	1	0.003	1002	655	135	0.002	1	1	1
3600	1.12E-05	0.014	0.754	0.007	899	688	33.69	0.003	2.702	0.37	0.667
3800	3.74E-06	0.005	1	0.003	956	729	135	0.002	1	1	1
4000	3.74E-06	0.005	1	0.003	542	764	135	0.002	1	1	1
4200	3.74E-06	0.005	1	0.003	943	805	135	0.002	1	1	1
4400	1.87E-05	0.015	1	0.007	294	841	33.69	0.004	1.553	0.644	0.909

4600	7.48E-06	0.009	1	0.004	836	870	116.565	0.002	2	0.5	1
4610	7.48E-06	0.008	1	0.004	324	872	153.435	0.002	2	0.5	1
4620	4.12E-05	0.033	0.461	0.014	322	874	146.31	0.007	2.56	0.391	0.647
4630	1.05E-04	0.058	0.39	0.021	512	882	41.186	0.011	1.843	0.543	0.644
4640	3.74E-06	0.005	1	0.003	576	876	135	0.002	1	1	1
4650	1.27E-04	0.075	0.281	0.031	257	882	7.125	0.008	4.628	0.216	0.708
4660	3.74E-06	0.005	1	0.003	258	879	135	0.002	1	1	1
4670	3.74E-06	0.005	1	0.003	637	880	135	0.002	1	1	1
4680	3.74E-06	0.005	1	0.003	531	881	135	0.002	1	1	1
4681	3.74E-06	0.005	1	0.003	562	881	135	0.002	1	1	1
4682	3.74E-06	0.005	1	0.003	574	881	135	0.002	1	1	1
4683	7.48E-06	0.008	1	0.004	589	881	153.435	0.002	2	0.5	1
4684	3.74E-06	0.005	1	0.003	652	881	135	0.002	1	1	1
4685	3.74E-06	0.005	1	0.003	709	881	135	0.002	1	1	1
4686	3.74E-06	0.005	1	0.003	866	881	135	0.002	1	1	1
4687	3.74E-06	0.005	1	0.003	947	881	135	0.002	1	1	1

➢ SEM analysis results of scoria with 10000X magnification

	Area	Perim.	Circ.	Feret	FeretX	FeretY	FeretAngle	MinFeret	AR	Round	Solidity
1	693.965	161.815	0.333	39.03	0	0	139.205	25.501	1.154	0.866	0.921
10	8.36E-04	0.082	1	0.041	472	34	135	0.029	1	1	1
20	0.004	0.303	0.572	0.129	375	59	153.435	0.082	1.665	0.601	0.588
30	8.36E-04	0.082	1	0.041	92	93	135	0.029	1	1	1
40	8.36E-04	0.082	1	0.041	761	138	135	0.029	1	1	1
50	0.002	0.164	0.785	0.082	782	243	45	0.041	2.646	0.378	0.667
60	8.36E-04	0.082	1	0.041	59	317	135	0.029	1	1	1
70	0.017	0.613	0.559	0.273	900	358	147.995	0.123	2.644	0.378	0.678
80	0.005	0.327	0.589	0.129	213	422	63.435	0.087	1.418	0.705	0.632
90	0.002	0.164	0.785	0.082	12	465	45	0.041	2.646	0.378	0.667
100	8.36E-04	0.082	1	0.041	812	519	135	0.029	1	1	1
110	8.36E-04	0.082	1	0.041	590	594	135	0.029	1	1	1
120	8.36E-04	0.082	1	0.041	519	708	135	0.029	1	1	1
130	8.36E-04	0.082	1	0.041	554	744	135	0.029	1	1	1
140	8.36E-04	0.082	1	0.041	97	759	135	0.029	1	1	1
150	8.36E-04	0.082	1	0.041	179	817	135	0.029	1	1	1
160	8.36E-04	0.082	1	0.041	37	862	135	0.029	1	1	1
161	0.003	0.327	0.393	0.129	56	865	26.565	0.073	2.179	0.459	0.5
162	0.002	0.14	1	0.065	56	866	116.565	0.029	2	0.5	1
163	0.003	0.303	0.457	0.145	938	874	126.87	0.056	3.85	0.26	0.571
164	8.36E-04	0.082	1	0.041	49	877	135	0.029	1	1	1
165	8.36E-04	0.082	1	0.041	51	878	135	0.029	1	1	1
166	0.002	0.123	1	0.065	941	879	153.435	0.029	2	0.5	1

- SEM analysis results of scoria with 5342X magnification

	Area	Perim.	Circ.	Feret	FeretX	FeretY	FeretAngle	MinFeret	AR	Round	Solidity
1	678785	18534.4	0.025	1348.87	0	0	139.389	882	1.118	0.895	0.752
50	1	2.828	1	1.414	177	227	135	1	1	1	1
100	8	10.485	0.914	4.472	491	262	153.435	3	1.308	0.764	0.8
150	27	24.971	0.544	10	613	292	36.87	6.2	1.779	0.562	0.675
200	2	4.243	1	2.236	312	316	153.435	1	2	0.5	1
250	10	11.657	0.925	5.385	114	349	158.199	2	2.5	0.4	1
300	249	117.983	0.225	41.617	0	416	54.782	14.68	3.366	0.297	0.586
350	2	5.657	0.785	2.828	252	415	135	1.414	2.646	0.378	0.667
400	9	13.314	0.638	5.831	11	460	30.964	3.479	2.05	0.488	0.643
450	6	9.071	0.916	4.472	39	491	26.565	2	2.237	0.447	0.857
500	1	2.828	1	1.414	583	521	135	1	1	1	1
600	279	126.61	0.219	33.838	104	608	55.84	17.938	1.908	0.524	0.593
650	8	9.899	1	4.472	87	613	153.435	3	1.554	0.644	0.8
700	3	5.657	1	2.828	0	673	45	2	1.464	0.683	0.857
750	1	2.828	1	1.414	98	754	135	1	1	1	1
760	9	10.485	1	4.472	155	797	63.435	3	1.185	0.844	0.857
770	12	11.899	1	5	495	852	36.87	4	1.135	0.881	0.857
780	2	4.243	1	2.236	40	866	153.435	1	2	0.5	1
790	7	13.071	0.515	6.083	121	881	170.538	2	3.579	0.279	0.737
791	3	5.657	1	2.828	456	880	135	2	1.464	0.683	0.857
792	1	2.828	1	1.414	1007	881	135	1	1	1	1
793	3	6.243	0.967	3.162	1021	881	161.565	1	3	0.333	1

- SEM analysis results of scoria with 2000X magnification

	Area	Perim.	Circ.	Feret	FeretX	FeretY	FeretAngle	MinFeret	AR	Round	Solidity
1	579526	21083.9	0.016	1350.52	0	0	139.113	884	1.25	0.8	0.652
200	1	2.828	1	1.414	1023	88	135	1	1	1	1
400	1	2.828	1	1.414	856	144	135	1	1	1	1
600	2	4.828	1	2.236	577	192	116.565	1	2	0.5	1
800	3	6.828	0.809	3.162	686	241	108.435	1	3	0.333	1
1000	1	2.828	1	1.414	371	285	135	1	1	1	1
1200	1	2.828	1	1.414	815	337	135	1	1	1	1
1400	2	4.828	1	2.236	623	372	116.565	1	2	0.5	1
1600	3	5.657	1	2.828	598	408	135	2	1.464	0.683	0.857
1800	639	212.978	0.177	38.328	548	502	7.496	28.86	1.419	0.705	0.715
2000	13	25.799	0.245	7.071	1006	523	135	5.2	1.563	0.64	0.481
2200	2	4.828	1	2.236	951	563	116.565	1	2	0.5	1
2400	2	4.828	1	2.236	92	588	116.565	1	2	0.5	1
2600	1	2.828	1	1.414	449	614	135	1	1	1	1
2800	9	15.314	0.482	6.325	706	642	108.435	3	2.01	0.497	0.643
3000	1	2.828	1	1.414	999	671	135	1	1	1	1
3200	3	6.828	0.809	3.162	866	715	108.435	1	3	0.333	1
3400	1	2.828	1	1.414	247	757	135	1	1	1	1
3600	1	2.828	1	1.414	885	810	135	1	1	1	1
3800	2	4.828	1	2.236	959	866	116.565	1	2	0.5	1
3850	1	2.828	1	1.414	851	883	135	1	1	1	1
3851	1	2.828	1	1.414	982	883	135	1	1	1	1
3852	2	4.243	1	2.236	1022	883	153.435	1	2	0.5	1

- SEM analysis results of scoria with 1000X magnification

	Area	Perim.	Circ.	Feret	FeretX	FeretY	FeretAngle	MinFeret	AR	Round	Solidity
1	258.175	111.29	0.262	28.074	52	0	156.337	17.624	1.868	0.535	0.759
100	0.167	1.634	0.785	0.817	501	53	45	0.409	2.646	0.378	0.667
200	0.501	3.438	0.532	1.685	189	113	30.964	0.721	3.231	0.31	0.6
300	0.501	4.086	0.377	1.634	494	178	45	0.904	1.979	0.505	0.522
400	0.083	0.817	1	0.409	207	270	135	0.289	1	1	1
500	0.083	0.817	1	0.409	527	326	135	0.289	1	1	1
600	0.167	1.395	1	0.646	960	386	116.565	0.289	2	0.5	1
700	0.25	1.804	0.967	0.914	731	418	161.565	0.289	3	0.333	1
800	0.083	0.817	1	0.409	259	449	135	0.289	1	1	1
900	0.083	0.817	1	0.409	878	484	135	0.289	1	1	1
1000	0.083	0.817	1	0.409	0	513	135	0.289	1	1	1
1100	0.417	3.199	0.513	1.556	983	593	158.199	0.548	4.051	0.247	0.667
1200	0.083	0.817	1	0.409	903	674	135	0.289	1	1	1
1300	0.167	1.395	1	0.646	656	735	116.565	0.289	2	0.5	1
1400	0.25	2.043	0.754	1.042	531	791	146.31	0.517	2.702	0.37	0.667
1500	0.083	0.817	1	0.409	509	845	135	0.289	1	1	1
1580	0.584	3.029	0.8	1.226	551	879	135	0.867	1.247	0.802	0.824
1585	0.167	1.226	1	0.646	180	881	153.435	0.289	2	0.5	1
1586	0.083	0.817	1	0.409	189	881	135	0.289	1	1	1
1587	0.083	0.817	1	0.409	673	881	135	0.289	1	1	1
1588	0.083	0.817	1	0.409	685	881	135	0.289	1	1	1
1589	0.083	0.817	1	0.409	915	881	135	0.289	1	1	1