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THE EFFECT OF FINE COAL IN TUBE MOLDS WHEN POURING ALUMINUM ALLOY 6061 ON WEAR RATE AND HARDNESS VALUE

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ABSTRACT: Aluminum alloy 6061 material, which is widely used in daily life, has been melted in a crucible. The pouring of aluminum liquid is carried out into a cylindrical tube that functions as a mold, which has already been filled with finely ground and sifted sub-bituminous coal. Due to the temperature difference is large enough, fine coal has burned, and combustion products will react to the aluminum alloy. The results of the Brinell hardness test and the Ogoshi method wear have been influenced by three main elements of coal combustion, namely moisture content, volatile matter, and fixed carbon. The addition of fine coal has reduced hardness values. The addition of at least 12.5 grams of fine coal has reduced hardness from 31.66 BHN to a very minimum of 29.90 BHN. However, when fine coal has been added again, it has increased the value of hardness. Wear rates have increased with the addition of fine coal combustion, but with the amount of fine coal increasing again, the wear rate have decreased. The addition of at least 12.5 grams of fine coal has increased the wear rate to a maximum, i.e., from 5.20E-07 mm^2/kg to 7.25E-07 mm^2/kg. The addition of at least 12.5 grams of fine coal has increased the wear rate to a maximum, i.e., from 5.20E-07 mm^2/kg to 7.25E-07 mm^2/kg.

Keywords: Aluminum alloy 6061, Fine coal, Hardness, Wear

1. INTRODUCTION

The metal most widely used today is a ferrous metal, while the second metal that is most commonly used is aluminum. Both of these metals have unique characteristics. For high-strength ferrous metals that can be used, namely iron or steel. Whereas for particular uses such as loads that are not too large, many are used aluminum. Aluminum is the most widely used commercial metal in the fields of construction, machinery, households, and aircraft. A large number of uses of aluminum in daily life produces considerable metal waste. Waste aluminum from various activities, among others, from beverage cans, cooking utensils, scrap, cable waste, can be recycled. Recycling work is carried out by almost all countries in the world. Commercial aluminum is classified based on the form of load, type of maintenance, and the results of manufacturing work.

The properties of aluminum that make metals and their alloys the most economical and attractive for a variety of uses are appearances, lightweight, ease of craft, physical properties, mechanical properties, and corrosion resistance [1]. It is generally known that the ratio between strength and weight of aluminum is higher than iron or steel. Apart from that, aluminum corrosion-resistant properties have been formed while cooling aluminum castings. A thin layer of aluminum oxide is found in the outer portion of the aluminum alloy, which is tight and tightly attached to the surface, the nature of this layer is stable and can protect the inside.

Some tests of material physical properties that are commonly known are tensile strength, hardness, impact, and wear. The ability of the material to accept dynamic loads is included in material fatigue or fatigue testing. While research on the amount of material activation energy due to alloy decomposition has also been carried out by several researchers.

Some researchers have carried out physical testing of aluminum materials, fatigue tests, and measurements of the activation energy of aluminum alloys [2-5].

This research uses aluminum alloy 6061, which is included in the category of aluminum that can be heated and forged. Aluminum alloy is one type of aluminum that contains pre-dominant elements of Magnesium and Silicon, which have excellent fatigue properties and are resistant to corrosion and are used in heavy-duty. This type of material is widely used for various purposes in life.

Aluminum alloy 6061 were melted and then added new elements obtained from coal combustion. Coal, which is one type of fuel, combustion, will produce volatile substances, fixed carbon, and ash. Methane gas is part of the volatile material, which decomposes because burning will increase the temperature of the aluminum metal liquid. While carbon will still burn like methane gas. On the other hand, ash, which is a residue from combustion, is expected to be trapped in the combustion residue of aluminum and liquid gas. Thus the relationship between aluminum 6061 smelting and the addition of other alloying elements will result in a new aluminum alloy material. It should be noted that the use of aluminum is a simulation of waste or scrap machine products. So the results of the machining process, i.e., chips or scrap can be reused by recycling.

The addition of Fe in $AlSi_{10}MgMn$ has reduced tensile stress. The element Fe was added in four compositions. Of the four compositions, almost all new alloys affect the tensile strength. The presence of iron in the recombination of recycled Aluminum-Silicon materials has become a problem. This has been measured by tensile testing and looking at microstructure. From observing the microstructure, it can be seen that the presence of the Fe element in the primary material affects [6].

The addition of the Lithium (Li) element to the A320 molten aluminum alloy has been carried out under the influence of hardness and tensile strength of the material. By adding four types of percentage Li to a permanent mold, liquid aluminum alloys are poured into it. There has been a decrease in hardness and an increase in material tensile strength [7].

Al-Mg-Si Aluminum material used as the main material has been combined with elements of Mg, Si, Fe, Cu, and Mn in relative concentrations and quantities. Research has been carried out to see the effect of adding these elements to the melted Al-Mg-Si. Tensile testing shows changes in magnitude, and also the level of material hardness [8] Aluminum waste powder has also been compacted in a certain way, and its mechanical properties have been investigated [9].

Recycled aluminum material added with Al_2O_3 (alumina) is made into a composite. The mixture between AA6061 and Al_2O_3 is then compacted to heat to reach a temperature of 530^oC. The addition of Al_2O_3 is 1, 2, 3, 4, and 5% (weight fraction). Tensile strength increases with Al_2O_3 alloy 2% but then decreases [10].

$Al_6Si_{0.5}Mg$ alloy added with Cu element and then given T6 heat treatment can increase the value of tensile stress, ductile, impact, and hardness. Cu is added in a certain percentage [11].

Aluminum alloy 6061 reinforced with particles measuring 6-18 microns from 10% Al_2O_3 in the volume fraction. The addition of this element has increased the wear resistance of aluminum composite materials [12].

With the addition of 0 to 12% graphite variation in the casting process of aluminum alloy 6082 material, wear-resistance and hardness of the material have been reduced. This decrease in wear resistance and hardness of composites is evident in the addition of micro and macro-sized graphite [13]. Some studies that add an element of coal ash or ash from other elements have been conducted by several researchers [14-16].

In the case, as stated above, it is clear that there is an effect of changing the mechanical properties of the material each time the liquid material is added with other elements, both additional metals and non-metallic additives. In addition to other elements in the form of coal, fine coal will burn and will become ash, where the ash will be trapped in the castings.

Speight [17] said, the temperature of the evaporation of water vapor levels ended up to a temperature of 106^oC which is heated with nitrogen-free oxygen flow, while for the burning of volatile matter that is heated to a temperature of around 950^oC which is maintained with-in a heating period of about 7 minutes, and the rest of the heating is called as coke or can be said as fixed carbon. Speight [17] also said that on rapid heating, the volatile matter would quickly disappear. The formation of fixed carbon, generally, there are two types of behavior. First, the formation occurs at low temperatures, at temperatures around 600^oC, and high temperatures, around 900^oC. At low temperatures, it is called the slow carbonization process, whereas at high temperatures, it is used in the process of making gas and coke. It is generally known that coke formation occurs in a limited oxygen atmosphere.

As one of the main chemical elements in metals, carbon generally has the ability to dissolve and chemically blend in iron-carbon alloys and is thermodynamically stable. However, the presence of carbon as part of the aluminum alloy, which is thermodynamically fused, has been debated. There is an opinion that carbon is rarely said to be an impurity because, in an aluminum alloy, it will form as Aluminum Carbide (Al_4C_3), which is thermodynamically stable. However, Al_4C_3 will be thermodynamically unstable when it comes in contact with water, and this is analogous to the instability of Al_2O_3, which is a thin layer on the surface of aluminum alloy as an oxidation coating that will come in contact with atmospheric oxygen at normal temperatures [18].

2. EXPERIMENTAL PROCEDURE

2.1 Material

The material that has been used for this research is aluminum alloy 6061, which is a commercial aluminum alloy. The aluminum cylindrical rod has been cut to 30 cm, and this has been done because the height of the container is 30 cm, and this has been considered as a recycling simulation of the chip aluminum alloy 6061 produced by the machining process.

Coal is taken from PT Tambang Batubara Tanjung Enim, a sub-bituminous type. The coal is finely ground and then sieved with the fine sieve of 20, 40, 60, and 100 mesh. When coal is heated and burned, it can be observed by proximate analysis. This proximate analysis includes the percentage value of moisture, volatile matter, and ash, while the total difference of 100% is the percentage value or level of fixed carbon [17].

Evaporation of moisture content occurs at an early stage of heating, followed by the burning of volatile matter and forming fixed carbon, and after burning at high temperatures, coal combustion will leave ash. The coal used has a moisture content of 3.58%, 43.65% volatile material, 6.5% ash, and 46.27% fixed carbon.

The amount of fine coal added to each mold cylinder was 12.5; 25; and 37.5 grams. In comparison, melted aluminum has been poured without the addition of fine coal.

2.2 Melting and Molding Process

Smelting has been done with material in the form of pieces of aluminum that have been put into crucible until melted, but previously inserted aluminum scrap so that it can melt first. The melting temperature has been measured with a Handheld Infrared thermometers, a minimum temperature range of 700oC, and to achieve even melting, it has been held for about 5 to 15 minutes before pouring into the mould, while removing waste that appears on the surface. Moulds cylindrical steel tube with a diameter of 5 cm and 30 cm high was prepared, hold with long tongs holder, where the previous tube has been heated above the crucible.

Test samples were obtained from pouring aluminum alloy coal. Aluminum castings in the form of cylinders were cut by one cm. For the hardness test, the sample was formed in the form of a circle with a diameter of 5 cm thick 1 cm. As for the wear test, a sample size of 10 mm thick, 25 mm wide and 30 mm long was made.

The hardness test has been used the Brinell method while the wear test has been used the Ogoshi method. In the Brinell method hardness test, a 5 mm diameter steel ball indenter, given a 500 kg load, is pressed to the surface to form an indentation. The hardness testing machine that has been used is the Brinell Hardness Tester type BH-3CF. The relationship between the load size, the diameter of the steel ball indenter ball and the diameter of the indentation on the surface of the test sample has been formed the basis for calculating the Brinell hardness value. In the Ogoshi method wear test, disk thickness of 3 mm, disk radius of 13.3 mm, abrasion distance of 66.6 m, and measured wear marks were parameters in the calculation of wear of aluminum material samples in this study, and from this parameter, values have been obtained wear. The wear testing machine that has been used is Ogoshi High-Speed Universal Wear Testing Machine type OAT-U.

3. RESULTS AND DISCUSSION

Pouring this high-temperature aluminum into a cylindrical mould has given rise to a high amount of flame, indicating the burning of coal in the cylinder. This combustion has caused continuous heating of aluminum material in the tube. However, it has also been estimated that not all fine coal is burned, and this fine coal has been trapped in castings. So it has been estimated that there were three remaining components of fine coal from this heating, namely unburnt fine coal, fixed carbon, and ash.

From the Melting and Molding Process, several samples have been obtained for hardness values and wear rates testing. Samples were given a codification such as woc (without fine coal), twf (12.5 grams), ttf (25 grams), and tsf (37.5 grams). The number of hardness test samples with code woc, twf, ttf, and tsf, each of 3 samples, and each sample has been loaded with indenter ball as much as 5 points. As for the wear test, a total of 5 samples each for woc, twf, ttf, and tsf.

3.1 Brinell Hardness

The results of the calculation of the average Brinell hardness value from the measurement results can be made graphically, as shown in Fig.1.

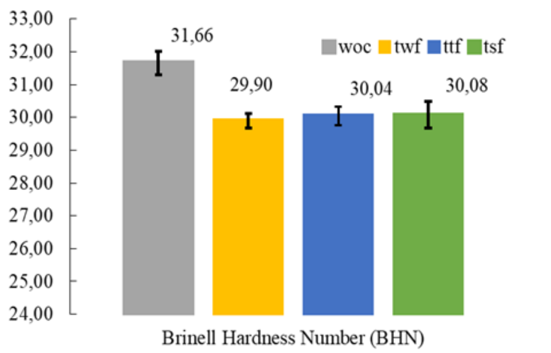


Fig.1 Brinell Hardness Number

From Fig.1, it can be seen that by adding fine coal into the mold just before pouring the molten aluminum, the result has reduced the value of material hardness. The addition of 12.5 grams of fine coal has reduced the value of violence, which was initially 31.66 BHN to 29.90 BHN. However, with the addition of 25 grams of fine coal, the hardness value dropped to 30.04 BHN. Likewise, adding 37.5 grams of fine coal reduced the hardness value to 30.08 BHN. This impairment is appropriate

[9], wherein this case, the presence of elements other than the main material, has decreased the hardness value of aluminum material. The addition of other elements to the main material has also changed the values of hardness [7,8,10,11,19]. Likewise, the addition of fly ash resulting from coal combustion in the fabrication of composite materials has changed the values of the mechanical properties of the material [14,15].

However, when looking at samples that have been given fine coal, it has been seen that more refined coal added has increased Brinell hardness. There has been a mismatch in this regard, the addition of fine coal has generally reduced hardness, but with the amount of fine coal added more, the hardness has increased. So it can be estimated that the presence of unburnt fine coal in aluminum samples cannot be said to increase hardness. However, when examined in samples fed with fine coal, it seemed that the fine coal added has increased the hardness of Brinell. Fine coal that has been put into a cylindrical tube before pouring has been burnt (Fig.2a), which has left carbon or ash traces and then extinguished by leaving white smoke (Fig.2b), which thus has a further heating effect on aluminum samples.

a. The burning of coal. b. White smoke comes out

Fig.2 Sample casting

3.2. Wear Rate

By calculating the average value, the wear of the sample could be made in the form as shown in Fig.3.

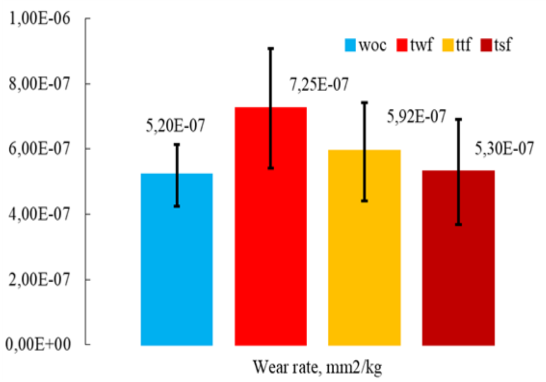
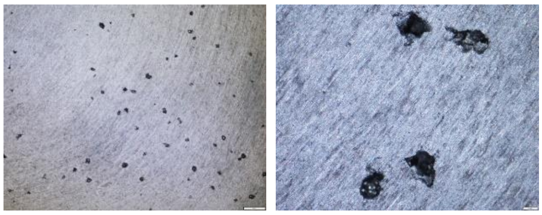


Fig.3 Wear rate

When observed at Fig.3, it appears that in general the addition of fine coal has increased the wear of the sample, where the increase occurred from 5.2E-7 mm2/kg (for samples without the addition of fine coal - woc) to 7.25E-07 mm2/kg (for samples that received additional fine coal 12.5 grams-twf). However, if observed from the amount of fine coal put into a cy-lindrical cylinder, the more fine coal that is given has reduced wear. Where the addition of 25 grams (twf), has reduced wear to 5.92E-07 mm^2/kg and when added more, by 37.5 grams (tsf), the wear has decreased to 5.3E-07 mm^2/kg. The standard deviation for each average sample value looks large. This happens because the results of the measurement of wear samples vary greatly.

This has been different from the phenomenon of hardness testing, where the fine coal that has been given turns out to have increased the value of hardness. The phenomena of changes in wear due to the addition of other elements in the parent material such as this are following what has been previously studied by several researchers [12,13,16]. So it can be estimated that the fine coal added has partially burned to form ash and that some has not burned in the form of fine coal and fixed carbon, and these three elements fill the pore formed and have given a new shape to the surface of the sample, as shown in Fig.4.



a. magnification (60x) b. magnification (450x)

Fig.4 Porous hole filled with fine coal.

When pouring aluminum into a cylindrical tube that already contains fine coal, the pouring temperature has been measured around 650°C. In this case, liquid aluminum has directly heated fine coal, at which the moisture content has been released completely. This temperature reduction due to temperature differences has reduced the temperature of the molten aluminum, but rapidly burned the volatile combustible gas, and naturally raised the temperature of the molten aluminum again. It is estimated that the formation of fixed carbon at that temperature, according to what was said by Speight [17]. It is estimated that the formation of ash almost did not occur because the temperature in the cylinder tube did not reach 900°C.

It is estimated that the chance of fixed carbon burning due to the heat of aluminum liquid is minimal, especially if the amount of mass to be burned is increasingly magnified. Thus it can be estimated that the not burning of fine coal has affected the value of hardness and wear of the sample. From Fig.1, it can be seen that the excessive amount of coal mass has increased Brinell hardness value, but conversely from Fig.4, it appears that excess coal mass or fixed carbon has decreased the value of sample wear.

In this study, it can be said that the presence of carbon on the surface of aluminum alloys results from the burning of fine coal, which can be said to be thermodynamically stable because carbon forms carbides [18]. The formation of these carbides takes place in furnaces [20], which can be interpreted as the process of forming aluminum carbides due to the high temperature of molten aluminum. It is not only a fixed carbon that takes part but also ash. Carbon and ash instability due to contact with water only occurs on the surface. It is estimated that ash can be evenly combined in aluminum alloys because the dimensions of the ash are physically more refined than fixed carbon or fine coal. The formation of aluminum carbide directly does not affect the hardness value or the rate of wear of aluminum alloys.

4. CONCLUSION

From the discussion, it can be concluded that the research by adding fine coal into the cylindrical tube influences the hardness and wear of aluminum castings. Burnt fine coal can be seen from the presence of fire and white smoke that comes out when pouring liquid aluminum into a cylindrical tube. The formation of a new shape on the surface of the sample shows that a certain amount of fine coal has formed a porous hole filled with fine coal that is not burned, fixed carbon, or ash. The presence of pores, which is indicated by not burning fine coal or burning fine coal and being trapped in carbon, can be said that the pore formed is a new form for aluminum alloys. So it can be concluded that a new material has been made, namely porous aluminum filled with fine coal/carbon/ash from coal combustion. This addition has reduced sample hardness. However, if we look at samples that have been given fine coal, it is seen that the more refined coal added will increase the Brinell hardness value. In other word, that with the addition of at least 12.5 grams of fine coal has reduced hardness from 31.66 BHN to a very minimum of 29.90 BHN. Overall the addition of fine coal has increased the wear of the sample, and when observed on the side of the amount of fine coal put into the cylindrical tube, the much fine coal given has decreased the wear value. The addition of at least 12.5 grams of fine coal has increased the wear value to a maximum, i.e., from 5.20E-07 mm^2/kg to 7.25E-07 mm^2/kg.

5. ACKNOWLEDGEMENTS

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