# INVESTIGATION OF PROPERTIES OF MBEYA PUMICE LIGHTWEIGHT AGGREGATES

**Oscar John Shiganza[1], Hieronimi Alphonce Mboya[2], Joseph John Msambichaka[3]**

Department of Civil Engineering,
Mbeya University of Science and Technology,
P. O. Box 131, Mbeya, Tanzania
Email: [1]shiganzaoj@outlook.com, [2]hamboya@gmail.com, [3]jvmfatti@yahoo.com

## ABSTRACT

The properties of concrete depend partly on the type and mechanical properties of aggregates used in the concrete mix. The paper presents an investigation designed to study the properties of pumice lightweight aggregates and assess their suitability to structural lightweight concrete. The properties of pumice lightweight aggregates mainly aggregates shape, water absorption, specific gravity and organic impurities were examined. The results indicated that pumice lightweight aggregates have the flakiness and elongation close to upper limits as set by BS 812-105.1:1989 low density, high water absorption in comparison to normal weight aggregates, and are weather resistant. It was concluded that pumice lightweight aggregates are suitable for manufacture of structural lightweight concrete.

**Key words:** Pumice lightweight aggregates, fineness modulus, water absorption, aggregates shape

## 1. INTRODUCTION

Pumice is from natural volcanic emissions–which is extrusive volcanic rock which is produced when lava with a very high content of water and gases is discharged from a volcano. When this lava cools and hardens, the result is a very light rock material filled with tiny bubbles of gas, (Harness 2018). Pumice aggregates have been used before as coarse aggregates in normal weight concrete. Pumice aggregates are used in the production of lightweight concrete in a number of countries, such as Italy, Turkey, United States, and Some of the Eastern Africa countries covered by the great rift valley include Ethiopia, Kenya, Uganda, Tanzania, Rwanda and Burundi (https://www.bgs.ac.uk, 2020, Mbakisya et al., 2020). The pumice aggregates are seen in Figure 1.

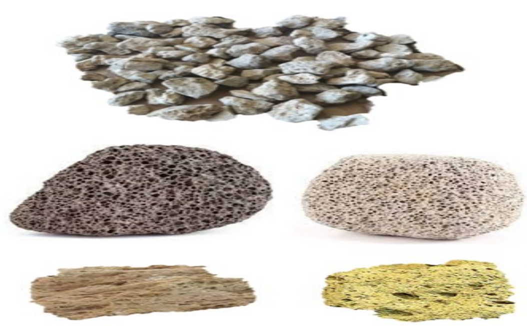

**Figure 1:** Pumice aggregates types

Pumice is available in abundance in Mbeya and is not used for preparation of structural concrete.

## 2. OBJECTIVE AND SCOPE

The objective of the study was to evaluate the properties of pumice lightweight aggregates available in Mbeya, for the purpose of making lightweight structural concrete. The aim was to determine whether the aggregates are lightweight and subsequently to determine their suitability to making of lightweight structural concrete. The evaluation was limited to study of aggregates shape, water absorption, specific gravity and organic impurities of Mbeya pumice aggregates.

## 3. REVIEW OF PROPERTIES OF AGGREGATES

### 3.1 Concrete technology

Building and construction activities are as old as the human existence, as man has always required shelter for residence and other activities so as to guarantee survival, safety, comfort and endurance (Ede, 2011). A high percentage of structures in developed and developing nations are made of reinforced Portland cement concrete. The concrete is commonly used worldwide because of the availability of its constituent materials. It is universally adopted in multi-purpose constructions because of its strength, economy-related to availability and sustainability of its constituent materials (Ede and Olofinnade, 2017). Concrete is a man-made stone-like composite material produced by mixing cement, aggregate, and water with or without additives and allowed to cure and harden. It can be cast into any shape, form, texture, and colour for aesthetics. According to ACI 213R-14, concrete is defined as the mixture of hydraulic cement, aggregates, and water, with or without admixtures, fibers, or other cementitious materials. It is one of the basic materials used in the construction because of its availability and affordable cost.

Concrete ingredient materials are locally available and can easily be modified and mixed or combined to yield the desired properties of fresh and hardened concrete, Ferraris (1992) argued that, the advances of concrete technologies continue to modify and improve the properties of both fresh and hardened concrete that enhances strength, stability and durability of concrete structures. Zongjin (2011) defines the structural lightweight concrete as a concrete having compressive strength in excess 17 $N/mm^2$ with a bulk density less than 1950 $kg/m^3$. As far as lightweight concrete is concerned, light weight aggregates are to be integrated. Nowadays, structural lightweight concrete can be made 25% lighter than normal-weight concrete but with a compressive strength of up to 60 $N/mm^2$. Ferraris (1992) stresses that, the rheology of fresh concrete is very important because it influences the quality of the hardened concrete. Workability and stability of concrete against bleeding and segregation is influenced by optimum proportioning of concrete ingredients. The aggregates properties such as shape, maximum nominal size, texture, absorption, mineralogy and fineness also affect the final quality of hardened concrete. Zongjin (2011) stresses that, water is considered as an essential component in concrete and in the processes of mixing, placing, compacting, curing and hardening as it provides lubrication necessary for hydration of cement. Although water is necessary for the hydration reaction of cement, proper gradation of aggregates is essential for optimum water cement ratio which is one of the governing factor for strength and durability of final product.

### 3.2 Ingredients of concrete

Most of concrete used in the construction industry is produced by varying the proportions and /or types of the main ingredients. They are also produced by substituting cementitious materials, adding admixtures or mineral additive. In this case, the finished concrete products find their application through varying strength, density, and thermal resistance properties in different structures. The concrete mix design depends on the type, exposure environment, uses and safety level required for the structure. On the other hand, it is also vital to consider batching, mixing, transportation, placing and compaction to attain the structure needs.

### 3.3 Aggregates

Aggregates are inert granular materials such as sand, gravel, or crushed stone, fine and coarse aggregates that make up the bulk of a concrete mixture, normally constitute 60 % to 70 % of a concrete mix (Mboya, 2013). It is a fact that, the physical characteristics of the aggregates will influence the physical properties of the concrete produced. Aggregates in concrete are divided into two distinct categories mainly fine and coarse aggregates. The fine aggregates generally are of natural sand or crushed stone with particles passing through the 4.75 mm sieve. The coarse aggregates are any particles greater than 4.75 mm, mostly range between 9.5 mm to 37.5 mm in diameter (Francois, 1966). Gravels and crushed stone are both used as coarse aggregates in concrete. Lightweight concrete strength relies fully on the quality of lightweight aggregates and rheology strength of mortar (Erdogan, 2002 and ACI, 2007). Properties of aggregates such as chemical composition, shape, and size have significant impact on the workability, durability, strength, density, shrinkage and economy of the concrete. These properties of aggregates give the flexibility in the design and construction requirements. Aggregates processing consists of crushing, screening, and washing the aggregates to obtain appropriate clean and graded proportion. Aggregates are classified according to their density or unit weight (Erdogan, 2002 and ACI, 2007). Aggregates are classified into three categories basing on the density or specific gravity (Demirboga and Kan, 2013). Firstly the lightweight aggregates having a specific gravity less than 2.40, these are widely used in lightweight concrete. The second category is normal weight aggregates having specific gravity between 2.40 to 2.90. These are the most commonly used type of concrete. The last category is heavyweight aggregates whose density range from 3 to 5.

### 3.4 Role of aggregates in concrete

Chung *et al.,* (2017) states that, the role of aggregates in concrete is to provide dimensional stability and wear resistance. The aggregates provide strength and durability properties of concrete. They occupy most of the volume of the concrete and act as a filler material to provide the structural integrity and lower the cost of concrete. When concrete is freshly mixed, the aggregates normally swing in the cement paste. According to Zongjin (2011), the behaviour of fresh concrete such as fluidity, cohesiveness, and rheology is usually influenced by the amount, type, surface texture, and size gradation of the aggregates. The selection of aggregates has to meet the requirements of the end use. Although there is little chemical reaction between aggregates and cement paste, but aggregates contribute many qualities to the hardened concrete. It extends the advantages to reduce the cost, shrinkage and creep in concrete. Moreover, aggregates have a big influence on stiffness, density, strength, thermal properties, bond, and wear resistance of concrete (Zongjin, 2011).

### 3.5 Properties of aggregates

Aggregates should be transported and stored well to minimize segregation, degradation and prevention to contaminations. Aggregates influence not only mix proportions but also properties of freshly and hardened concrete. Consequently, proper selection of aggregates is necessary to achieve desired properties of fresh and hardened concrete. The selection of aggregates is based on gradation, aggregate shape and size, absorption and surface moisture, unit weight, voids and specific gravity.

### 3.5.1 Aggregates gradation

Aggregate gradation pattern is assessed by sieving a sample successively through standard sieves mounted in order of size, with larger sieve on the top and the smallest at the bottom. The material retained on each sieve after shaking represents the fraction of aggregates coarser than the sieve in the question and finer than the sieve above. Naseem *et al.,* (2016) classified aggregates in four categories namely: - dense or well-graded aggregates, gap-graded aggregates, uniformly graded aggregates, and open-graded aggregates (Figure 2). Proper gradation of coarse aggregates is one of the most important factors in producing workable concrete. Proper gradation ensures that a sample of aggregates contains all standard fractions of aggregate in a required proportion such that it contains minimum voids. A sample of well graded aggregates containing minimum voids requires minimum paste in filling the voids around the aggregates. Minimum paste is attributed to less cement paste and water; leading to increased strength, low shrinkage, greater durability and less cost. The cement paste has to be more than sufficient to fill up the voids between the aggregates particles so that there would be “excess paste” to provide a thin film of paste coating to each aggregate particle to lubricate the concrete (Wong et al., 2008). Concretes made from poorly graded aggregates results into excessive voids and hence porous and permeable concrete which is susceptible to deterioration under the action of carbonation and chlorine ions.

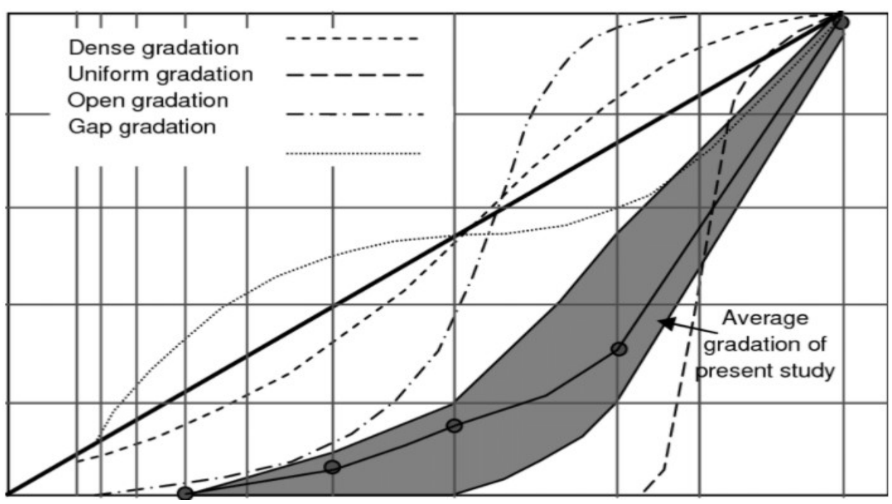


**Figure 2:** Gradation curves.

Source: Naseem et al., (2016)

### 3.5.2 Aggregate shape and size

Aggregates shape and size are the most important factors when selecting aggregates for a specific job (Mboya, 2013). Aggregates size larger than 5 mm are classified as coarse aggregates, while anything smaller than 5 mm are termed as fine aggregate (BS 12620: 2002). Generally, the largest aggregates should not be greater than one-third the depth of a slab or one-fifth the smallest dimension of the form. Generally, coarse aggregates are blended with fine aggregates to obtain a desired gradation for a specific requirement and this reduces cement content as well as shrinkage resulting from setting process of concrete. Aggregates shape influences strength, but has more immediate impact on the workability of the fresh concrete (Mboya, 2013). Rough-textured, angular, and elongated particles require more water to produce workable concrete than smooth rounded aggregates. Consequently, higher cement content is required to maintain the water-cement ratio. Usually flat and elongated particles are avoided or limit to about 15 percent by weight of the total aggregates.

### 3.5.3 Unit weight, specific gravity, density and voids

The unit weight is defined as the weight per unit bulk volume for bulk aggregates. In addition to the pores inside each single aggregate, the bulk volume also includes the space among the particles. Zongjin (2011) stated that, the unit weight of aggregates is obtain when all void spaces of the sample are completely filled with air, and when without water. It is also defined as the mass or weight of aggregates required to fill a specified unit volume. The bulk density of aggregates common in normal-weight concrete ranges from about 1200 to 1800 kg/m$^3$ but that of lightweight aggregates ranges from 500 to 1000 kg/m$^3$ (Smith, 2001). Zongjin, (2011) states that, the unit weight of lightweight aggregates is between 500 and 1120 kg/m$^3$. Examples of lightweight aggregates include cinder, blast-furnace slag, volcanic pumice, and expanded clay.

The specific gravity of an aggregate is the ratio of its mass to the mass of an equal volume of water. It is used in computations of mix proportions and control in the absolute volume method of mix design. Specific Gravity is not a quality measure of aggregates though some porous aggregates exhibit accelerated freeze-thaw deterioration and have low specific gravity. Specific gravity of natural aggregates common in normal-weight concrete ranges between 2.4 and 2.9, that is, densities of between 2400 kg/m$^3$ and 2900 kg/m$^3$. Experiment conducted by Vidya (2021) in pumice aggregates found to be 1.05. Choudhry and Hadley (2009) defines lightweight aggregates as construction materials that have a bulk density lower than that of common construction aggregates. Lightweight concrete is defined as concrete with dry densities in the range of 800 kg/m$^3$ to 2000 kg/m$^3$ (Schlaich and Zareef, 2008). Such concrete can be either a structural or non-structural depending on what type of aggregate is used.

The void content between particles affects the amount of cement paste required for the mix. Rounded particles have fewer voids while angular aggregates increase the void content. Larger sizes of well-graded aggregates and improved grading decrease the void content.

### 3.5.4 Water Absorption and surface moisture

Water absorption and surface moisture of aggregates should be determined so that the total water content of the concrete can be controlled and correct batch weights determined, Shetty, (2009). There is a tendency of bulking of fine aggregates due to absorption. Bulking is the increase in total volume of moist fine aggregate compared to when it is dry over the same mass. Surface tension is the surface moisture, which holds the particles apart causing an increase in volume. Vidya (2021) found the pumice aggregate water absorption to be about 50%.

### 3.5.5 Organic Impurities

Presence of organic impurities in aggregates may delay setting and hardening of concrete, may reduce strength gain, and may cause deterioration of concrete, Kisunge (2012). Organic impurities such as peat, humus, and organic loam may not be as detrimental but should be avoided. Potentially harmful impurities in coarse aggregates can be identified by using ASTM C 123 (AASHTO T 113).

### 3.5.6 Fineness modulus

Fineness modulus of coarse aggregates is the average size of the particles in the aggregates expressed by an index number. Fineness modulus index number is calculated by performing sieve analysis with standard sieves sizes. Limits of fineness modulus for structural concrete are as indicated in Table 1.

**Table 1:** Limits of fineness modulus for structural concrete

| Maximum size of coarse aggregate (mm) | Fineness modulus range |
|---|---|
| 20 | 6.0 – 6.9 |
| 40 | 6.9 – 7.5 |
| 75 | 7.5 – 8.0 |
| 150 | 8.0 – 8.5 |

Source: BS 812-103.1(1985)

#### 3.5.7 Lightweight aggregates

According to Nodehi (2021), lightweight aggregates divided into three types, which are industrial waste lightweight aggregates (includes pelletized products), Naturally occurring lightweight aggregates (such as pumice, light sand, and volcanic cinder) and artificially made lightweight aggregates (such as expanded perlite and Ceramsite), and their properties vary in terms of density, water absorption, elastic properties, durability and fire resistance. The suitability of structural lightweight concrete depend on the type of lightweight aggregate utilized in the concrete (Chandra and Berntsson, 2002). In recent years, techniques have been developed to produce varieties of lightweight aggregates in factories. The lightweight aggregates are produced from natural raw materials such as expanded clay, shale and slate. The industrial produced or manufactured light aggregates have bulk density varying from 400 kg/m$^3$ for expanded pearlite to 1150 kg/m$^3$. Combination of this low specific gravity with high inter-particle voids results in lightweight aggregates bulk dry densities of about 720 kg/m$^3$ (Holm and Valsangkar, 2001).

#### 3.5.8 Pumice lightweight aggregates

There are a variety of lightweight materials that can be used in the production of pumice lightweight aggregates. These are natural materials like volcanic pumice and thermal-treated natural raw materials like expanded glass, clay, shale, etc. There are also other types of pumice lightweight aggregates which are made from industrial by-products including fly ash. The final properties of the pumice lightweight concrete depend on the type and mechanical properties of pumice lightweight aggregates used in the concrete mixture. According to the American Concrete Institute (ACI), pumice lightweight aggregates can be used for structural applications. To be considered as structural lightweight concrete, the minimum 28-day compressive strength and maximum density have to be 17 N/mm$^2$ and 1840 kg/m$^3$, respectively. The practical range for the density of Structural Pumice Lightweight Concrete is between 1400 and 1840 kg/m$^3$. Pumice lightweight concrete with compressive strength less than 17 N/mm$^2$ is considered as non-structural pumice lightweight concrete. There are several benefits of using Pumice lightweight aggregates. The benefits include improved thermal specifications, better fire resistance, and dead load reduction which results in lower cost of labour, transportation, formworks, etc. (Hedjazi, 2019).

## 4. METHODOLOGY

### 4.1 Materials

The research involved studying and evaluating the suitability of pumice lightweight aggregates found in Mbeya Region, Tanzania as the constituent of structural lightweight concrete. The pumice lightweight aggregates used are naturally available at Iyunga ward. The material was graded and prepared for tests of its properties in accordance to structural lightweight concrete as stipulated in Building Code Requirements for Structural Concrete (ACI 318-14) , ACI Standard and Commentary on Building Code Requirements for Structural Concrete (ACI 318R-14) an ACI Report, as reported by ACI Committee 318 and Shetty, (2009).

### 4.2 Gradation, Specific gravity and water absorption test

A Sieve analysis or gradation test was conducted to determine the distribution of aggregates particles by size within a sample and Particle size distribution was based on the procedure as outlined on BS 812-103.1: 1985.

Specific gravity of aggregates and Water absorption of aggregates was measured in accordance to BS 812: Part 2: 1995 code in which case measured and recorded were the weight of saturated pumice lightweight aggregates, the weight of vessel alone, the weight of vessel and aggregates filled with water.

### 4.3 Organic impurities test

Pumice aggregates were examined for organic impurities. In this case, three percent (3 %) of Sodium Hydroxide (NaOH) was dissolved in distilled water, the pumice lightweight aggregates were immersed in a saturated water for 24 hours. After 24 hours, the aggregate sample was compared to the colour plate translation. The results were interpreted based on standards specified in Table 2.

**Table 2:** Colour plate translation

| Colour type | Remark to materials | Remark |
|---|---|---|
| Greenish | Excellent | Standard Materials |
| Lime | Good | |
| Orange | Standard | |
| Yellowish | Poor | Poor Materials |
| Red | Very Poor | |

Source: Kisunge (2012)

### 4.4 Shape tests

The particle shape tests of aggregates were conducted by determining the percentages of flaky and elongation of the pumice lightweight aggregates. Flaky particles are the particles whose thicknesses are less than 0.6 of their mean size and elongated particles are the particles whose lengths are more than 1.8 of their mean size, these values were determined by the equation ((1) and equation ((2), respectively.

$$\text{Flakiness}-\text{index}(FI) = \frac{X_i}{w_i} x100 \quad (1)$$

$$\text{Elongation}-\text{index}(EI) = \frac{Y_i}{w_i} x100 \quad (2)$$

Where, $X_i$ and $Y_i$ are the weight of aggregates passing through the flaky and elongated width gauge respectively, and $W_i$ is the total weight of aggregates sample.

### 4.5 Fineness modulus

Fineness modulus index number was calculated by performing sieve analysis with standard sieves sizes, Maximum size of aggregates used was 20 mm, the cumulative percent of pumice lightweight aggregates retained on 4.75 mm sieve size was used to determine Fineness Modulus Index. Fineness modulus of aggregates is given by cumulative percentage retained on standard sieve of 4.75 mm divided by 100. Determination of Fineness modulus was based on the procedure as outlined on BS 812-103.1: 1985

## 5. RESULTS AND DISCUSSIONS

### 5.1 Gradation and fineness modulus

Results from sieve analysis showed that most of the pumice lightweight aggregates particles lie in the range between 6.0 mm and 10 mm sieve size (Figure 3), with the fineness modulus of 6.8 (Table 3). The grading limits, that is the maximum and minimum size of aggregates to be utilized in the concrete mix are classified in four categories mainly dense or well-graded aggregates which means they have gradation close to the maximum density grading curve, gap-graded aggregates which have only a small percentage of particles in the mid-size range, uniformly graded aggregates which are composed mostly of particles of the same size and Open-graded aggregates which contain only a small percentage of small sized particles, (Naseem *et al.,* 2016). Results of this study show that the pumice lightweight aggregates are well-graded aggregates (Figure 4).

The results also showed that the pumice aggregates attained a fineness modulus of 6.8 which being within the range of 6.0 – 6.9 (Table 3).

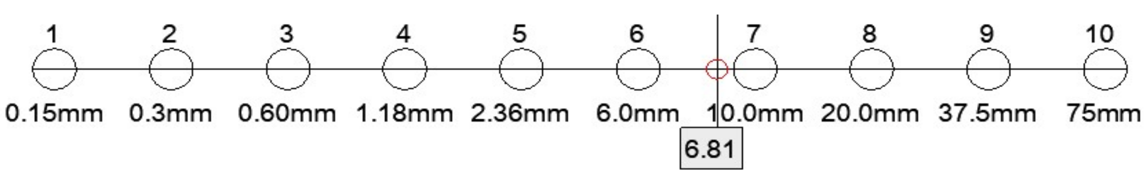


**Figure 3**: Gradation tree

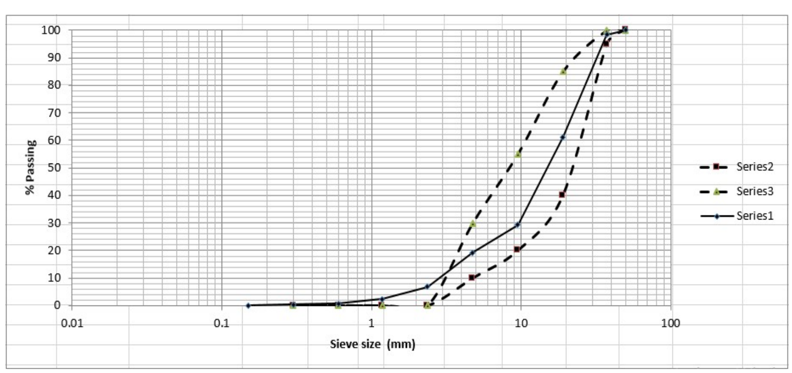


**Figure 4:** Grading envelope for course aggregates

**Table 3:** Properties of pumice lightweight aggregates

| Parameters | Value | Standard value | Reference |
|---|---|---|---|
| Specific gravity(SSD) | 1.1 | < 2.4 (lightweight) | BS 812: Part 2: 1995 |
| Water absorption (%) | 98.3 | - | BS 812: Part 2: 1995 |
| Fineness modulus Index | 6.8 | 6.0 – 6.9 | BS 812-103.1: 1985 |
| Flakiness Index [%] | 25.3% | 25 % for general work, 30 | BS 812-105.1:1989 |
| Elongation Index [%] | 23.0% | 25 % for general work, 30 | BS 812-105.1:1989 |
| Organic Impurities | Orange | See Table 2 | Kisunge (2012) |

## 5.2 Specific gravity and water absorption

The results showed that the pumice aggregates attained a specific gravity of 1.1 which being less than 2.4 showed that the pumice aggregates were lightweight aggregates. Specific gravity of aggregates also generally indicate strength of materials in which case aggregates with higher specific gravity are normally considered as having higher strength. This is a weakness of the pumice lightweight aggregates which has to be considered in concrete design and mixtures.

The results showed also that the pumice lightweight aggregates attained water absorption of 98.3% (Table 3). This showed that water absorption of pumice aggregates is very high compared to normal weight aggregates which is not greater than 3% (BS EN 1097-6:2000). The water absorption of pumice aggregates was high compared to light weight aggregates as which can be as low as 50% Vidya (2021). It should be noted, absorption begins to take place immediately as soon as the aggregates is stored.

Water absorption of aggregates as a measure of porosity of the aggregates measures materials ability to sustain the weathering effects, (BS 812:2:1995) which is the weakness of the pumice lightweight aggregates as it has high porosity. Water absorption of aggregates also results to high demand of water for concrete mixture which has negative effects to concrete. The high water demand in pumice aggregates concrete is reduced by immersing the pumice lightweight aggregates in water for 24 hours and allow it to dry for at least 15 minutes before being utilized such that the water content as well as w/c ratio for their concrete do not change much from that of normal concrete.

## 5.3 Organic impurities

The colour plate displayed an orange colour (Table 3), which means the materials are free from organic impurities which means that the pumice lightweight aggregate is a standard material which can be used for structural lightweight concrete.

## 5.4 Shape

Results for Flakiness Index of 25.3% for pumice lightweight aggregates slightly exceeds the limit of 25% whereas the Elongated Index of 23% for pumice lightweight aggregates is within the range for use in structural concrete works as shown in Table 3 (BS 812-105.1:1989).

A high percentage of flaky particles reduces fresh concrete mix workability which in turn leads to a reduced hardened concrete strength. To compensate for the reduced workability of a fresh concrete mix more quantity of binder material is demanded so as to achieve the desired fresh concrete workability and hardened concrete strength. The Flakiness Index of pumice lightweight aggregates is just above the upper limit, hence, effect of the pumice aggregates on workability of fresh concrete mix and strength of hardened concrete strength is expected to be moderate.

## 6. CONCLUSIONS AND RECOMMENDATIONS

### 6.1 Conclusion

(1) Pumice aggregates qualified as lightweight aggregates as exhibited by their low specific gravity which may be used for preparation of lightweight concrete.

(2) Pumice lightweight aggregates had flakiness and elongation indices close to upper limits as per BS 812-105.1:1989 which may have moderate effect on fresh and hardened concrete.

(3) Pumice lightweight aggregates had high water absorption in comparison to normal weight aggregates hence it is necessary to mitigate effects of high water absorption of the pumice aggregates on fresh and hardened concrete.

(4) Pumice lightweight aggregates were free from organic impurities which means that the pumice lightweight aggregate is a standard material suitable for use in structural concrete.

(5) Generally the properties of pumice aggregates are suitable for manufacture of structural lightweight concrete.

### 6.2 Recommendation

(1) Investigation is recommended on mitigation measures against shortfalls due to pumice aggregates high water absorption property.

(2) It is also recommended to study the effect of pumice aggregate on fresh concrete workability and hardened concrete strength.

(3) A study of properties of mixture of normal aggregates and pumice is recommended.

## ACKNOWLEDGEMENTS

Acknowledgement is made to the Directorate of Postgraduate Studies, Research and Publications of Mbeya University of Science and Technology (MUST) for funding the research work.

## REFERENCE

ASTM (2005) ASTM Standard C 567 - 05, in *Standard Test Method for Determining Density of Structural Lightweight Concrete*. ASTM International, West Conshohocken, PA, www.astm.org.

ASTM C127-01. (2001) *Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate*. West Conshohocken, PA: ASTM International.

ASTM C136-01. (2001) *Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates*. West Conshohocken, PA: ASTM International.

BS 812-103.1:1985, *Methods for determination of particle size distribution*

BS 812-105.1:1989, *testing aggregates. Methods for determination of particle shape Flakiness index*

BS 812-2: 1995, *testing aggregates; Methods of determination of density*

BS EN 1097-6:2000, *Tests for mechanical and physical properties of aggregates. Determination of particle density and water absorption*

Chung, Sang-Yeop, Abd Elrahman, Mohamed, Stephan, Dietmar (2017). *Effect of Different Grading of Lightweight Aggregates on the Properties of Concrete. Applied Sciences*, 7(6), 585–. Doi: 10.3390/app7060585.

Ede A. N., Olofinnade O. M., Bamigboye G. O., K. K. Shittu and Ugwu E. I., (2017) *Prediction of Fresh and Hardened Properties of Normal Concrete Via Choice of Aggregate Sizes, Concrete Mix-Ratios and Cement*, International Journal of Civil Engineering and Technology, 8(10), pp.288–301. Available on [http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=8&IType=10].

Hedjazi, S. (2020). *Compressive Strength of Lightweight Concrete*. In P. Kryvenko (Ed.), *Compressive Strength of Concrete*. Intechopen. https://doi.org/10.5772/intechopen.88057

Holm T.A. and Valsangkar A. J. (2001), Expanded Shale, Clay and Slate (ESCS), Lightweight Aggregate Soil Mechanics, Properties and Applications, Publication No. 6610. U.S.A.

Kaplan M. F (2015), The effects of the properties of coarse aggregates on the workability of concrete, Magazine of concrete research, Volume 10 Issue 29, August 1958, pp. 63-74

Kisunge J. (2012). *Road Construction Materials, basic knowledge and test procedure.*

Lorraine Murray - *Sydney Opera House*, (November 01, 2019), [https://www.britannica.com/topic/Sydney-Opera-House], visited on 4th December, 2020.

Mbakisya Onyango, Jalalya Mabojano, Masudi Senzia, Joseph Dotto, Daudi Mtavangu, (2020). *Valuation of Northern Tanzania Cinder Gravel for Roads Construction*. Journal of the Institution of Engineers Tanzania, VOL. 17 NO. 1, pp.24.

Mboya, Hieronimi & Makunza, John & Mwishwa, Yazidi. (2011). *Assessment of Pumice Blocks in Comparison to Cement Sand Blocks and Burnt Blocks* 'The Case of Mbeya City - Tanzania'. Journal of Civil Engineering Research and Practice. 8. 10.4314/jcerp.v8i1.69524.

Mohd Roji Samidi, (1997). *First report research project on lightweight concrete*, Universiti Teknologi Malaysia, Skudai, Johor Bahru.

Naseem, Shahid & Hussain, Khalid & Shahab, Bushra & Erum, Bashir & Bilal, Muhammad & Hamza, Salma. (2016). Investigation of Carbonate Rocks of Malikhore Formation as Coarse Aggregate and Dimension Stone, SE Balochistan, Pakistan. British Journal of Applied Science & Technology. 12. 1-11. 10.9734/BJAST/2016/20389.

Neville A. M. and Brook J. J. (2005), *Properties of concrete*, 4th Edition, Pearson.

Nodehi, M. A (2021), Comparative review on foam-based versus lightweight aggregate-based alkali-activated materials and geopolymer. Innov. Infrastruct. Solut. 6, 231 (2021). https://doi.org/10.1007/s41062-021-00595-w

Satish Chandra and Leif Berntsson (2002), *Lightweight Aggregate Concrete* (Science, Technology, and Applications) Chalmers University of Technology, Noyes Publications / William Andrew Publishing Norwich, New York, U.S.A

Schlaich. M. & El Zareef M. (2008), *Infra-lightweight concrete*, Taylor & Francis Group, London, ISBN 978-0-415-47535-8.

Shetty, M. S. (2009). *Concrete technology: Theory and practice*. S. Chand. https://library.dctabudhabi.ae/sirsi/detail/1227884

Vidya, Priya. (2021). Experimental study on lightweight concrete using pumice aggregate. Materials Today: Proceedings. 43. 1606-1613.

Wong, H. & Kwan, Albert. (2008). Rheology of Cement Paste: Role of Excess Water to Solid Surface Area Ratio. Journal of Materials in Civil Engineering - J MATER CIVIL ENG. 20. 10.1061/ (ASCE) 0899-1561(2008)20:2(189).