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DETERMINATION OF GEOPOLYMER MORTAR CHARACTERIZATION USING FLY ASH AND PUMICE SAND

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ABSTRACT: The cement-making process is one of the highest contributors to atmospheric CO_2 levels, leading to wide consideration and analysis of alternative cement substitutes. One of the materials widely used as a substitute is fly ash, whose properties are similar to cement. It is also abundant in nature due to the combustion of coal furnaces at the Rum Steam Power Plant. Therefore, this study aims to determine the effect of heating in the geopolymer mortar treatment process. The test object was a cube mortar containing a mixture of cement, fly ash, water, and an activator, with dimensions of $5 \times 5 \times 5$ cm^3. The utilized Class-C fly ash also had a calcium content above 10%. In this process, the specimens produced were then heated in an oven for 24 h at temperatures of 20°C, 40°C, 60°C, 80°C, and 100°C. This heating process emphasized the determination of the best temperature responsible for the production of maximum compressive strength in geopolymer mortar. Based on the results, higher heating temperatures led to better compressive strength. This indicated that the 8M and 10M geopolymer mortar produced compressive strength of 17.60 and 18.60 MPa at 100°C heating, respectively. In addition, higher molarity provided better compressive strength in geopolymer mortar.

Keywords: Pumice Sand, Compressive Strength, Geopolymer Mortar, Light Mortar

1. INTRODUCTION

Indonesia is one of the largest coal-producing countries in the world, whose yearly increase in Steam Power Plants development is observed in Java, Sulawesi, Kalimantan, and North Maluku. Based on these plants, the operation process uses coal as fuel, with the waste generated producing 5% solid materials of the total composition. These materials are often observed as bottom and fly ashes with 80-90% and 10-20% contents, respectively. In this case, fly ash is commonly dumped or used as landfill material, leading to a bad environmental effect. In many developed countries, this material has been ogled as an alternative for environmentally friendly concrete. This is to replace conventional cement, suspected to be the largest CO_2 contributor during the production process, which has contributed 2.8 million tons of CO_2 gas yearly, or approximately 7% of the world's total pollution [1]. Since this solid waste has no specific handling processes, it is often placed in an open area, leading to potential environmental pollution. One of the solutions emphasizes its utilization as an added material in the field of civil engineerings, such as a mixture of concrete and mortar [2, 3, 4].

Several studies have analyzed the use of fly ash as a binder to replace cement in geopolymer concrete or mortar. The contained silica and aluminum elements were reportedly dissolved by adding an activator solution [5, 6]. In this process, the geopolymer material was then combined with fine aggregates to produce a G.M. (geopolymer mortar) without the use of cement. This indicates that geopolymer concrete is environmentally friendly due to its industrial waste usability and non-requirement of high energy during the production process. Many reports have also been conducted on geopolymer as a binder, including those examining the effect of molarity on the compressive strength of G.M. The results concluded that molarity affected compressive strength [7, 8, 9, 10]. In geopolymer mortar production, a treatment method is very important, such as the heating technique, which helps to polymerize the material's paste [11, 12, 13, 14].

As the basic material for wall/partition brick production, mortar often influenced the addition of dead loads to the building structure. In this context, an alternative prioritizes the use of lightweight aggregate as a mortar constituent, whereas pumice sand is commonly used as a fine particle. This sand is an abundant material in Indonesia, mostly distributed in Jambi, Lampung, West Java, Banten, Jogjakarta, West and East Nusa Tenggara, as well as North Maluku. For the North Maluku region, the aggregate deposits are precisely located on Tidore Island [15].

According to several previous reports, the use of pumice sand was also confirmed, including its replacement for coarse aggregate at volumes of 20%, 80%, and 100%. The results showed that compressive strength was only used for non-structural purposes [16]. The addition of lightweight aggregate as a substitute for coarse aggregate causes workability, compressive strength, and mass density to decrease. The use of coral pumice aggregates of 50% to 100% can be categorized as lightweight concrete. This lightweight aggregate utilization is not for structural components but can be used for non-structural components to help reduce the load received by the structure. [17]. Fine fly ash (passed sieve No. 200) could be used to improve the strengths of high-volume fly ash mortar for uses in various architectural and structural works requiring high-strength products [18]. As a coarse and fine aggregate, the use of this sand was often carried out by testing the compressive strength of a 15 x 30 cm cylinder test object. Based on the results, the concrete's compressive strength was 13.88 MPa at 28 days. This value indicated that the pumice sand qualified as an aggregate for the manufacture of lightweight structural concrete. The results also proved that a Moderate Strength Concrete was produced, with a compressive strength value of less than 16.35 MPa [19]. In this case, the six 15 x 30 cm test objects (cylindrical concrete) produced were tested for their compressive strength. This showed that 3 test objects each contained pumice and ordinary sand, respectively. For all test specimens, the coarse aggregate utilized was crushed stone. Based on these results, the use of pumice sand as a substitute for fine aggregate decreased the compressive strength and weight of concrete by 23.53% and 7.03%, respectively. This confirmed that pumice concrete was better than those ordinary sand in weight-based construction [20]. In the concrete mixture, the use of pumice as a fine aggregate also produced an NSTS (normal split tensile strength) and STS (split tensile strength) of 6.133 and 3.556 MPa, respectively. This showed a decrease in the tensile strength of 42.02% at the concrete connection [21]. Therefore, this study aims to determine the effect of heating in the geopolymer mortar treatment process using pumice sand. This emphasizes the determination of the optimal temperature suitable for use in the development of lightweight G.M. (geopolymer mortar).

2. RESEARCH SIGNIFICANCE

Pumice sand material is widely available in North Maluku, Indonesia, although its utilization is limited as embankment material, indicating a relatively low economic value. This explains the need to introduce the use of the material for the acquisition of more values. It is also used as a base material in the production process of lightweight mortar/brick, with fly ash utilized as a binder. Therefore, the importance of this study emphasizes the utilization of the pumice sand and fly ash waste from the Rum power plant to produce lightweight geopolymer bricks.

3. METHOD

3.1 Design

This laboratory-based analysis was specifically performed to determine various variables and their interrelated relationships. The analysis was also conducted by applying temperature variations (20ºC, 40ºC, 60ºC, 80ºC, and 100ºC) in the mortar curing process. In this process, the fly ash binder was mixed with an activator, as well as 8 and 10 Molar (M) NaOH solutions [22, 23, 24, 25]. The diametric dimensions of the 150 test objects (mortar cubes) were also 5x5x5 cm^3, as shown in Fig. 1. In addition, the compressive strength and absorption tests were carried out, with the comprehensive details of mortar cubes presented in Table 1.

Inspection of aggregate properties is based on ASTM [26, 27, 28, 29] which includes:
1. Density
2. Volume
3. Absorption
4. Filter analysis

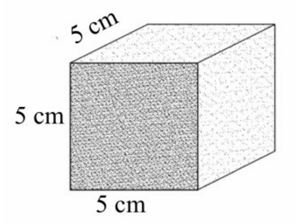


Fig 1. Model of the specimen for compressive strength and absorption test

Table 1 Test object details

Heating temperature (ºC)	Molarity 10	Molarity 8	Total (unit)
20	15	15	30
40	15	15	30
60	15	15	30
80	15	15	30
100	15	15	30

3.2 Equipment

The equipment used included a sieve, digital scales, oven, as well as mortar mixer and press test instrument.

3.3 Material

The utilized fine aggregate was pumice sand, with the binder consisting of NaOH (sodium hydroxide) and Na_2SiO_3 (sodium silicate). Meanwhile, the composition of fly ash-based geopolymer binder contained a Type C component, 8 and 10M NaOH solutions, as well as Na_2SiO_3 fibers. The ratio of the activators used was also 2:2, with the analysis emphasizing the determination of heating effects on compressive strength and absorption. This used a cube specimen of 5 x 5 x 5 cm with a mixed weight, as shown in Fig. 2.

3.4 Heating Test Object

The utilized temperature variations included 20°C, 40°C, 60°C, 80°C, and 100°C, with the heating process carried out for 24 h when the mortar was one day old. The inserted test object was then spaced and evenly distributed throughout the analytical process. Moreover, the heating time was calculated after the oven was closed, leading to the adjustment of temperatures until suitable results were obtained. After this process, the oven was turned off, with the mortar removed and cooled at room temperature. In this case, the physical condition, weight, and volume of the test object were observed, with the analysis of the compressive strength and absorption subsequently carried out.

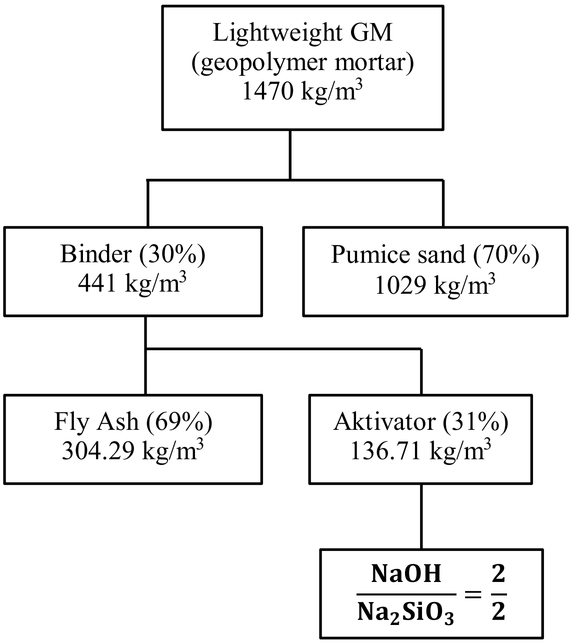


Fig. 2. Lightweight G.M. composition

3.5 Compressive Strength

The tests carried out at this stage emphasized the determination of the mortar's compressive strength (C.S.). Before testing, the dimensions and visual observations of the specimens were initially measured, weighed, and recorded. These were then placed into a manual compressive strength machine and pressed. The method of testing the C.S. of portland cement mortar also used the standard SNI–03–6825–2002, with the calculation conducted through the following formula 1. The pressure test mechanism is also shown in Fig. 3.

$$F'_M = \frac{P}{A} \quad (1)$$

Where, F'_M = the compressive strength of mortar (MPa), P = the maximum load (N), and A = the cross-sectional area of the test object (mm^2).

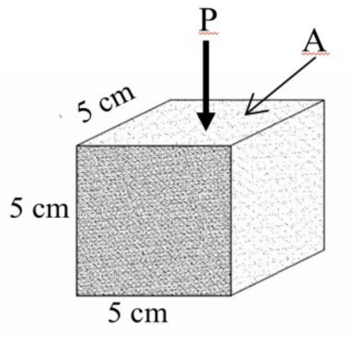


Fig. 3. Mortar compressive strength testing mechanism

4. RESULTS AND DISCUSSION

4.1 Pumice Sand Properties

The physical examination of pumice sand was conducted to determine the characteristics of fine aggregate, as presented in Table 2.

Table 2 Physical properties of pumice sand

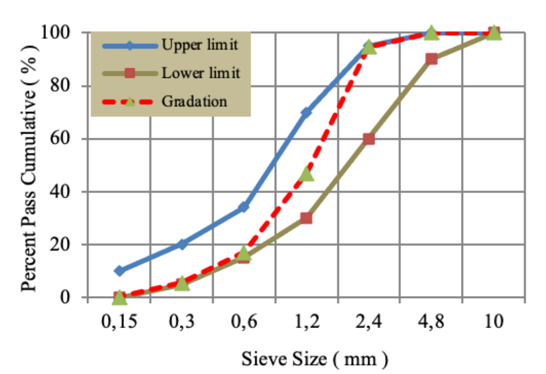
Properties	The results	Specification
Specific gravity	1.79	1.0 – 1.8
Absorption	0.91%	max 20%
Volume weight	870 kg/m^3	max 880
Floating level	4%	max 5%

Table 3 XRF test results for fine aggregate pumice sand

Compound	Composition (%)
SiO_2	70.65
Fe_2O_3	7.89
MgO	6.34
Al_2O_3	5.96
CaO	5.07
K_2O	2.54
TiO_2	0.801
MnO	0.376
SrO	0.149
ZrO_2	0.045

Based on Table 3, the XRF test on the fine aggregate material of pumice sand contained several compounds. With SiO_2 as much as 70.65%.

The pumice sand was also categorized into zone 1, regarding the fine aggregate with coarse grains (Fig. 4).



a. Gradation of the fine aggregate of pumice sand is in zone I

a. Pumice aggregate visualization

Fig. 4. Gradation of the fine aggregate of pumice sand

4.2 Fly Ash

Coal-burning waste (fly ash) has been in existence since the 1930s as an additive in mortar mixes and cement production. The density of this material is between 1.9–2.55 kg/m³. This density in loose and compact conditions subsequently ranged between 540–860 kg/m and 1120–1500 kg/m³, respectively, as shown in Fig. 5.

Fly ash is obtained from burning coal and is a fine-grain-sized material with grey coloration. This essentially contains chemical elements such as silica (SiO_2), alumina (Al_2O_3), as well as ferrous and calcium oxides (Fe_2O_3 and CaO). It also contained other additional elements, namely Carbon (C), magnesium, phosphorus, and titanium oxides (MgO, P_2O_3, and TiO_3), alkali (Na_2O and K_2O), and sulfur trioxide (SO_3). In addition, fly ash is very rich in silica and alumina, which are the main sources of the geopolymerization process. For this material to be used as a binder, an activator was then required [30].

Fig 5. Gradation of fly ash on rum steam power plant

ASTM C618 is one of the most used benchmarks for fly ash characterization and classification, which divided fly ash into two classes, i.e., class F, which is normally produced from burning anthracite or bituminous coal, and class C, which is normally produced from lignite or sub-bituminous coal. From the chemical composition requirements, ASTM prescribes the total composition of silicon oxide (SiO_2) plus alumina oxide (Al_2O_3) plus iron oxide (Fe_2O_3) as a minimum of 70% (by weight) for class F fly ash and 50% (by weight) for class C fly ash [31]. Fly ash is produced by the Rum power plant, as shown in Table 4.

Table 4 XRF test results for fine fly ash Rum

Compound	Composition (%)
SiO_2	38.97
Fe_2O_3	19.93
CaO	15.05
Al_2O_3	13.84
SO_3	8.36
K_2O	2.15
TiO_2	0.92
P_2O_5	0.37
SrO	0.166
BaO	0.098
ZrO_2	0.060
Nb_2O_5	0.0257
Rb_2O	0.0193
MoO_3	0.0185
SnO_2	0.0079
Nb_2O_5	0.0257

One of the other standards that also classify fly ash is Canadian Standard, CAN/CSA-A3000-03. This standard divides fly ash into three categories, where calcium oxide as one of the chemical composition of fly ash becomes the major differentiator. Fly ash with the calcium compound below 8% (by weight) classified as F type, whereas those with the calcium compound in the range of 8-20% (by weight) belong to type CI, and when it is above 20% (by weight), the fly ash categorized as type CH [32].

The CSA standard classifies the fly ash according to the CaO contents, while ASTM standardly classifies according to the total contents of SiO_2, Al_2O_3, and Fe_2O_3. It also can be derived that CSA type F and type CI fly ash is similar to the ASTM class F, while CSA type C.H. is similar to the ASTM class C fly ash [33].

4.3 Activator

The type of activator used in this analysis was NaOH and Na_2SiO_3 (Sodium Hydroxide and Sodium Silicate).

4.4.1 Sodium hydroxide

Fig. 6. Sodium hydroxide in the form of flakes

The utilized sodium hydroxide (NaOH) was observed as 98% purified crystals (flakes), as shown in Fig. 6. This needs to be initially dissolved with water to form a NaOH solution. In this case, the utilized crystal concentrations were 8 and 10M.

4.4.2 Sodium silicate

Fig. 7 shows that the utilized sodium silicate (Na_2SiO_3) is a thick liquid.

Fig. 7. Sodium silicate in gel form

4.4 Geopolymer Lightweight Mortar

Besides the activator comparison of 2.2, the mortar also contained a Type C fly ash-based geopolymer binder, 8 and 10M NaOH solutions, and Sodium Silicate (Na_2SiO_3).

4.5 Mortar Compressive Strength

Based on fly ash, the compressive strength of geopolymer mortar used 15 specimens for each temperature variation, as shown in Fig. 8.

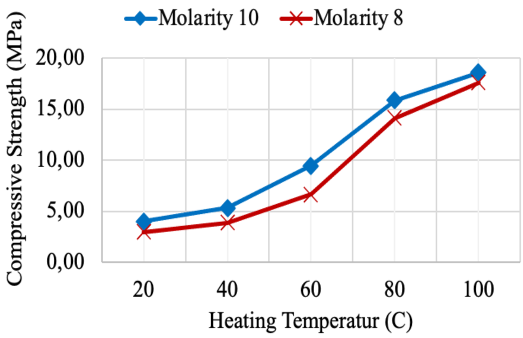


Fig. 8. Relationship between Mortar Compressive Strength and Heating Temperature

According to Fig. 8, the heating process of the mortar showed an increase in compressive strength (C.S.) and temperature using an oven for 24h. This was in line with a previous report, where the heating time for 8 and 10M mortars showed an increase in compressive strength (C.S). As a binder, the use of fly ash also proved that a longer curing time caused greater compressive strength produced. Therefore, the optimum C.S. was obtained within 24h of treatment.

Based on the data and graphs obtained from the Molar comparisons, the geopolymer mortar with 10M NaOH concentration produced a higher compressive strength than that of the 8M concentration. This was in line with a previous study, where the utilization of fly ash and *porong* mud as a geopolymer mixture, binder, and concrete treatment was carried out at room temperature. Another report also showed that the optimum compressive strength value of G.M. was found in the mixture with a 10M activator at room temperature treatment of 32.9 MPa for 28 days. Regarding visualization, the mortar treated at 20°C was more brittle than that at 40°C (Fig. 9). From Fig. 6, the damage to the test object decreased with an increase in the oven temperature when loaded during treatment.

Since a similar surface area was observed in each test sample, the compressive strength quality produced was influenced by the magnitude of the resistance force provided by the sample to loading. This force was subsequently affected by the constituent mass and the sample weight density.

This indicated that the heating temperature and the activator's molarity influenced the quality of the geopolymer lightweight brick produced during treatment, as presented in Fig. 10.

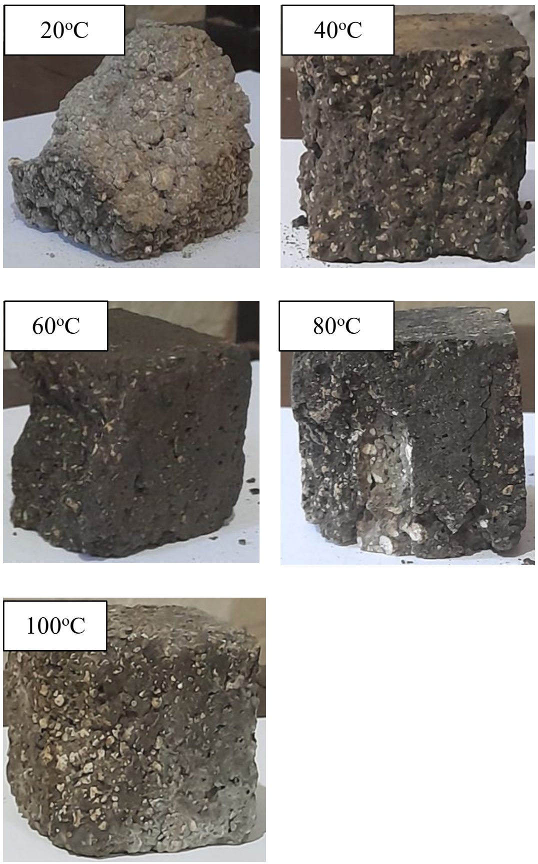


Fig. 9. Visualization of the test object after compression test at each curing temperature

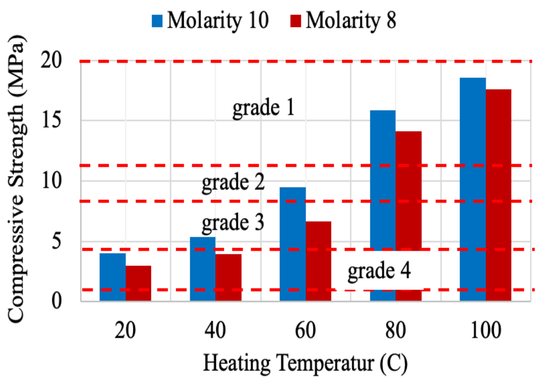


Fig. 10. Quality of geopolymer lightweight brick based on compressive strength

According to Fig. 10, the light brick quality (LBQ) varied between grades 4 and 1 at 20°C. Meanwhile, the heavy brick quality (HBQ) with molarity 10 and molarity 8 varied between grades 3 and 4 at 40°C, respectively. At 60°C heating, the LBQ was categorized in grades 2 and 3 at molarity 10 and molarity 8, respectively. Meanwhile, grade 1 was achieved for the LBQ with 10M after 80°C heating.

4.6 Mortar Absorption

The analysis of fly ash-based geopolymer mortar absorption was carried out using 5 test objects for each temperature variation, as shown in Fig. 11.

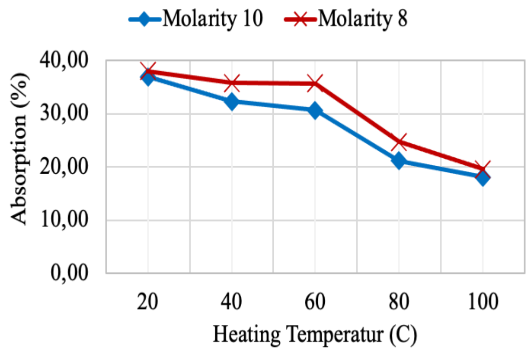


Fig. 11. Graph of the relationship between heating and absorption

According to Figs. 8 and 11, the compressive strength (C.S.) and porosity of the mortar increased and decreased through a heating treatment at 100°C, respectively. Both graphs indicated that compressive strength and porosity were inversely proportional. This was in line with several previous reports. Using a mathematical model equation, a relationship was observed between the concrete's compressive strength and porosity [34]. The characteristics of the pore structure and porosity also affected the concrete's compressive strength [35]. Moreover, the relationship between aggregate porosity and C.S. was very strong, indicating close similarities between both variables [36, 37, 38].

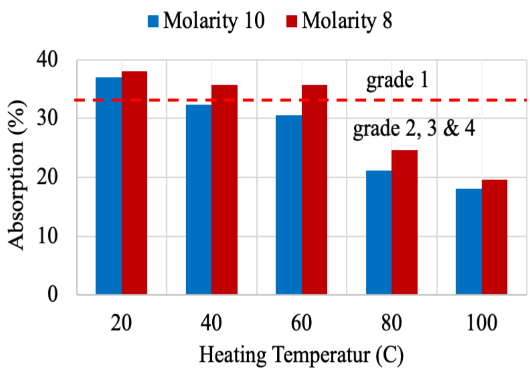


Fig.12. Geopolymer lightweight brick quality based on absorption

The ability to absorb water was also influenced by the density of the test object, indicating that the sample with H.D. (high density) had fewer mass voids. This showed that less water seeped and occupied the cavity. When the produced absorption rate was adjusted to the light brick quality, classification was carried out, as shown in Fig. 12.

Based on Fig. 12, the light brick quality was observed between grades 2 and 1 regarding the absorption rate.

4.7 Volume Weight

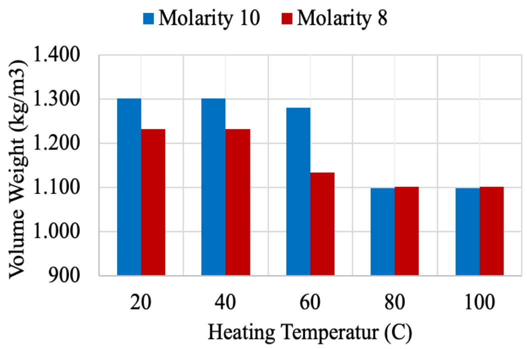


Fig. 13 Relationship of volume weight with heating temperature

Figure 13 presented the volume weight of the geopolymer mortar (G.M.), which used pumice sand as fine aggregate at a maximum of 1,300 kg/m^3. This confirmed the classification of the G.M. as lightweight [39, 40, 41, 42, 43].

5. CONCLUSIONS

From the test results of lightweight geopolymer bricks containing the waste pumice sand and fly ash from the Rum power plant, the following conclusions are drawn:

- The compressive strength of lightweight geopolymer bricks increased with an increase in temperature.
- The molarity of the geopolymer greatly influenced the compressive strength of the bricks.
- It was observed that there was a synergetic action between the morality binder and the temperature effect along with the curing period.
- Based on the analytical results, the maximum G.M. volume obtained was 1300 kg/m^3, leading to its categorization as a light mortar.
- For 10M and 8M, the compressive strength of 18.60 and 17.60 MPa were also produced at 100°C, respectively.

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