

**ADDIS ABABA UNIVERSITY**  
**ADDIS ABABA INSTITUTE OF TECHNOLOGY**  
**SCHOOL OF CIVIL AND ENVIRONMENTAL**  
**ENGINEERING**



# The Effect of Ground Pumice on the Strength of Normal Concrete

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**A Thesis in Structural Engineering**

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A Thesis

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## UNDERTAKING

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## ABSTRACT

Concrete is the most widely used material in today's infrastructure needs all around the world. The production of Portland cement is however expensive, energy intensive, and results in globally significant GHGs emissions. Production of Portland cement, contributes to over 7% of worldwide GHGs which is equal to 1.6 billion tons of GHGs. On average, production of each ton of portland cement results in releasing one ton of CO<sub>2</sub>. Current average consumption of concrete is about one ton per year per every living human being, according to the International Energy Agency. And hence, there is a significant and positive global impact, even small reductions in GHGs emissions. Natural pozzolans, such as pumice, can be used in concrete as a partial replacement for Portland cement, lowering production costs and GHGs emissions while also improving concrete performance. Pumice as a cement alternative in ordinary concretes could pave the way to a more sustainable future. Furthermore, pumice is abundant in the Eastern and northern regions of Ethiopia, as seen by Ethiopian industrial mineral occurrence map, thus it may be an interesting option. This paper summarizes the findings of a study that looked into the impact of partially replacing GP with cement on the physical and mechanical properties of concrete. To determine the influence of ground pumice on compressive strength and tensile strength of standard concrete, eight concrete mixtures with varying pozzolana levels up to 30% were cast and evaluated. It should also be noted that the chemical composition and qualities of pumice vary by location, and hence may have varying effects on concrete properties; thus, the data presented here represent materials with specific properties. Based on this investigation, the results indicated that using ground pumice as a cement replacement in normal concrete improved the compressive and tensile strength of normal concrete at 20% replacement ratio.

**Key Words:** - Ground Pumice, Natural Pozzolana, Ordinary Portland Cement, GHGs, concrete, Compressive and Tensile Strength.

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## LIST OF ABBREVIATIONS

A	Cross sectional area
ACI	American Concrete Institute
Al <sub>2</sub> O <sub>3</sub>	Aluminum Oxide
ASTM	American Society of Testing Materials
Ca(OH) <sub>2</sub>	Calcium Hydroxide or Portlandite
C-A-H	Calcium Aluminate Hydrate
CaO	Calcium Oxide
CO <sub>2</sub>	Carbon di-oxide
C-S-H or (4CaO.Al <sub>2</sub> O <sub>3</sub> .13H <sub>2</sub> O)	Calcium Silicate Hydrate
C <sub>2</sub> S or (Ca <sub>2</sub> SiO <sub>4</sub> )	Belite or Dicalcium Silicate
C <sub>3</sub> A or (Ca <sub>3</sub> Al <sub>2</sub> O <sub>6</sub> )	Aluminate or Tricalcium Aluminate
C <sub>3</sub> S or (Ca <sub>3</sub> SiO <sub>5</sub> )	Alite or Tricalcium Silicate
C <sub>4</sub> AF or (Ca <sub>2</sub> AlFeO <sub>5</sub> )	Ferrite is Tetracalcium Aluminoferrite
CuKα	Copper radiation source
E	Modulus of elasticity
G	Shear modulus
Fe <sub>2</sub> O <sub>3</sub>	Iron Oxide
Gm	Gram
H <sub>2</sub> O	Water
ITZ	Interfacial Transition Zone
Kg	Kilogram
K <sub>2</sub> O	Potassium Oxide
L	Length
LAA	Los-Angeles Abrasion and attrition test
LoI	Loss on Ignition
M	Meter
m <sup>2</sup>	Square meter
m <sup>3</sup>	Cubic meter
mm	Thousands of a meter
MgO	Magnesium Oxide
MnO	Manganese Oxide
MPa	Mega Pascal
N	Order of reflection
Na <sub>2</sub> O	Sodium Oxide
OPC	Ordinary Portland Cement
P <sub>2</sub> O <sub>5</sub>	Phosphorous Oxide
PC	Pervious Concrete
PCCP	Pervious Cement Concrete Pavement
PDF	Powder Diffraction File

PPC	Portland Pozzolanic Cement
PSD	Particle size distribution
SCM	Supplementary/ Sustainable Cementitious Materials
SiO <sub>2</sub>	Silicon di-oxide
SSD	Saturated Surface dry condition
TiO <sub>2</sub>	Titanium Oxide
UTM	Universal Testing Machine
W/C	Water to cement ratio
w/b	Water to binder ratio
XRD	X-ray Powder diffraction
°C	Degree Celsius
$\theta$	Angle of Incidence
$\lambda$	Wave length
$\mu m$	Millionth of a meter

## CHAPTER 1 INTRODUCTION

### 1.1 General Background of the Study

Cement is one of the most widely used construction materials in the world. The rapid growth of development and industrialization has resulted in a high demand for cement and concrete. As a result, several articles have been written about the quest for alternative binders or cement replacement materials. Many studies have demonstrated that using pozzolanic elements can improve the characteristics of concrete up to a certain degree of replacement (Kabay et al., 2021).

One of the biggest sources of CO<sub>2</sub> emissions is increased cement production, which will be reduced by using Ground Pumice as a cement substitute.(Cabrera-Luna et al., 2021)

Pozzolanic materials, such as Grounded Pumice are mostly composed of siliceous compounds, with a SiO<sub>2</sub> content of 73.06% in the GP employed in this study. These compounds will allow these pozzolanic materials to build more C-S-H and C-A-H structures, resulting in increased long-term strength, according to different research results. During the hydration of cement, amorphous silicates in pozzolanic materials react with Ca(OH)<sub>2</sub>, forming new C-S-H gels (Uluslu et al., 2016). Pozzolans could assist increase concrete's durability by reducing heat cracking, alkali-aggregate expansion, and sulfate attack (Cabrera-Luna et al., 2021).

Because the importance of using natural pozzolans in the cement industry necessitates a detailed study of their effects on concrete, more research on the use of such natural pozzolans as cement replacement materials is still needed, and their effects on concrete properties should be investigated. Pumice was used as a natural pozzolan in this study because it is readily available in Ethiopia and can be quickly ground into powder without consuming a lot of energy.

This research presents the effect of ground pumice as a cement replacement on the properties of fresh and hardened normal concrete. Different types of concrete mixtures are evaluated, including those prepared with ordinary Portland cement as a control (i.e., 0% pumice) and those made with ground pumice as a cement replacement (5%, 10%, 15%, 20, 25%, and 30% replacement of cement) in various curing days.

## **1.2 Statement of the problem**

Cement manufacturing is responsible for seven percent of global CO<sub>2</sub> emissions (Ulusu et al., 2016). Production and use of mixed cement with pozzolans should be expanded in this regard. As a result, more research is required. The question of this research is to see if pumice can be used as partial replacement of cement, what the performance attributes are as a result of adding ground pumice in normal concrete.

## **1.3 Objective of the study**

### **1.3.1 General objective**

Comparing the compressive strength and tensile strength of concrete made with ground pumice as a cement replacement with that of control mixture.

### **1.3.2 Specific objective**

- To Investigate the impact of adding ground pumice on concrete's mechanical properties such as compressive strength and tensile strength.
- To investigate the chemical and physical properties of ground pumice.
- To figure out the optimum replacement of ground pumice to mix with Portland cement to make normal concrete.
- Based on the research findings, to draw conclusions and make recommendations, as well as to suggest areas for further investigation

## **1.4 Scope of the study and Limitation**

- ✓ Examining and testing the characteristics of concrete made with ground pumice as a partial cement replacement.
- ✓ Review and research of environmental feasibility.
- ✓ Concrete specimens consisting of ground pumice as a partial cement replacement are casting and testing.
- ✓ Analysis of test results and recommendations for further research area.

## **1.5 Significance of the study**

Ground pumice's successful integration into the construction industry has the ability to greatly alleviate environmental concerns. The usage of this material has two main advantages: first, it minimizes CO<sub>2</sub> emissions from cement production, and second, it opens a potential market for ground pumice production in Ethiopia.

## **1.6 Thesis structure**

There are six chapters in this study. The first chapter introduces the research paper's main concept, major problems to be investigated, objectives, scope, and significance. The second chapter discusses past work with pumice. The materials used for experimentation are briefly described in Chapter 3. The experimental methodologies and procedures employed in this study are explained in Chapter 4. The findings of the experiments are discussed in Chapter 5, followed by analysis and interpretation. Finally, in Chapter 6, conclusions and fundamental recommendations for further work are given.

## CHAPTER 2 LITERATURE REVIEW

### 2.1 Concrete

Concrete is a man-made stone in the most basic sense. Concrete, in its most basic form, is a mixture of cement, water, and aggregates, in which the cement and water have combined to bond the aggregate particles into a monolithic whole.

Concrete is characterized by the type of aggregate or cement used, by the specific qualities it manifests, or by the methods used to produce it. The nature of conventional structural concrete is largely influenced by the water-to-cement ratio. The stronger the concrete is, all else being equal, the lower the water content. The concrete must have just enough water in it to ensure that each aggregate particle is entirely encased in cement paste, that the spaces between the aggregate are filled, and that the concrete is liquid enough to be poured and spread properly. The amount of cement in relation to the aggregate (represented as a three-part ratio cement to fine aggregate to coarse aggregate) is another aspect that affects durability of concrete. There will be less aggregate in places where more strength is required. Environmental conditions, particularly temperature and moisture, have an impact on the strength of concrete. If it is allowed to dry too quickly, it may be subjected to uneven tensile forces that cannot be withstood in an inadequately hardened state. Curing is the act of keeping concrete damp for a period of time after it has been poured in order to delay the shrinkage that happens as it hardens. Its strength is also harmed by low temperatures. To compensate for this, a calcium chloride addition is put into the cement. These speeds up the setting process, which provides enough heat to compensate for the somewhat low temperatures (Britannica, 2020).

Concrete use is expected to be over 11 billion metric tons per year around the world. Concrete's remarkable technical capabilities, as well as its economic value, are the reasons for this. One of the main reasons is that it is water resistant, making it an excellent building material for regulating, conveying, and carrying water. The second reason is its adaptability (ability to adapt to a wide range of forms and sizes), which is mostly due to its plastic consistency, which allows the material to flow into predefined shapes. The formwork could then be removed once the concrete had set. The abundance of the material, as well as the material's economy, would be the third factor. The essential ingredients for

creating concrete, namely gravel, water, and Portland cement, are very affordable and widely available relative to other construction material (P. Kumar Mehta and Paulo J. M. Monteiro, 2014).

### **2.1.1 Types of Concrete**

Different varieties of concrete are made depending on the constituent materials, mix design, construction process, application area, and hydration reaction form (Mishra, 2020).

#### **i. Normal Strength Concrete**

Normal strength concrete is made by mixing the fundamental ingredients of cement, water, and aggregate. These types of concrete have strengths ranging from 10 MPa to 40 MPa. The initial setting time of normal strength concrete varies between 30 and 90 minutes, depending on the cement characteristics and the meteorological conditions at the construction site.

#### **ii. Plain Concrete**

There will be no reinforcing in the plain concrete. Cement, aggregates, and water are the key components. The most frequent mix design is 1:2:4, which is also known as the standard mix design. The plain concrete's density will range between 2200 and 2500 Kg/meter cube. Compressive strength ranges between 200 and 500 kg/cm<sup>2</sup>. These forms of concrete are mostly utilized in the construction of pavements and structures, particularly in locations where great tensile strength is not required. The durability provided by this form of concrete is extremely good.

#### **iii. Reinforced Concrete**

Reinforced cement concrete is defined as concrete that has had reinforcement added to it to increase its tensile strength. Plain concrete has a low-tension strength but a high compression strength. As a result, the reinforcement will take on the burden of supporting the tensile stresses. R.C.C. operates by combining the actions of plain concrete and reinforcement. Steel reinforcement in concrete can take the shape of rods, bars, or meshes. Fibers are already being produced for use as reinforcement.

#### **iv. Prestressed Concrete**

Prestressed concrete units are used in the majority of massive concrete projects. This is a unique approach in which the concrete bars or tendons are stressed before the real service load is applied. These tensioned bars were inserted firmly and held

from each end of the structural unit during the mixing and placement of the concrete. The structural unit will be compressed once the concrete has set and hardened. The lower section of the concrete member will be stronger against tension as a result of this prestressing process. Prestressing will necessitate heavy machinery and labor expertise (jacks and equipment for tensioning). As a result, the prestressing units are manufactured and built on-site. Bridges, heavy-loaded constructions, and roofs with longer spans all make use of these.

**v. Precast Concrete**

Various structural pieces can be manufactured and cast at the factory according to specifications and then transported to the assembly site. Precast concrete refers to these concrete units. Concrete blocks, stair units, precast walls and poles, concrete lintels, and many other parts are examples of precast concrete units. Because just assembling is required, these units have the advantage of being quick to create. Quality is ensured because the manufacturing is done on-site. Their conveyance is the only safeguard taken.

**vi. Lightweight Concrete**

Lightweight concrete is defined as concrete with a density of less than 1920kg/m<sup>3</sup>. We will have lightweight aggregates as a result of the usage of lightweight aggregates in concrete design. Aggregates are an important component that contributes to the concrete's density. Pumice, perlites, and scoria are examples of light weight aggregates. Lightweight concrete is used to protect steel buildings and for the construction of long-span bridge decks. These are also utilized in the making of the building blocks.

**vii. High-Density Concrete**

Concretes with densities ranging from 3000 to 4000 kg/m<sup>3</sup> are referred to as heavyweight concrete. Heavy-duty aggregates are employed here. As coarse aggregates, crushed rocks are employed. Barytes are the most often utilized heavy weight aggregates. A lot of these aggregates are used in the construction of nuclear power plants and other comparable projects. The structure's heavy weight aggregate will aid in its resistance to all types of radiation.

**viii. Air Entrained Concrete**

These are concrete kinds in which 3 to 6 % of the concrete is purposefully entrained with air. The addition of foams or gas-foaming agents to the concrete achieves air entrainment. Resins, alcohols, and fatty acids are examples of air entraining agents.

Concrete's compressive strength and workability are both affected by air entrainment. It improves the workability of concrete without increasing the water-cement ratio significantly. Concrete workability is inversely related to its compressive strength. Concrete's compressive strength diminishes as its workability improves. As a result, increasing concrete workability to improve concrete placement and compaction will reduce concrete strength. To boost workability without adding water, an air entraining admixture is used in this circumstance. However, the impact of air entrainment on concrete qualities, particularly concrete strength, must be thoroughly investigated.

**ix. Ready Mix Concrete**

Ready-mix concrete is concrete that has been mixed and soaked at a central mixing plant. A truck-mounted transit mixer transports the mixed concrete to the job site. Once you've arrived at the spot, you can use it right away without any more treatment. Ready-mix concrete is very accurate, and specialized concrete can be made with the highest quality based on the specifications. The production of this concrete will necessitate the use of a centralized mixing facility. These plants will be placed at a distance from the construction site that can be adjusted. The setting of concrete will occur if the transit is too long. The employment of retarding agents, which postpone the setting, is used to deal with such concerns of time delay.

**x. Polymer Concrete**

When compared to traditional concrete, aggregates in polymer concrete are bound with polymer rather than cement. The use of polymer concrete in the aggregate will help to reduce the volume of voids. As a result, the amount of polymer required to bind the aggregates will be reduced. As a result, the aggregates are graded and blended to obtain the lowest voids and thus the highest density. There are several types of concrete in this category: Partially Impregnated, Polymer Impregnated Concrete and Polymer cement concrete. Because of the following reasons, polymers are utilized in concrete: Hardened concrete's strength, durability, chemical resistance and impermeability improved by polymers and also it altered fresh concrete's flow characteristics to meet specific requirements and it able to improve the bonding properties of old and fresh concrete.

It is low permeable and corrosive resistance concrete. It used in swimming pools, sewer structures applications, drainage channels, construction and rehabilitations of manholes, etc.

**xi. High-Strength Concrete**

High-strength concrete is defined as concrete with a strength more than 40 MPa. The water-cement ratio is reduced even more below 0.35 to attain this improved strength. In terms of performance, high-strength concrete might perform worse in terms of workability, which is an issue. The voids are filled with silica fumes, making the concrete stronger. This kind of concrete also contains fly ash. If the fine modulus of fine and coarse aggregates is high, the concrete will be durable and of high quality.

**xii. Self - Consolidated Concrete**

Self-consolidated concrete is defined as a concrete mix that compacts by its own weight when placed. There is no need to give vibration for the same individually. This mixture is more workable. Between 650 and 750 will be the decline value. This concrete is also known as flowing concrete because of its increased workability. Self-consolidating concrete performs best in regions with thick reinforcement.

**xiii. Pervious Concrete**

Concrete that is pervious or permeable allows water to pass through it. When designed, these forms of concrete will have 15 to 20% voids. Pervious concrete is made possible by a unique mixing process, performance, and application methods, among other factors. In areas where storm water concerns persist, these are used in the construction of pavements and driveways. Storm water will travel through the pervious concrete pavements and into the groundwater system. As a result, the majority of drainage problems have been addressed.

**xiv. Limecrete**

This is a type of concrete in which lime replaces cement. This product is most commonly used in floors, domes, and vaults. Unlike cement, these have numerous environmental and health advantages. These materials are biodegradable and simple to clean.

**xv. Asphalt Concrete**

Asphalt concrete is a composite material made up of aggregates and asphalts that is often used to cover roadways, parking lots, airports, and embankment dams. Asphalt concrete is also known in North America as asphalt, blacktop, or pavement, and in the United Kingdom and Ireland as tarmac, bitumen macadam, or rolled asphalt.

**xvi. Roller Compacted Concrete**

These are concrete slabs that have been poured and compacted using earth moving equipment such as big rollers. This concrete is mostly used for excavation and filling purposes. These concretes have a lower cement concentration and are filled to the required area. These concretes give great density after compaction and eventually cure into a strong monolithic block.

**xvii. Rapid Strength Concrete**

These concretes will gain strength within a few hours of being made, as the name implies. As a result, formwork removal is simple, and the building construction is completed quickly. These are often used in road repairs since they may be reused after a few hours.

**2.1.2 Strength of concrete**

The capacity of a material to endure applied loads without failure or plastic deformation is referred to as its strength. The strength of concrete is extremely important in concrete design and quality control, owing to the fact that measuring its strength is relatively simple compared to testing other qualities of concrete. Furthermore, other attributes are directly related to its strength, and because compressive loads are more suitable for concrete than tensile loads, the compressive strength of concrete is often indicated (P. Kumar Mehta and Paulo J. M. Monteiro, 2014).

The qualities of both fresh and hardened concrete are greatly influenced by the properties of the concrete ingredients. To begin, aggregates, which make up 60-80 percent of concrete, must meet certain specifications, including being free of chemicals and other contaminants that could interfere with the hydration process. Second, the qualities of cement, a raw material made up of limestone, shale, clay, and iron ore, require the correct proportions of lime, silica, alumina, and iron. The paste made up of cement, water, and entrained air, which is affected by the water to cement ratio, is the third factor that impacts the strength of concrete. Although a lower water-to-cement ratio makes the concrete stronger, it also makes it more difficult to work with. As a result, the optimum balance must be struck in order to obtain the desired strength while maintaining workability. Water, specifically the PH level, is the fourth component that affects concrete. Almost all-natural drinking water can be used for mixing, but not the other way around. Water with a PH level of 4.5 to 8.5 is normally preferred (Shafi, 2015).

### 2.1.3 Workability of concrete

Fresh concrete's workability is a quality that reflects how easy it is to cast. The term "workable concrete" refers to concrete that can be easily placed and compacted without separating. After mixing, the concrete goes through different operations such as transportation, flow, finishing, and compaction.

The cement content in concrete is one aspect that impacts its workability. The more cement we add to the mix, the better the paste will be able to coat the aggregate surface. This will help to reduce friction between aggregates and promote smooth aggregate movement, making concrete more workable during mixing, transport, placement, and compacting.

Adding water to the mix, on the other hand, can improve or decrease the workability of concrete. The mixing operations are affected when not enough water is added, making it tough to work with. Adding too much water, on the other hand, may cause the concrete to segregate and lose its workability. Its workability is also influenced by the cement and aggregates we utilize. Increasing the fineness of the cement necessitates the addition of more water in order for it to be more workable. Increased aggregate size necessitates the addition of more cement to make it more workable (Tattersall, 1991).

The following factors affect concrete's workability:

- The method of transportation and the time it takes to get there
- Cementitious materials' quantity and properties
- The consistency of concrete
- Fine and coarse particles' grading, shape, and surface texture
- The temperatures of the concrete and the surrounding air
- Admixtures
- Water content

Workability is determined by consistency. The consistency or moisture of concrete is measured using slump. The consistency of a low slump concrete is rigid. Segregation and honey combing can occur if the mix is too moist; therefore, for placement utilizing available consolidation equipment, the consistency should be as optimum as possible (Kosmatka et al., 2002).

## 2.2 Cement

Cement is made up of a complex mix of inorganic phases, chiefly calcium silicates and aluminates. It's made by heating a clay and limestone mixture together. Alite, belite, aluminate, and ferrite are the major stages in a typical Portland cement. Tricalcium silicate ( $\text{Ca}_3\text{SiO}_5$ ,  $\text{C}_3\text{S}$ ) is the main component of alite, accounting for 50 to 70% of its total mass. It is the most significant stage in ordinary cement since it influences setting time and short-term strength up to 28 days.

Belite ( $\text{Ca}_2\text{SiO}_4$ ,  $\text{C}_2\text{S}$ ) is a dicalcium silicate that makes up 15-30% of Portland cement clinkers. Because it reacts slowly with water, it makes a small contribution during the first 28 days. It mostly aids in the development of strength in later ages.

Aluminate ( $\text{Ca}_3\text{Al}_2\text{O}_6$ ,  $\text{C}_3\text{A}$ ) is a tricalcium aluminate ( $\text{Ca}_3\text{Al}_2\text{O}_6$ ,  $\text{C}_3\text{A}$ ) that makes up 5-10% of Portland cement clinkers. It interacts quickly with water, and unless a set-control agent, such as gypsum, is added, it can induce unwanted fast setting.

Ferrite ( $\text{Ca}_2\text{AlFeO}_5$ ,  $\text{C}_4\text{AF}$ ) is a tetracalcium aluminoferrite ( $\text{Ca}_2\text{AlFeO}_5$ ,  $\text{C}_4\text{AF}$ ) constituting of 5-10% of Portland cement clinkers. Its rate of reaction with water is somewhat varied. It is high at first, then intermediate between those alite and belite at later ages (Taylor, 1990).

### 2.2.1 Types of Cement

According to their uses and productions, cement can be classified as (Mishra, 2020):

#### I. Ordinary Portland Cement (OPC)

The most extensively used type of cement is ordinary Portland cement, which is suited for all types of concrete works rather than sulphate susceptible areas. With yearly global production of roughly 3.8 billion cubic meters, it is the most widely produced and utilized form of cement on the globe. This cement can be used in any type of concrete building.

#### II. Portland Pozzolana Cement (PPC)

Grinding pozzolanic clinker with Portland cement produces Portland pozzolana cement. It can also be made by combining fine pozzolana with gypsum or calcium sulfate, or by blending Portland cement and fine pozzolana closely and uniformly.

When compared to standard portland cement, this cement has a higher resistance to various chemical attacks on concrete, and as a result, it is frequently employed. It's employed in maritime constructions, sewage works, and underwater concrete laying, such as bridges, piers, dams, and mass concrete works, among other things.

### **III. Rapid Hardening Cement**

Rapid hardening cement achieves high strength quickly and is identical to ordinary portland cement. It is utilized in concrete where formwork is removed early in the process. This cement has a higher lime content, higher  $C_3S$  content, and finer grinding, resulting in a stronger early strength development than OPC. Rapid hardening cement has a three-day strength that is comparable to OPC's seven-day strength when the water-cement ratio is the same. As a result, the advantage of this cement is that formwork can be removed early, increasing building speed and lowering construction costs by reducing formwork costs. Prefabricated concrete building, road construction, and other applications use rapid hardening cement.

### **IV. Quick setting cement**

The only difference between quick-setting and rapid-hardening cement is that quick-setting cement sets faster. Simultaneously, the rate of strength increase is comparable to Ordinary Portland Cement, but quick hardening cement gains strength rapidly. In both circumstances, the formwork can be removed sooner.

Quick setting cement is used for concreting in static or running water and where work must be done in a short period of time. The quick setting property of quick setting cement is accomplished by lowering the Gypsum concentration during the clinker grinding process.

### **V. Low Heat Cement**

Low heat cement is made by increasing the quantity of  $C_2S$  while keeping the percentage of tricalcium aluminate below 6%. The concrete produces low heat of hydration due to a small amount of tricalcium aluminate. Because of the low heat of hydration, low heat cement is suitable for mass concrete construction such as gravity dams, as it prevents concrete cracking owing to heat. This cement offers stronger resistance to sulphates, is less reactive, and has a longer initial setting time than OPC.

### **VI. Sulfates Resisting Cement**

Sulfate-resistant cement is used in the construction of foundations where the soil has a high sulfate content to limit the risk of sulfate attack on concrete. Many studies have shown that cement with a low  $C_3A$  concentration reduces sulphate attack more effectively. Sulphates-resistant cement contains a high silicate percentage and low  $C_3A$  and  $C_4AF$ . Sulfate-resistant cement is utilized in sites like canal linings, culverts, retaining walls, and siphons that are subjected to significant sulfate action by water and soil.

**VII. Blast Furnace Slag Cement**

Blast furnace slag cement is made by grinding clinkers with around 60% slag and has qualities that are similar to Portland cement. It can be utilized for projects when cost is a major consideration.

**VIII. High Alumina Cement**

High alumina cement is made by melting a bauxite-lime combination and mixing it with clinker. It's a quick-setting cement that takes around 3.5 and 5 hours for initial and final setting time, respectively. This cement has a higher compressive strength and is more workable than standard portland cement, making it ideal for projects involving high temperatures, frost, or acidic action.

**IX. White Cement**

It is made from iron oxide-free raw materials and is a white variant of conventional portland cement. It is more expensive and is used for architectural purposes such as precast curtain wall and facing panels, terrazzo surfaces, and interior and exterior decorative work such as building exterior renderings, facing slabs, floorings, ornamental concrete products, garden paths, swimming pools, and so on.

**X. Colored cement**

It's made by combining 5- 10% mineral pigments with regular cement. They're commonly employed for decorative floor work.

**XI. Air Entraining Cement**

During the grinding of clinker, air-entraining agents such as resins, glues, sodium salts of sulfates, and other indigenous air-entraining agents are added. This type of cement is particularly well suited to improving workability with a lower water-cement ratio and improving concrete's frost resistance.

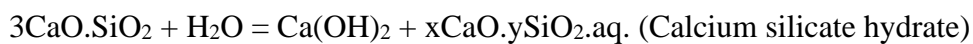
**XII. Expansive Cement**

Expansive cement expands slightly over time but does not shrink during or after the hardening process. Anchor bolts and prestressed concrete ducts are typically grouted using this cement.

### 2.2.2 Hydration of cement

Hydration is the term for the exothermic chemical processes that occur when anhydrous cement and water interact. In other words, silicates and aluminates develop hydration products in the presence of water, resulting in a stiff and hard mass - the hydrated cement paste - over time.

Cement-type compounds can react with water in two ways: first, there is a direct addition of water molecules, which is a real hydration process. The nature of the second sort of water reaction, hydrolysis, can be explained using the C<sub>3</sub>S hydration equation.



Different approaches can be used to determine the progress of cement hydration:

- ✓ The amount of Ca(OH)<sub>2</sub> can be measured from the results of hydration of silicates;
- ✓ The amount of Ca(OH)<sub>2</sub> can be measured from the results of silicate hydration;
- ✓ The paste's specific gravity;
- ✓ The amount of water that has been chemically mixed;
- ✓ The amount of unhydrated cement present (determined by XRD);
- ✓ Indirectly from the strength of the hydrated paste (Potgieter and Kaspar, 1999).

### 2.2.3 Environmental Effects of Cement Manufacturing

The cement sector contributes significantly to environmental pollution, according to data collected from European cement kiln emissions. The principal environmental pollutants generated by European cement kilns in tons per year are listed in Table 2-1.

**Table 2-1: Masses of emitted pollutants from the European cement kilns per year (Dunuweera and Rajapakse, 2018).**

Pollutant	Mass emitted (tons per year)
CO <sub>2</sub>	1.5456 million
CO	460–11500
SO <sub>2</sub>	Up to 11125
NO <sub>x</sub> as NO <sub>2</sub>	334–4670
Dust	0.62–522
TOC/VOC	2.17–267
HCl	0.046–46
HF	0.21–23.0
PCCD/PCDF	0.0000276–0.627 g per year

Total organic compounds, comprising volatile organic compounds, polychlorinated dibenzo-p-dioxins, and polychlorinated dibenzofurans, are represented by TOC/VOC, PCCD, and PCDF, respectively. Abiotic depletion, global warming, acidification, and marine ecotoxicity are having consequences of these environmental consequences (Dunuweera and Rajapakse, 2018). Cement is made from a variety of basic materials that have been handled and reacted under harsh circumstances such as high temperatures. The high-temperature processes are known as pyroprocessing procedures, and they use fuel sources such as coal, fuel oil, natural gas, tires, hazardous wastes, petroleum coke, and virtually anything combustible to heat raw materials to high temperatures for solid-state reaction to take place. Organic waste from other industries, such as rubber production, is used in some cement making plants. As a result, the cement sector is responsible for a considerable portion of anthropogenic carbon dioxide emissions, accounting for about 5–7% of total anthropogenic carbon dioxide emissions. In the clinker burning process, 1.52 tonnes of raw materials are utilized on average to generate 1 tonne of clinkers. Processes such as  $\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$  convert the remaining 0.52 tonne of raw materials primarily to carbon dioxide. Because an increase in carbon dioxide in the atmosphere has direct consequences on global warming, this is a severe worldwide environmental issue. Dust, other carbon oxides such carbon monoxide (CO), nitrogen oxides (NO<sub>x</sub>s), sulphur oxides (SO<sub>x</sub>s), polychlorinated dibenzo-p-dioxins, dibenzofurans, total organic carbon, metals, hydrogen chloride, and hydrogen fluoride, which are serious health-hazardous substances and some are hilariously odorous. The type and extent of air pollution created by the cement industry, on the other hand, is dependent on a number of factors, including inputs (raw materials and fuels used) and the sort of process used in the industry. Supplementary

cementitious materials such as coal fly ash, slag, and natural pozzolans such as rice husk ash and volcanic ashes are used in the manufacture of cement to reduce the amount of raw materials utilized. This will minimize not just the amount of trash that must be disposed of in landfills, but also the cost of cement manufacture (Dunuweera and Rajapakse, 2018).

### 2.3 Pozzolanas

According to ASTM C 618, a pozzolan is "a siliceous or asiliceous and aluminous material that has little or no cementitious value in itself but will chemically react with calcium hydroxide at ordinary temperature to form compounds with cementitious properties when finely divided and in the presence of moisture." Because of these properties, pozzolans are an excellent additive to Portland cement concrete mixtures.

The physical and chemical requirements of pozzolanic materials are outlined in ASTM C 618. Natural pozzolans (class N) and by-product materials are examples of pozzolanic materials. Volcanic ashes, diatomaceous earth, calcined clay, metakaoline clay, and rice hull ash are examples of natural pozzolans. The most common by-product material is fly ash, which is classed as either class F or class C, depending on its chemical composition and origin.

Pozzolanas' chemical composition has little bearing on how they behave. Their mineralogy, namely the ratio of crystalline to glassy phases, is more significant. The glassy structures are chemically active, while the crystalline phases are not. The characteristics of pozzolanic actions will be influenced by both of these structures.

**Table 2-2: Standard Specification of Class (N, F & C) Pozzolans according to ASTM C 618**

	Mineral Admixture Class		
	N	F	C
Silicon dioxide (SiO <sub>2</sub> ) plus aluminum oxide (Al <sub>2</sub> O <sub>3</sub> ) Plus iron oxide (Fe <sub>2</sub> O <sub>3</sub> ), min, %	70	70	50
Sulfur trioxide (SO <sub>3</sub> ), max, %	4	5	5
Moisture content, max, %	3	3	3
Loss on ignition, max, %	10	6.0 <sup>A</sup>	6

<sup>A</sup> The use of class F pozzolan containing up to 12.0 % loss on ignition maybe approved by the user if either acceptable performance records or laboratory test results are made available.

### **2.3.1 Pozzolanic materials**

Pozzolans were categorized by Ramezaniapour (2014) based on their origin:

- A. Natural Pozzolana and
- B. Artificial Pozzolana

### **2.3.2 Natural Pozzolanas**

The majority of naturally occurring pozzolan deposits are volcanic in origin. They are abundant in locations with a geological history of volcanic activity and can be found as tuffs, volcanic ash, and pumicite. Meaningful use of such volcanic debris can transform them into natural resources, and does not only provide a lower cost of cement and concrete but can also help to decrease CO<sub>2</sub> emissions related to Portland cement production by replacing clinker. In general, a good natural pozzolan has a low proportion of unreactive minerals such alkali feldspar and quartz and a high proportion of reactive minerals like zeolite minerals and volcanic glass. The alkaline cement pore solution dissolves the silicates, allowing them to react quickly as the cement hydrates. Natural pozzolans are mostly made up of silicon and aluminum oxides chemically.

The following are the materials that have been studied or even commercially employed as natural pozzolans in recent years:

- i. Pumice and Volcanic ash (VA)
- ii. Scorias
- iii. Tuffs
- iv. Diatomite
- v. Hydrothermal siliceous sinters
- vi. Bentonite
- vii. Perlite

### **2.3.3 Artificial Pozzolanas**

Artificial pozzolans are materials with low pozzolanic activity that require additional treatment to achieve pozzolanic activity; they emerge from chemical or structural alterations of materials that had no or relatively mild pozzolanic qualities at the start (Ramezaniapour, 2014). According to (Shetty, 2009), artificial pozzolans include:

- i. Blast furnace slag
- ii. Fly ash
- iii. Silica Fume
- iv. Matakaoline
- v. Rice Husk ash

## **2.4 Geology of Pumice Stone**

Pumice stone is defined as a volcanic rock consisting of bubbles or vesicles in a glass matrix generated by the effervescence of gases and rapid freezing of molten material after an eruption, according to (Doanld, 1992). Volcanic materials are referred to in a variety of ways, such as pyroclastic and tephra. These phrases refer to deposits that are either fractured or unconsolidated. Pumice stone is classified as extrusive, meaning it was created by the fast cooling of magma at the earth's surface (Assfawossen, 2006). As a result, pumice deposits are susceptible to weathering and the majority of pumice deposits are geologically young.

Volcanic ash and pumice are non-consolidated materials that are ejected during volcanic eruptions and consist of a mixture of minerals and glassy phases. The fine counterpart is volcanic ash, whereas the coarse counterpart is pumice. They are frequently found combined or interstratified because during volcanic eruptions, coarse material is deposited first, followed by finer material. Volcanic ashes and pumices have long been mixed with Portland cement and other ingredients to form blended cements. This material's pozzolanic action is linked to its siliceous components. Over the last few years, much research on the utilization of volcanic ash and pumice in cement and concrete production has been carried out.

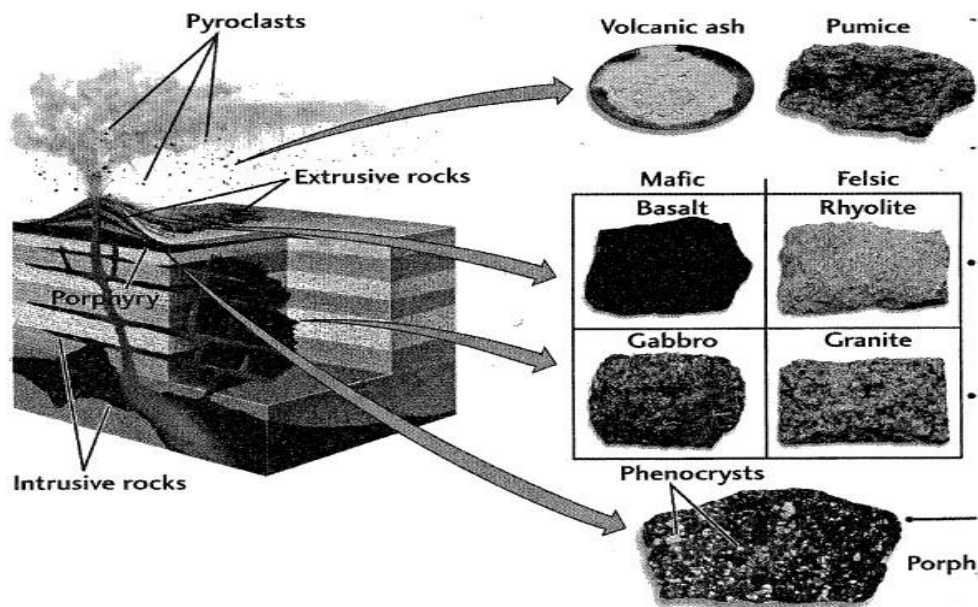
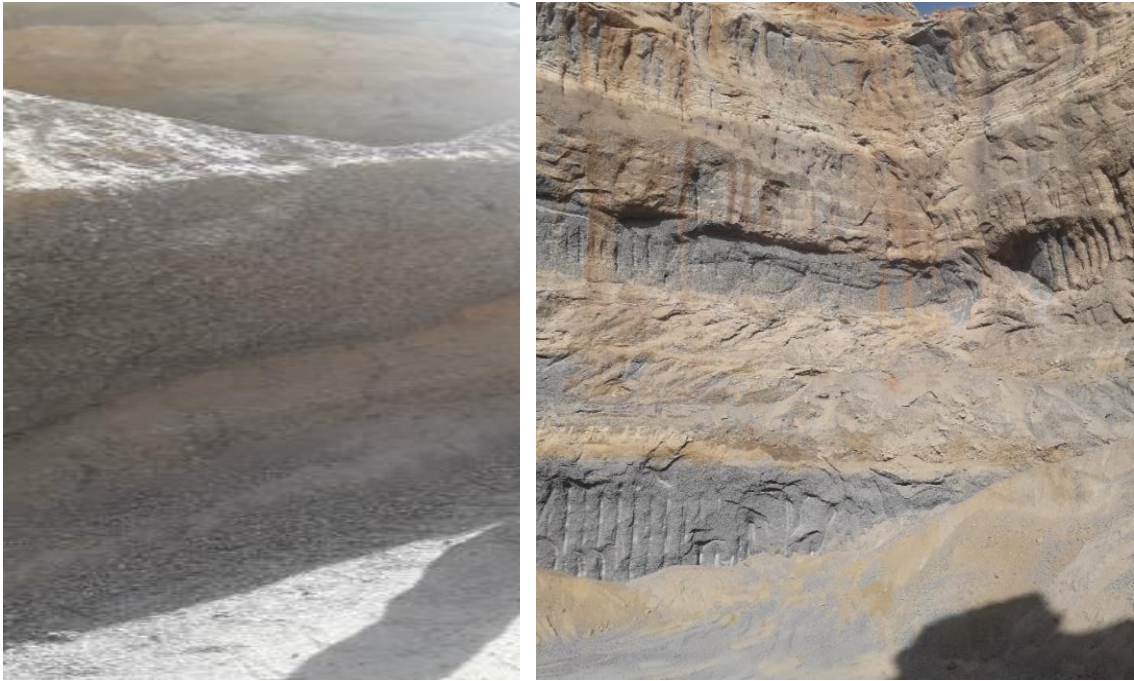


Figure 2-1: Volcanic formation of Pumice (Assfawossen, 2006)

Pumice deposits in Ethiopia are mostly found in the country's central and eastern regions. The location of the pumice map is included in Appendix G. The pumice deposits around Nazreth are described in a publication by (Taye, 2007). The pumice for this research was taken in the area around Melka Eida (Adama, Nazreth), as depicted in the Figure 2-1.



**Figure 2-2: Pumice deposits at Melka Eida, (Adama, Nazreth)**

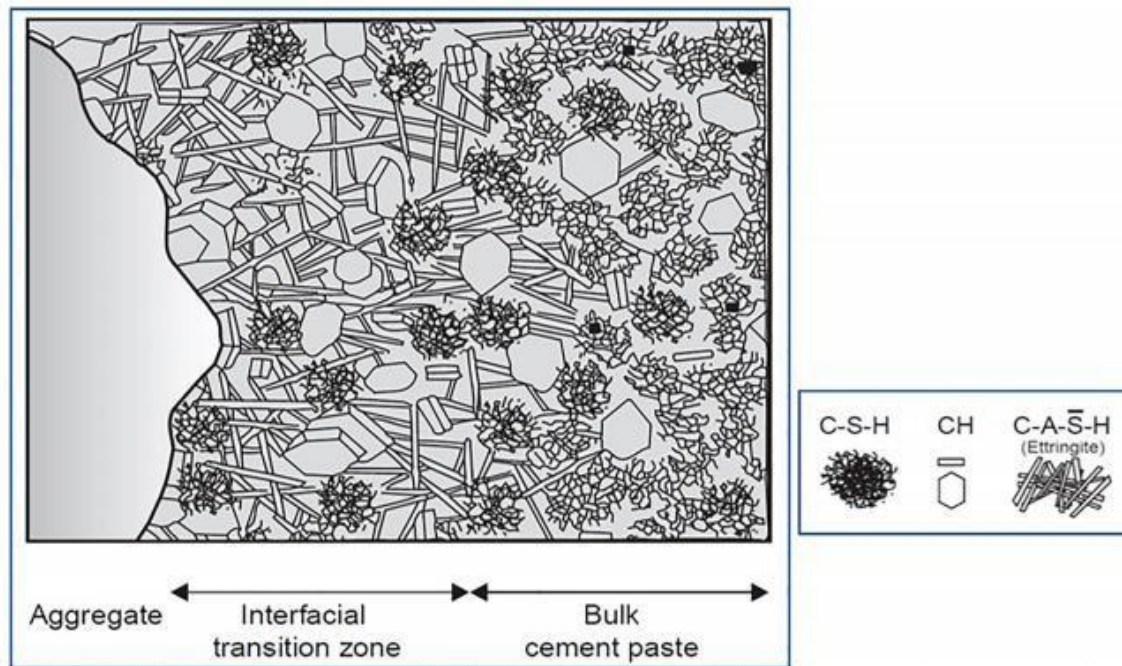
#### **2.4.1 Environmental impact of ground pumice**

Since ground pumice is used as a cement substitute, its environmental impact is directly proportional to the reduction in CO<sub>2</sub> emissions associated with cement manufacturing. The use of Portland cement in concrete has a significant impact on greenhouse gas emissions; cement producers account for around 7% of global man-made CO<sub>2</sub> emissions, which is why new rules and legislation are requiring reductions in greenhouse gas emissions. As a result, cement makers and concrete contractors are looking for alternatives, such as less CO<sub>2</sub>-intensive supplemental cementitious ingredients, to reduce their carbon footprint (Little, 2010). The use of ground pumice instead of cement will result in significant CO<sub>2</sub> reductions, paving the path for a more sustainable future.

#### **2.5 Interfacial transition zone (ITZ)**

Concrete is made up of a binding medium and aggregate particle. HCP (hardened cement paste), aggregate particles (coarse and fine), and the interfacial transition zone (ITZ) are all be modeled as a single mass in a concrete mix. but The interfacial transition zone (ITZ) between an aggregate and a cement matrix is known to be the weakest component of concrete (Liu et al., 2019). The cement paste's structure in the ITZ differs from the bulk paste's in terms of morphology, composition, and density. When compared to bulk-paste,

it contains less unhydrated cement, less C-S-H, larger calcium hydroxide crystals, higher ettringite concentration, and more porosity (lower density) (Hilal, 2015).



**Figure 2-3: Schematic diagram of ITZ in concrete (Hilal, 2015)**

When concrete is subjected to loads, microcracks may form initially in the 30-50  $\mu\text{m}$  thick ITZ due to its weakness, which results in the quasi-brittle nature of the concrete (Hilal, 2015).

## 2.6 Analysis of cementitious materials using XRD

XRD is an effective method for determining the chemical compositions of a samples. It is a strong tool to investigation of crystalline materials. The Rietveld refining process currently allows for a high degree of precision in determining the amounts of distinct phases in anhydrous cementitious materials (Scrivener et al., 2004).

The principle of XRD is based on the notion that high-energy accelerated electrons displace electrons from an atom's inner electron shells (e.g., K shells). This high energy, released from irradiating elements, so called X-rays (Wu et al., 2017).

By assessing peak positions and relative pattern intensities, the XRD pattern permits the investigation of cement hydration products at various curing ages and with various materials additions. Because peak intensity is proportional to weight fraction, quantitative

phase analysis (QPA) can also be used to measure the concentration of (hydrated) cement phases (Silva et al., 2020). A pattern of peaks at separate diffraction corners of varying intensities is produced by X-ray diffraction by a crystalline substance. The symmetry and size of unit cell crystalline material determine the diffraction angle or position of the peaks, while the nature and placement of the atoms in the unit cell of the material dictate the intensities of the peaks.

A pattern of peaks at separate diffraction corners of varying intensities is produced by X-ray diffraction by a crystalline substance. The diffraction angle or position of the peaks is determined through the law of Bragg's law ( $2d\sin\theta = n\lambda$ , where  $d$  = interplanar spacing,  $\theta$  = angle of incidence/Bragg's angle,  $n$  = order of reflection and  $\lambda$  = wave length of the X-ray source) 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 (Scrivener et al., 2016).

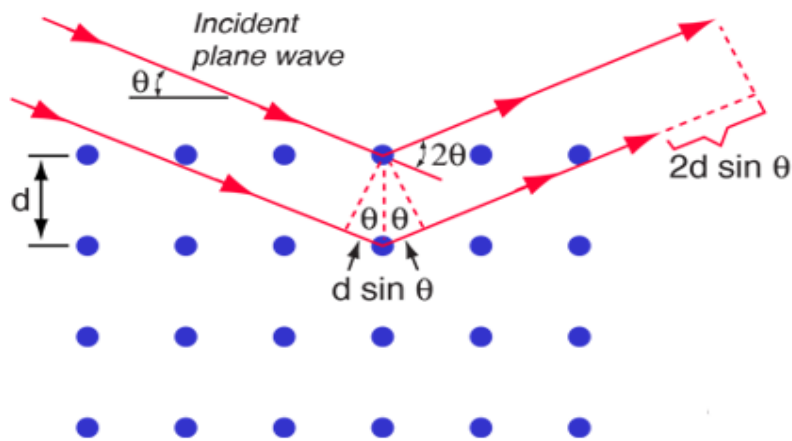


Figure 2-4: Bragg's Law

## 2.7 Abundance of Pumice in Ethiopia

According to Ethiopia's industrial mineral occurrence map, there are a number of main areas where pumice can be found in abundance. For further information, the map is attached in APPENDIX G.

## CHAPTER 3 MATERIALS AND PROPERTIES

The materials employed in this study properties, type and qualities are discussed in this chapter. The materials are prepared and tested at Addis Ababa Institute of Technology's Construction Material Laboratory. The XRD results brought from the College of Natural and Computational Science at Addis Ababa University, while the entire silicate analysis brought from the Ethiopian Geological Survey. Moreover, the material results are checked with the various standards to see the fulfillments of their requirement's.

### 3.1 Cement

Cement is a finely crushed substance that, while not a binder in and of itself, develops the ability to bind when exposed to water (i.e., from chemical reactions between cement minerals and water). When the hydration products in a cement remain stable in an aqueous environment, the cement is referred to as hydraulic. Portland cement, which is mostly made up of hydraulic calcium silicates, is the most extensively used hydraulic cement for concrete production. The calcium silicate hydrates generated during the hydration of Portland cement are principally responsible for its adhesive properties and are aqueous stable (Mehta and Monteiro, 2005). The cement utilized in this study is a Dangote brand Ordinary Portland Cement (OPC).

### 3.2 Ground Pumice

The pumice material utilized in this experiment is taken from Melka Eida, Adama (Nazreth). That pumice is first dried in the oven till all the moisture has been dried out. Then it subjected to the LAA machine and converted to powder once. After that, the powder is sieved through a 0.075mm sieve. The material that passes through the chosen sieve is utilized to partially replacement of OPC.

The physical and chemical properties of ground pumice and cement are presented in Table:3.1. APPENDIX F contains the complete chemical analysis of cement and ground pumice results obtained from Geological Survey of Ethiopia.

Since the chemical composition of volcanic pumice is known, a silicate analysis was performed to determine the oxide composition. The most common oxides found in

pozzolanic materials are  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ , and  $\text{Fe}_2\text{O}_3$ . As a result, pozzolanic materials are classified based on their existence and amount. According to ASTM C 618, the volcanic pumice employed in this study has 88.49% significant oxides as shown in the table below, making it a class N pozzolanic supplemental cementitious material. Furthermore, particle size distribution of pumice powder is determined by hydrometer analysis and Sieve analysis. The hydrometer analysis is based on Stokes' law, which is used to calculate a falling sphere's terminal velocity in a liquid. This method depends upon variations in the density of suspended particles contained in a 1000ml graduated cylinder. The density of suspension is estimated using a hydrometer at predetermined time intervals, and the coarsest diameter of suspended particles at a given time, as well as the proportion of particles finer than the coarsest suspended particle diameter, are computed (Murthy, 2002). The hydrometer analysis test and steps are carried out in accordance with the guidelines of (ASTM D422, 2007). The PSD curve of ground pumice is presented in Figure 3-1. The hydrometer and sieve analysis results of Cement and ground pumice is attached in APPENDIX C3.

**Table 3-1: Chemical and physical properties of cement and Ground Pumice**

Chemical Composition	Cement %	Ground Pumice %
$\text{SiO}_2$	26.18	73.06
$\text{Al}_2\text{O}_3$	7.16	9.65
$\text{Fe}_2\text{O}_3$	3.44	5.78
CaO	60.34	<0.01
MgO	1.14	0.06
$\text{Na}_2\text{O}$	0.48	1.50
$\text{K}_2\text{O}$	<0.01	2.60
MnO	<0.01	<0.01
$\text{P}_2\text{O}_5$	0.20	0.10
$\text{TiO}_2$	0.12	0.05
$\text{H}_2\text{O}$	0.71	01.14
LOI	0.04	5.97
Blaine fineness ( $\text{m}^2/\text{kg}$ )	351	392
Specific gravity	3.15	2.24
Physical form	Fine powder	Fine Powder
Color	Grey	Light grey

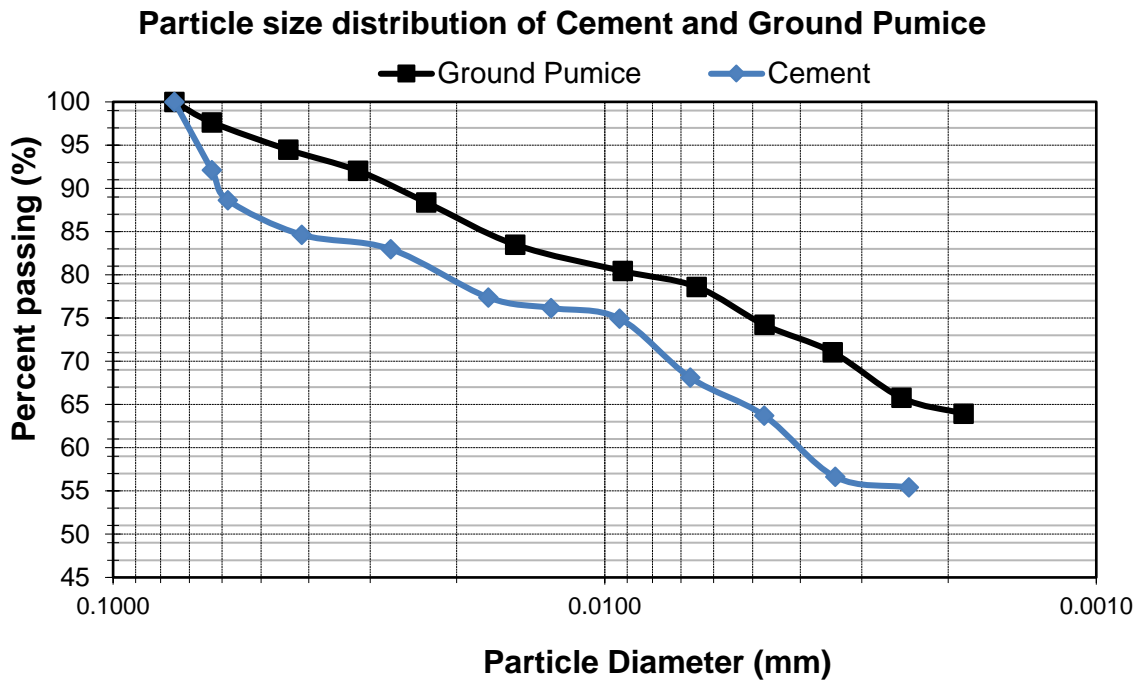


Figure 3-1: PSD of Ground pumice and Cement using sieve and hydrometer analysis

### 3.3 Coarse Aggregate

Aggregate particles larger than 4.75 mm (No. 4 sieve) are referred to as coarse aggregate. The coarse aggregate utilized in this study has a nominal size of 25mm, crushed basaltic and is graded according to the requirements of (ASTM C33, 2018).

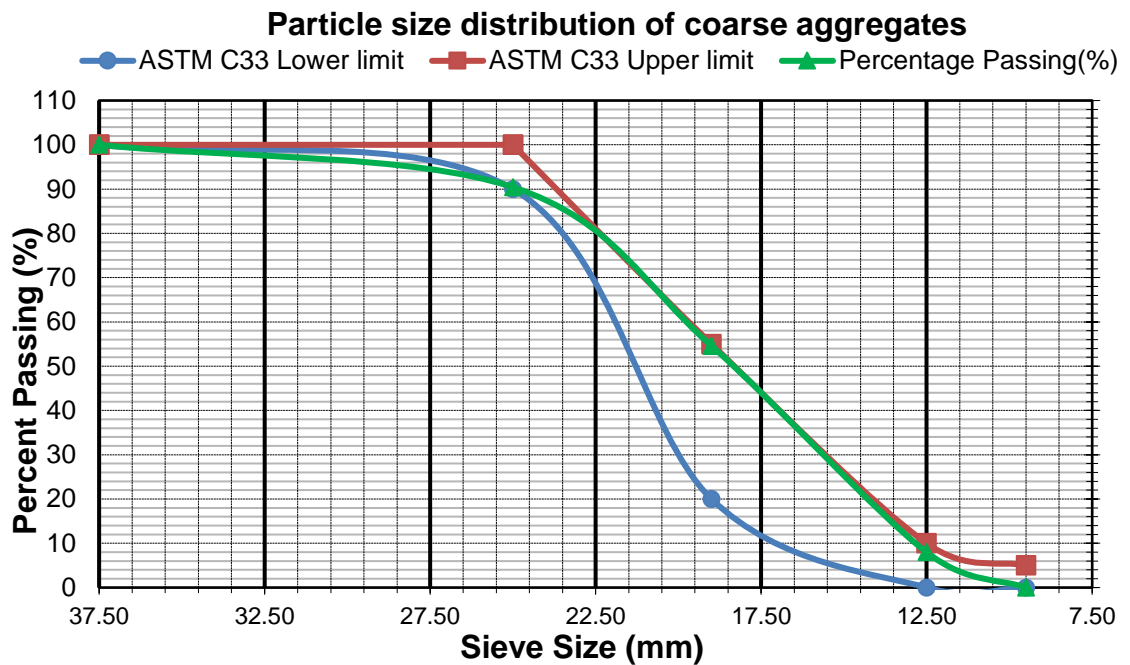
The coarse aggregates' PSD, weighted absorption capacity, weighted moisture content, and basic characteristics are shown in the table below.

Table 3-2: The basic properties of coarse aggregates

No.	Test description	Test result	
1.	Nominal size	25mm	
2.	Moisture content	0.54%	
3.	Absorption capacity	0.73%	
4.	Unit weight	1623.7Kg/m <sup>3</sup>	
5.	Specific gravity	Bulk	2.65
		Bulk (SSD)	2.67
		Apparent	2.70

**Table 3-3: The PSD of coarse aggregates**

Sieve size (mm)	Percent passing (%)	ASTM C 33 Standard passing range (%)
37.5	100	100
25	90.438	90-100
19	54.582	40-85
12.5	7.968	10-40
9.5	0	0-15
4.75	0	0-5
Pan	0	0



**Figure 3-2: The PSD curve of coarse aggregates**

### 3.4 Fine aggregate

Fine aggregate refers to aggregate particles that are less than 4.75 mm in diameter but more than 0.075 m in diameter (No. 200 sieve). Natural sand was used as the fine aggregate in this experiment. The mass of this sand was washed to eliminate extra silt.

The PSD and the basic properties of fine aggregates are presented below.

**Table 3-4: The basic properties of fine aggregates**

No.	Test description	Test result	
1.	Silt content	2.12%	
2.	Moisture content	5.78%	
3.	Absorption capacity	3.96%	
4.	Finesse modulus	2.87%	
5.	Unit weight	1569.9Kg/m <sup>3</sup>	
6.	Specific gravity	Bulk	2.41
		Bulk (SSD)	2.51
		Apparent	2.67

**Table 3-5: The PSD of fine aggregates**

Sieve size (mm)	Percent passing (%)	ASTM C 33 Standard passing range (%)
9.5	100	100
4.75	99.9	95-100
2.36	89.5	80-100
1.18	67.0	55-85
0.60	37.0	25-60
0.30	14.9	5-30
0.15	4.2	0-10
Pan	0	0

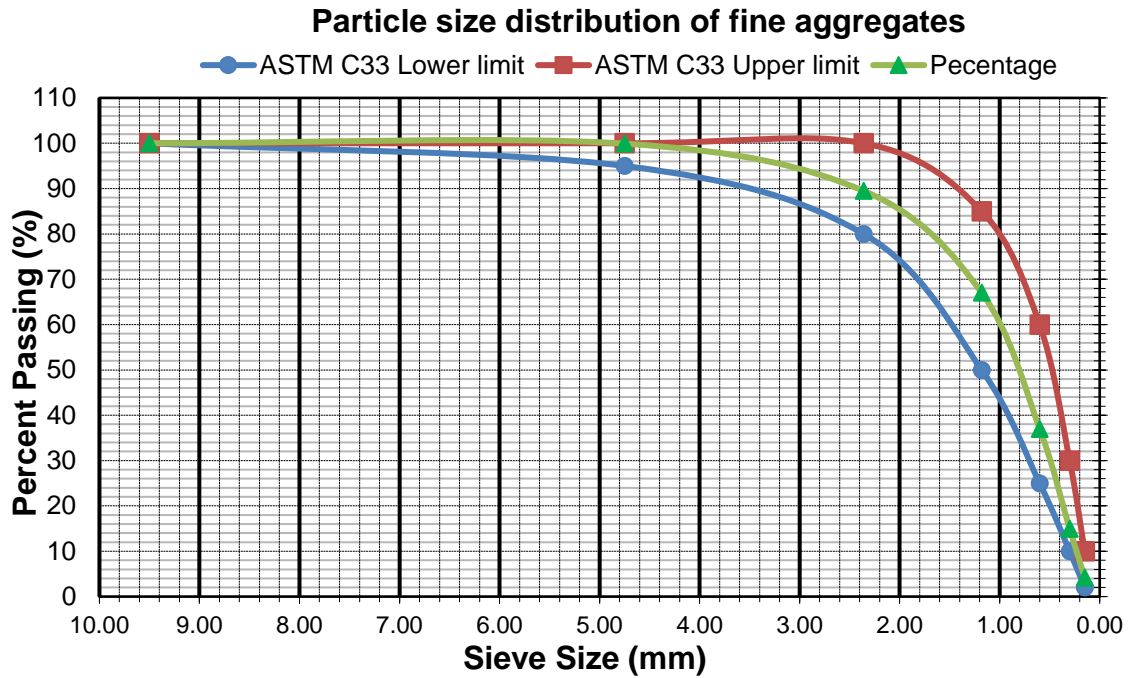


Figure 3-3: The PSD curve of fine aggregates

### 3.5 Water

The water utilized in this study was underground water at the Addis Ababa Institute of Technology's Construction Material Laboratory.

## **CHAPTER 4      EXPERIMENTAL PROGRAM**

The major goal of this study is to conduct an experiment to see how ground pumice affects the compressive and tensile strength of normal concrete. Except for the XRD and silicate analysis of cement and pumice, all experimental programs for this study are carried out in the Construction Material Laboratory at Addis Ababa Institute of Technology.

### **4.1 Test types and specimens**

Concrete testing is the subject of this study. Concrete samples were tested both fresh and hardened. Compressive machines and UTM were used to examine the characteristics of hardened concrete, whereas slump tests were employed to see how fresh concrete behaved. Compression testing were performed on a 15cm x 15cm x 15cm concrete cube, and splitting tensile strength tests were performed on a 15cm x 30cm concrete cylinder. A total of 168 samples have been tested.

### **4.2 Mix design**

The process of determining the proper quantities of coarse aggregate, fine aggregate, water, and cement for a predetermined concrete strength is known as mix design. Despite the fact that there are numerous papers and criteria for establishing mix design, the right mix design can only be mastered via repeated trial mixes and following the correct path, which results in a continuous error reduction when compared to the expected outcome. Material property changes between locations could be the main reason of the iteration. For this experiment, I used mix design processes to produce the required characteristic compressive strength of 30 MPa. I used the (ACI 211-2) mix design procedure as shown APPENDIX - I, which provided me specified compressive strengths that were quite close to the required after trials.

### **4.3 Experiments**

The mixer was used to mix all of the concretes in the laboratory. After adding the coarse aggregate, cement, and fine aggregate respectively to the mixer, then we made dry mixed for about one minute. Two-thirds of water was added, and the mixing was continued for

one minute more. After that, the remaining water is added, and the entire process takes three minutes. Slump tests of freshly mixed concrete were performed shortly after mixing to ensure consistency and workability. Finally, the concrete was vibrated for 30 seconds after being placed in 15cm x 15cm x 15cm cube molds and 15cm x 30cm cylinder. The cubes were removed from their molds after 24 hours and placed in a water tank to cure.

#### 4.3.1 Experiment 1

The goal of this experiment is to create strength-controlled parent concretes. A single mix was used to make 12 cubes and 12 cylinders. These cubes and cylinders were crushed after 3, 7, 28, and 56 days of curing to determine their compressive and tensile strength.

#### 4.3.2 Experiment 2

The aim of this experiment is to compare the compressive strengths of various percentages of powdered pumice concrete to control concrete. Ground pumice was utilized to replace cement in proportions of 5, 10, 15, 20, 25, and 30%, respectively.

Table 4-1 show the notations for concrete mixtures in the concrete series for easy reference. The mix proportions are attached at APPENDIX D.

**Table 4-1: Sample Code for mixtures, Code expansion, mix design, and series**

Notation	Expansion of notation
P0D3	Concrete containing 0% pumice 3 days curing period
P5D3	Concrete containing 5% pumice 3 days curing period
P10D3	Concrete containing 10% pumice 3 days curing period
P15D3	Concrete containing 15% pumice 3 days curing period
P20D3	Concrete containing 20% pumice 3 days curing period
P25D3	Concrete containing 25% pumice 3 days curing period
P30D3	Concrete containing 30% pumice 3 days curing period
P0D7	Concrete containing 0% pumice 7 days curing period
P5D7	Concrete containing 5% pumice 7 days curing period
P10D7	Concrete containing 10% pumice 7 days curing period
P15D7	Concrete containing 15% pumice 7 days curing period
P20D7	Concrete containing 20% pumice 7 days curing period
P25D7	Concrete containing 25% pumice 7 days curing period
P30D7	Concrete containing 30% pumice 7 days curing period
P0D28	Concrete containing 0% pumice 28 days curing period
P5D28	Concrete containing 5% pumice 28 days curing period
P10D28	Concrete containing 10% pumice 28 days curing period
P15D28	Concrete containing 15% pumice 28 days curing period
P20D28	Concrete containing 20% pumice 28 days curing period

P25D28	Concrete containing 25% pumice 28 days curing period
P30D28	Concrete containing 30% pumice 28 days curing period
P0D56	Concrete containing 0% pumice 56 days curing period
P5D56	Concrete containing 5% pumice 56 days curing period
P10D56	Concrete containing 10% pumice 56 days curing period
P15D56	Concrete containing 15% pumice 56 days curing period
P20D56	Concrete containing 20% pumice 56 days curing period
P25D56	Concrete containing 25% pumice 56 days curing period
P30D56	Concrete containing 30% pumice 56 days curing period

## CHAPTER 5 RESULTS AND DISCUSSION

The test results of the experimental programs are presented and discussed in this chapter.

### 5.1 Test on fresh concrete

#### 5.1.1 Slump test

Slump testing is used to determine the consistency and workability of concrete. The results of all of the experiments' slump tests are shown below.

##### 5.1.1.1 Experiment slump test results

To assess the workability of ground pumice concrete, a consistency test was performed prior to the slump test. As a result, the water-to-cement ratio of the regular mix with ground pumice was 0.31 and 0.27, respectively. When compared to the control mix, concrete with ground pumice has a lower workability for the same amount of water. However, because the consistency findings are so near, there is no need to apply admixture.

Table 5-1 shows the slump test results for the specimens under investigation. The results show that as the ground pumice replacement percentage increases, the workability of the mixtures decreases. This is supported by the consistency test as well as the previous points.

**Table 5-1: Slump test results for this experiment**

Sample Code	P0	P5	P10	P15	P20	P25	P30
Slump (mm)	75	65	55	55	50	45	40

The workability of concrete containing ground pumice as cement replacement declines with an increase in ground pumice content. Pozzolanic materials (pumice, fly ash, and slag) are characterized by unburned carbon, increased fineness, and a rough porous structured surface texture. It is well known that materials with a higher percentage of unburned carbon, fineness, and a rough porous structured surface texture require more water to be wet (Aïtcin, 2016).

## 5.2 Test on hardened concrete

### 5.2.1 Compressive strength

For different replacement amounts of grounded pumice, the compressive strength of cubic specimens was tested at different days of curing. The specimens were cured for 3, 7, 28, and 56 days, respectively. Figure 5-1 depicts the compressive strength of the specimens at various curing days.

When we see Figure 5-1, The average compressive strength of concrete containing 10% Ground Pumice as a cement replacement is highest, as shown by the results. The 28th-day average compressive strength increases by 8.1%, 12%, and 6% for 5%, 10%, and 15% Ground Pumice replacements, respectively, but declines by 3.9%, 16.9%, and 17.5% for 20%, 25 percent, and 30% Ground Pumice replacements. Furthermore, for 5%, 10%, and 15% Ground Pumice replacements, the 56th-day average compressive strength increased by 5.4%, 8.7%, and 1%, respectively. However, for 20%, 25%, and 30% Ground Pumice replacements, the 28th and 56th-day average compressive strength decreased.

But when we see the average compressive strength of P0D28 (40.17 MPa) and P20D28 (38.59 MPa) do not appear to differ much, so they need ‘hypothesis testing’.

**Table 5-2: Mean, Standard Deviation and Variances of P0D28 and P20D28**

No	P0D28	P20D28
1	39.94	37.95
2	39.47	38.97
3	41.11	38.86
Sum	120.52	115.78
Mean(average) ( $\bar{X}$ )	40.17	38.59
Standard deviation (S)	0.845	0.560
Variance ( $S^2$ )	0.714	0.314
Covariance (X, Y)	0.067	
Correlation (X, Y)	0.302	

#### A) Hypothesis Test using t – Distribution

Here  $N_{P0} = 3$ ,  $S_{P0} = 0.845$ ,  $\bar{X}_{P0} = 40.17$ ,  $N_{P20} = 3$ ,  $S_{P20} = 0.56$  and  $\bar{X}_{P20} = 38.59$

Here null hypothesis  $H_0: \sigma^2_{P0} = \sigma^2_{P20}$

The alternative hypothesis  $H_a: \sigma^2_{P0} \neq \sigma^2_{P20}$

Level of significance  $\alpha = 0.05$

The critical for rejection of null hypothesis is  $p - \text{value} > \alpha$

Where  $p - \text{value}$  is the value for  $t$ , degree of freedom (DoF) and  $\alpha/2 = 0.025$  and  $\alpha = 0.05$  respectively.

$$\begin{aligned}\text{Now, DoF} &= (S^2_{P0}/N_{P0} + S^2_{P20}/N_{P20}) / ((S^2_{P0}/N_{P0})^2 / N_{P0} - 1) + (S^2_{P20}/N_{P20})^2 / N_{P20} - 1) \\ &= (0.845^2/3 + 0.56^2/3) / (((0.845^2/3)^2/3-1) + ((0.56^2/3)^2/3-1)) \\ &= 3.5\end{aligned}$$

$$S_e = \text{Sqr} (S^2_{P0}/N_{P0} + S^2_{P20}/N_{P20}) = \text{Sqr} (0.845^2/3 + 0.56^2/3) = 0.5853$$

$$t = (\bar{X}_{P0} - \bar{X}_{P20}) / S_e = (40.17 - 38.59) / 0.5853 = 2.699$$

So, using  $t = 2.699$ ,  $\text{DoF} = 3.5$  and  $\alpha/2 = 0.025$  can be get  $p - \text{value}$  which is 0.06308.

Decision: - Fail to reject the null hypothesis

Reason: -  $p - \text{value} > \alpha$ , i.e.  $(0.06308 > 0.05)$

Conclusion: - There is not sufficient evidence to conclude there is a difference between mean compressive strength of P0D28 and P20D28.

#### B) Covariance and correlation

Here  $N_{P0} = 3$ ,  $S_{P0} = 0.845$ ,  $\bar{X}_{P0} = 40.17$ ,  $N_{P20} = 3$ ,  $S_{P20} = 0.56$  and  $\bar{X}_{P20} = 38.59$

$$\text{Cov} (X, Y) = \sum((X - \bar{X})(Y - \bar{Y})) / N - 1 = 0.067$$

$$\text{Corr} (X, Y) = \text{Cov} (X, Y) / ((X - \bar{X})^2 (Y - \bar{Y})^2) = 0.302$$

Decision: - Have a positive correlation

Reason: - correlation of covariance has positive value (+0.302)

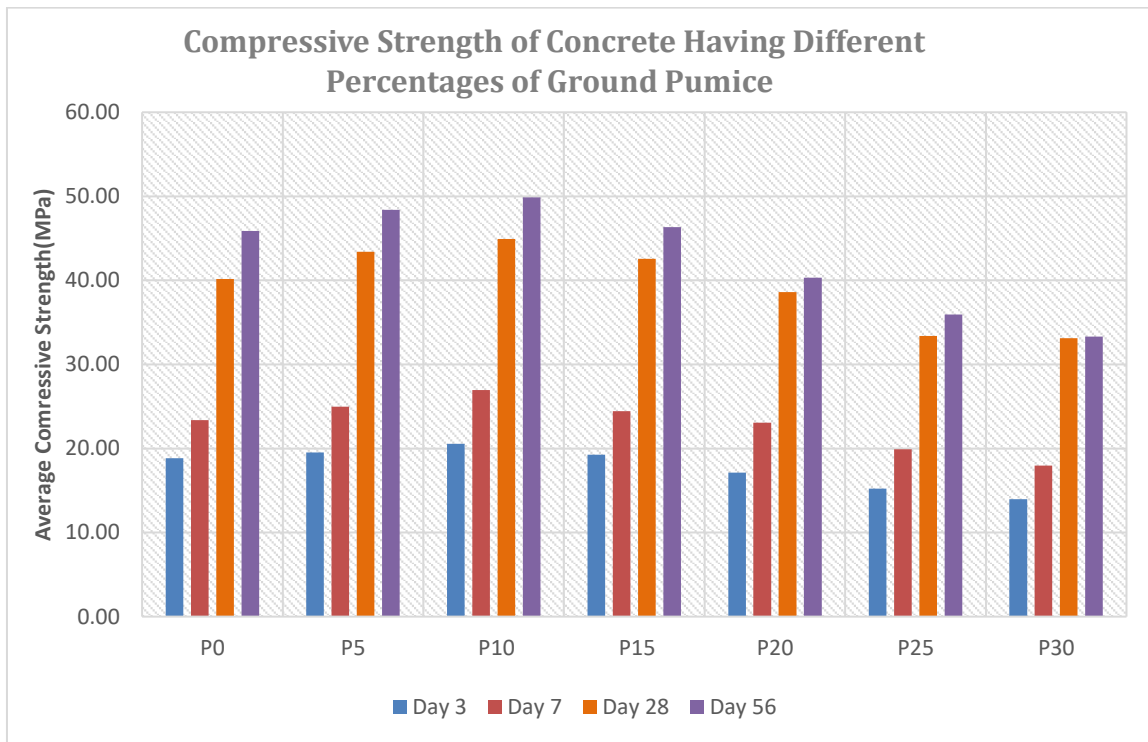
Conclusion: - Compressive strength of P0D28 and P20D28 have almost same strength character.

From the hypothesis test and covariance correlation result can be concluded that 20% of replacement also has a positive significance in replacement of OPC based on economy.

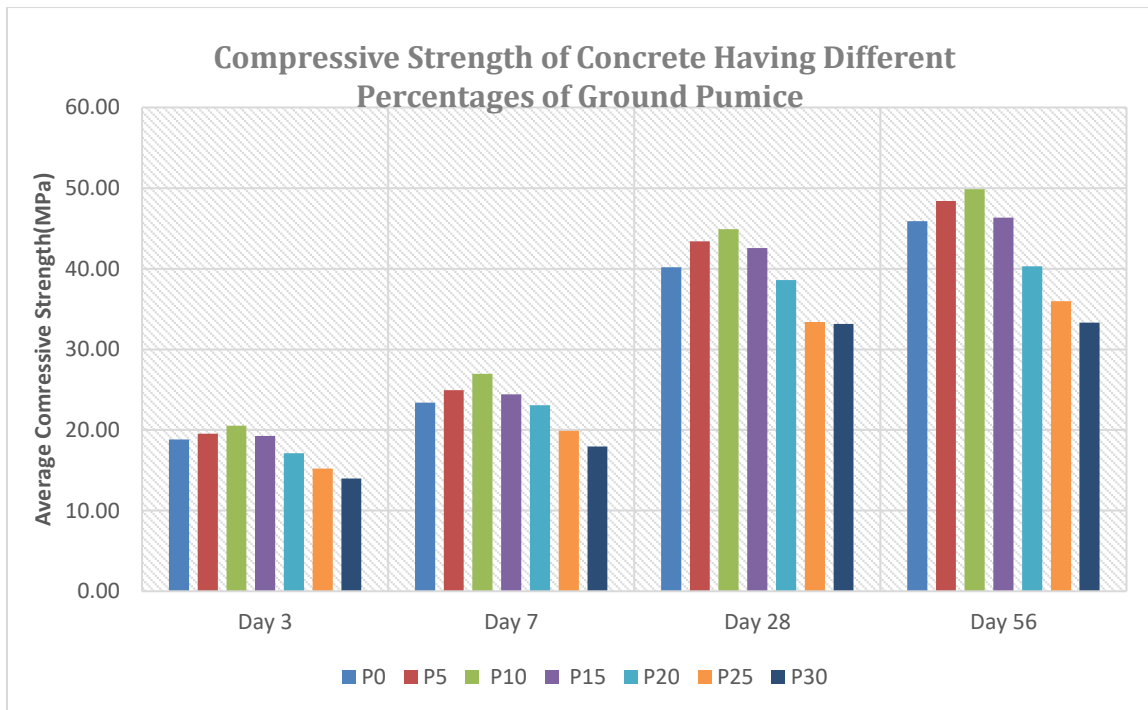
There are a variety of reasons for the increased strength that can be achieved by adding ground pumice. According to various researches, the presence of SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> favors the formation of extra C-S-H and C-A-H by reacting with portlandite and generating a denser matrix, resulting in an improvement in strength.

**Table 5-3: Average compressive strength of concrete produced**

Sample Code	Average compressive strength (MPa)			
	Day 3	Day 7	Day 28	Day 56
P0	18.84	23.37	40.17	45.88
P5	19.53	24.96	43.41	48.39
P10	20.55	26.96	44.92	49.88
P15	19.25	24.44	42.58	46.34
P20	17.13	23.08	38.59	40.32
P25	15.22	19.91	33.38	35.96
P30	13.98	17.97	33.14	33.32



(a)



(b)

**Figure 5-1: Variation of average compressive strength of concrete with (a) amount of ground pumice percentage (b) curing days.**

As a result, ground pumice can be used to replace Ordinary Portland cement at replacement levels of 5%, 10%, 15% and 20% without losing strength. The ideal replacement level for higher compressive strength is 10%, while other replacement levels such as 5%, 15% and 20% are also possible.

### 5.2.2 Splitting Tensile Strength

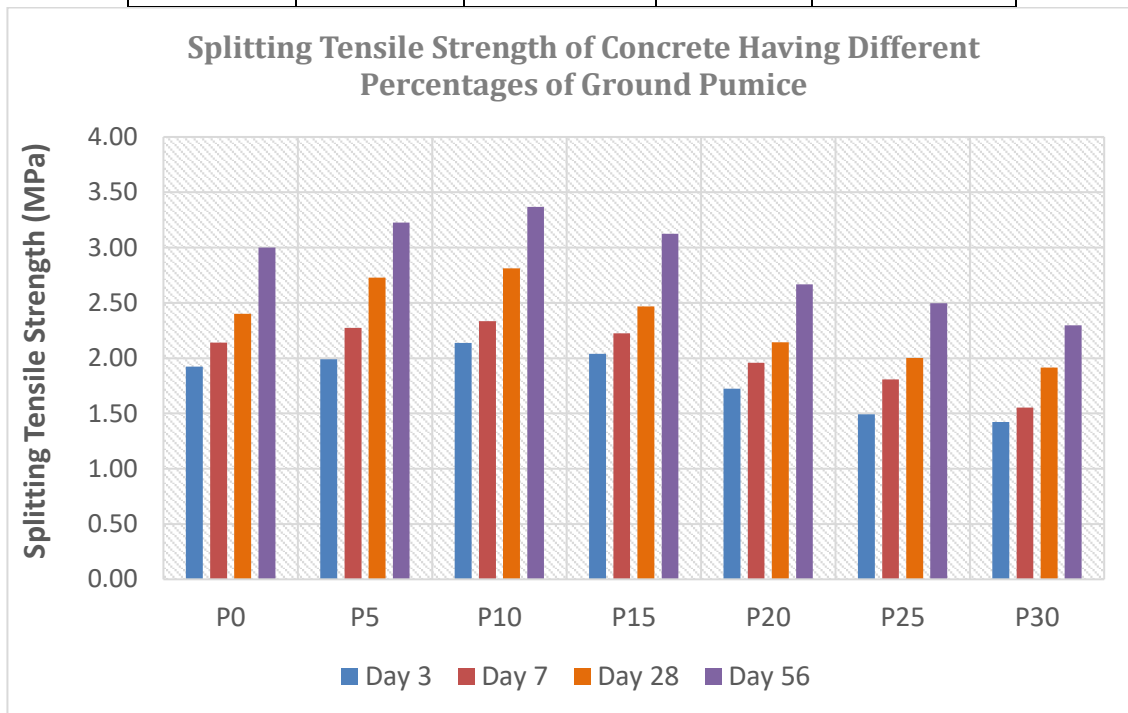
For varied replacement levels of grounded pumice, the splitting tensile strength of cylindrical specimens was tested at different days of curing. The specimens were cured for 3, 7, 28, and 56 days, respectively. The splitting tensile strength of the specimens at various curing days is shown in Figure 5-2.

The results show that concrete containing 10% Ground Pumice as a cement substitute had the highest average splitting tensile strength. The 28th-day average splitting tensile strength increases by 13.8%, 17.1%, and 2.9% for 5%, 10%, and 15% Ground Pumice replacements, respectively, but drops by 10.7%, 11.3%, and 15% for 20%, 25%, and 30% Ground Pumice replacements respectively. Furthermore, with 5%, 10%, and 15% Ground Pumice replacements, the 56th-day average splitting tensile strength increased by 7.7%,

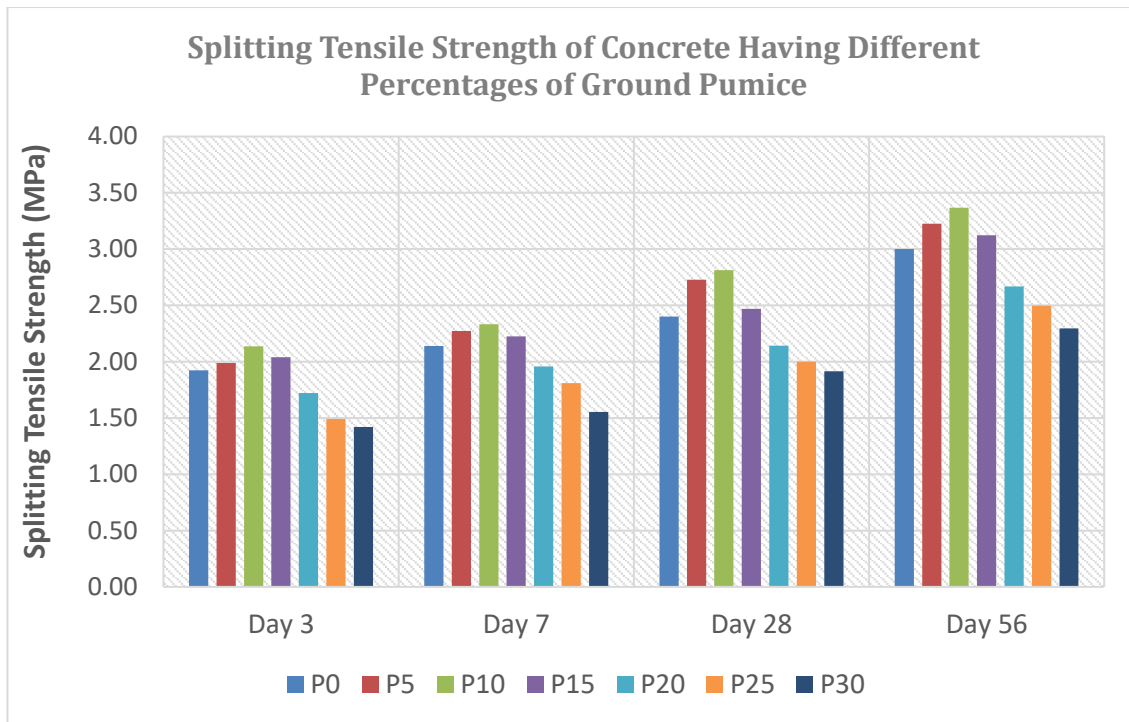
7.7%, and 4%, respectively. Ground Pumice's average splitting tensile strength declined for 20%, 25%, and 30% at the 28th and 56th days.

**Table 5-4: Average Splitting Tensile strength of concrete produced**

Sample Code	Average Splitting Tensile strength (MPa)			
	Day 3	Day 7	Day 28	Day 56
P0	1.92	2.14	2.40	3.00
P5	1.99	2.27	2.73	3.23
P10	2.14	2.33	2.81	3.37
P15	2.04	2.22	2.47	3.12
P20	1.72	1.96	2.14	2.67
P25	1.49	1.81	2.00	2.50
P30	1.42	1.55	1.92	2.30



(a)



(b)

**Figure 5-2: Variation of average splitting tensile strength of concrete with (a) amount of ground pumice percentage (b) curing days.**

## CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS

### 6.1 Conclusions

The effects of ground pumice on the compressive and splitting tensile strengths of normal concrete were explored in this research. The powdered pumice used in this experiment was prepared from laboratory smashing pumice using the LAA machine.

The following conclusions and recommendation were drawn from a laboratory study that looked at the effect of adding ground pumice to normal concrete's compressive and tensile strength:

- With an increase in ground pumice content, the workability of concrete incorporating it as a cement replacement declines.
- The use of an appropriate amount of ground pumice as a cement replacement increases the compressive strength of normal concrete.
- The ground pumice used as a cement replacement enhances the splitting tensile strength of concrete.
- The performance of normal concrete incorporating ground pumice has been evaluated at various replacement amounts. When compared to a control group and an experimental group, the use of grounded pumice resulted in higher compressive strength. The 10% replacement level with a 12% increase in comparison of the control mix yielded the maximum compressive strength so that it is an optimal strength replacement level. Other degrees of replacement up to 20% will improve the compressive strength of normal concrete. As a result, grounded pumice can replace up to 20% of the cement in normal concrete while having little effect on physical properties like density and workability.
- The impact of replacing cement with ground pumice performance in terms of splitting tensile strength has also been determined. What has been discovered is that adding grounded pumice to normal concrete increases its splitting tensile strength. At a replacement level of 10%, the strongest gain in strength was recorded, the increase in strength was found to be 17.1% so that it is an optimal strength replacement level. With replacement levels up to 20% can be used ground pumice in normal concrete.
- Concretes containing ground pumice had slightly lower weights than the control.
- Other uses that can be considered are the partial replacement of cement with ground pumice the added benefit of enhancing the strength of the cement production, as well as the reduction of environmental consequences by cement bulk manufacture.

- LAA machine can be used for the preparations of ground pumice with the best achievement level of the appropriate fineness.

## 6.2 Recommendations

It is well known that construction material innovation has been increasing from the beginning of mankind's desire to modify nature for his own consumption. Consideration of value for money and environmental implications have been goals in this process. The addition of SCMs to concrete has allowed the industry to address environmental issues while also generating a cost-effective building material.

In normal concrete:

- Ground pumice can partially replace OPC in normal cement concrete, with the added benefit of increased strength.
- Grounded pumice can be used to partially replace OPC in normal cement concrete, up to 15%, without affecting the physical properties of the concrete.
- Incorporating grounded pumice into normal concrete manufacturing is environmentally friendly, however a thorough environmental impact analysis is required.

The work can be expanded to include the following items based on this research and other comparable studies conducted in this area:

- Use of ground pumice as cement replacement in high strength concrete.
- Thermal behavior of concrete with ground pumice as cement replacement
- Shrinkage, durability, and creep properties of concrete with ground pumice as cement replacement.
- A comprehensive environmental and economic research of concrete with ground pumice as a cement substitute.
- SEM and XRD microstructural studies to characterize ground pumice from additional Ethiopian sources, as well as a detailed analysis of the ITZ incorporating ground pumice as a cement replacement

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APPENDIX

APPENDIX A: - Tests on Fine Aggregate

A.1 Sand Sieve Analysis

No	Sieve size(mm)	Weight of Sieve (gm)	Wt. of Sieve & Retained (%)	Weight of Retained (%)	Percentage Retained (%)	Cumulative Coarser (%)	Cumulative Passing (%)	Percentage Passing (%)
1	9.50mm		0	0	0	0	100	100
2	4.75mm	426.3	426.9	0.6	0.08	0.08	99.92	95-100
3	2.36mm	387.5	465.2	77.7	10.42	10.50	89.50	80-100
4	1.18mm	525.5	693	167.5	22.47	32.97	67.03	50-85
5	600µm	324.5	548.3	223.8	30.02	62.99	37.01	25-60
6	300µm	303.5	468.1	164.6	22.08	85.07	14.93	10.-30
7	150µm	274.6	354.4	79.8	10.70	95.77	4.23	2.-10
8	Pan	416.7	448.2	31.5	4.23	100.00	0	
Total						287.39		
FM						2.87		

A.2 Specific Gravity and Absorption of Fine Aggregates

Description	Test 1	Test 2	Average
Pycnometer No.	1	2	
Temperature of Water ( °C)	24	24	
[A] Mass of Oven Dry Sample in Air (g)	480.7	481.2	
[B] Mass of Saturated Surface Dry (SSD) in air (g)	500	500	
[C] Mass of Flask + Water (g)	734.1	734.1	
[D] Mass of Flask + Water + Sample (g)	1033.5	1036.7	
Absorption (%) = ((B - A) / A) *100	4.01	3.91	3.96
Apparent Specific Gravity = ((A/(A-(D-C))) *K	2.65	2.69	2.67
Bulk Specific Gravity (Oven Dry) = ((A/(B-(D-C))) *K	2.39	2.43	2.41
Bulk Specific Gravity (SSD basis) = ((B/(B-(D-C))) *K	2.49	2.53	2.51
Correction Factor K @ 24 °C = 0.9991			

A3 Dry Rodded Unit Weight of Fine Aggregate

Description	Test 1	Test 2	Test 3
[A] Mass of Mold (g)	4,845	4,845	4,845
[B] Mass of Mold and Sample (g)	26,645	26,780	26,810
[C] = [B] - [A] Mass of sample (g)	21,800	21,935	21,965
[D] Volume of Mold (cm <sup>3</sup> )	13,950	13,950	13,950
Unit Weight of Sand [C/D]	1.5627	1.5724	1.5746

Average Unit Weight of Sand	1.5699		
<i>A4 Moisture contents of sand</i>			
Description	Test 1	Test 2	Test 3
[A] Mass of Original Sample (g)	500	500	500
[B] Mass of Oven Dry Sample (g)	472.8	473.9	471.3
$[w] = (([A] - [B])/B) * 100$ Moisture Content	5.7530	5.5075	6.0895
Average Moisture Content of Sand	5.7833		

## APPENDIX B: - Tests on Coarse Aggregate

### B.1 Coarse Aggregate Sieve Analysis

No	Sieve size (mm)	Weight of Retained (gm)	Percentage Retained (%)	Cumulative Coarser (%)	Percentage Passing (%)	range Passing (%)
1	37.5mm	0	0	0	100	100
2	25mm	191.24	9.562	9.562	90.438	90-100
3	19mm	717.12	35.856	45.418	54.582	20-55
4	12.5mm	932.28	46.614	92.032	7.968	0-10
5	9.5mm	159.36	7.968	100	0	0-5
6	4.75mm	0	0	100		
8	Pan		0	100		
Total		2000				

### B.2 Specific Gravity and Absorption of Coarse Aggregates

	Trial 1	Trial 2	Average
[A] Mass of Oven Dry Sample, kg	5045	5075	
[B] Mass SSD, kg	5081.9	5111.9	
[C] Mass SSD in Water, kg	3170.9	3200.9	
Bulk sp gr = $[A]/([B]-[C])$	2.64	2.66	2.65
Bulk sp gr (SSD) = $[B]/([B]-[C])$	2.66	2.67	2.65
Apparent sp gr = $[A]/([A]-[C])$	2.69	2.71	2.70
Absorption, % = $(([B]-[A])/[A]) * 100$	0.73	0.73	0.73

### B3 Dry Rodded Unit Weight of Coarse Aggregate

Description	Test 1	Test 2	Test 3
[A] Mass of Mold (g)	4,845	4,845	4,845
[B] Mass of Mold and Sample (g)	27,410	27,535	27,540
[C] = [B] - [A] Mass of sample (g)	22,565	22,690	22,695
[D] Volume of Mold (cm <sup>3</sup> )	13,950	13,950	13,950
Unit Weight of Sand [C/D]	1.6176	1.6265	1.6269

Average Unit Weight of CA	1.6237
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*B4 Moisture contents of Course Aggregates*

Description	Test 1	Test 2	Test 3
[A] Mass of Original Sample (g)	2000	2000	2000
[B] Mass of Oven Dry Sample (g)	1989.7	1987.9	1990.4
[w] = $(([A] - [B])/B) * 100$ Moisture Content	0.5177	0.6087	0.4823
Average Moisture Content of CA	0.5362		

**APPENDIX C: - Tests on Ground Pumice**

*C.1 Density of Ground Pumice*

	Trial 1	Trial 2	Average
[A] Mass of Pycnometer & 1ml gas, gm	326.3	326.4	326.2
[B] Mass of Pycnometer + 1ml gas+ Pumice, gm	378.7	377.8	377.1
[C] Initial reading	0.9	1	1
[D] Final reading	24	24	24
[J] Density of Pumice = $[B-A]/[D-C]$ ,	2.27	2.23	2.21
Average	2.24		

*C.2 Fineness of Grounded Pumice by Air Permeability Method (Blain Apparatus)*

	Trial 1	Trial 2	Average
Density of Pumice (gm/cm <sup>3</sup> ), $\rho$	2.24	2.24	2.24
Volume of Sample (cm <sup>3</sup> ), V	1.852	1.852	1.852
Desired porosity, $\epsilon$	0.5	0.5	0.5
Weight of sample (gm), $W = V * \rho * (1 - \epsilon)$	2.07424	2.07424	2.07424
T <sub>s</sub> (s), Measured time interval of standard sample	37.8	37.8	37.8
S <sub>s</sub> (cm <sup>2</sup> /gm), Specific Surface of standard sample	3,774	3,774	3,774
T (s), Measured time interval of sample	40.3	41.4	40.85
S (cm <sup>2</sup> /gm), Specific surface of the sample = $(S_s * \text{Sqrt}(T))/\text{Sqrt}(T_s)$			

Average	3,896.8	3,949.63	3,923.22
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*C.3 Hydrometer Analysis of Grounded Pumice and Cement*

Cement		Ground Pumice		Method of PSD determination
Diameter (mm)	Percent Finer (%)	Diameter (mm)	Percent Finer (%)	
0.075	100	0.075	100	Sieve analysis
0.063	92.1	0.063	97.64	
0.0584	88.63	0.0440	94.47	
0.0413	84.632	0.0317	92.03	Hydrometer analysis
0.0273	82.977	0.0231	88.37	
0.0173	77.386	0.0152	83.49	
0.0129	76.166	0.0092	80.44	
0.0093	74.946	0.0065	78.61	
0.0067	68.11	0.0047	74.21	
0.0047	63.714	0.0034	71.04	
0.0034	56.626	0.0025	65.78	
0.0024	55.406	0.0019	63.95	
0.0020	55.306	0.0018	61.85	

**APPENDIX D: - Concrete Mix Proportions Per Cubic Meter**


	Composition of binder		Water	Fine Aggregate	Coarse Aggregate
	Cement	Ground Pumice			
P0D3	357.41	0	181.3	796.63	1082.3
P0D7	357.41	0	181.3	796.63	1082.3
P0D28	357.41	0	181.3	796.63	1082.3
P0D56	357.41	0	181.3	796.63	1082.3
P5D3	339.54	17.9	181.3	796.63	1082.3
P5D7	339.54	17.9	181.3	796.63	1082.3
P5D28	339.54	17.9	181.3	796.63	1082.3
P5D56	339.54	17.9	181.3	796.63	1082.3
P10D3	321.67	35.74	181.3	796.63	1082.3
P10D7	321.67	35.74	181.3	796.63	1082.3
P10D28	321.67	35.74	181.3	796.63	1082.3
P10D56	321.67	35.74	181.3	796.63	1082.3
P15D3	303.8	53.61	181.3	796.63	1082.3

P15D7	303.8	53.61	181.3	796.63	1082.3
P15D28	303.8	53.61	181.3	796.63	1082.3
P15D56	303.8	53.61	181.3	796.63	1082.3
P20D3	285.93	71.48	181.3	796.63	1082.3
P20D7	285.93	71.48	181.3	796.63	1082.3
P20D28	285.93	71.48	181.3	796.63	1082.3
P20D56	285.93	71.48	181.3	796.63	1082.3
P25D3	268.1	89.35	181.3	796.63	1082.3
P25D7	268.1	89.35	181.3	796.63	1082.3
P25D28	268.1	89.35	181.3	796.63	1082.3
P25D56	268.1	89.35	181.3	796.63	1082.3
P30D3	250.2	107.2	181.3	796.63	1082.3
P30D7	250.2	107.2	181.3	796.63	1082.3
P30D28	250.2	107.2	181.3	796.63	1082.3
P30D56	250.2	107.2	181.3	796.63	1082.3

**APPENDIX E: - Ground Pumice Replacement Amount in 1m<sup>3</sup> for each replacement percent's**

No	Fw	W/C	W	C+P	P	C
1	1.00E-20	0.54	193	357.4074	3.57E-18	357.4074
2	0.05	0.54	193	357.4074	17.87	339.537
3	0.1	0.54	193	357.4074	35.74	321.6667
4	0.15	0.54	193	357.4074	53.61	303.7963
5	0.2	0.54	193	357.4074	71.48	285.9259
6	0.25	0.54	193	357.4074	89.35	268.0556
7	0.3	0.54	193	357.4074	107.22	250.1852

**APPENDIX F: - Chemical Properties of Ground Pumice and Cement**

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


Issue Date: -23/07/2020  
 Request No:- GLD/RQ/418/20  
 Report No:- GLD/RN/443/20  
 Sample Preparation: - 200 Mesh  
 Number of Sample:- Two (2)


Customer Name: -Gebeyehu Ayele  
 Sample type:- Rock  
 Date Submitted: - 19/05/2020  
 Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides  
 Analytical Method: LiBO<sub>2</sub> FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS

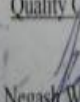
Collector's code	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	Na <sub>2</sub> O	K <sub>2</sub> O	MnO	P <sub>2</sub> O <sub>5</sub>	TiO <sub>2</sub>	H <sub>2</sub> O	LOI
G-Cement	26.18	7.16	3.44	60.34	1.14	0.48	<0.01	<0.01	0.20	0.12	0.71	0.04
G-Pumice	73.06	9.65	5.78	<0.01	0.06	1.50	2.60	<0.01	0.10	0.05	1.14	5.97


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

Analysts  
 Lidet Endeshaw  
 Yohannes Getachew

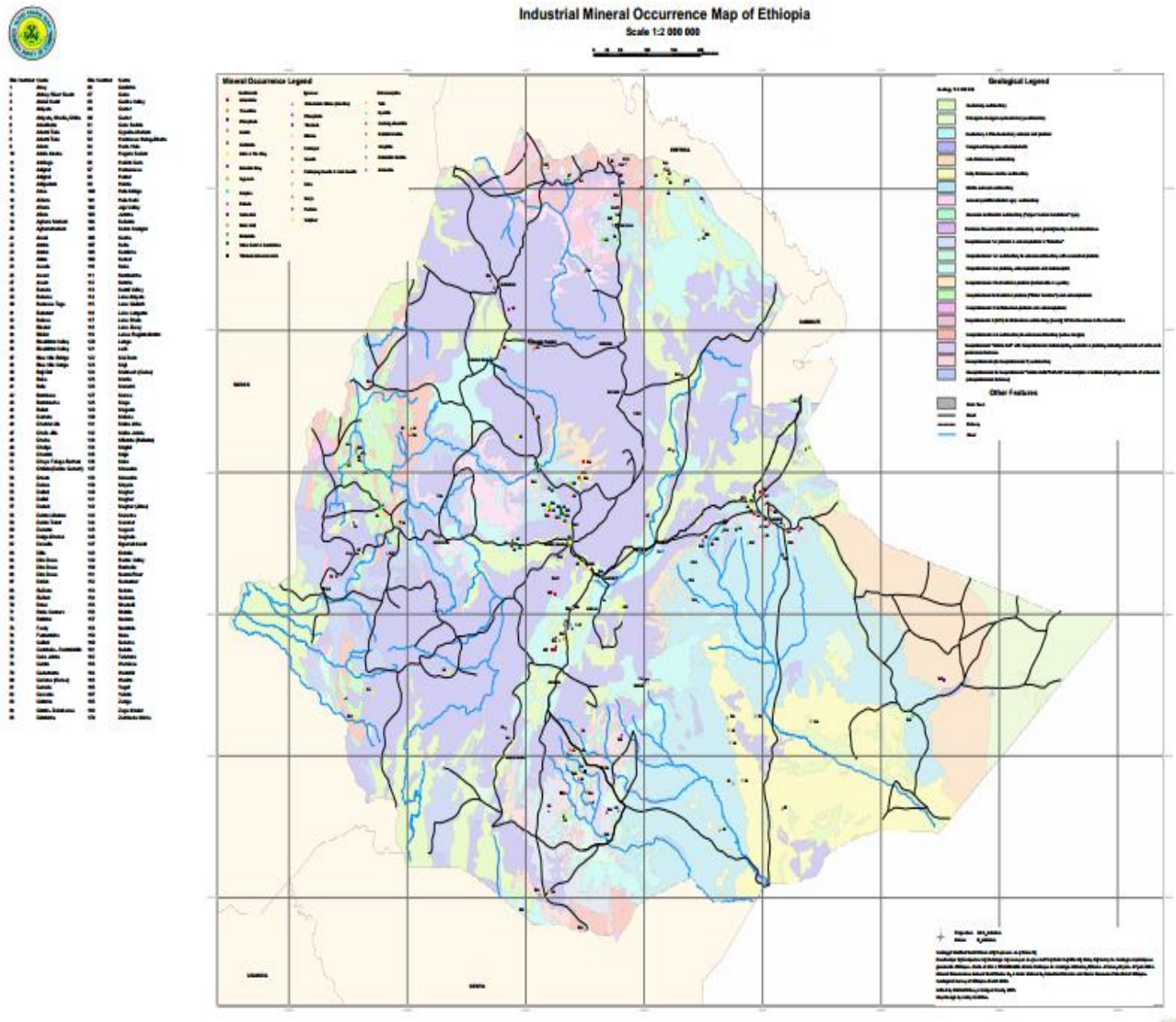
Checked By  
  
 Yohannes Getachew

Approved By  
  
 Gosa Haile

Quality Control  
  
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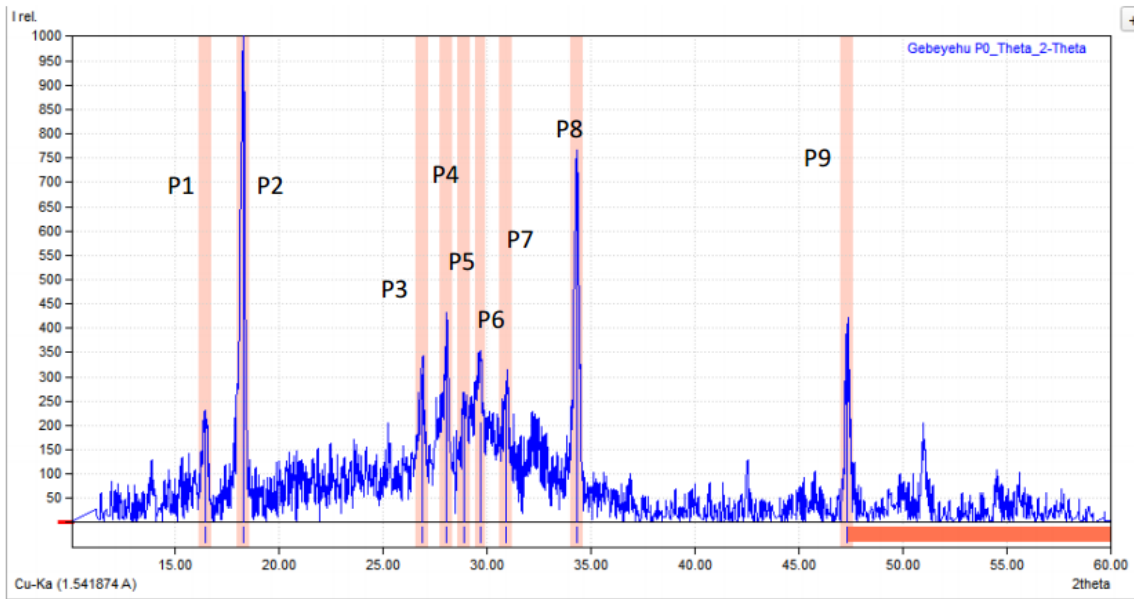


APPENDIX G: - Industrial Occurrence Maps of Ethiopia



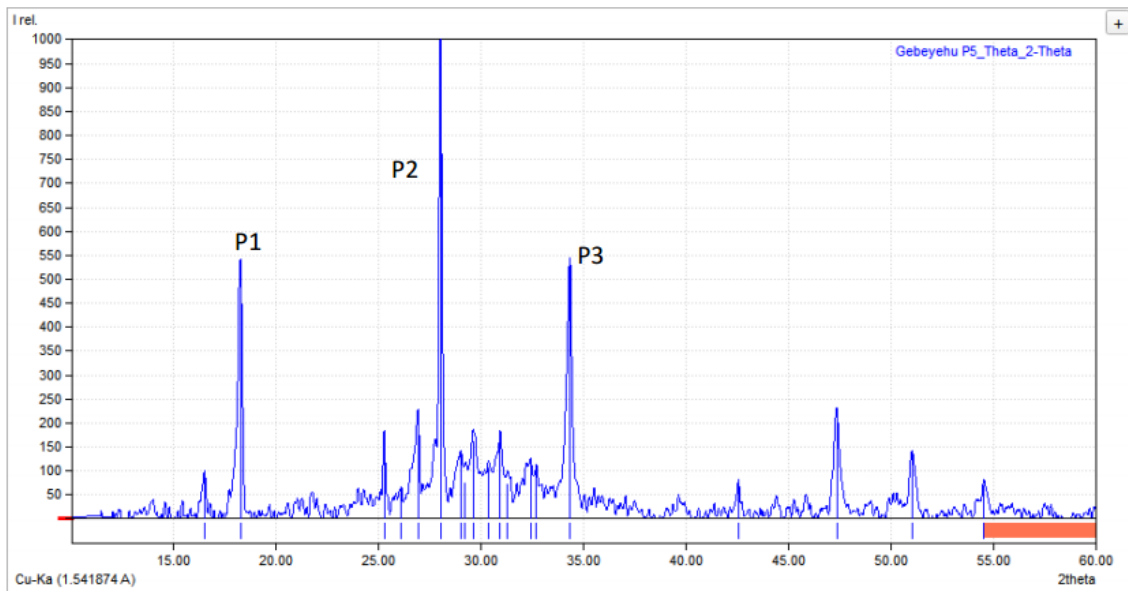
**APPENDIX H: - XRD Analysis Result**

*H.1 Hydrated past from P0 sample*



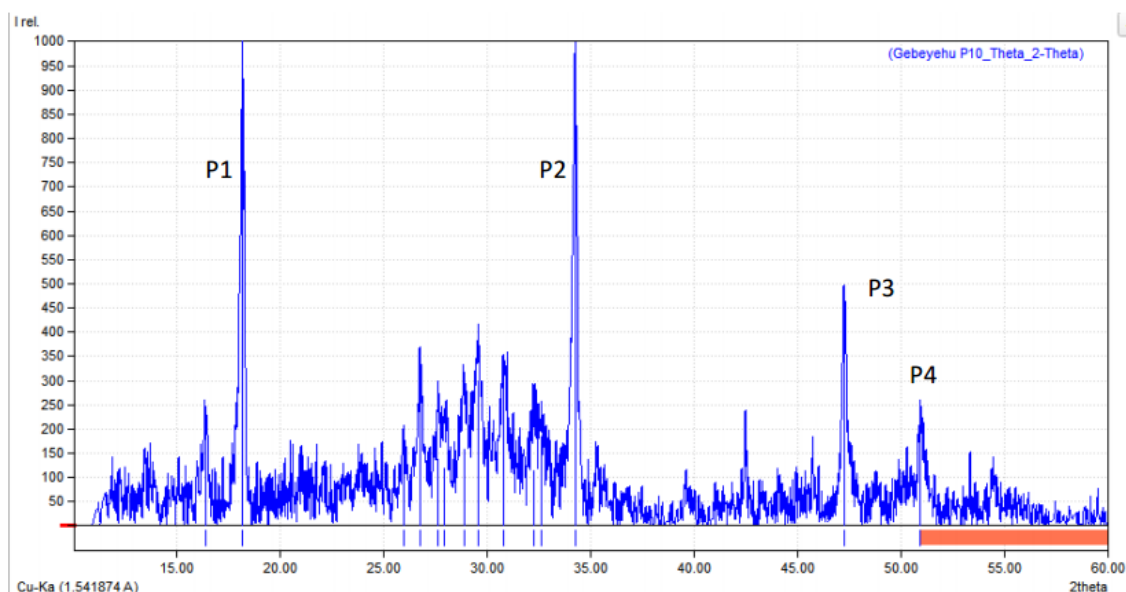
No.	Compound Name	Chemical Formula
P1	Aluminum Hydroxide	Al(OH) <sub>3</sub>
P2	Calcium Aluminum Silicate	Ca <sub>2</sub> Al <sub>2</sub> SiO <sub>7</sub>
P3	Portlandite	Ca(OH) <sub>2</sub>
P4	Silicon Oxide	SiO <sub>2</sub>
P5	Manganese Sulfide	MnS
P6	Calcium Silicate	Ca <sub>2</sub> Si O <sub>4</sub>

*H.2 Hydrated past from P5 sample*



No.	Compound Name	Chemical Formula
P1	Calcium Silicate Hydrate	Ca <sub>6</sub> Si <sub>6</sub> O <sub>17</sub> (OH) <sub>2</sub>
P2	Calcium Silicate	Ca <sub>2</sub> SiO <sub>4</sub>
P3	Calcium Aluminum Silicate	CaAl <sub>2</sub> Si <sub>2</sub> O <sub>8</sub>

### H.3 Hydrated past from P10 sample



No.	Compound Name	Chemical Formula
P1	Calcium Silicate Hydrate	Ca <sub>6</sub> Si <sub>6</sub> O <sub>17</sub> (OH) <sub>2</sub>
P2	Calcium Silicate	Ca <sub>2</sub> SiO <sub>4</sub>
P3	Calcium Aluminum Silicate	CaAl <sub>2</sub> Si <sub>2</sub> O <sub>8</sub>
P4	Aluminum Iron Oxide	AlFeO <sub>3</sub>

## APPENDIX I: - Mix Design

### Concrete Mix Design According To ACI

Target of compressive strength = C30/37.5 MPa (C-37.5)

28-day Cylindrical Strength  $f_{ck,cylinder}$  = 30 Mpa

28-day Cubic Compressive Strength  $f_{ck,cube}$  = 37.5 MPa

Materials parameters are described as follow:

Cement; specific gravity = 3.15

Bulk specific gravity C. A = 2.67

Compacted unit weight C. A = 1623.66 kg/m<sup>3</sup>

Moisture content of C.A = 0.54%

Absorption capacity of C.A = 0.73%

Bulk specific gravity F.A = 2.51

Fines modulus F. A=2.87

Moisture content of F.A = 5.78%

Absorption capacity of F.A = 3.96%

Density of water=1000 kg/m<sup>3</sup>

**Step 1:** Choice of Slump

**TABLE A1.5.3.1 – RECOMMENDED SLUMPS FOR VARIOUS TYPES OF CONSTRUCTION (SI)**

Types of construction	Slump, mm	
	Maximum*	Minimum
Reinforced foundation walls and footings	75	25
Plain footings, caissons, and substructure walls	75	25
Beams and reinforced walls	100	25
Building columns	100	25
Pavements and slabs	75	25
Mass concrete	75	25

For beams and reinforced walls slump is 25mm – 100mm. take 75mm.

**Step 2:** Choice of nominal maximum aggregate size

The nominal maximum aggregate size is 25mm.

**Step 3:** Estimation of mixing water and air content

**TABLE A1.5.33 – APPROXIMATE MIXING WATER AND AIR CONTENT REQUIREMENTS FOR DIFFERENT SLUMPS AND NOMINAL MAXIMUM SIZES OF AGGREGATES (SI)**

Water, Kg/m <sup>3</sup> of concrete for indicated nominal maximum sizes of aggregate								
Slump, mm	9.5*	12.5*	19*	25*	37.5*	50†*	75†‡	150†‡
Non-air-entrained concrete								
25 to 50	207	199	190	179	166	154	130	113
75 to 100	228	216	205	193	181	169	145	124
150 to 175	243	228	216	202	190	178	160	—
Approximate amount of entrapped air in non-air-entrained concrete, percent	3	2.5	2	1.5	1	0.5	0.3	0.2

The estimated mixing water for a slump of 75 to 100 mm in non-air-entrained concrete made with 25 mm aggregate is found to be 193 kg/m<sup>3</sup>

Entrapped air is 1.5%.

**Step 4:** Selection of water-cement ratio

**TABLE A1.5.3.4(a) – RELATIONSHIPS BETWEEN WATER-CEMENT RATIO AND COMPRESSIVE STRENGTH OF CONCRETE (SI)**

Compressive strength at 28 days, MPa*	Water-cement ratio, by mass	
	Non-air-entrained concrete	Air-entrained concrete
40	0.42	—
35	0.47	0.39
30	0.54	0.45
25	0.61	0.52
20	0.69	0.60
15	0.79	0.70

w/c ratio for non-air entrained concrete with cubic compressive strength of 25MPa is 0.69. Thus, w/c ratio for non-air entrained concrete with cubic compressive strength of 37.5Mpa and Cylindrical Compressive Strength of 30 MPa is 0.54

**Step 5:** Calculation of cement content

The required cement content is  $193/0.54 = 357.41 \text{ kg/m}^3$

**Step 6:** Estimation of coarse aggregate content

**TABLE A1.5.3.6 – VOLUME OF COARSE AGGREGATE PER UNIT OF VOLUME OF CONCRETE (SI)**

Nominal maximum size of aggregate, mm	Volume of dry-rodded coarse aggregate* per unit volume of concrete for different fineness moduli† of fine aggregate			
	2.40	2.60	2.80	3.00
9.5	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
19	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
37.5	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
75	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

The quantity of coarse aggregate from the above table with 25mm aggregate and 2.87 fineness modulus of fine aggregate is  $0.663\text{m}^3$  by interpolation.

The required dry mass is  $= 0.663 \times 1623.66 = 1076.49 \text{ kg}$ .

**Step 7:** Estimation of fine aggregate content

**TABLE A1.5.3.7.1 – FIRST ESTIMATE OF MASS OF FRESH CONCRETE (SI)**

Nominal maximum size of aggregate, mm	First estimate of concrete unit mass, kg/m <sup>3</sup> *	
	Non-air-entrained concrete	Air-entrained concrete
9.5	2280	2200
12.5	2310	2230
19	2345	2275
25	2380	2290
37.5	2410	2350
50	2445	2345
75	2490	2405
150	2530	2435

Mass basis: the mass of a cubic meter of non-air entrained concrete made with aggregate having a nominal maximum size of 25mm is estimated to be 2380 kg/m<sup>3</sup>

Masses already known are:

Water (net mixing)	193 kg
Cement	357.41 kg
Coarse aggregate	<u>1076.49 kg</u>
Total	1626.9kg

The mass of fine aggregate is  $2380 - 1626.9 = \underline{753.1 \text{ kg}}$

**Step 8: Moisture adjustment**

Absorbed water does not become part of the mixing water and it must be removed from the mixing water, if moisture content is greater than absorption capacity. But, if absorption capacity is greater than moisture content of aggregate, we need to add water up to its moisture capacity.

Coarse aggregate (wet) =  $1076.49(1.0054) = \underline{1082.3\text{kg}}$

Fine aggregate (wet) =  $753.1(1.0578) = \underline{796.63\text{kg}}$

Water =  $193 + 1076.49((0.73-0.54)/100) + 753.1((3.96-5.78)/100) = \underline{181.3\text{kg}}$

Water (to be added)	181.3 kg
Cement	357.41 kg
Coarse aggregate	1082.3kg
Fine aggregate	<u>796.63kg</u>

**APPENDIX J: - Compressive Strength of Concrete Produced**

Sample No	Sample Code	Load(kN)	Stress (MPa)
1	P0D3	430.20	19.12
2	P0D3	438.90	19.50
3	P0D3	402.50	17.89
Average		423.87	18.84
1	P0D7	503.60	22.38
2	P0D7	538.90	23.95
3	P0D7	535.30	23.79
Average		525.93	23.37
1	P0D28	898.70	39.94
2	P0D28	888.10	39.47
3	P0D28	924.90	41.11
Average		903.90	40.17
1	P0D56	1052.10	46.76
2	P0D56	1047.80	46.57
3	P0D56	996.90	44.31
Average		1032.27	45.88
1	P5D3	425.91	18.93
2	P5D3	471.25	20.94
3	P5D3	421.22	18.72
Average		439.43	19.53
1	P5D7	570.60	25.36
2	P5D7	554.85	24.66
3	P5D7	559.35	24.86
Average		561.60	24.96
1	P5D28	978.08	43.47
2	P5D28	995.40	44.24
3	P5D28	956.48	42.51
Average		976.65	43.40
1	P5D56	1140.75	50.70
2	P5D56	1080.23	48.01
3	P5D56	1045.13	46.45
Average		1088.70	48.39
1	P10D3	450.00	20.00
2	P10D3	447.80	19.90
3	P10D3	489.61	21.76
Average		462.47	20.55
1	P10D7	586.30	26.05
2	P10D7	639.90	28.44
3	P10D7	593.80	26.39
Average		606.67	26.96
1	P10D28	993.40	44.15

2	P10D28	1021.10	45.38
3	P10D28	1017.70	45.23
Average		1010.73	44.92
1	P10D56	1101.38	48.95
2	P10D56	1131.08	50.27
3	P10D56	1134.68	50.43
Average		1122.38	49.88
1	P15D3	442.10	19.65
2	P15D3	445.10	19.78
3	P15D3	411.90	18.31
Average		433.03	19.25
1	P15D7	536.85	23.86
2	P15D7	559.13	24.85
3	P15D7	553.50	24.60
Average		549.83	24.44
1	P15D28	963.90	43.84
2	P15D28	965.70	43.92
3	P15D28	944.55	42.98
Average		958.05	43.58
1	P15D56	1037.25	47.10
2	P15D56	1032.75	46.90
3	P15D56	1057.73	48.01
Average		1042.58	47.34
1	P20D3	406.60	18.07
2	P20D3	383.85	17.06
3	P20D3	365.90	16.26
Average		385.45	17.13
1	P20D7	515.50	22.91
2	P20D7	522.20	23.21
3	P20D7	520.40	23.13
Average		519.37	23.08
1	P20D28	853.90	37.95
2	P20D28	876.80	38.97
3	P20D28	874.90	38.86
Average		868.53	38.59
1	P20D56	921.15	40.94
2	P20D56	900.23	40.01
3	P20D56	900.00	40.00
Average		907.13	40.32
1	P25D3	339.50	15.09
2	P25D3	333.00	14.80
3	P25D3	354.80	15.77
Average		342.43	15.22
1	P25D7	445.90	19.82
2	P25D7	442.80	19.67

3	P25D7	455.60	20.25
Average		448.10	19.91
1	P25D28	751.30	33.39
2	P25D28	736.90	32.75
3	P25D28	764.80	33.99
Average		751.00	33.38
1	P25D56	834.75	37.10
2	P25D56	807.30	35.88
3	P25D56	785.03	34.89
Average		809.03	35.96
1	P30D3	327.20	14.54
2	P30D3	345.80	15.37
3	P30D3	270.50	12.02
Average		314.50	13.98
1	P30D7	394.40	17.53
2	P30D7	448.20	19.92
3	P30D7	370.40	16.46
Average		404.33	17.97
1	P30D28	727.70	32.34
2	P30D28	760.90	33.82
3	P30D28	748.20	33.25
Average		745.60	33.14
1	P30D56	742.05	32.98
2	P30D56	763.20	33.92
3	P30D56	743.63	33.05
Average		749.63	33.32

**APPENDIX K: - Splitting Tensile Strength of Concrete Produced**

Sample No	Sample Code	Load (kN)	Stress (MPa)
1	P0D3	118.75	1.68
2	P0D3	129.36	1.83
3	P0D3	159.75	2.26
Average		135.95	1.92
1	P0D7	135.01	1.91
2	P0D7	168.58	2.23
3	P0D7	156.22	2.21
Average		151.27	2.14
1	P0D28	188.73	2.67
2	P0D28	181.66	2.57
3	P0D28	138.54	1.96
Average		169.65	2.40
1	P0D56	198.63	2.81
2	P0D56	235.38	3.33
3	P0D56	202.16	2.86

Average		212.06	3.00
1	P5D3	135.01	1.91
2	P5D3	154.09	2.18
3	P5D3	132.89	1.88
Average		128.41	1.99
1	P5D7	139.96	1.98
2	P5D7	181.66	2.57
3	P5D7	160.46	2.27
Average		160.69	2.27
1	P5D28	202.16	2.86
2	P5D28	174.59	2.47
3	P5D28	201.45	2.85
Average		192.74	2.73
1	P5D56	231.14	3.27
2	P5D56	207.11	2.93
3	P5D56	245.99	3.48
Average		228.08	3.23
1	P10D3	160.46	2.27
2	P10D3	165.40	2.34
3	P10D3	127.23	1.80
Average		151.03	2.14
1	P10D7	162.58	2.30
2	P10D7	158.34	2.24
3	P10D7	173.89	2.46
Average		164.93	2.33
1	P10D28	0.00	2.36
2	P10D28	0.00	2.88
3	P10D28	0.00	3.20
Average		0.00	2.81
1	P10D56	241.04	3.41
2	P10D56	233.97	3.31
3	P10D56	238.91	3.38
Average		238.01	3.37
1	P15D3	142.79	2.02
2	P15D3	134.30	1.90
3	P15D3	155.51	2.20
Average		144.20	2.04
1	P15D7	159.75	2.26
2	P15D7	154.80	2.19
3	P15D7	156.92	2.22
Average		157.16	2.22
1	P15D28	184.49	2.61
2	P15D28	173.41	2.45
3	P15D28	165.44	2.34
Average		174.45	2.47

1	P15D56	214.88	3.04
2	P15D56	240.05	3.40
3	P15D56	207.42	2.93
Average		220.78	3.12
1	P20D3	105.32	1.49
2	P20D3	143.77	2.03
3	P20D3	116.14	1.64
Average		121.74	1.72
1	P20D7	159.27	2.25
2	P20D7	130.42	1.85
3	P20D7	125.52	1.78
Average		138.41	1.96
1	P20D28	152.21	2.15
2	P20D28	134.54	1.90
3	P20D28	167.64	2.37
Average		151.46	2.14
1	P20D56	172.69	2.44
2	P20D56	200.69	2.84
3	P20D56	192.28	2.72
Average		188.55	2.67
1	P25D3	97.94	1.39
2	P25D3	114.37	1.62
3	P25D3	103.89	1.47
Average		105.40	1.49
1	P25D7	130.57	1.85
2	P25D7	113.08	1.60
3	P25D7	139.96	1.98
Average		127.90	1.81
1	P25D28	146.62	2.07
2	P25D28	115.84	1.64
3	P25D28	141.42	2.29
Average		150.81	2.00
1	P25D56	173.42	2.45
2	P25D56	205.70	2.91
3	P25D56	150.50	2.13
Average		176.54	2.50
1	P30D3	109.81	1.55
2	P30D3	100.28	1.42
3	P30D3	91.33	1.29
Average		100.47	1.42
1	P30D7	101.78	1.44
2	P30D7	118.13	1.67
3	P30D7	109.46	1.55
Average		109.79	1.55
1	P30D28	134.32	1.91

2	P30D28	129.84	1.84
3	P30D28	142.10	2.01
Average		135.42	1.92
1	P30D56	140.12	1.98
2	P30D56	202.80	2.87
3	P30D56	143.87	2.04
Average		162.27	2.30