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MATERIAL POWER INFLUENCE OF BUCKET TEETH EXCAVATORAISI 4140 USING ABRASIVE WEAR TEST WITH OGOSHI UNIVERSAL HIGH SPEED TESTINGMETHOD

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ABSTRACT

The hard work of excavator should be absolutely supported by power influence and material strength of the excavator. In excavator, the part used as digging machine and lifting gear of material called excavator bucket. Direct contact of metal component with soil needs steel which has strength and high endurance of abrasion. The end part of this bucket functions as claws called bucket teeth which is the most possible part to fail when excavator operated. Bucket teeth material often used is *mild carbon steel*with C composition is about 0,33%-0,5%, so that the material is considered not able to hold the pressuring and the hardness of pressured material in *bucket teethexcavator*.Even, it is frequently found many *bucket teethexcavator*experienced*abrasive* or even fracture when doing hard work in the field. The hardness difference on *bucket teeth*surface and a bad material are the causes of failure. Power influence of *bucket teeth*can be known from chemical composition test, hardness test, micro graphy test, and abrasive wear test. From chemical composition test, it is found that *bucket teeth* material by using alloy steel AISI 4140 after treatment process is included into *medium carbon steel* with Carbon composition is about 0.38%.Hardness test uses *Rockwell Hardness Tester* hardness tool by using C Scale (HRC) with hardness value is47.75 HRCutilizing oil*quenching*.Abrasive wear test uses *Ogoshi Universal High Speed Testing*method which its wear value is 2.19 x 10^{-10}mm^2/kg. From analysis result, it is found that the harder the material, the lower the wear level.

KEYWORDS: bucket teeth, excavator, micro structure, abrasive wear test, hardness test.

INTRODUCTION

Excavator is heavy equipment frequently used for construction and mining industry to dig a hole and make a foundation and others. Excavator bucket is made from solid steelmaterial and generally equipped with protruding teeth in its sectioning edge to disunite hard material and avoild wear and damage of bucket.Excavator bucket teeth should have good power use towards material like wet ground, stone, and the field which has abrasion caused by ground natural properties when bucket teethused for grinding the material. Alloy steel generally used to make excavator bucket teeth [1].

Direct contact of metal component with soild needs alloy which has strength and high endurance of abrasion. High hardness value is also needed on the surface loading the moving material or even hard material to produce mining digging machine. In excavator, the part used as digging machine and material lifting machine called excavator bucket.The end part of this bucketfunctioning as claws called bucket teeth, is the most possible part to fail when excavator operated [2].

Bucket teeth material often used is mild carbon steel with C composition is about 0,33%-0,5%, so that the material is considered not able to hold the pressuring and the hardness of pressured material in bucket teethexcavator [3].Even, it is frequently found many bucket teethexcavator experiencedabrasive or even fracture when doing hard work in the field [4]. Medium carbon steel can be given heat treatment like austenization, quenching, and tempering to improve mechanical properties. So many people do tempering on this medium carbon steel to get the expected micro structure. Pure medium-carbon steel has low hardenability and can be given heat treatment on that very thin part with fast quenching [5].

Hardness test method used is *Rockwell*. Rockwell method inclueds one of hardness measurement method based on indentation. In this method, penetrator is pressed in testing object. Hardness value is obtained from depth difference of major and minor loads. So, hardness value is based on used pressuring depth [6]. This material wear

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test uses *Ogoshi Universal High Speed Testing*method in which the object is swiped by getting loadig from revolving disc with wearing duration is 1 minute. This swipe pressuring will result a continuous contact among surfaces in which at the end it will take a part of material on sample's surface. The magnitude of surface trace is taken as the decision base of wear level of material [7].

MATERIAL AND METHOD

Material of AISI 4140

Material of AISI 4140 is based on the chemical composition categorized as chromium molybdenum steel. This steel can get heat treatment with quenching of some media. AISI 4140 material is used for high-power machine like: sprocket, collect, crankshaft, piston rod and axle.

Table1Chemical Composition of AISI 4140 [8].

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

Steel

Steel is metal alloy of Iron (Fe) and Carbon (C) and other elements as residue elements, in which the most dominant element is Iron (Fe), Carbon (C), Manganese (Mn), and Silicon (Si) [9].

Low Carbon Steel

This steel contains chemical composition of Fe and carbon less than 0.25%. It is usually made in form of plate, strip, and bar. Low carbon steel has tenacity but less formidable. Low carbon steel is also hard to make a martensite phase because of the very low carbon composition [9].

Tabel 2Chemical Composition of AISI 1020Steel [9].

Element	Content
Carbon, C	0.17 - 0.230 %
Iron, Fe	99.08 - 99.53 %
Manganese, Mn	0.30 - 0.60 %
Phosphorous, P	≤ 0.040 %
Sulfur, S	≤ 0.050 %

Medium Carbon Steel

Carbon composition in this steel is between 0.25%-0.60%. It is usually made in form of instrument of machine part, gear, pedal, and others. Medium carbon steel can be given heat treatment like austenization, quenching, and tempering to improve mechanical properties. Many people do tempering on this medium carbon steel to get the expected micro structure. The pure Medium carbon steel has low hardenability and can be given heat treatment on the very thin part with fast quenching [9].

Table3Chemical Composition of AISI 1020Steel [9].

Element	Content
Carbon, C	0.420 - 0.50 %
Iron, Fe	98.51 - 98.98 %
Manganese, Mn	0.60 - 0.90 %
Phosphorous, P	≤ 0.040 %
Sulfur, S	≤ 0.050 %

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High Carbon Steel

High carbon steel is the hardest and the most brittle carboon steel. This type of steel contains carbon composition between 0.60%-1.40%. Compared to low carbon steel and medium carbon steel, this type of carbon has the highest tensile stress and many used for tools and utensils, like hammer, saw, and chisel [9].

Table 4Chemical Composition of AISI 1020Steel [9].

Element	Content (%)
Iron, Fe	98.38 - 98.8
Carbon, C	0.90 - 1.03
Sulfur, S	≤ 0.050
Phosphorous, P	≤ 0.040
Manganese, Mn	0.30 - 0.50

Method

In the beginning, the thing needed to do is preparing the tools and materials. Preparation needed like preparing material for casting, sectioning material to be smaller dimension, weighing material mass, andputting charcoal into furnace. Casting process was done by using furnace fueled bricket charcoal. Smelting process was done with the temperature approximately ±1600^{0}C.Afterwards, the melted materials in clay container are removed to continue to the casting process of liquied steel into the cast with pressure 5 MPa in order that liquid metal can fill the cast space.

The next process is doing heat treatment process until 950^{0}C. Then, quenching process is done by using oil media [11]. The speciment of casting result via heat treatment is then investigated to know whether it is same as the cast form or not feasible to the next phase. If the material is considered feasible, then laboratory test is done to know the characterization from the testing speciment. This laboratory test covers: micro structure test, hardness test, and abrasive wear test. The laboratory test steps are explained as follows:

Micro Structure Test

Micro structure tesFt refers to AISI 4140testing standard after doing testing speciment which got *polishing* and*etching*, until testing speciment shines and no scratch on its surface. This speciment test uses OLYMPUS BX41M microscope.Before observing microstructure, the testing material should pass some preparation processes which are as follows:

- Sectioning
  Speciment is sectioned into some parts. The part's length taken in the tip of bucket teeth is 4 cm.
- Grinding
  Grinding aims to level the testing material surface after sectioning it. Hard grinding is done until the testing material surface is genuinely level, while medium grinding is done to get softer testing material surface. When doing testing material grinding, it should be given coolant to avoid the overheating caused by heat from grinding process.
- Polishing
  Polishing process aims to get level testing material surface and very soft surface to look shiny without scratch on testing material. Polishing process uses velvet fabric oiled with autosol metalpolish.
- Etching
  Etching aims to show micro structure of testing result using microscope. The testing material that will be etched should be free from structure change caused by deformation and polished carefully and evenly on all testing material surface that its micro structure will be tested. Etching solutions used are a compound of 2.5 ml HNO3, 1 ml HF, 1.5 ml HCL, and 95 ml *aquades* [10].After all preparation process is done, then the next step is doing observation using optical microscope with 100xand 200xZoom

Speciment

Testing speciment grinding

Polishing Output

Optical Microscope and optilab

Figure 1. Preparation Process of Micro Structure Test [12].

Hardness Process

Hardness process is done in testing specimen using heating furnace with oil quenching media.After doing hardeness test, grinding should be conducted first to get level speciment on its both surfaces. Then, it is polished using velvet fabric in order that speciment surface is level. This hardness research uses hardness testing tool namely*Rockwell Hardness Tester* by using C Scale (HRC). Its loading is 150 Kgf us and it uses diamond cone [6].Hardnessvalue is taken from four point on speciment surface

Speciment before grinding

Grinding Machine and Polishing

Rockwell Hardness Tester

Speciment after Hardness Test

Figure 2.SpecimentandHardness Testing Tool [12].

Abrasive Wear Test

This abrasive wear test aims to know the magnitude of specific wear value presented in mm^2/kg unit. In this research, the test uses *Ogoshi Universal High Speed Testing*method in which testing object is swiped with a 19.08 kg load from revolving disc with wear duration is 1 minute.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 basis of determining the wear level of material.After doing test, sample is then observed by using microscope to measure the gauge of abraded surface. Abrasive wear test is done in four different points [7].

Abrasi Wear Tool with OgoshiMethod

Speciment after Abrasive Wear Test

Figure 3.Tool and Speciment of Abrasive Wear Test [13].

THEORY

Bucket teeth (teeth or also called bucket claws) is the part of bucket teeth, the component which frequently gets wear and fracture when excavator operated, because this part contacts directly with the media of excavator. The failure frequently happens is caused by alloy steel characterization when having heat treatment and wear when bucket teeth contacts directly with other materials [14].

Heat Treatment

Heat treatment is the combination between heating process and controlled quenching in pure metal and allow in form of solid, aiming to obtain the expected material properties. Heat treatment is divided into three parts: heating process on certain temperatue and heating containment.

Hardening is the heat treatment process to harden steel. This process is done in furnace by heating steel with certain temperature over austenization temperature, then it is hold on the temperature for quite long to ensure the uniformity of heat and in order all carbon is changed to be austenit phase. Then, steel is removed from furnace and it is given quenching by using the right quenching media.

One of factors influenching stiffening result is quenching speed. To get good result, itt needs a very fast quenching. However, the very fast quenching will cause crack, crook, and distortion on material. The bigger the material mass, the lower quenching speed. Thereore, quenching media selection must be right to cool material with the right quenching speed to get the expected result. [15].

Oil is included into quenching media with medium quenching speed. Its quenching speed is slower than salt and water, but it is faster than air. Oil, diesel fuel, and fuel oil areincluded into this type of quenching media. In this research, the quenching media used is oil. [10].

Abrasive Wear

The good function of a structure component and a machine depends on material properties. The available material and can-be-used material by engineer are really various, such as: metal, polymer, ceramic, glass, and composite. Properties had by material sometimes limit its performance. However, it is very rare to have material performance decided by one property, but it is more on 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[16].

Abrasive wear can be done with some methods and techniques. All aims to stimulate the actual wear condition. One of them is *Ogoshi*method in which a testing object gets swipe load from revolving disc. Swipe loading will

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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 basis of determining the wear level of material. The bigger and the deeper wera trail, the higher material volume from testing object.All materials will experience adhesive wear, abrasive wear, erosion wear, and oxidation wear [17].

Abrasive Wearoccurs when asperity from certain material slides on other material's surfaces which are more lenient so that penetration or sectioning of more lenient material occurs [17].

CALCULATION

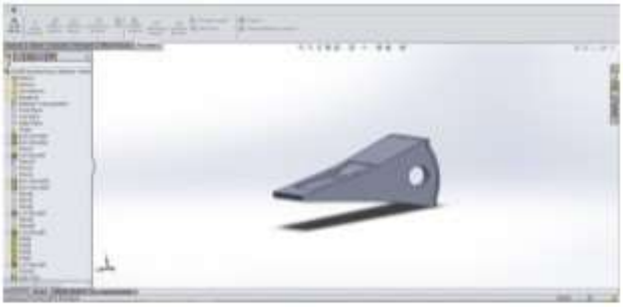
Bucket Teeth Modeling

By using AISI 4140 alloy steel material, below is the specification of bucket teeth that will be modeled:

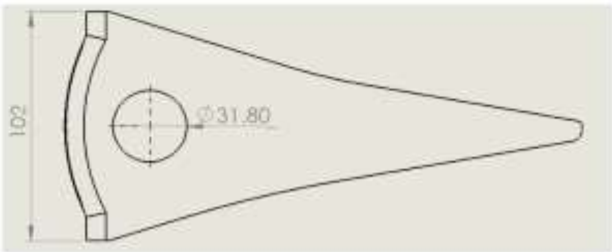
Table 5 Bucket Teeth Specification

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

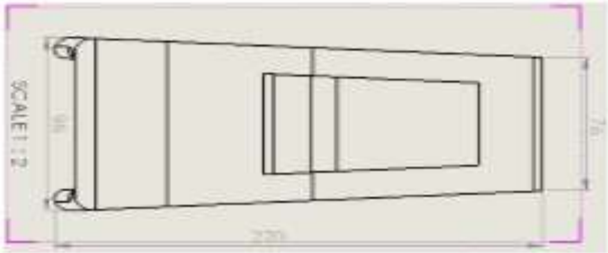
Based on the specifications, bucket teeth modelling is made by using CAD software. CAD Software used to model is SolidWorks 2014.



Bucket teeth 3D Modeling



Bucket teeth dimensional size from upside



Bucket teeth dimensional size from side

Figure 4. Bucket Teeth Modeling [18].

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Chemical Composition Test

Table6 Composition Test Result

No	Element	% Element Composition
1.	C	0.3804
2.	Si	0.3302
3.	S	0.0183
4.	P	0.0177
5.	Mn	1.0351
6.	Ni	0.0222

From chemical composition test, it is found that meterial of bucket teeth after having treatment process is included into medium carbon steelwith Carbon composition is about 0.38%.

Hardness Test

Table 7 Material Hardness Value before Heat Treatment.

No	Speciment (HRC)
1	24
2	25
3	27
4	26
Average	25.5

Based on the data shown in Table 4.2, it reveals the hardness value before heat treatment is very low which only 25.5 HRC is.

Table8Market product hardness value.

No	Speciment (HRC)
1	43
2	44
3	47
4	45
Average	44.75

While, the market product hardness value is 44.75 HRC

Table9 Hardness value using oil quenching media

No	Speciment (HRC)
1	46
2	48
3	50
4	47
Average	47.75

From table 4.3, it is found that hardness value of speciment using oil *quenching*media. The value of point 1 is 46 HRC, point 2 is 48 HRC, while point 3 is 50 HRC, andpoint 4 is 47 HRC. The speciment's average hardness value is 47.75 HRC.

Abrasive Wear Test

Table10Abrasive Wear Area Test Result

Point	Scratch Total			Area	Average Area	bo (mm)
1	30	25	19	24.67	19.92	0.6492
2	22	18	16	18.67		0.4913
3	19	18	16	17.67		0.465
4	20	19	17	18.67		0.4913

Calculation sample to know bo (mm) is in point 2, in which every 100x Zoom= 38 stripes [7].

$$bo = \frac{\sum \text{area}}{38\ stripes}$$
$$bo = \frac{18.67}{38}$$
$$bo = 0.4913\ mm$$

After getting bo, then the value is inserted to the formula to know specific abrasive wear value. The formula is as follows [7]:

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

Detail:
Ws= Specific Abrasive Wear Value (mm^2/kg)
B = Disc thickness of Wearer (mm)
Bo = Width of speciment wear (mm)
Po = Pressuring on Wear Test (kg)
Lo = Mileage on Wear process (m)
Calculation sampe of one of points (point 3) in which it has known:
B = 3 mm
r = 15 mm
Po = 19.08 kg
Lo = 60 m = 600000 mm

$$Ws = \frac{3\ \text{mm} \times (0.465)^3}{8 \times 15\ \text{mm} \times 19.08\ \text{kg} \times 600000\ \text{mm}}$$
$$Ws = 2.19 \times 10^{-10}\text{mm}^2/\text{kg}$$

Table11Abrasive Wear Test Result

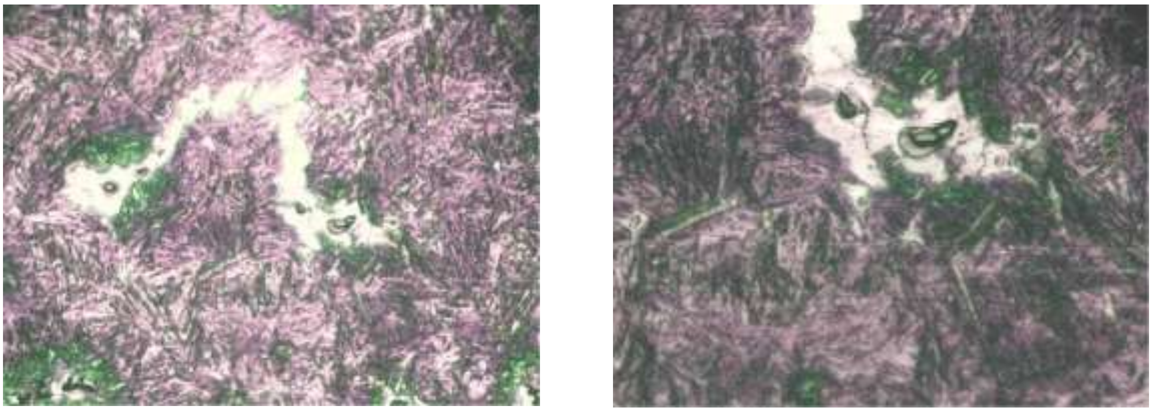
Point	bo (mm)	bo^3 (mm)	Ws (mm^2/kg)
1	0.6492	0.27361	5.97 x 10^{-10}
2	0.4913	0.11858	2.58 x 10^{-10}
3	0.465	0.10054	2.19 x 10^{-10}
4	0.4913	0.11858	2.58 x 10^{-10}

RESULT AND DISCUSSION

Micrography Test Result

Micro structure test is done in testing speciment using heat treatment and using oil quenching. This test is done to know micro structure of testing speciment.

From observation result by microscope, it obtains the figure that micro structure result in the speciment which has got heat treatment using oil quenching media with 100x and 200xzoom. The figure is as follows:



100x Zoom 200x Zoom

Figure5.Speciment micro test result with furnace heating using oil quenching.

Figure 4.6 clearly shows that material structure of micro speciment test result using oil quenching has become martensite phase.

Hardness Test Discussion

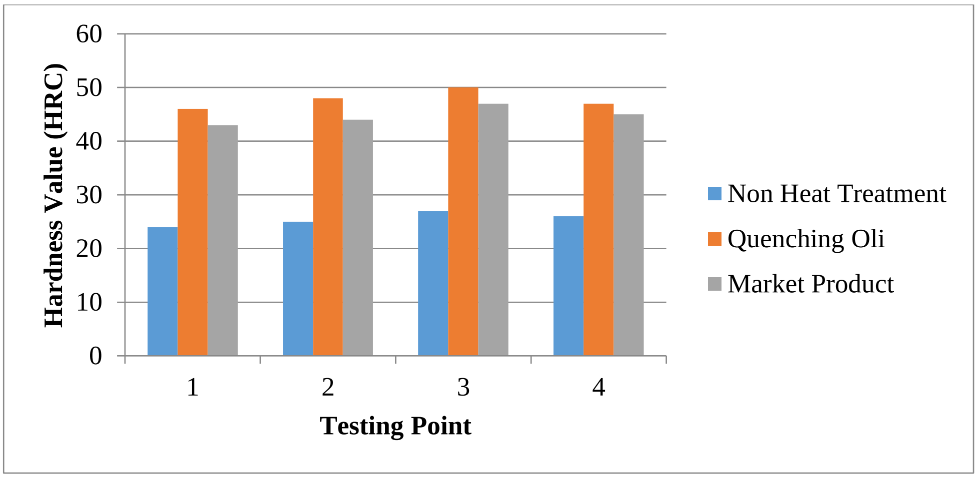


Figure 6.Comparison Chart of Hardness Value.

The chart clearly reveals that speciment resulted from heat treatment using oil quenching media has higher hardness value than speciment without heat treatment, and market product. This hardness value only occurs on speciment surface because it is only heated on its surface. The highest hardness value is on point 3, in which point 3 is the center point of tested speciment with its hardness value is 50 HRC. Then, point 2 and point 4 are on left and right side of point 3. The hardness value of point 2 is 48 HRC and point 4 is 47 HRC.While, point 1 is on the front tip of speciment with its hardness value is 46 HRC. Hence, the highest hardness value is in point 3 with its hardness value is 50 HRC.

Abrasive Wear Test Discussion

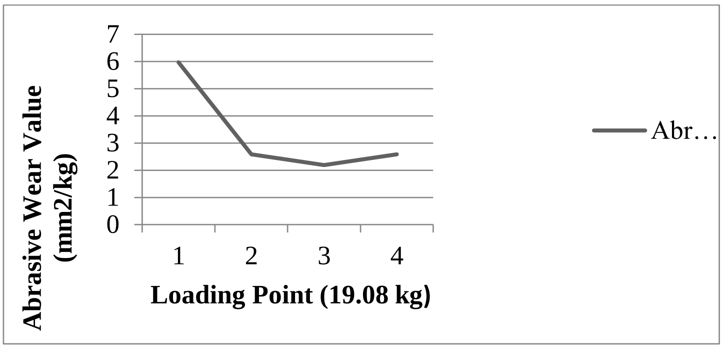


Figure 7.Chart of Abrasive Wear Test Result.

Figure 4.8 tangibly shows that abrasive wear value of material is different. The point selection on testing speciment is done randomly. Point 1 is in the front tip of speciment which its abrasive wear value is 5.97 x 10^{-10}mm^2/kg. Then, point 2 is in the right side of specimentwhich its abrasive value is 2.58 x 10^{-10}mm^2/kg meaning that abrasive wear of point 2 is lower than point 1.

Afterwards, point 3 is in the center of speciment which its abrasive wear value is 2.19 x 10^{-10}mm^2/kg. It is much lower than point 1 and point 2. Then, point 4 is in the left side of speciment which its abrasive wear value is 2.58 x 10^{-10}mm^2/kg.

Therefore, it can be concluded that point 3 has the lowest abrasive wear value meaning that point 3 has the lowest abrasive wear value. While, point 1 has the highest abrasive wear value. This point is easy to get abrasive wear.

CONCLUSION

- Result of hardness test obtains testing result value for material hardness value before getting heat tereatment which its average value is 25.5 HRC. Hardness value result in speciment with oil quenching media in point 1 is 46 HRC, point 2 is 48 HRC, point 3 50 HRC, andpoint 4 is 47. The speciment's average hardness value is 47.75 HRC. While, the average value of market product hardness test is 44.75 HRC. Besides, martensite phase is obtained by micro test using oil quenching media.
- Abrasive wear test result using *Ogoshi Universal High Speed Testing* reveals that point 1 is in the front tip of speciment which has abrasive value in the amount 5.97 x 10^{-10}mm^2/kg. Then, point 2 is in right side of speciment which its abrasive wear is 2.58 x 10^{-10}mm^2/kg, meaning that abrasive wear of point 2 is lower than point 1. Afterwards, point 3 is in the center of speciment which its abrasive wear value is 2.19 x 10^{-10}mm^2/kg. It is much lower than point 1 and point 2. Then, point 4 is in the left side of speciment which its abrasive wear value is 2.58 x 10^{-10}mm^2/kg. Therefore, it can be concluded that point 3 has the lowest abrasive wear value meaning that point 3 has the lowest abrasive wear value. While, point 1 has the highest abrasive wear value. This point is easy to get abrasive wear.

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