Analysis of AISI material power of AISI 4140 bucket teeth excavator using influence of abrasive wear

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Analysis of Aisi Material Power of Aisi 4140 Bucket Teeth Excavator Using Influence of Abrasive Wear

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Abstract. Excavators are often used in the mining and construction projects. They are the digger machines normally used for dredging materials in mine, digging, leveling the ground, dredging the river, etc. One of the components of excavator that is frequently replaced is bucket teeth. The replacement of bucket teeth is mainly due to the wear factor occurring in this component. To decrease the wear of the material, heat treatment is applied to increase the material hardness value and eventually, to have high competitiveness in product marketing. Material used in this research was AISI 4140, and the heating process was performed on laboratory's furnaces. The selected cooling medium was water. Analysis was done to determine the values of wear factor, hardness, and micro structure. The investigation of micro structure was done by using optical microscope, hardness test was done using Rockwell hardness tester, and wear test was performed using Ogoshi High Speed Universal Wear Testing. From the results of the analysis, it can be concluded that hardness value is inversely proportional with wear value, the harder the material, the lower the wear value. Meanwhile, the influence of material hardness is the magnitude of Mn in a bucket tooth.

BACKGROUND

Nowadays, the advancements of science and technology in the development era are supported by the human resources' intelligence. It is realized that the growth of science is due to the increasingly complex competitions and the needs of society. Therefore, many scientists continuously develop and invent new methods for the demand of modern society, while educational practitioners also do the same in order to improve discourses and new nuances in the educational aspect as required by the market. Moreover, global market demands high competition regardless of the actors, the ways and the locations since the most important thing is to face and win the competition in the global market [1].

Current development becomes more rapid and more complex hence people should encourage themselves to create a more sophisticated tool to facilitate their working process and to minimize working hours, particularly in developing projects such as highway construction, sky-scrapper buildings, flyover, airport, etc. Thus, the designation of tools which capable of performing hard work, such as excavation and soil transport, in more efficient time is required [2].

One of the heavy equipment mostly used in construction activities is excavator. This heavy equipment, which is best known as backhoe, is a digging machine used for various applications such as mine materials dredging, digging, leveling of the ground, river dredging and demolition. In excavator, the component used for digging and loading

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material is called excavator bucket [3]. Excavator bucket is generally equipped with protruding teeth on its edge, which is named bucket teeth. In the application of excavator, bucket teeth will have a direct contact to the ground so that it has a significant impact on the performance in a whole. Therefore, the material used for making the component of bucket teeth should have high endurance to wear and high power [2].

Bucket teeth is a component of excavator which is replaced periodically since it has relatively short usage time and is very crucial for ground penetration. One of the failures of bucket teeth is a wear in the part of bucket teeth itself.

In this research, hardness test, micro structure test, and abrasive wear test were done. Hardness test was aimed to determine the hardness value of bucket teeth's material, micro structure test was used to determine the phase contained in the bucket teeth's material, and abrasive wear was used to determine the wear value of the material.

Bucket teeth are one of important parts of an excavator. Bucket teeth functions as material digger. It consists of some components, i.e., bucket, adaptor, and teeth [4].

MATERIAL AND RESEARCH METHOD

Steel Classification

Steel is an alloy of Iron (Fe) and Carbon (C) with small number of other elements. The most dominant elements are Iron (Fe), Carbon (C), Mangan (Mn), and Silicon (Si) [5]. Mechanical properties of steel depend on the carbon in the steel, which also affects the hardness value and the endurance to wear. Pure carbon steel contains less Mangan (Mn) and less residue of impurity elements. The content of carbon in the steel is in range between 0.0% - 2.2%. One of the examples is strip steel or coil steel [6].

Carbon Steel

Based on the content of carbon in the steel, it can be classified into low carbon steel, medium carbon steel, and high carbon steel [6].

1. Low Carbon Steel

Steel contains chemical composition of Fe and carbon less than 0.25% [6].

2. Medium Carbon Steel

Carbon composition in this steel is between 0.25%-0.60% [6].

3. High Carbon Steel

The hardest and the most brittle carbon steel. This type of steel contains carbon composition between 0.60%-1.40% [6].

Alloy Steel

Even though carbon steel can be made from various compositions depending on the needs and the cost, its mechanical properties unnecessarily fulfill the requirement for the engineering use, therefore the alloy steel is made [7].

AISI 4140 Steel

Based on its chemical composition, AISI 4140 steel is classified into chromium molybdenum steel. This type of steel can endure heat treatment with some quenching media. It can be used in high temperature although its power will get decrease rapidly along with the increase in temperature. AISI 4140 steel is available in the forms of bar, hammering, sheet, plate, strip, and casting. This material is widely used for high power machine such as connecting rods, crankshaft, axle of wheel, piston rod, wrench, and sprocket. It has 0.38-0.43% of C and <1% of Mn as demonstrated in Table 1.

TABLE 1. Chemical Composition of AISI 4140 [8]

Element	Composition (%)
C	0.38-0.43
Mn	0.75-1.00
Si	0.20-0.35
Cr	0.80-1.10
Mo	0.15-0.25
P	≤ 0.035
S	≤ 0.04

Research Method

In the first stage, the tools and materials were prepared. Preparation included preparing material for casting, cutting material into smaller dimension, weighing material mass, and preparing furnace tools. Casting process was done in Ceper, Klaten, Central Java by using furnace fueled with charcoal briquettes. Smelting process was done at the temperature of approximately ±1600^{0}C. Afterwards, the melted materials in clay container were removed to continue to the casting process of liquid steel into the cast.

After liquid steel was frozen in the cast, heat treatment process was done until a temperature of 950^{0}C. After the specimen achieved the temperature, the quenching was done using water [9]. The specimen of casting as the result of heat treatment was investigated to determine its feasibility to be included in the next phase. If the material was considered feasible, it could be continued to the next phase, but if it was not, the smelting process should be done again. The next phase was laboratory test. This process aimed to know the mechanical characteristics of the specimen.

The first step of laboratory test was micro structure test. In this step, specimen was tested by using Olympus BX41M microscope with a magnification 200x and 400x.

The next laboratory test was hardness test. This test utilized *Rockwell Hardness Tester* with scale C (HRC) in which the scale has 150 kg loading with diamond cone penetrator [10].

The last step was abrasive wear by using Ogoshi Universal Speed Testing. In this process, it utilized 19.08 kg loading in which the specimen was swiped with revolving disc with 1-minute wear [11]. The test was done with four different points.

THEORIES

Bucket Teeth

Bucket teeth are one of important components of an excavator. Bucket teeth function as the material digger. They are divided into three sub-components: bucket which functions as container vessel, adaptor functions as connecting tool between bucket and teeth, and teeth or bucket nail which functions as material digger.

The component of bucket teeth which frequently wear and failure is the teeth. It is because teeth are the part that has direct contact with the ground [2].

The main purpose of teeth is to protect bucket from bump against the ground so it can decrease the damage. This research used a type of long teeth. It is usually used in regular work.

Heat Treatment

Heat treatment is the combination between heating process and controlled cooling, aimed to obtain the expected material properties. Heat treatment is divided into three parts: heating process on certain temperature, heating phase and cooling down the specimen [12].

Hardening is one of heat treatment process to harden the steel. This process was done in furnace by heating the steel at certain temperature over easternization temperature. The temperature was maintained for specific duration to ensure the uniformity of heat and the change of carbon to austenite phase. Subsequently, steel was removed from the furnace and quenched by using the appropriate cooling media [13].

The quenching medium in this stage was water. Water can be used to cool the hot steel with fast cooling speed. However, water tends to absorb gases on the air when steel is on cooling process. These gases tend to make vesicles on steel surface and eventually can make a hole which leads to a crack [14].

Abrasive wear

The good function of a component structure depends on the material properties. The available materials that can be used by engineer are numerous such as metal, polymer, ceramic, glass, and composite. The properties of a material frequently limit its performance. However, it is very rare to evaluate a material's performance based on its property since it is more affected by the combination of some properties. One of the examples is wear-resistance which is the function of some material properties (hardness, power, etc), friction, and lubrication [15].

Abrasive wear can be done with some methods and techniques. All of them aim to stimulate the actual wear condition. One of them is Ogoshi method in which a tested object gets swipe load from revolving disc [11]. Swipe loading will result a continuous contact among surfaces in which at the end it can take some materials on testing object material. The magnitude of trail surface from swiped material is taken as the basis of determining the wear level of material. The bigger and the deeper the wear trail, the higher the material volume from testing object [16]. The scheme of Ogoshi method can be seen in Fig. 1.

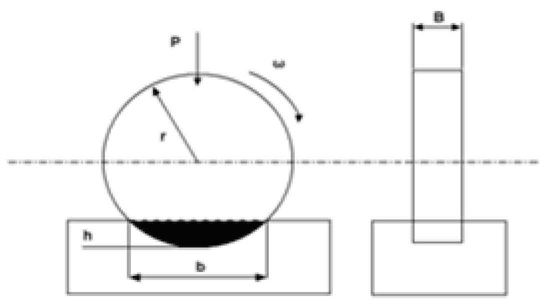


FIGURE 1. The Scheme of *Ogoshi* Test [11].

It occurs when the asperity of certain materials slide on other material's surfaces, which are more lenient, thus the penetration or cutting of more lenient material occurs. The factors of material endurance against abrasive wear are: material hardness, micro structure condition, abrasive size and form [16].
To obtain the wear value, the formula is: [11]:

$$Ws = \frac{B.bo^3}{8.r.Po.lo} \tag{1}$$

RESULTS AND DISCUSSION

Geometric Modelling of Bucket Teeth

Modelling was made by scale 1:1 based on the real size. Data of dimension such as length, width, and height were obtained by referring on the dimension size of bucket and teeth adapter excavator resulted from the field measurement. The obtained data were sufficient to fulfill parameters, which are the size of the bucket teeth. By using AISI 4140 steel, the specifications of bucket teeth in the modeling are as follows:

- Overall length = 220 mm
- Overall width = 98 mm
- Overall height = 102 mm
- Mass = 4669.45 gram
- Volume = 595213.17 mm^3
- Surface area = 89576.48 mm^2

Based on the specifications, bucket teeth modelling was made by using CAD software of SolidWorks 2014. Figure 2 shows the 3-dimension modelling of bucket teeth using Solidwork 2014.

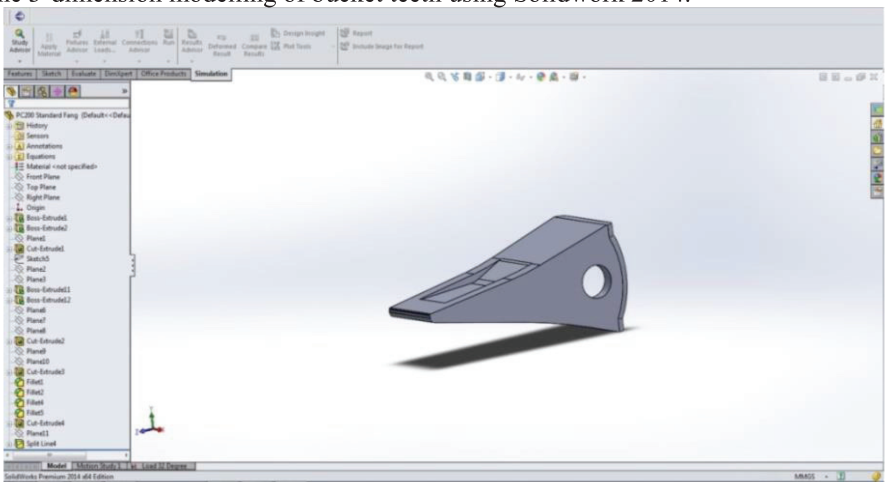
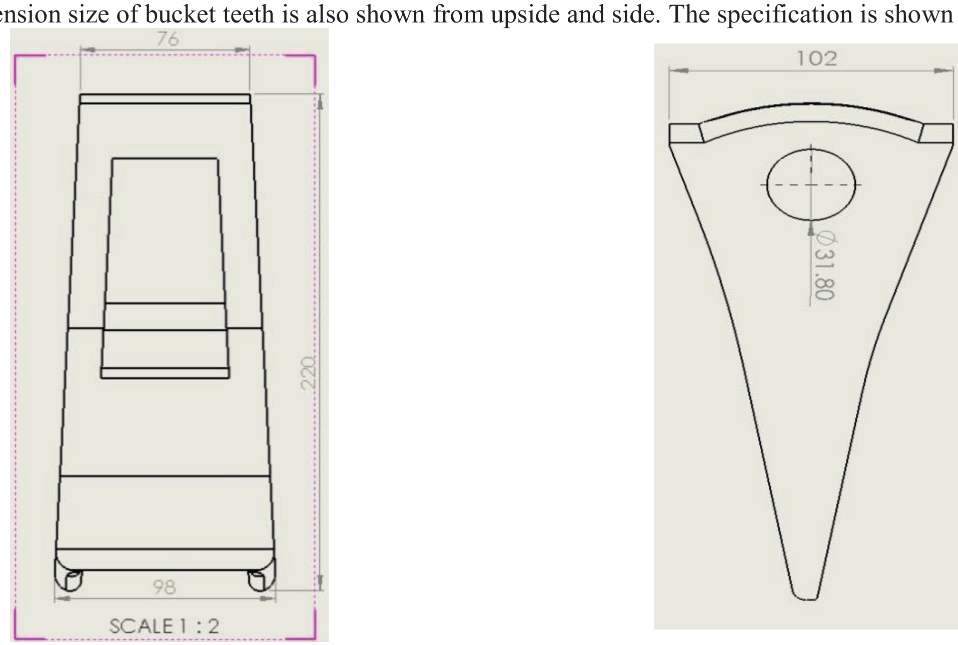


FIGURE 2. The 3-dimension Modelling.

The dimension size of bucket teeth is also shown from upside and side. The specification is shown on figure 3.



(a) (b)

FIGURE 3. *Bucket teeth* dimension size (a) upside (b) side.

Characterization of Composition

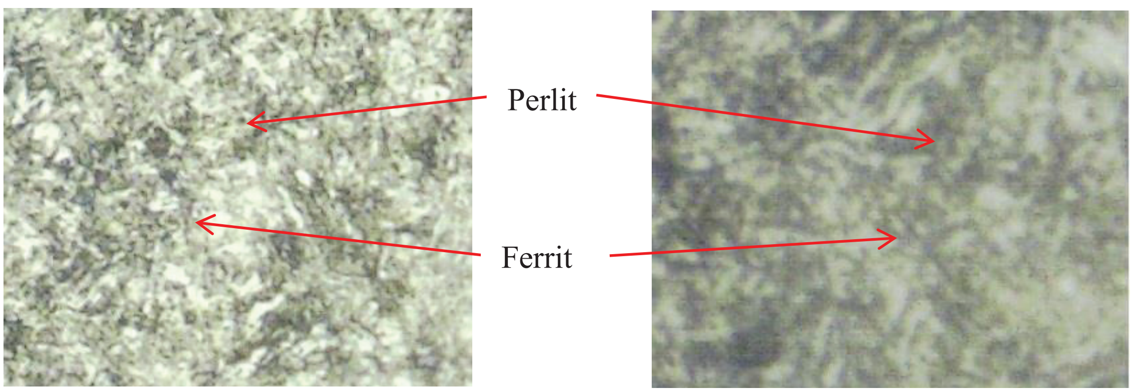
The first step to carry out the utilization study of AISI 4140 steel as bucket teeth material was characterization study. The data obtained from the characterization study of AISI 4140 steel were used as references for the next step. Table 2 shows the testing result of material composition after the treatment. It demonstrates the result of composition test is the same with the standard composition of AISI 4140.

TABLE 2. Material Composition

Element	Standard (%)	Composition Test
C	0.38-0.43	0.40
Mn	0.75-1.00	1.03
Si	0.20-0.35	0.34
Cr	0.80-1.10	1.00
Mo	0.15-0.25	0.24
P	≤ 0.035	0.01
S	≤ 0.04	0.01

Results of Micro Structure Test

Heat treatment process can change the micro structure of a material. The formed micro structure can be customized based on the willingness and its properties. The type of micro structure can be influenced by chemical composition, heat treatment, and the making process. Figure 4 shows the result of the structure test, it can be seen that the material has ferrite and perlite phase.



(a) (b)

FIGURE 4. Micro structure of: (a) Magnification 200x, and (b) Magnification 400x.

Hardness Test Result

In this study, the hardness test was performed on specimen with water quenching as shown on Table 3.

TABLE 3. Hardness value with water quenching (HRC Scale).

Point	Product X (HRC)	Market Product (HRC)
1	53	47
2	56	49
3	59	51
4	55	48
Average	55.75	48.75

From the data, it can be seen that material which has been quenched by water has higher hardness value than the market product. It made the material harder and tougher. It also can increase the lifespan of the bucket teeth. From the data of Table 3, the chart of hardness value in specimen can be illustrated in Figure 5.

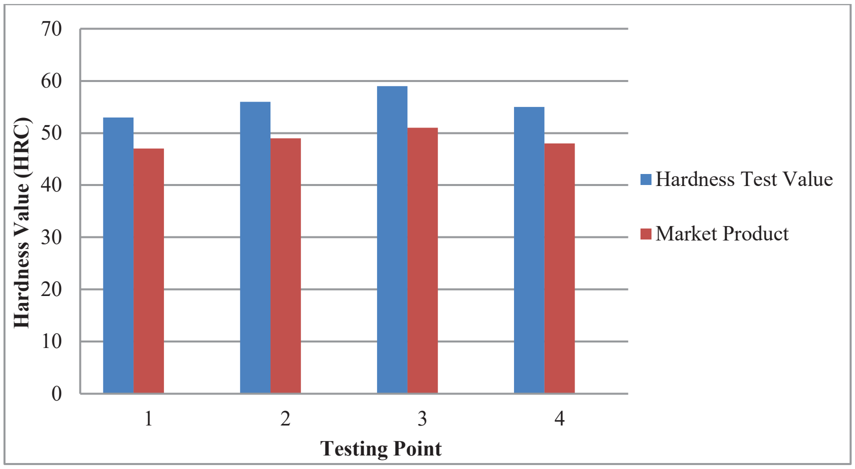


FIGURE 5. Hardness Value Chart.

Results of Abrasive Wear

The abrasive wear test was done by using *Ogoshi Universal High Speed Testing* method. Figure 6 demonstrates the specimen has 4 (four) points of test and the results of the test can be seen in Table 4.

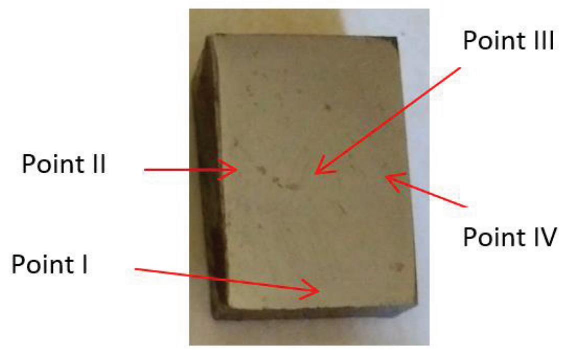


FIGURE 6. Specimen of Ogoshi test.

TABLE 4. Abrasive Wear Result Data

Point	Number of Strokes			Area Width	Average of Area Width	bo (mm)
I	25	30	20	25	20.25	0.657895
II	18	22	17	19		0.5
III	18	19	17	18		0.473684
IV	19	20	18	19		0.5

The sample calculation is using the result of point I. The value of bo (mm) is calculated using the formula [11]:

$$bo = \frac{\sum \text{area width}}{38 \text{ stripe}} \tag{2}$$

$$bo = \frac{25}{38}$$

\

$$bo = 0.657895 \text{ mm (point I)}$$

The determination of specific abrasive wear value uses the equation 1 [13] as follows:

$$Ws = \frac{B.bo^3}{8.r.Po.lo} \tag{3}$$

$$Ws = \frac{3 \text{ mm X } (0.5 \text{ mm})^3}{8 \text{ X } 15 \text{ mm X } 19.08 \text{ kg X } 600000 \text{ mm}}$$

$$Ws = 2.72 \text{ x } 10^{-10} \text{ mm}^2/\text{kg (point II)}$$

Subsequently, the formula was applied to calculate the specific abrasive wear of all points of specimen. The results can be seen in Table 5.

TABLE 5. Data of Abrasive Wear Result

Point	bo (mm)	bo^3 (mm)	Ws (mm^2/kg)
Point I	0.65	0.2746	5.99×10^{-10}
Point II	0.50	0.125	2.72×10^{-10}
Point III	0.47	0.1038	2.26×10^{-10}
Point IV	0.50	0.125	2.72×10^{-10}

By obtaining the specific abrasive wear value, the chart can be shown on Figure 7.

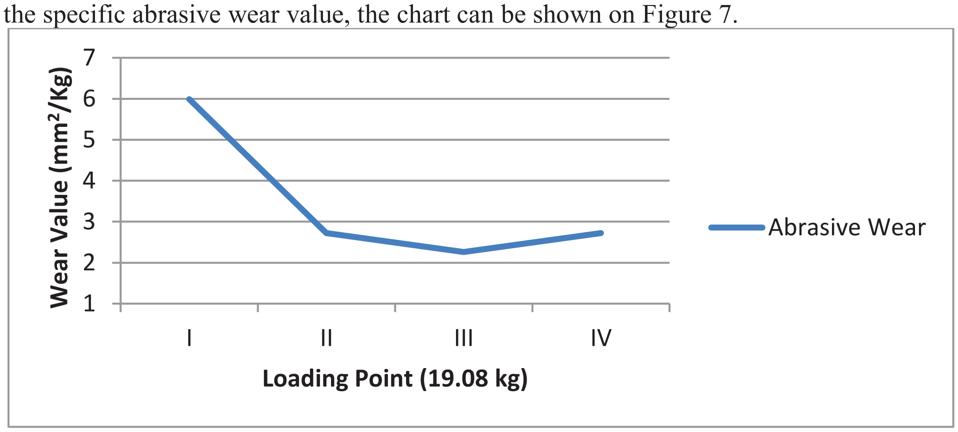


FIGURE 7. Chart of Abrasive Wear Data.

From Table 5 and Figure 7, it can be seen clearly that the material wear values of each point are different. The point is drawn randomly on the test specimen. The point I is taken at the front end of the specimen (the front of the specimen), which has a wear value of 5.99×10^{-10} mm^2/kg. Point II is taken on the right side of the specimen with a wear value of 2.72×10^{-10} mm^2/kg, which means the point of wear value is smaller than point I. The point III is taken at the center of the specimen which has a value of 2.26×10^{-10} mm^2/kg, which is much smaller than the point I and II. Meanwhile, the point IV is taken on the left side of the specimen with the same wear value with the point II, which is equal to 2.72×10^{-10} mm^2/kg. Thus, it can be concluded that the wear value of point III has the lowest wear value, implying the wear value is very small. While point I has the highest wear value, hence it is very easy to experience wear and tear on this point.

CONCLUSION

Based on the findings of some tests and analyses that have been conducted previously, the conclusions are as follows:

1. Micro test result obtains the existence of ferrite and perlite phase. From the hardness tests, it is found that the test result value of point I is 53 HRC, point II is 56 HRC, point III is 59 HRC, point IV is 55 HRC. While, from the abrasive wear test, it is found the value of point I is 5.99 x 10^{-10} mm^2/kg, point II is 2.72 x 10^{-10} mm^2/kg, point III is 2.26 x 10^{-10} mm^2/kg, and point IV is 2.72 x 10^{-10} mm^2/kg. It indicates the lowest wear value obtained by point III. Thus, the test result reveals that the material is AISI 4140 steel.
2. The comparison result between the bucket teeth developed in this study and market product's bucket teeth shows the material of this study has better performance than those of market product. The assessment is done by comparing the mechanical property of the hardness value level.

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