Analyze The Strength of Ceramics Made from Clay, Sinabung Volcanic Ash and Sea Water in The Term of The Structure

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Abstract. Ceramics made from clay, Mount Sinabung ash and sea water have been made using the die pressing method. Sinabung clay and ash were sieved through a 200 mesh sieve. Ceramics are printed with a mixture of clay, Sinabung mountain ash and sea water in a ratio of 10:0:0 gr; 10:9:1 gr; 10:8:2 gr; 10:7:3 gr; 10:5:5 g, etc. Ceramics are sintered with a sintering temperature of 1000 °C with a holding time of 3 hours. Ceramics are characterized by determining physical properties (shrinkage, porosity and density), mechanical properties (compressive strength), surface morphology and pore size (SEM) and XRD. The characterization results show that the optimum value occurs in a mixture of clay, Mount Sinabung ash and seawater at a mixed variation of 10:5:5 gr with a shrinkage value of 31.2%; porosity = 27.16%; density = 2.09×10³ kg/m³ %; compressive strength = 86.66 MPa. Surface morphology (SEM) showed that the optimum variation experienced agglomeration and significant unification of grains occurred and the structure formed was hexagonal with a crystal size of 45.44 nm.

1. Introduction

With the increasing growth of the construction sector in Indonesia. For this reason, in order to accelerate the construction of structures, it is necessary to encourage development in strengthening the domestic construction industry, so that it is expected to reduce our dependence on imported raw materials (1). In science and technology that continues to advance, many scientists quickly, precisely and practically in creating something new but useful for life in the material field, one of which is ceramic technology that can support the construction industry in terms of development.

In 2010 to 2021, Mount Sinabung, which is located in the highlands of Karo Regency, North Sumatra, is still experiencing prolonged eruptions so that Sinabung emits thick volcanic ash. In a previous study conducted by Nain Felix Sinuhaji (2011), volcanic ash from Mount Sinabung contains silica (SiO₂) as much as 59.92%. Therefore, volcanic ash from Mount Sinabung can be used for ceramic raw materials as a substitute for quartz.

The use of seawater with a percentage of 15% reaches a concrete compressive strength of 17.71 MPa which has increased from normal concrete of 13.33 MPa. At 30% seawater mixture, the concrete compressive strength is 18.59 MPa. So that the percentage of sea water use of 30% is the maximum increase from mixing sea water in making concrete (2).

In this study, a ceramic material was made as a raw material for clay by mixing Mount Sinabung ash and sea water with conventional compression molding techniques. So that the mixture is expected to...
produce a ceramic material that has good physical and mechanical properties, characterization test for construction ceramics.

2. Method

2.1 Fabrication of Clay Based Ceramic

Clay and mountain ash as the main ingredients for making samples were obtained from Mount Sinabung, while sea water was obtained from the coast of the Mirror Beach, Deli Serdang. In this study, the clay was dried in the sun for 3 days to remove its moisture content. The results of the drying will produce clay powder. After that, the clay and ash of Mount Sinabung were each sieved using a 200 mesh sieve. 10 grams of clay mixed with Mount Sinabung ash and sea water using a mixer. The mass between Mount Sinabung ash and sea water is determined by 3 variations i.e. 9:1, 8:2, 7:3, 6:4, 5:5, 4:6, 3:7, 2:8 and 1:9 in grams. All of the samples were denoted as L10, L20, L30, L40, L50, L60, L70, L80 and L90, respectively. As a control variable, samples without the addition of Mount Sinabung ash were also prepared and denotes as L0. All of the above samples were printed in a cylindrical shape with a diameter of 5 cm and a height of 1 cm using the Die Pressing method. The printed sample was dried for 24 hours in the sun to remove the moisture content, then the sample was sintered at the 1000 °C for 3 hours and dried at room temperature.

2.2 Characterizations

The structural properties of ceramic-based clay samples were studied by using X-ray diffraction (XRD) patterns recorded using an X-ray diffractometer (Miniflex series Benchtop powder X-ray diffraction Instruments, Rigaku Corporation, Japan). The scanning rate of 5/min was applied to record the patterns in the range of 7°–90°. The mean crystallite size of these ceramic based clay samples was calculated using a modification of Debye Scherer's formula,

\[ D = \frac{k \lambda}{\beta \cos \theta} \]  

Where k is the shape factor and has a typical value of 0.9, \( \lambda \) is the wavelength (Cu Kα = 1.5405 am), is the full width at half maximum of the several peaks (in radians), and \( \theta \) is the Bragg angle of the peak. For calculation, the several peaks were taken for calculation. The surface morphologies of ceramic based clay samples were characterized by scanning electron microscopy (Hitachi SU-3500) operated at 10 kV with a thin layer of gold sputter coated prior to analysis. And the grain size in each sample was measured through quantitative analysis using the ImageJ application. Physical tests such as porosity, density and volume loss were also carried out manually and for mechanical testing in the form of compressive strength using a universal testing machine (UTM).

3. Results and Discussions

3.1 Volume Loss

The volume loss graph in figure 1 shows that the burn loss value for each variant of the construction ceramic mixture has increased and decreased. The higher the sintering temperature, the ceramic will undergo a high compaction process so that it will produce a relatively high volume loss value. The lowest burn loss value was owned by sample L20 of 6.02%, while the highest value of burn loss was owned by sample L50 of 31.21%.
Figure 1. Volume loss graph with different compositions on clay-based ceramic samples.

Figure 2. Graph of the relationship between porosity and compositional variations in clay-based ceramic samples.

Figure 2 shows a graph of the porosity in each sample. Low porosity indicates that the material has a solid alloy because the pores in the material are relatively lower, the L80 sample has the most optimum level of porosity with the value of 17.68%. The low porosity in sample L80 when compared to other samples indicates that the cavities formed in sample L80 are fewer and smaller so as to form a material with an optimum level of homogeneity and interparticle occupancy.

Density test data on samples using seawater solvents show that the L50 sample has the highest density as shown in figure 3. An increase in density indicates that the mass density of the sample is getting higher in each volume, or in other words the L50 sample has the strongest bond between particles because the mass density reaches its optimum point.
Figure 3. Plot of density values in each seawater composition in clay-based ceramic samples.

Figure 4. Plot of density values in each seawater composition in clay-based ceramic samples.

From the test data on the compressive strength of the sample on the figure 4, the lowest compressive strength was found in the L90 sample with a value of 47.96 MPa, while the highest compressive strength was found in the L50 sample with a value of 86.66 MPa. This value is even higher when compared to the previous study of 15.2086 MPa (Hendra L. Nababan).
Figure 5. X-ray diffraction patterns of clay-based ceramic samples of L0 (a), L10 (b), L50 (c) and L90 (d).

In the picture above, which displays the XRD diffraction pattern in the sample using seawater, it shows the same crystalline phase, namely SiO2, according to the peaks formed. However, there are some differences between the diffraction patterns formed, where the L10 sample produces several new peaks when compared to the L0 sample. Based on the data sheet obtained, the new peaks that appear still show the SiO2 phase. As the concentration of Mount Sinabung ash decreases to 50% at L50 to 90% in the L90 sample, the peaks formed have decreased in intensity, this indicates that a reduction in the ash concentration of Mount Sinabung by more than 10% will reduce the level of crystallinity in the sample.
As well as the crystal size can be determined using the Debye Scherrer equation. The largest crystal size was found in the sample L0 which was 162.57 nm, while the L10 sample had a significant decrease in crystal size to 33 nm. In sample L50, the crystal size increased again with the decrease in the concentration of Mount Sinabung ash and along with the increase in the concentration of seawater. The crystal size again decreased in sample L90 with a relatively low decrease. From the results of the crystal size analysis above, it was found that the concentration between Mount Sinabung ash and seawater sufficiently affected the size of the crystals formed, resulting in a certain crystal size. According to Beknalkar, the concentration of Mount Sinabung ash as an additive and seawater as a concentration solvent in the sample has a major role in changing the morphology of the sample surface and the size of the crystals formed in the sample can only be influenced by microscopy by these two variables (Beknalkar et al., 2020).

Table 1. Crystal size in ceramic samples using seawater

| Sample | Crystal size (nm) |
|--------|------------------|
| L0     | 162.57           |
| L10    | 33               |
| L50    | 45.44            |
| L90    | 41.23            |
Figure 7. SEM images of clay-based ceramic samples of L0 (a), L10 (b), L50 (c) and L90 (d)

In figure 7.a, which shows sample L0 shows a much more even distribution of granules when compared to what happened in the sample with Aquadest solvent. The shape of the grains also looks more regular and the grain boundaries are clearer, after further analysis the grains are flat and rectangular. Figure 7. B shows that the L10 sample has agglomerated, causing the distance between the grains to be closer so that it has an impact on decreasing the number of grain boundaries formed. In sample L50, which is shown in Figure 7.c, the phenomenon of agglomeration is getting stronger in the sample, this can be seen from the occurrence of a significant unification process between grains so that they lose grain boundaries. In Figure 7.d, the L90 sample has decreased grain density, the level of agglomeration in this sample is also quite high, but much lower than that of the L50 sample. This also proves that the agglomeration phenomenon will reach its maximum condition when the concentration between Mount Sinabung ash and sea water has the same ratio.

4. Conclusion
The size of the crystal atoms in clay-based ceramics have been investigated with variations in the composition of Mount Sinabung ash with seawater or aquadest of L0: 162.57 nm; L10: 33 nm; L50: 45.44 nm and L90: 41.23 nm. The composition of Mount Sinabung ash with seawater or aquadest in the sample can affect the physical and mechanical properties of ceramics. The optimum physical properties are indicated by the lowest porosity value, namely 17.68% in sample L80, while the optimum density is obtained at 2.09 x 103 Kg/m3 which is the highest density possessed by sample L50. The mechanical properties of the L50 sample also showed an optimum value of 86.66 Mpa. The crystal structure and morphology of the sample have a significant influence on the mechanical strength of the ceramic. The crystal structure with hexagonal shape has relatively more optimal mechanical strength when compared
to the monoclinic structure, this is because the crystal bonds in the hexagonal structure are stronger so that it has an impact on increasing the morphological structure formed.

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