Effect of Firing Holding Time on Density, Porosity, and Hardness, Crucible Materials Based on Evaporation Boats

Evaporation boats are conductive advanced ceramic composites with the best thermal evaporation source for metalizing applications. The short life time of the evaporation boats causes the metalizing industry to produce large amounts of evaporation boats waste. However, studies on the utilization of evaporation boat waste are still limited. Therefore, this study aims to determine the effect of firing holding time on the density, porosity, and hardness of crucible materials made from evaporation boats waste. The material used in this research is a mixture of evaporation boats waste powder, kaolin, and graphite, with a composition of 50%, 25% and 25%, respectively. During the mixing process, 15% of the water is added. The compacting process carried out with a compaction pressure of 25 MPa. The firing process is carried out at a temperature of 1000°C with holding times of 60, 90, 120, 150, and 180 minutes. The test results show that the holding time of firing has an effect on density, porosity, and hardness. The highest density value was 1,91 g/cm³ at a holding time of 180 minutes, and the lowest was 1,77 g/cm³ at a holding time of 60 minutes. The highest porosity value is 4,10% at a holding time of 60 minutes, and the lowest is 2,16% at a holding time of 180 minutes. The highest hardness value was 12,84 HV at a holding time of 180 minutes, and the lowest was 8,3 HV at a holding time of 60 minutes. The longer holding time in the firing process results in a decrease in the porosity content. The decrease in the porosity content results in an increase in density and hardness of the crucible specimens.

Keywords: Firing Holding Time, Crucible, Evaporation Boats, Waste

1. INTRODUCTION

Industrial growth in Indonesia has increased, especially in the manufacturing industry which is the largest contributor to the national economy. According to the Central Statistics Agency in 2020, the growth of the manufacturing industry in 2019 increased by 4.01% compared to 2018. As the number of industries increases, the waste generated also increases. The waste as the remaining material of a business, is not desired by the environment because it has no economic value [1]. One of the wastes that can be reused is evaporation boats which are leftover material from PT. 3M Indonesia is engaged in the food industry. This waste is not used properly, even though it contains compounds that can be useful for other sectors. Elements in evaporation boats include boron nitride and titanium diboride which are refractory materials (ceramic materials) capable of maintaining strength and shape at high temperatures [2]. Refractory materials are often used in the manufacture of crucibles in the metal casting industry to melt metal materials in the casting process. The small-scale metal casting industry has experienced many obstacles, due to the kowi available in the market which is expensive, difficult to obtain, and cannot last longer [3]. These objects are easily damaged and cannot be used for the smelting process for a long time, it is necessary to develop in terms of crucible performance efficiency [4].

Evaporation boats have similar material properties to graphite (a material often used in the manufacture of crucibles) and have material characteristics such as electrical conductivity and good thermal shock resistance.
Crucibles can be said to be tools made of ceramic materials, where ceramic according to the Greek (keramikos) which means "burnt goods" indicates that the desired properties of these materials are usually achieved by a high temperature heat treatment process called firing. During combustion, the particles shrink, and undergo a reduction in porosity and an increase in mechanical integrity [6].

According to Aisyah et al., changes can occur due to the incorporation of powder particles into a denser and stronger mass below the melting temperature that called the sintering process [7]. Sintering occurs below the melting point temperature which is carried out at a temperature of 0.7-0.9 from the melting point so that atomic transport events occur which involve the formation of a liquid phase. Factors that affect the combustion process are shape, particle size, material, temperature, and holding time [8]. Previous research has various studies regarding the combustion factors in crucible materials in the form of heating rate and temperature, but have not investigated further about firing or combustion holding time. The holding time of firing has an effect on reducing porosity and increasing the density value so that it can affect the hardness value [9].

2. MATERIALS AND METHODS

2.1 Research Tools and Materials

This research uses evaporation boats waste, graphite, and kaolin to make crucibles or tools used to heat metals [10]. The material used in this research is a mixture of evaporation boats waste powder, kaolin, and graphite, with a composition of 50%, 25% and 25%, respectively. The use of these compositions results in the highest average impact resistance [11]. Evaporation boats waste are used as the main material to utilize industrial waste which is still underutilized. Graphite has the characteristics of not burning and not easily soluble in water and kaolin as an additive or mixture to increase volume and increase hardness or strength (as a binder). The composition mixture used has the characteristics of high thermal conductivity, high resistance to corrosion, and high thermal stability so that it can be used as a refractory material [12].

2.2 Research Methods and Steps

The evaporation boat waste that has been crushed using a crusher machine is filtered with 100 mesh to produce evaporation boat waste powder. The material used in this research is a mixture of evaporation boats waste powder, kaolin, and graphite, with a composition of 50%, 25% and 25%, respectively. The mixing process of the evaporation boats waste powder, kaolin, and graphite carried out with a mixer for 2 hours to obtain a homogeneous mixture. Water is added during the mixing process by 15% of the total weight. The compacting with a pressure of 25 MPa is carried out to produce a crucible specimen. Specimens that have been made undergo a drying process that is allowed to stand for several days (± 7 days) at room temperature. The dried specimens were then fired at a temperature of 1000°C with holding times of 60, 90, 120, 150, and 180 minutes. During the firing process, bonds between particles are formed, densification, shrinkage, and grain boundaries [13]. The fired specimens were then tested for density, porosity, and hardness.

3. RESULTS AND DISCUSSION

3.1 Density Test

Density testing was carried out using the Archimedes method in order to determine the dry mass and mass in water of the specimen. Density testing on crucible material aims to determine the object density value. Density is obtained from weighing the mass of the test specimen from the calculation of the amount of substance (mass) per unit volume. Density is one of the physical properties in the test.

Table 1. Density Test Average Results

<table>
<thead>
<tr>
<th>Firing Holding Time (minutes)</th>
<th>Density Value (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>1.77</td>
</tr>
<tr>
<td>90</td>
<td>1.82</td>
</tr>
<tr>
<td>120</td>
<td>1.87</td>
</tr>
<tr>
<td>150</td>
<td>1.89</td>
</tr>
<tr>
<td>180</td>
<td>1.91</td>
</tr>
</tbody>
</table>

Table 1 shows that there are differences in the value of the density test results for each holding time firing variations. Based on this, it can be concluded that the holding time firing has an influence on the density
value. Based on the test results, each holding time firing produces a different density value and the higher the holding time firing, the higher the density value.

Figure 1. The effect of firing holding time on density

Figure 1 shows the average density value for each specimen given the firing holding time of 60, 90, 120, 150, and 180 minutes. The graph shows that there is a difference in the average density value for each firing holding time. The graph shows an increase in the density value caused by the firing holding time from 60 minutes to 180 minutes. The longer the holding time, the higher the density value. The highest average density value of 1.91 g/cm³ was obtained at the holding time treatment of 180 minutes, and the lowest average density value of 1.77 g/cm³ was obtained at the 60 minute holding time treatment. Each treatment experienced an increase in density. This indicates the effect of holding time firing on density.

The results of the density test are in accordance with Suprapto's research, which reveals that the longer treatment of heating holding can have an effect on increasing the density of the material [8]. The longer holding time results in a higher density value and the shorter holding time results in a lower density value. The increase in the density of the material is in accordance with Seprianto's research (2010) which reveals that the holding time affects the density value which has increased due to the incorporation of particles getting stronger along with the length of holding time [9]. The increase in the density value that continues to increase occurs gradually along with the firing holding time [14].

3.2 Porosity Test

Porosity testing on crucible material aims to determine the percentage of cavities or pores of an object. Porosity is obtained by weighing the mass of the test specimen from the calculation of the difference between the wet mass and the dry mass divided by the difference between the wet mass and the mass in water.

Porosity is one of the physical properties in the test. A material is said to have good porosity if the voids in a material are interconnected and are usually smaller than the pore voids.

Table 2. Average Results of Porosity Test

<table>
<thead>
<tr>
<th>Firing Holding Time (minutes)</th>
<th>Porosity Value (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>4.10</td>
</tr>
<tr>
<td>90</td>
<td>3.64</td>
</tr>
<tr>
<td>120</td>
<td>2.78</td>
</tr>
<tr>
<td>150</td>
<td>2.63</td>
</tr>
<tr>
<td>180</td>
<td>2.16</td>
</tr>
</tbody>
</table>

Table 2 shows that there are differences in the value of the porosity test results for each holding time firing variation. Based on this, it can be concluded that the holding time firing also has an influence on the porosity value. Based on the test results, each holding time firing produces a different porosity value and the higher the holding time firing, the lower the porosity value.
Figure 2. The effect of firing holding time on porosity content

Figure 2 shows the average porosity value for each specimen given different firing holding time of 60, 90, 120, 150, and 180 minutes. The graph shows that there is a difference in the average density value for each holding time firing. The test specimens given holding time firing treatment gave different porosity values. The highest average porosity value of 4.10% was obtained at the 60 minute holding time treatment. and the lowest average porosity value of 2.16% was obtained at the holding time treatment of 180 minutes.

Each treatment experienced a decrease in porosity. This indicates the effect of holding time firing on porosity. The shorter holding time results in a higher porosity value and the longer holding time results in a lower porosity value. This is in accordance with research conducted by Pan, et al (2020) which states that the porosity decreases as the holding time increases because the shorter the heating holding time can lead to less than the maximum bonding between particles [15]. This statement is in line with research by Ramlan and Bama (2011) which concluded that the length of the heating process can minimize and eliminate pores or cavities in solid materials so that the material is more compact [16].

3.3 Vickers Hardness Test

Hardness testing on crucible material is carried out to determine the value of the strength of the object. The hardness value is obtained from the calculation of the surface area of the former being stepped on by the indenter.

Table 3. Hardness Test Average Results

<table>
<thead>
<tr>
<th>Firing Holding Time (minutes)</th>
<th>Hardness Value (HV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>8.3</td>
</tr>
<tr>
<td>90</td>
<td>10.56</td>
</tr>
<tr>
<td>120</td>
<td>11.63</td>
</tr>
<tr>
<td>150</td>
<td>11.87</td>
</tr>
<tr>
<td>180</td>
<td>12.84</td>
</tr>
</tbody>
</table>

Table 3 shows that there are differences in the value of the hardness results for each variation of holding time firing. Based on this, it can be concluded that holding time firing has an influence on violence.

Figure 3 shows the different results of different hardness at each holding time firing. The test specimens given holding time firing treatment gave different hardness values. The highest average hardness value of 12.84 HV was obtained at a holding time of 180 minutes. and the lowest average hardness value of 8.3 HV was obtained at a holding time of 60 minutes. Each treatment experienced an increase in violence. This indicates the effect of holding time firing on hardness. The longer the holding time used, the higher the hardness value and the shorter the holding time the lower the hardness value. The increasing value of hardness is influenced by the longer heating holding time so that bonds between particles will form and become more compressed as the holding time increases. The results of this study are in line with the research of Yafiedan (2014) which concluded that the hardness value will be higher with increasing heating resistance [17]. The study of Shojai and Mantyla (2001) also concluded that holding time had an effect on the high increase in hardness [18].
CONCLUSION

Based on the results of the research conducted, it can be concluded that there is an effect of holding time firing on density, porosity, and hardness. The best density value was obtained in the 180 minute holding time firing treatment of 1.91 g/cm$^3$. The lowest average density value was obtained at the 60 minute holding time firing treatment of 1.77 gram/cm$^3$. The highest porosity value was obtained in the 60 minute holding time firing treatment of 4.10%. The lowest porosity value was obtained in the 180 minute holding time firing treatment of 2.16%. The highest hardness value was obtained in the holding time firing treatment of 180 minutes of 12.84 HV, while the lowest was obtained in the treatment of holding time firing of 60 minutes of 8.3 HV. The longer the holding time used, the higher the density and hardness value, while the lower the porosity value. This is because the longer heating holding time causes bonds between particles to form and become more compressed as the holding time increases.

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REFERENCES


