INTERNATIONAL JOURNAL OF SUSTAINABLE CONSTRUCTION ENGINEERING AND TECHNOLOGY
VOL. 14 NO. 4 (2023) 64-78

© Universiti Tun Hussein Onn Malaysia Publisher's Office

IJSCET

http://publisher.uthm.edu.my/ojs/index.php/ijscet

ISSN : 2180-3242 e-ISSN : 2600-7959

International Journal of Sustainable Construction Engineering and Technology

A Study on The Suitability of Pumice Stone Powder As A Cementitious Material in Sustainable Green Concrete Production

Teklu Amenu[1], Anteneh Geremew[1], Habtamu Ayene[1]*

[1]Faculty of Civil and Environmental Engineering,
Jimma University, 378 Jimma, ETHIOPIA

*Corresponding Author

DOI: https://doi.org/10.30880/ijscet.2023.14.04.006
Received 08 December 2022; Accepted 20 September 2023; Available online 15 October 2023

Abstract: This experimental considered involves on the performance properties of pumice powder as a supplementary cementitious material for ordinary Portland cement materials. The results showed that the pumice powder can be categorized as a pozzolanic constituents according to the ASTM C 618 standard, its main chemical composition SiO2 + Al2O3 + Fe2O3 must be higher than 70% and it was confirmed as suitable for its potential use as a supplemental cementitious resources in the production of concrete materials. As the amount of replacement of cement by the pumice powder increases its workability and density become decreases, it's delayed in setting time observed, and it requires more water to achieve standard consistency. At 25%, it was a weight reduction of up to 3.83% was observed, as a weight of cement substituted with powdered pumice, and the compressive strength of the powdered pumice specimens was replaced with a cement at different levels of 5wt%, 10wt%, 15wt%, 20wt%, and 25wt% cement resulted in a decrease after 7, 28, 56 and 90 days. In addition, it was observed in this study that its strength decreased with increasing curing age; however; replacing ordinary Portland cement with 5wt% to 10wt% pumice powder achieved the specified minimum compressive strength after a curing time of 28 days. But, a concrete sample prepared with 15% partial replacement achieved the specified minimum compressive strength after 56 days. From 15% replacement, there is then a gradual drop in its compressive strength, and the specified minimum strength was not achieved even after a curing time of 56 days it was found that the maximum strain of the concrete was replaced with a powder pumice stone is lower than conventional concrete. Based on the above property, it indicates the suitable pumice powder as a cementitious supplementary material in various concrete construction.

Keywords: Pozzolanic materials, pumice stone powder, supplementary cementitious materials, compressive strength, percentage by weight

1. Introduction

Nowadays most construction projects around the world use concrete works in various civil engineering infrastructures such as apartments, bridges or culverts, and concrete pavements (Geremew, A., et al., 2021). Various ingredients are used to produce concrete, comprising of cement, sand (fine aggregate), coarse aggregate, water, and with or without chemical additives. Nevertheless; using cement alone as a binding material generates a massive amount of heat of hydration required through a processing steps (Manjunatha, M., & Jeevan, H., 2016). However, the amount of CO_2 released into the environment during the production of ordinary Portland cement (OPC) is of the order of a ton of limestone in a cement kiln for its processing, which is the second source of environmental carbon emissions and air

---

*Corresponding author: habtamu.ayene@ju.edu.et pollution. For this reason; Total cement production contributed around 5.0-7.0% of entire carbon dioxide emissions to the atmosphere, this is one of the currently leading to global warming problems (Kumar Das, S. et al., 2018). The worldwide manufacturing of Portland cement become stated to be 4.650 billion tons in 2016 and is expected estimated to increase by approximately by exceeded 7.0 billion tons in 2050. Such cement manufacturing needs a massive quantity of natural resources and energy; it accounts for a higher proportion of CO_2 emissions in the next coming year to the environment (Rivera, R. A. et al., 2020). Nowadays, cement manufacturing companies in the industrialized country have taken initiative to reduce carbon dioxide emissions by incorporating a pozzolanic material as prescribed by ASTM C 618. Currently, ordinary Portland cement (OPC) is being replaced by supplementary cementitious materials (SCM, because of its pozzolanic properties) in concrete to preserve natural resources and promote a sustainable development in green concrete utilization. Therefore; Pozzolanic materials while reacting with a hydration product of cement materials by generating their cementing compounds. Based on this; Pozzolanic materials are divided into artificial and natural categories. Artificial pozzolanic include silica fume, fly ash, slag, and rice hull ash, while tuff, clay, shale, and pumice fall into natural categories. When OPC is replaced by pozzolanic materials, additional calcium silicate hydrate (CSH) is obtained during the hydration reaction due to the presence of pozzolanic materials that increase the strength when partially mixed with cement (Ahmad, M. R. et al., 2019). Several researchers are studying the properties of the pozzolanic material (Ishak, R., Shapie, S. S., & Lai, J. C., 2020). (Jhonatan A. Becerra-Duitama & D. Rojas-Avellaneda, 2022) (Karim , Md., 2014) (Shukla, A. et al., 2020) (Hossain, Md. U. et al., 2021). Among these pumice stones is natural pozzolanic material used as a cementitious material studied by researchers (Rashad,A. M., 2021) (Zeyad , A. M. et al.,2019) (Hedayatinia, F.et al., 2019) (Seraj, S. et al., 2017) (Ulusu, H., Aruntas, H. Y., & Gencel , O., 2016). In a particular case, in Ethiopia, there was a huge amount of this natural resource available around Wonji Melka Ida, a town in the vicinity of Adama, Ethiopia, about 110.0 km away from the capital city; Addis Ababa. Therefore; this study examines the suitability of pumice powder as a cementitious supply in sustainable green concrete production.

2. Material and Methods

2.1 Material Required

Ordinary Portland cement (Dangote cement), fine aggregate (river Sand), crushed coarse aggregate, Pipe water (drinking water), and pumice stone.

2.1.1 Ordinary Portland Cement (Dangote Cement)

The cement used during the experiment consideration was ordinary Portland cement (OPC42.5R) in according to the pre-described requirements of the ASTM C 150 standard conditions. The chemical composition of oxide, physical, and mechanical properties of the Dangote cement are given in Table 1.

Table 1 - The chemical and physical properties of Dangote cement used

Chemical Composition of major oxides		Physical properties		
Oxides	**Average value**	**Description**		**Average value**
SiO_2 (%)	21.05	Residue (%) on 75µm		9.85
Al_2O_3 (%)	5.04	Standard Consistency		29.0
Fe_2O_3 (%)	3.36	Setting Time (minutes)	I.S.T	162
CaO (%)	62.21		F.S.T	253
MgO (%)	1.39	Compressive Strength (MPa)	One day	10.26
SO_3 (%)	2.32		Three days	16.84
LOI	0.86		Twenty-eight days	41.57

2.1.2 Crushed Stone Aggregates

The coarse aggregate used in this study was a crushed stone, its nominal maximum size 20mm according to ASTM C33 stander specification. The physical properties of the coarse aggregate used are summarized in Table 2 and particle size distribution is illustrated in Figure 1.

Table 2 - Physical properties of crushed stone aggregates used

It. No.	Description		Coarse aggregate	Test methods
1	Specific gravity, (SSD)		2.76	ASTM C 127
2	Fineness modulus		6.94	ASTM C 136
3	Unit weight, (kg/m^3)	Loose	1506	ASTM C 29
		Rodded	1712	ASTM C 29
4	Water absorption capacity, (%)		0.75	ASTM C 127
5	Amount of moisture content, (%)		0.39	ASTM C 566
6	Maximum size of aggregate, (mm)		20	ASTM C 136

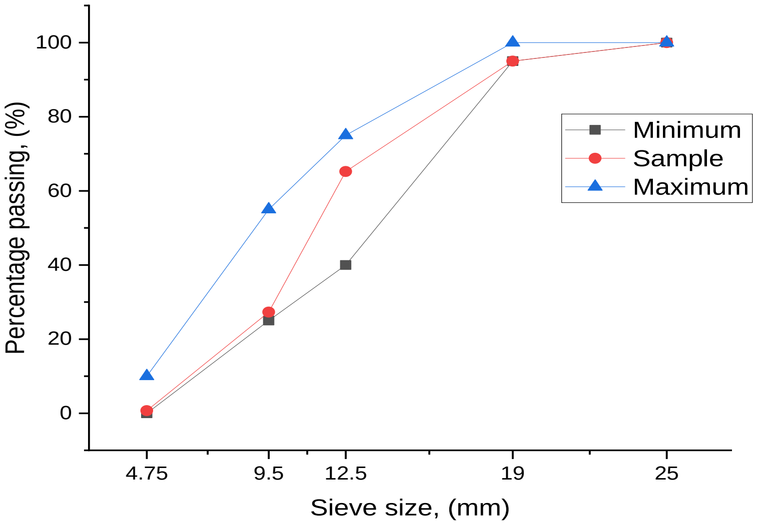

Fig. 1 - Particle size distribution curve of crushed stone aggregate

2.1.3 Fine Aggregate (Sand)

The fine aggregate used was river sand from the Gambella region (Dima sand), Ethiopia. Its Sieve analysis was carried out on typical trials conducted in according to per ASTM C 136 standard specifications. This sand was classified as a fine zone. The Physical properties of the fine aggregate (sand) used as shown in Table 3 and its Sieve size distribution curve is illustrated in Figure 2.

Table 3 - Physical properties of fine aggregate (sand) used

It. No.	Description		Fine aggregate	Test methods
1	Specific gravity, (SSD)		2.63	ASTM C 128
2	Fineness modulus		2.45	ASTM C 136
3	Unit weight, (kg/m^3)	Loose	1472	ASTM C 29
		Rodded	1657	ASTM C 29
4	Silt content, (%)		1.10	ASTM C 117
5	Water absorption capacity, (%)		1.63	ASTM C 128
6	Moisture content, (%)		0.47	ASTM C 566
7	Maximum size of aggregate, (mm)		4.75	ASTM C 136

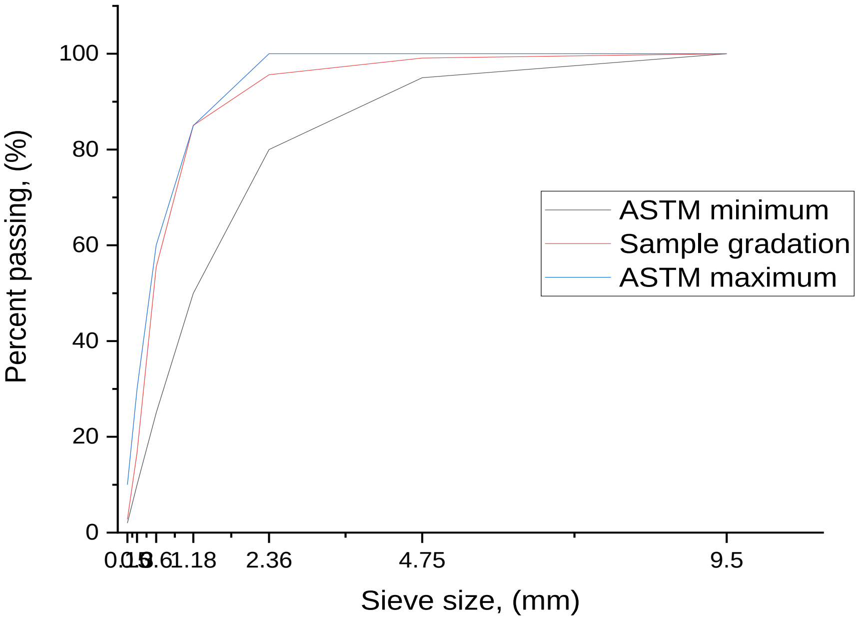

Fig. 2 - Particle size distribution curve of fine aggregate (sand)

2.1.4 Pumice Stone

In a particular case, in Ethiopia, there was a huge amount of this natural resource available around Wonji Melka Ida, a town in the near vicinity of Adama, Ethiopia, approximately 110.0 km away from the capital city; Addis Ababa in the form of fractured aggregate.

2.1.5 Pipe Water (Drinking Water)

Tape water which is used for drinking purposes was used in this experimental work for mixing and curing concrete specimens.

2.2 Preparation Process of Pumice Stone Powder

The primary stage is to prepare the pumice stone for partial replacement of cement, it shall be grounded to a fine powder. Its fineness degree depends on the process and effort of the grounding method used during preparation. In this study, LAA (Los Angeles Abrasion) machine was used to ground the pumice. Therefore, LAA machine was used to ground the whole amount of pumice stone used in this study. As in Figure 3 shows the Preparation of the process of Pumice stone powder by using Los Angeles Abrasion Machine.

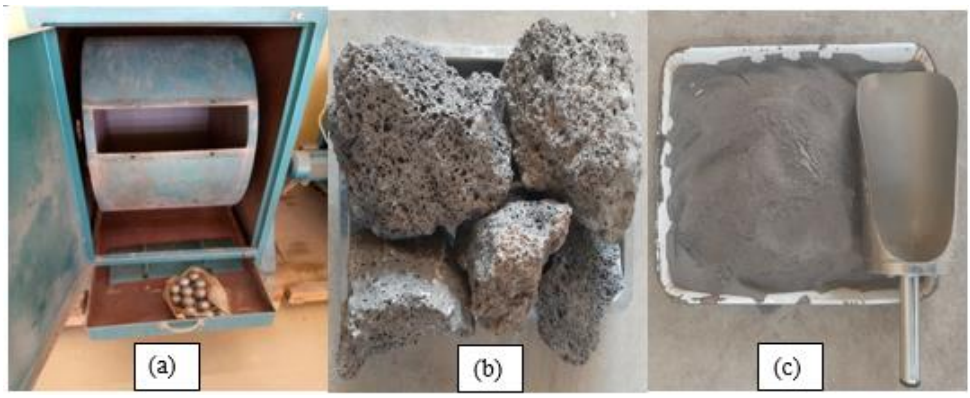

Fig. 3 - (a) Los Angeles Abrasion machine; (b) pumice stone; (c) grounded pumice powder

The following procedure was used during the preparation process for Grounded pumice powder formation:

i. First, the raw pumice stone was oven-dried for around 24.0 hrs at a temperature of 110.0 ℃ to an electric oven to make the pumice stone surface dried and this; helps to facilitate LAA machine for the grounding process.
ii. Secondly; Grounded pumice powder was collected with a pan and further a sieving process was carried out by using 75-micron standard sieve size; until it passed this sieve size.
iii. In order to make assured that a fineness degree was similar to or greater than OPC until attained, a trial practice was implemented to arrive a reasonable level of fineness achieved in the process. After this, in each trial, with a specified revolution, the fineness of the grounded pumice was measured using the Air Permeability method adopted specifically by the Blain apparatus.

2.3 Research Design

To attain this study an experimental research method was adopted. The characteristics of the constituents for the concrete were determined in order to prove the suitability of the ingredients for concrete product. The right combination of cement (binder), fine aggregate (sand), coarse aggregate, and water for a C-25 grade concrete was attained by using ACI 211.1 mix design method. Based on this Mix design different experiments were carried out on the fresh and hardened mechanical properties of concrete with varied pumice powder content as a partial substitute of cement in concrete production.

2.4 Sample Size and Sampling Procedure

The sampling technique that was adopted was the non-probability selection technique which is a purposive technique used to collect sampling, and this practice was fulfilled in according to ASTM and ACI standards. For a concrete experimental investigation, the samples were prepared based on the types of test requirements that is available and required standards procedures. A total number of 72 concrete cubic specimens of standard size 150 mm using one cement type was cast and tested for compressive strength at the ages of 7, 28, 56, and 90 days.

2.5 Sample Preparation for Concrete Production

2.5.1 (Mix Proportioning)

In this investigation, the ACI 211.1 method of concrete mix design was used as in mix design guideline to design a concrete grade having a minimum strength of 25 MPa with 28 days of curing (C-25). The design inputs such as dry rodded unit weight of coarse and fine aggregate, absorption of coarse and fine aggregate, density, and specific gravity of the ingredients have first been determined in the laboratory as described in the material section of this study. The water-cement ratio of 0.54 was adopted based on trial mixes. On this base, six different types of concrete mixes were prepared grounded on different levels of Pumice powder replacement (0%, 5.0%, 10.0%, 15.0%, 20.0%, and 25.0% by weight of cement). The concrete was designed to be at the slump value of 25-75mm. But since the trial mixtures slump value has been measured 20 mm at the start of the experimental study, extra water has been added to the trial concrete mixture and other mixtures. So, the water-cement ratio of the control mixture has come to the value 0.54 with a slump measurement of 42mm. For the whole mixes, 1:1.94:3.10 binder, fine and coarse aggregate ratio respectively, and water to binder ratio was kept constant at 0.54 by weight of cementitious material. Based on this; the proportions of all the mixes are presented in Table 4.

Table 4 - Quantity of concrete ingredients for 1 m^3 by ACI 211.1 method

Ingredients	Source	Quantity/m^3
Cement, kg/m^3	Dangote	370
Fine aggregate, kg/m^3	Dima; Ethiopia	718
Coarse aggregate, kg/m^3	Jimma; Ethiopia	1143
Water, kg/m^3	Tape water	199.8
Water-to-cement ratio	-	0.54

2.5.2 (Mixing, Casting and Curing Process

Firstly; a mixing process started: at this step a batching of cement, aggregates, and water was done by weighing. A pan-type mixer with a maximum output capacity of 125 litter was used to produce the concrete mixtures. Mixing the concrete materials was performed by loading the coarse aggregate first followed by the cement, the sand, and finally the water. Before mixing concrete, the pumice powder was dry and mixed with cement until a uniform texture is obtained. Before starting the rotation of the mixer, the coarse aggregate, and some of the mixing water were added. After starting the mixer, the fine aggregate, cement, and water were added to the stopped mixer after permitting it to turn a few revolutions following charging with coarse aggregate and some of the water. After all, the ingredients are in the mixer, the concrete was mixed for 3-minutes followed by a 2-minutes rest, followed by a 2-minutes final mixing. To eliminate isolation of aggregates from mix, the mixed concrete was deposited in the clean, damp mixing tray and remixed by shovel until it appears to be invariant as per ASTM C 192.

Secondly casting and curing process: The concrete mixtures were cast in molds in three layers and consolidated using a tamping rod. Each layer was tamped 25 times with a standard 16 mm diameter and 600 mm length steel rod. After each layer was rodded, the outsides of the mold were lightly tapped 10 times with the mallet to close any holes left by rodding and to release any large air bubbles that may have been trapped. In all, the test samples included 150 mm concrete cubic specimens prepared for the compression test as shown in Figure 4. All the experiments were done at a room temperature of approximately 20℃ ± 3℃. The concrete specimens were removed from their moulds 24 hrs. After casting, they were further wet-cured until the moment of testing. Three samples were tested for each age date and the average result was reported.

Fig. 4 - Photos of casted cube specimens

2.6 Details of Experimental Tests Carried Out

2.6.1 Normal Consistency of Blended Paste

To ensure a complete chemical response between water and cement, a certain minimum volume of water has to be mixed with cement. Lower water volumes would result in a deficient chemical response, resulting in a reduction in strength. Furthermore, adding more water would increase the water-cement rate, reducing the strength. To achieve proper strength while using cement in the structure, the correct proportion of water to cement is required. A standard consistency test of blended cement pastes was performed to determine the appropriate amount of water. According to ASTM C 187 is used to determine the standard consistency of cement pastes and blended pastes.

2.6.2 Setting Times of Blended Paste

The Vicat apparatus, which measures the resistance of a standard consistency cement paste to needle penetration, is used to determine the initial and final setting times. Setting times and soundness of standard consistency paste prepared by replacing cement with 5%, 10%, 15%, 20%, and 25% pumice were determined according to ASTM C 191. In general, a standard consistency paste has a water-to-cement ratio of 26% to 33%, according to ASTM C 187. The initial setting time of cement should not be less than 45 minutes, and the final setting time should not be more than 375 minutes, according to ASTM C 150.

2.6.3 Workability

In accordance with ASTM C 143, a slump test was used to determine the workability of fresh concrete. Concrete was placed in the slump cone in three roughly equal layers and consolidated by rodding each layer 25 times with a round, straight steel rod, as specified by this standard. After compacting the top layer, the excess concrete was struck off and the mould was slowly removed, as shown in Figure 5. Workability was also determined by measuring the difference in position between the height of the inverted cone and the top point of the subsided concrete and reporting the result as a slump value.

Fig. 5 - Workability of concrete with (a) 0% and; (b) 10% pumice content

2.6.4 Density (Unit Weight) Fresh Concrete

The density of fresh concrete was determined as per ASTM C-138. For fresh density specimens, the mass and capacity of volume of the measure have first been measured. Then the mass of the measure with the specimen is measured. The net mass of the concrete was determined by calculating the difference between the mass of the measure, M_m, from that of the mass of the measure filled with a concrete, M_c. Then; the unit weight, γ_c, of concrete is obtained from the ratio of the net mass of concrete to the volume of the measure Vm; as follows:

$$\gamma c = \frac{\mathrm{Mm}-\mathrm{Mc}}{\mathrm{Vm}} \qquad (1)$$

2.6.5 Compressive Strength

The test for uniaxial compressive strength was carried out as per in accordance with ASTM C 39 and BS1881: part 116:1983. The compressive strength of the concrete was evaluated from cubic specimens by applying a compressive force which is loading a constant rate of 0.3 MPa/sec until the specimen become fails. A total of 72 cubic concrete specimens were prepared for the compression tests of 7, 28, 56, and 90 days. For each testing age, three specimens were tested after the curing ages using an adjustable encoded compression testing machine having a capacity of 2000 KN.

2.7 Mix Designations

The following are the details of descriptions and designations of concrete mixes used in the experimental study illustrated in Table 5.

Table 5 - Mix designations

Designation	Description
PP_0	Portland cement concrete produced with 0 % replacement of pumice powder
PP_5	Portland cement concrete produced with 5 % replacement of pumice powder
PP_{10}	Portland cement concrete produced with 10 % replacement of pumice powder
PP_{15}	Portland cement concrete produced with 15 % replacement of pumice powder
PP_{20}	Portland cement concrete produced with 20 % replacement of pumice powder

PP_{25}	Portland cement concrete produced with 25 % replacement of pumice powder

2. Results and Discussion

3.1 Chemical Characterization of Pumice Powder

The analytical analysis manner was adopted to determine its chemical compositions elemental of Grounded stone pumice powder and the obtained result was compiled in Table 6. The pumice powder used in this consideration has 84.18 % of the prominent oxides ($SiO_2 + Al_2O_3 + Fe_2O_3 = 84.18$ %). These outcomes confirmed that the crucial chemical compositions, which are ($SiO_2 + Al_2O_3 + Fe_2O_3 = 84.18\%$), are greater than 70.0%. As per ASTM C 618 specification, the pumice powder is satisfying the conditions of natural pozzolans for use in concrete and is classified as class N pozzolanic supplementary cementitious material as per ASTM C 618. The amount of $SiO_{2\ \mathrm{in}}$ pumice powder was higher than that of the content in ordinary Portland cement. The Pumice powder had cementitious compounds like calcium oxide, aluminum oxide, and iron oxide with a aggregate of about 21.05%. However, the CaO content of pumice powder (PP) was very low (2.65%) when compared with ordinary Portland cement (OPC). This indicates that pumice stone powder would produce lower satisfactory results in terms of strength when compared to OPC. Aluminum oxide makes a little direct contribution to the strength of Portland cement. Fe_2O_3 content (6.29%), which is nearly low, has no effect on cement but acts as a flux to prop cement and gives it a grey color. The other some minor ingredients like TiO_2, MnO, and P_2O_3 which were less than 1.0% and don't affect the strength characteristics of cement products. Its physical property such as the Blaine-specific surface area (fineness-specific surface) of the pumice powder indicated 3560 cm^2/gm and a coarser of 30.05% in 45 microns' sieve. The test results satisfied the conditions based on ASTM C-618 specification. Therefore, it is acceptable to use pumice stone powder as a supplementary cementitious material in concrete production.

Table 6 - The chemical of the pumice powder used

Chemical Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	MnO	P_2O5	TiO_2	H_2O	LoI
Content (%)	65.82	12.07	6.29	2.69	0.94	2.95	0.66	0.19	0.06	0.15	0.89	4.62

3.2 Standard Consistency of The Paste

Table 7 shows the standard consistency results of the blended paste containing different replacement levels of pumice powder. The variation of standard consistency of cement pastes with different pumice powder contents is determined as per ASTM C 187. The control cement pastes has a normal consistency of 29.0%. All the other pastes containing partial added with pumice powder showed standard consistency lower than the reference paste. The usual range of water-to-cement ratio for normal consistency is between 26% and 33% [17]. The powder pastes with replacements 5% and 10.0% showed consistency within the standard limits; however, after 10% replacement level the results showed lower values of consistency. The results show that the incorporation of pumice powder as Supplementary Cementitious Material has resulted in increased water demand to achieve standard consistency, which could be due to the rough and high-water absorbing properties of pumice powder.

3.3 Setting Times of The Paste

The amount of setting times of the mixed paste containing different replacement levels of pumice powder are indicated in Figure 6. The Standard setting time was determined from a mean of three sets of samples of respectively replacement level of blended cement pastes. The partial replacement of 5% pumice powder delayed the initial setting time by 22 minutes and the final setting time by 32 minutes when compared to the reference paste. The partial replacements of 10.0% pumice powder delayed the initial setting time by 40 minutes and the final setting time approximately by 1 hour. The partial replacement of cement with 25% pumice powder delayed the initial setting time by 1 hour and the final setting time by 2 hours approximately. It was observed that the common impact of the pumice stone powder was higher both in the initial and final setting times of powder incorporated pastes. This could be because of the slow reaction process of pumice powder as compared to the reference cement paste. The Ethiopian code of standard limits requirements for the initial setting time of cement not to be less than 45 minutes and its final setting time not to exceed 10 hrs. The results of this investigation showed that the partial replacement of pumice powder in cement delayed the setting times; Still, this deceleration was within the ranges as per Ethiopian standard, ASTM C 150 standard, and other related standards.

Table 7 - Setting time, and Standard consistency of blended pastes with various PP content

Mix ID	Initial setting time, (minutes)	Final setting time, (minutes)	Normal consistency, (%)	The soundness of the paste, (%)
PP0	162	253	29.0	1.3
PP5	184	285	31.0	-
PP10	202	310	31.5	-
PP15	227	331	33.0	-
PP20	241	342	33.5	-
PP25	258	363	34.5	-

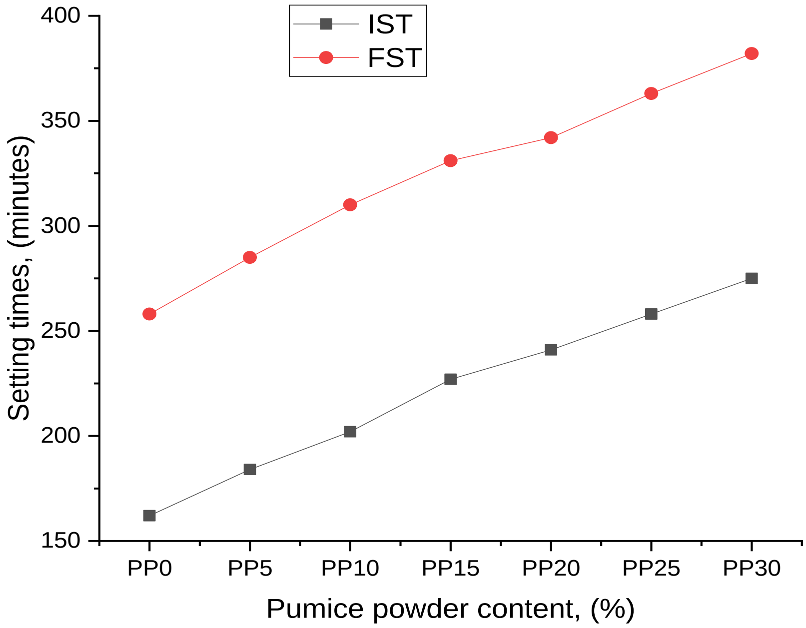

Fig. 6 - Graph of setting time versus pumice powder content

3.4 Effect of Pumice Powder Content on The Density of Fresh Concrete

The results of the density test of fresh concrete are shown in Table 8. The densities of fresh concrete at 0% pumice content, show higher densities than all other replacement levels. The density of fresh concrete at 0% pumice content is slightly higher than that of 5% pumice powder content. When the pumice powder content is increased from 0% to 25%, the density of fresh concrete is slightly reduced. Usually, the fresh density of normal-weight concrete is approximately 2200 to 2600 kg/m^3. The test result shows that as the replacement level of pumice powder increases the density of fresh concrete decreases as presented in Figure 7. The density reduction is directly related to pumice powder, which is a natural low-dense material that can significantly lower the dead load of concrete by reducing the cross-section of structural members and reducing the cost of concrete production.

Table 8 - Unit weight and slump of fresh concrete

Mix ID	Pumice powder content, (%)	Density of fresh concrete, (kg/m^3)	Density reduction, (%)	Slump value, (mm)	Slump reduction, (%)
PP0	0 (reference)	2454	—	42	0
PP5	5	2399	2.24	35	12
PP10	10	2392	2.53	29	26
PP15	15	2389	2.65	20	52
PP20	20	2377	3.14	11	74
PP25	25	2360	3.83	5	88

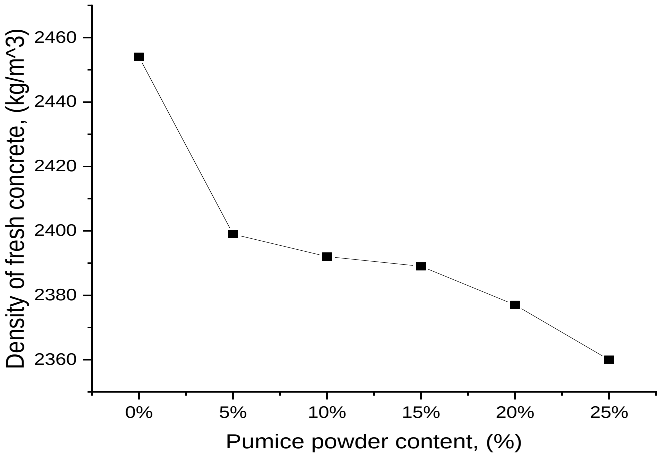

Fig. 7 - Graph of Density of fresh content versus pumice powder content

3.5 Impact of Pumice Stone Powder on Workability of Fresh Concrete

A slump test was performed to investigate the effect of pumice powder replacement on the workability of freshly mixed concrete. The summary of slump test results is presented in Table 8 above and in Figure 8 below. Based on this the reference mix shows better workability as compared to other mixtures. Therefore; as the replacement rate of pumice powder increases from 0 to 5 % the slump reduced by 12 % (7mm), since the replacement rate is significant the amount of water added to the concrete mixture during adjustment also increases, which balances the workability of the mixture. As the replacement rate of Pumice powder increases from 0 to 10%, the slump was decreased by 26% (13mm) the reason behind this is the increment in water demand due to the presence of pumice powder. Further, as the replacement rate of pumice powder increases from 0 to 25 %, there is a significant reduction in the slump by 88% (37mm) due to the significant increment of water demand at this replacement level. Indeed, though the workability is reduced as the replacement of pumice powder is increased, until the replacement level is 10% the slump value is within the standard ranges, that is 25 mm to 75 mm. In general, an increase in the replacement rate of pumice stone powder reduces the workability of freshly mixed concrete. The reason behind this is when a part of cement is partially replaced by the pumice powder the concentration of silicon is increased this, in turn, increases the water demand in order to produce concrete with satisfactory workability. This argument is also revealed by [18].

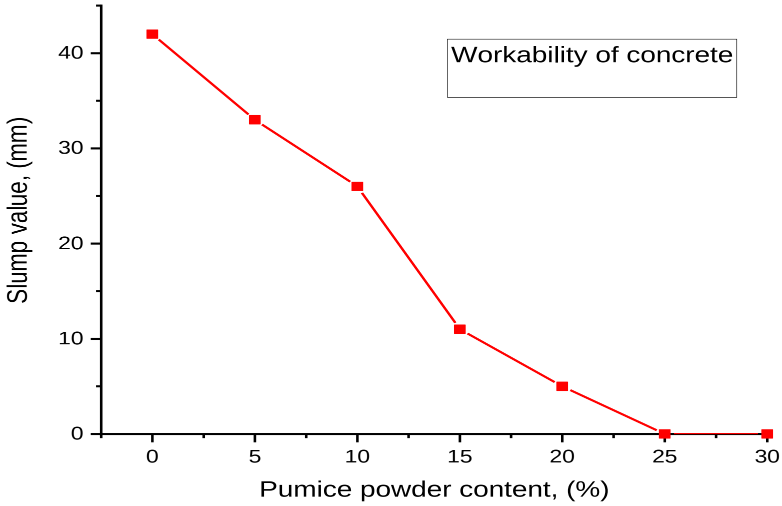

Fig. 8 - Graph of slump versus percentage replaced by pumice powder content

3.6 Effect of Pumice Powder Content on Compressive Strength of Hardened Concrete

The compressive strength of Pumice powder replaced concrete specimens and reference concrete specimens were determined at 7, 28, 56, and 90 days illustrated in Figure 9. The compressive strength test results as a function of curing age are presented in Figure 9. It can be seen that the compressive test results of specimens decrease as the replacement of pumice powder content increases. Concrete specimens made with 5 % and 10 % replacement level of cement with pumice powder achieved the target mean strength after 28 days of curing age. But specimens made with 15% partial replacement of cement with pumice powder satisfied the minimum specified concrete strength after 56-days curing age. The addition of pumice powder above 15% resulted in a decrease in compressive strength at later ages. To compare to the reference mixture, 28 days of compressive strength results indicated that the incorporation of 5%, 10%, 15% 20%, and 25% pumice powder led to a decrease of concrete compressive strength by 7%, 10%, 21%, 30%, and 41% respectively. Using the pumice powder content of 5%, 10%, 15%, 20%, and 25%; on each testing day, the compressive strength of specimens had shown a slight reduction when compared to that of reference specimens shown in Table 9. The reason behind this could be the partial substitution of cement for a relatively slow-reacting material or pumice powder. At 56 days 5% pumice powder replaced concrete specimens showed that 7.81% reduction in compressive strength when compared to that of 56 days' compressive strength of reference mixes (control mix). At 56 days 10% pumice powder replaced concrete specimens showed 11.67% reduction in compressive strength when compared to that of 56 days' compressive strength of reference mixes. At 56 days 25% pumice powder replaced concrete specimens showed 38.88% reduction in compressive strength when compared to that of 56 days' compressive strength of reference mixes. At 90 days 5% pumice powder replaced concrete specimens showed 11.26% reduction in compressive strength when compared to that of 90 days' compressive strength of reference mixes. At 90 days 10% pumice powder replaced concrete specimens showed 16.63% reduction in compressive strength when compared to that of 90 days' compressive strength of reference mixes. At 90 days 25% pumice powder replaced concrete specimens showed 43.79% reduction in compressive strength when compared to that of 90 days' compressive strength of reference mixes. Therefore, grounded pumice powder can replace Portland cement at replacement levels of 5.0%, 10.0%, and 15.0% without compromising strength and with a slight effect on workability and curing age. The best replacement level for a higher amount of compressive strength is at 5% and 10% other replacement level such as 15% is also possible but 15% replacement level requires more curing times to satisfy the specified strengths (56 days). The compressive strength results of pumice powder replaced concrete in the past agrees with the findings of this research. In general, the concrete specimens showed an increase in compressive strength with increasing curing time. However, as a replacement level of pumice stone powder increases the compressive strength results of concrete specimens showed a reduction when compared to that of reference mixes. This is consistent with the data collected by [19].

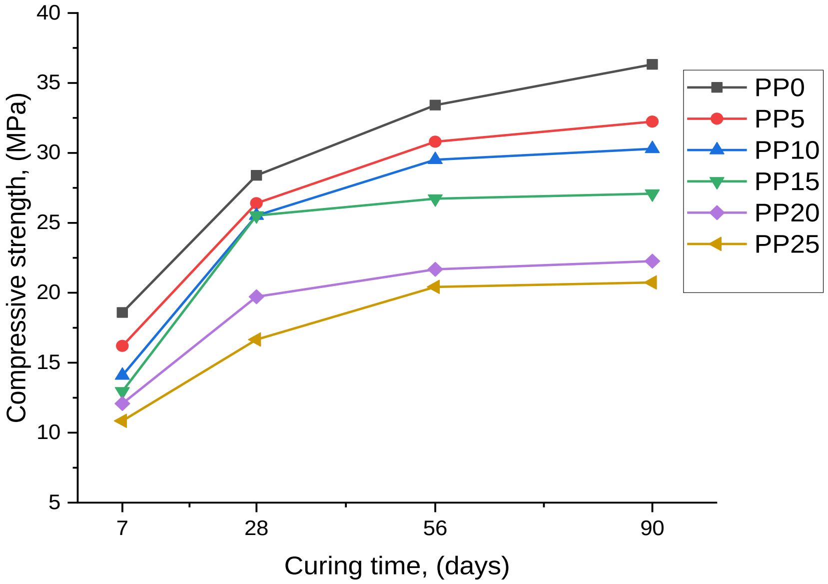

Fig. 9 - Compressive strength of concrete specimens versus time

Table 9 - Percentage reduction of mean compressive strength from the reference mix

Mix ID	Pumice powder replacement, (%)	Curing age (days)			
		7	28	56	90
PP0	0	-	-	-	-
PP5	5	12.86	7.01	7.81	11.26
PP10	10	24.21	10.11	11.67	16.63
PP15	15	30.34	20.64	19.99	26.42
PP20	20	35.02	30.54	35.11	40.32
PP25	25	41.69	41.32	38.88	43.79

3.7 Stress-strain Relationship for Compressive Strength Test Results

The graph of stress versus strain is drawn by selecting a better curve from each mixture and sample for comparison with the reference mixtures. Figures 10 to 13 depicts the maximum compressive stress and the corresponding strain for 7, 28, 56, and 90 days' test results. In the analysis of the stress versus strain relationship and specification of failure criteria in the concrete structure, one of the key parameters was a strain at maximum stress. In this study, the peak strain of pumice powder replaced concrete was found to be lower than conventional concrete. From the stress-strain results, pumice powder replaced concrete varied due to pumice powder content. From the stress-strain curve, for all mixtures, the compressive stress and the corresponding strain are directly related to some extent. This shows in the elastic range of concrete, once the peak load is reached, the load-carrying capacity (ductile properties of concrete) is changed for each mixture based on the replacement rate of pumice powder.

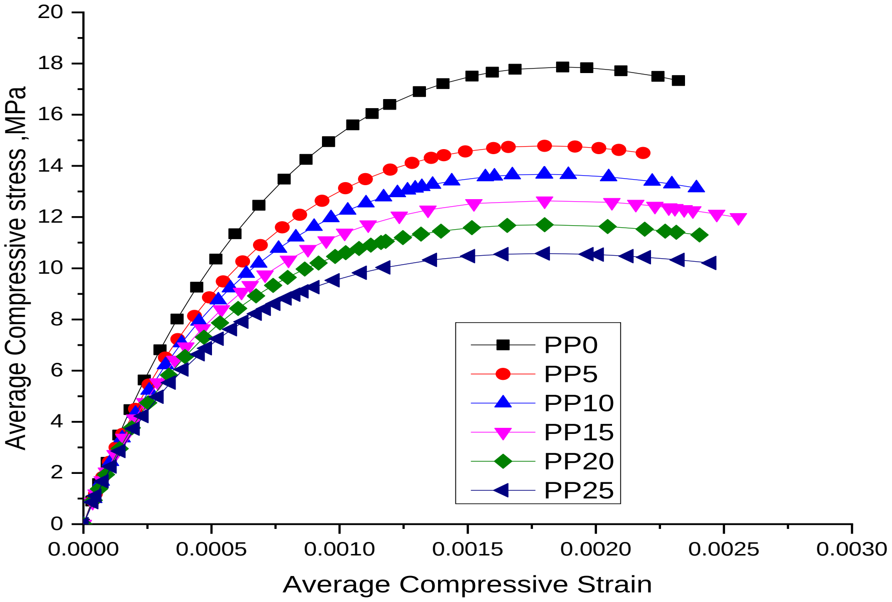

Fig. 10 - Stress-strain curve for 7-days compressive strength results

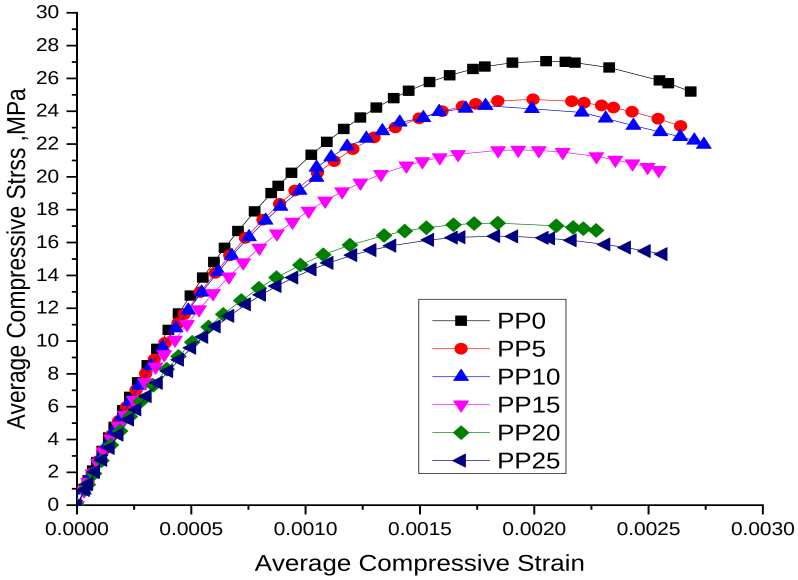

Fig. 11 - Graph of Stress-strain for 28-days results

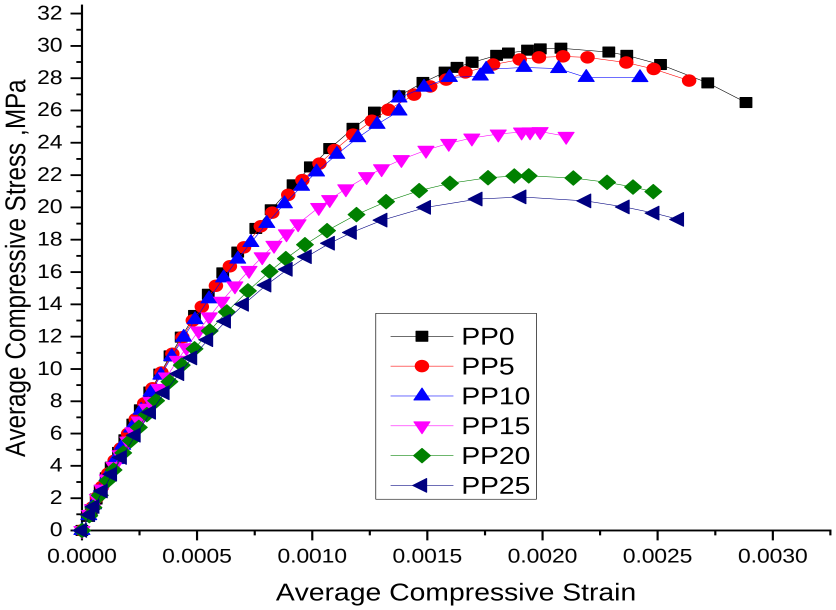

Fig. 12 - Stress-strain curve for 56-days compressive strength results

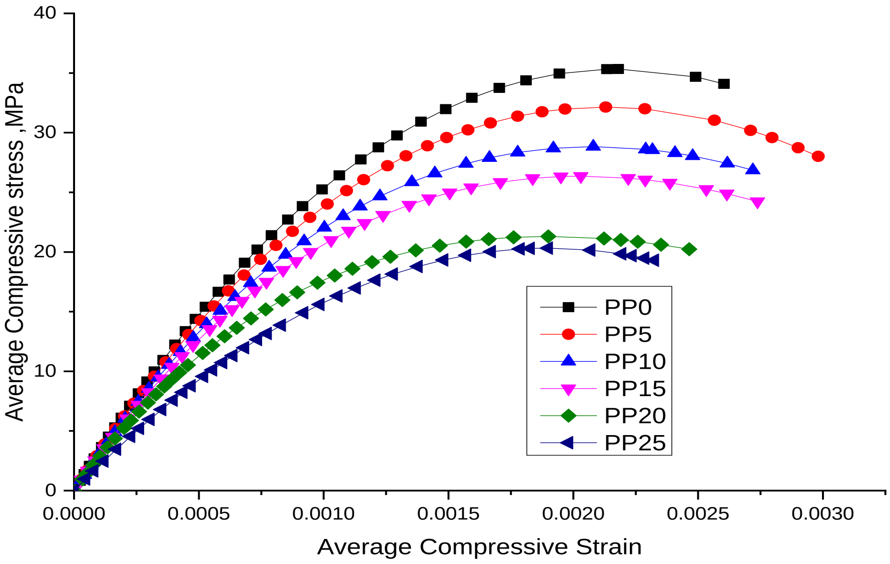

Fig. 13 - Stress-strain curve for 90-days compressive strength results

4. Conclusion

Based on this experimental study the following findings are highlighted:

- The results showed that the pumice powder can be classified as a natural pozzolan according to the ASTM C 618 standard, its main chemical oxides (SiO_2+ Al_2O_3+ Fe_2O_3) should be higher than 70 % and it was confirmed as suitable for its potential use as a supplementary cementitious material in the concrete constructions.
- As the amount of replacement of cement by the pumice powder increases its workability and density become decreases, it's delayed in setting time observed, and it requires more water to achieve standard consistency. At 25%, density reduction of up to 3.83% was observed, the weight of the cement was replaced with powdered pumice, and the compressive strength of the powdered pumice samples was determined with cement at different replacement levels of 5wt%, 10wt%, 15wt%, 20wt%, and 25wt% cement resulted in a decrease after 7, 28, 56 and 90 days.
- In addition, it was observed in this study that its strength decreased with increasing curing age; however; replacing ordinary Portland cement with 5wt% to 10wt% pumice powder achieved the specified minimum compressive strength after a curing time of 28 days. But, a concrete sample prepared with 15% partial replacement achieved the specified minimum compressive strength after 56 days. From 15% replacement, there is then a gradual drop in compressive strength, and the specified minimum strength was not achieved even after a curing time of 56 days it was found that the maximum strain of the concrete was replaced with a powder pumice stone is lower than conventional concrete.
- Based on the above property, it indicates the suitable pumice powder as a cementitious supplementary material in the production of concrete.

Acknowledgement

The authors would like to thank and acknowledge the Jimma University, Ethiopia for all kinds of support given.

References

Ahmad,M. R., Sharif, M. B., Ali , H. A., Hussain, M., & B. Chen. (2019). Experimental investigation of pozzolanic concrete containing wheat straw ash, *Can. J. Civ. Eng.*, 46(10), 941–951. doi: 10.1139/cjce-2017-0419.

Dinku, A.. (2002). Construction Materials-Laboratory Manual, Addis Ababa University

Geremew, A., De Winne, P., Demissie, T. A., & De Backer, H. (2021). Treatment of Natural Fiber for Application in Concrete Pavement, *Advances in Civil Engineering*, vol. 2021, 1–13. doi: 10.1155/2021/6667965.

Hedayatinia, F., Delnavaz, M., & Emamzadeh, S. S. (2019). Rheological properties, compressive strength and life cycle assessment of self-compacting concrete containing natural pumice pozzolan, *Construction and Building Materials*, 206, 122–129. doi: 10.1016/j.conbuildmat.2019.02.059.

Hossain, Md. U., Cai , R., Ng , S. T., Xuan, D., & Ye, H. (2021). Sustainable natural pozzolana concrete – A comparative study on its environmental performance against concretes with other industrial by-products, *Construction and Building Materials*, 270, p. 1-10. doi: 10.1016/j.conbuildmat.2020.121429.

Ishak, R., Shapie, S. S., & Lai, J. C. (2020). Use of Natural Pozzolanic Material as Partial Replacement Ordinary Portland cement (OPC) in Concrete, *IJARBSS*, 10(9), 1077-1087. doi: 10.6007/IJARBSS/v10-i9/7987

Jhonatan A. Becerra-Duitama & D. Rojas-Avellaneda. (2022). Pozzolans: A review, *Engineering and Applied Science Research*, 49(4), 495-504. doi: 10.14456/EASR.2022.49.

Kabay, N., Tufekci, M. M., Kizilkanat, A. B., & Oktay, D. (2015). Properties of concrete with pumice powder and fly ash as cement replacement materials," *Construction and Building Materials*, 85, 1–8. doi: 10.1016/j.conbuildmat.2015.03.026.

Karim , Md., Hossain , Md., Khan , M., Zain , M., Jamil , M., and Lai , F. (2014). On the Utilization of Pozzolanic Wastes as an Alternative Resource of Cement, *Materials*, 7(12), 7809–7827, Dec. 2014, doi: 10.3390/ma7127809.

Kumar Das, S., Mishra, J., & Mohammed Mustakim, S. (2018). An Overview of Current Research Trends in Geopolymer Concrete, 5(11), 376–381.

Malhotra, V M. Fly ash, silica fume, slag, and natural pozzolans in concrete. United States.

Manjunatha, M., & Jeevan, H. (2016). Study of Early Age Properties and Behaviour of Concrete with GGBS as Partial Replacement of Cement," *Sci. Technol. Arts Res. J.*, 4(4), 148-155. doi: 10.4314/star.v4i4.22.

Mboya, H. A., King'ondu , C. K., Njau , K. N., & Mrema , A. L.. (2017). Measurement of Pozzolanic Activity Index of Scoria, Pumice, and Rice Husk Ash as Potential Supplementary Cementitious Materials for Portland cement," *Advances in Civil Engineering*, 2017, 1–13. doi: 10.1155/2017/6952645.

Rashad,A. M. (2021). An Overview of Pumice Stone as a Cementitious Material – the Best Manual for Civil Engineer, *Silicon*, 13(2), 551–572. doi: 10.1007/s12633-020-00469-3.

Rivera, R. A., Sanjuán,M. Á., & Martín, D. A. (2020). Granulated Blast-Furnace Slag and Coal Fly Ash Ternary Portland Cements Optimization, *Sustainability*, 12(14), 1-15. doi:10.3390/su12145783.

Seraj, S., Cano , R., Ferron , R. D., & Juenger , M. C. G.. (2017). The role of particle size on the performance of pumice as a supplementary cementitious material, *Cement and Concrete Composites*, 80, 135–142. doi: 10.1016/j.cemconcomp.2017.03.009.

Shukla, A., Gupta, N., Gupta , A., Goel , R., & Kumar , S. (2020). Natural Pozzolans a Comparative Study: A Review," in *IOP Conference Series: Materials Science and Engineering*, 804, 1-9. doi: 10.1088/1757-899X/804/1/012040.

Ulusu, H., Aruntas, H. Y., & Gencel , O. (2016). Investigation on characteristics of blended cements containing pumice," *Construction and Building Materials*, 118, 11–19. doi: 10.1016/j.conbuildmat.2016.05.030.

Zeyad , A. M., Tayeh , B. A., &Yusuf , M. O. (2019). Strength and transport characteristics of volcanic pumice powder based high strength concrete," *Construction and Building Materials 216*, 314–324, doi: 10.1016/j.conbuildmat.2019.05.026.