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Paper ID number

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Paper Title

WEAR AND HARDNESS OF AA6061 ALLOY
ALUMINIUM ADDED WITH FINE COAL WHEN
POURING INTO THE MOLD

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ii. Quality

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v. Recommendation

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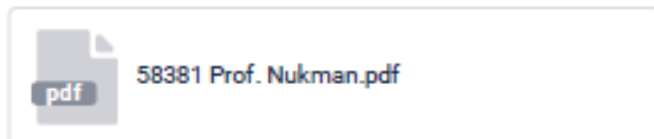
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WEAR AND HARDNESS OF AA6061 ALLOY ALUMINIUM ADDED WITH FINE COAL WHEN POURING INTO THE MOLD

Keywords: Four or five keywords (First characters of each key are in capital/uppercase letters), Italic. Leave one line before and after

Nukman*, Saloma, Kaprawi and Firdaus Muhammad Saleh

Faculty of Engineering, University of Sriwijaya, Indonesia

*@ft.unsri.sc.id, Received: 00 Febr. 2020, Revised: 00 Apr. 2020, Accepted: 00 Apr. 2020

ABSTRACT: AA6061 aluminium alloy material which is widely used in daily life, has been melted in a crucible. Melted aluminium has been poured into a cylindrical tube that functions as a mold, which was previously filled with fine coal. Due to the temperature difference is large enough, fine coal has burned and combustion products will react to the aluminium alloy. Brinell's hardness test results are influenced by three main elements of coal combustion, namely moisture content, volatile matter and fixed carbon. Hardness values have been reduced by the addition of fine coal. But when fine coal has been added again, it has increased the value of hardness. Wear values have increased with the addition of fine coal combustion, but with the amount of fine coal increasing again, the wear values have decreased.

Keywords: AA6061 aluminium, fine coal, hardness, wear

1. INTRODUCTION

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

The properties of aluminium that make metals and their alloys the most economical and attractive for a variety of uses are appearance, lightweight, ease of workmanship, physical properties, mechanical properties, and corrosion resistance [1]. It is generally known that the ratio between strength and weight of aluminium is greater than iron or steel. Apart from that aluminium corrosion-resistant properties have been formed while cooling aluminium castings. A thin layer of aluminium oxide is found in the outer portion of the aluminium 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 aluminium materials, fatigue tests and measurements of the activation energy of aluminium alloys [2,3,4,5].

This research uses commercial aluminium material AA6061 which is included in the category of aluminium that can be heated and forged. Aluminium alloy is one type of aluminium that contains predominant elements of Magnesium and Silicon, which have good 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.

AA6061 aluminium is 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 the main part of the volatile material, which decomposes because combustion will increase the temperature of the aluminium 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 aluminium and liquid gas. Thus the relationship between AA6061 aluminium smelting and the addition of other alloying elements will result in a new aluminium alloy material. It should be noted that the use of aluminium 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 AlSi₁₀MgMn 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 Aluminium-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 main material affects [6].

The addition of the Lithium (Li) element to the A320 molten aluminium 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 mould, liquid aluminium alloys are poured into it. There has been a decrease in hardness, and an increase in material tensile strength [7].

Al-Mg-Si Aluminium 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]. Aluminium waste powder has also been compacted in a certain way and its mechanical properties have been investigated [9].

Recycled aluminium 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 $530^\circ C$. 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].

Al6Si0.5Mg 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].

Aluminium 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 aluminium composite materials [12].

With the addition of 0 to 12% graphite variation in the casting process of Al6082 aluminium alloy 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 [14,15,16].

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.

2. EXPERIMENTAL PROCEDURE

2.1. The Material

The material that has been used for this research is AA6061 aluminium alloy, which is a commercial aluminium alloy. The aluminium cylindrical rod has been cut to 30 cm, this has been done because the height of the container is 30 cm and this has been considered as a recycling simulation of the AA6061 aluminium chip 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 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].

Speight [17] said, the temperature of the evaporation of water vapour levels ended up to a temperature of $106^\circ C$ which is heated with nitrogen-free oxygen flow, while for the burning of volatile matter that is heated to a temperature of around $950^\circ C$ which is maintained within 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 will quickly disappear. The formation of fixed carbon, generally there are two types of behaviour. First, the formation occurs at low temperatures, at temperatures around $600^\circ C$, and high temperatures, around $900^\circ C$. 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.

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 mould cylinder was 12.5; 25; and 37.5 grams. In comparison, melted aluminium 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 aluminium that have been put into crucible until melted, but previously inserted aluminium scrap so that it can melt first. The melting temperature has been measured with a Handheld Infrared thermometers, a minimum

temperature range of 700°C, 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. Pouring this high-temperature aluminium 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 aluminium 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.

Test samples were obtained from pouring aluminium alloy coal. Aluminium 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 hardness test, a steel ball indenter which was given a 500 kg load was pressed on the surface of the sample to form an indentation. 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 aluminium material samples in this study and from this parameter, values have been obtained wear.

3. RESULTS AND DISCUSSION

From the Melting and Molding Process, several samples have been obtained for hardness and wear testing. Samples were given a codification such as woc (without fine coal), twf (12.5 grams), ttf (25 grams) and tsf (37.5 grams).

3.1. Brinell Hardness

From Fig. 1 it can be seen, that by adding fine coal into the mould just before pouring the molten aluminium, the result has reduced the value of material hardness. The addition of 12.5, 25 and 37.5 grams of fine coal has affected Brinell hardness. This addition has reduced sample hardness. This impairment is appropriate [9], wherein this case the presence of elements other than the main material

has decreased the hardness value of aluminium material. The addition of other elements to the main material has also changed the values of hardness [7,18]. 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 [15].

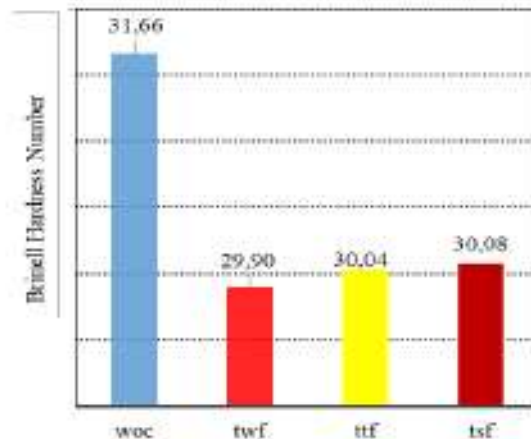


Fig. 1 Brinell Hardness

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. However, when examined in samples fed with fine coal, it seemed that the finer coal added has increased the hardness of Brinell. Fine coal that has been put into a cylindrical tube before pouring, has been burnt (Fig. 2) which has left carbon or ash traces and then extinguished by leaving white smoke, which thus has a further heating effect on aluminium samples.



Fig. 2 Sample casting

3.2. Wear

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

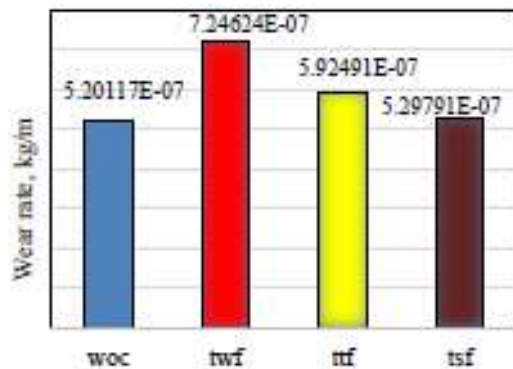


Fig.3 Wear

When observed Fig.3, it appears that in general the addition of fine coal has increased wear of the sample. However, when viewed from the side of the amount of fine coal put into a cylindrical tube, the more fine coal given has reduced wear. This has been different from the phenomenon of hardness testing, where the finer 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.

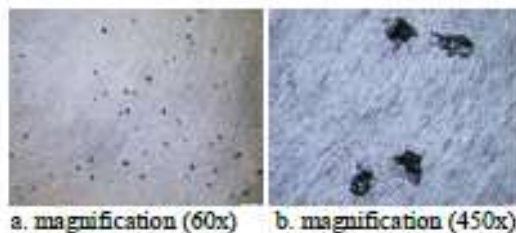


Fig.4 Porous hole filled with fine coal.

When pouring aluminium into a cylindrical tube that already contains fine coal, the pouring temperature has been measured around 650°C. In this case, liquid aluminium 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 aluminium, but rapidly burned the combustible volatile gas, and naturally raised the temperature of the molten aluminium again. It is estimated that the formation of fixed carbon at that temperature, according to what was said by Speight. 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 aluminium liquid is very limited, 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 Figure 1 it can be seen that the excessive amount of coal mass has increased the Brinell hardness value, but conversely from Figure 4, it appears that excess coal mass or fixed carbon has decreased the value of sample wear.

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 aluminium castings. Burnt fine coal can be seen from the presence of fire and white smoke that comes out when pouring liquid aluminium 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 aluminium alloys. So it can be concluded that a new material has been made, namely porous aluminium 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. 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 more fine coal given has decreased the wear value.

5. ACKNOWLEDGEMENTS

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

*Nukman¹, Saloma², Kaprawi Sahim³, and Firdaus Muhammad Saleh⁴

^{1,3}Department of Mechanical Engineering, Faculty of Engineering, University of Sriwijaya, Indonesia.

²Department of Civil Engineering, Faculty of Engineering, University of Sriwijaya, Indonesia. ⁴Doctoral Program on Engineering, Faculty of Engineering, University of Sriwijaya, Indonesia

*Corresponding Author, Received: 00 Febr. 2020, Revised: 29 Apr. 2020, Accepted: 00 Apr. 2020

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 mm³/kg to 7.25E-07 mm³/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 mm³/kg to 7.25E-07 mm³/kg.

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

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Recycled aluminum material added with Al₂O₃ (alumina) is made into a composite. The mixture between AA6061 and Al₂O₃ is then compacted to heat to reach a temperature of 530°C. The addition of Al₂O₃ is 1, 2, 3, 4, and 5% (weight fraction). Tensile strength increases with Al₂O₃ alloy 2% but then decreases [10].

Al₆Si₁₀Mg 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% Al₂O₃ 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°C which is heated with nitrogen-free oxygen flow, while for the burning of volatile matter that is heated to a temperature of around 950°C 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°C, and high temperatures, around 900°C. 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 (Al₄C₃), which is thermodynamically stable. However, Al₄C₃ will be thermodynamically unstable when it comes in contact with water, and this is analogous to the instability of Al₂O₃, 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 Ogooshi 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 Ogooshi 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 Ogooshi 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), tf (25 grams), and tsf (37.5 grams). The number of hardness test samples with code woc, twf, tf, 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, tf, 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.

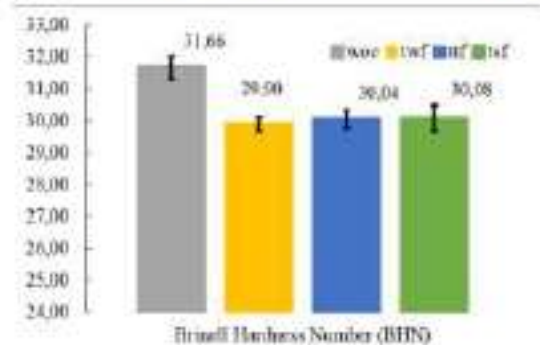


Fig. 1 Brinell Hardness Number

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.

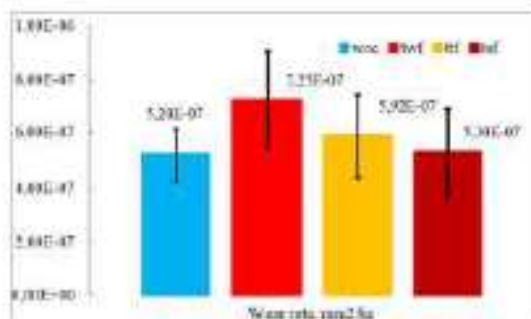


Fig.3 Wear rate

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-rwf). However, if observed from the amount of fine coal put into a cylindrical 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 mm²/kg and when added more, by 37.5 grams (tsf), the wear has decreased to 5.3E-07 mm²/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 words 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 more 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 $5.20E-07$ mm²/kg to $7.25E-07$ mm²/kg.

5. ACKNOWLEDGEMENTS

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RESPONSE BY AUTHORS TO REVIEWER'S REMARKS/COMMENTS

**WEAR AND HARDNESS OF AA6061 ALLOY ALUMINIUM
ADDED WITH FINE COAL WHEN POURING
INTO THE MOLD**

Authors: Nukman, Saloma, Kaprawi Sahim and Firdaus Muhammad Saleh

	Reviewer_A's Comments	Authors Response
1	Insert one-line space between abstract and keywords	It has been corrected according to suggestions.
2	Keywords; first character of each key should be in capital	It has been corrected according to suggestions
3	Remove email address from affiliation	It has been corrected according to suggestions
4	Abstract too short	In accordance with the suggestions, the abstract has been improved by adding the analysis results.
5	Check for grammar mistakes	Grammar has been improved and has used Grammarly Premium
6	Write reference according to template	References have been fixed according to the template
	Reviewer_B's Comments	Authors Response
1	Do not write the author's email, position and department in the author's section	It has been corrected according to suggestions
2	Keywords: Four or five keywords (First characters of each key are in Capital/ uppercase letters), Italic. Leave one Line before and after	It has been corrected according to suggestions
3	Fig. 3 The figure title is short	It has been corrected according to suggestions
4	The first level headings for chapter titles should be in 10pt, bold, justified, and upper case font. Leave one blank line before and after the first level headings, respectively.	It has been corrected according to suggestions
5	List of references: Rearrange all the authors name. No italic, author name should be followed by the abbreviation. Provide all authors name instead of et al. All the references should have pp.??-??. Provide English translation if other language.	It has been corrected according to suggestions

6	Try to adjust the blank spaces	It has been corrected according to suggestions
	Reviewer C's Comments	Authors Response
1	The title of the paper should be revised because the title does not represent the scientific paper in the international journal. AA in front of 6061 means 'aluminium alloy'.	Title has been changed to: The effect of fine coal in tube molds when pouring aluminum alloy 6061 on wear rate and hardness value.
2.	Abstract should consist the major point in the experimental results.	In the abstract has been added, the results of the calculation analysis
3.	Background needs to add some references at least consisting of carbon effects in the Al Alloys.	The effect of carbon in the smelting and molding of aluminum alloys has been added, although it is still being debated by experts.
4.	An experimental procedure: add the ball diameter size of indenter used to characterize Brinell hardness test and brand of Hardness tester. How many points on the surface specimens taken for Brinell test. Add the deviation standard in results.	The size of the diameter of the indenter ball has been added. The number of points on each sample surface has been clarified. Standard deviations have been calculated and added to the figure.
5.	In subsection of 2.1, 3.1 etc in the present manuscript the authors should use more a word to describe the experimental procedure as well as results and discussion. Do not please "The such as The hardness. Erase "the' in subsection of each sub chapter	Some sentences have been corrected and placed not in the experimental procedure section and have been arranged in the results and discussion section.
6.	Each figure should consist the caption describing the figure in the text (Fig. 1 to Fig. 3).	It has been corrected according to suggestions
7.	Fig. 2 has two photos. The author should explain both figures in the text. What is meaning of both figures in the text for supporting discussion. The color bar used in Fig. 1 and Fig. 3 should be the same.	It has been corrected according to suggestions
8.	Most important is how to the authors explain the Fig. 1, Fig. 3 and Fig. 4 deeply. The authors can analyze the deep discussions using the previous researches in literature. In other words, the paper is poor discussion.	The analysis has been improved according to the references used. The pictures have become part of more detailed writing.
9.	Conclusion should more stress the outcome of research results.	The conclusion has been added to the things that come from the review and analysis.



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- Q14. Does your paper contain at least 4 tables and/or figures? Answer (Yes or No): Yes
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2. Authors' Biography (Please write all authors' full name and biodata here)

Prof. Nukman is a head of Engineering Material Laboratory, Faculty of Engineering, University of Sriwijaya, Indonesia. Email: nukman@ft.unsri.ac.id

Dr. Saloma is a head of Magister Program, Civil Engineering, Faculty of Engineering, University of Sriwijaya, Indonesia. Experts in the field of building construction materials. email: salomaunsri@gmail.com

Prof. Kaprawi Sahim, data processing expert in the Department of Mechanical Engineering, Faculty of Engineering, University of Sriwijaya, Indonesia. Email: kaprawi@unsri.ac.id

Firdaus Muhammad Saleh is a Ph.D student in the Department of Mechanical Engineering, University of Sriwijaya, Indonesia. Email: firdaus.ms6@gmail.com

3. Authors' Contributions (Please write all authors' contribution here)

Prof. Nukman: Concepts, Planning, analysis of the article, final approval of the version to be submitted.

Dr. Saloma: analysis, Drafting the article.

Prof. Kaprawi Sahim, reviewer, Language understanding, data processing, data interpretation,

Firdaus Muhammad Saleh: Drafting the article.

4. Ethics (Please provide ethical issues that may arise after the publication of your paper)

This article is the result of research that has never been made and published. All members of the author understand the contents of this paper and agree to be published after being read and discussed together.



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