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THE INFLUENCE OF MATERIAL STRENGTHON EXCAVATOR TRACK SHOE USING ABRASIVE WEAR TESTINGWITH OGOSHI HIGH SPEED UNIVERSAL WEAR TESTING METHOD

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ABSTRACT

Excavator is heavy equipment used in construction, agriculture and forestry industries. Excavator has a primary function for digging and loading some materials, for instance rocky soil and others. Excavator has 3 sections consisting of attachment, base frame, and undercarriage. One section of undercarriage excavator that mostly needs routine maintenance is track shoe. Track shoe is the crawler or the outer wheel of excavator that serves as the motor of excavator. This section is always in direct contact with the soil which leads to wear. This research discussed the comparison of track shoe material before heat treatment and after heat treatment using quenching with oil media. The material was AISI 1526. The analysis conducted was micrographic test in which non-heat-treatment material went to ferrite and pearlite phases, while heat-treatment material turned into martensite phase. Hardness testing on non-heat-treatment material was 41 HRC, while heat-treatment material was 45.3 HRC. Wear testing on non-heat-treatment material was 1.28mm^3/day, while heat-treatment material was 1.12mm^3/day. Non-heat-treatment material had wear rate value of 0.51 mm/yr and heat-treatment material had 0.34 mm/yr. Microstructure testing of the sample was conducted by using optical microscope, hardness testing of the sample used Rockwell hardness tester, wear testing used Ogoshi high speed universal wear method, and corrosion testing used potentio dynamic polarization method. From the analysis results, hardness value was inversely proportional to wear and corrosion values; the harder the material, the smaller the wear rate.

Keywords: AISI 1526, track shoe, excavator, microstructure, wear testing, hardness testing, corrosion testing, ogoshi high speed universal wear, potentiodynamic polarization.

INTRODUCTION

Technological development increases rapidly from time to time. In addition, one of technologies that have rapid development is the technology of heavy equipment industry. It is because the use of heavy equipment is increasingly vital in the development of industrial world, such as mining, property, infrastructure and others. Particularly, there are several types of heavy equipment, depending on the function, one of which is the excavator unit (Indonesian Ministry of public works, 2012). Excavator takes the biggest role in the heavy equipment industry from all sectors. Based on the data from the Ministry of public works from 2013 to 2020, the need for heavy equipment is very high compared to the availability of heavy equipment itself. Therefore, it can be concluded that heavy equipment is vital in national development and the most widely used weight heavy equipment is excavator. It can be seen in Figure-1.

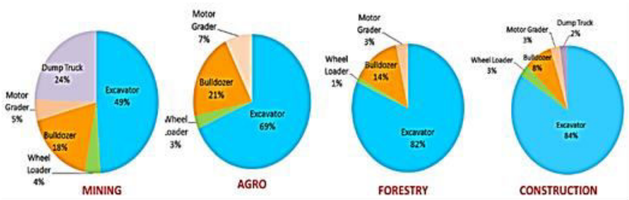

Figure-1. Diagram of comparison of the use of heavy equipment in Indonesia (Indonesian Ministry of public works, 2012).

Excavator is heavy equipment that is used in construction, agriculture or forestry industries. Excavator has a primary function for digging and loading materials such as soil and rocks into the truck or congested location. Excavator has several sections including attachment, base frame and undercarriage. Undercarriage is one of the most common motor tools in construction machinery that serve to move the excavator forward, backward, left and right. Undercarriage works in a system. High mobility in severe field condition can lead to damage to the vital part of the motor in the excavator; it is the chain link (Bošnjak *et al.*, 2013). Chain link is a major component of undercarriage (Ryu *et al.*, 2000; Rubinstein & Coppock, 2007). Wear or damage to chain link components mostly is due to the magnitude of the force that occurs in the excavator during the operating activity and the material strength values that are less suitable for the field (Bošnjak *et al.*, 2011; Dudek *et al.*, 2011).

Undercarriage consists of several sections, one of which is the excavator crawler. Crawler or excavator track shoe is the wheel of excavator, some have wheels of ordinary tires used for dense and flat streets called “Wheel Excavators” and some have wheels of chains iron that will make it easier to pass on the streets that are not dense or uphill. This chains-iron wheel excavator is also called “crawler excavators”. Most of excavators work on soft ground soil. Therefore, based on the experience, it causes problems to the track shoe. If the track shoe always works on harsh conditions, then the damage to the bottom part (track shoe) will be very soon, so in the selection of excavator, track shoe factor must be noticed and considered (Prasetya & Krisnaputra, 2014).

Track shoe is the outermost part of the undercarriage that serves as the "wheel" of the excavator. Section of track shoe is divided into 3 types: triple grouser section, double grouser section and single grouser section. Track shoe is designed in such a way to be able to withstand the load from the excavator and to withstand the force of the ground while running on it (United tractors school, 2008).

Track shoe must have good usage to materials such as wet soil and rocks as well as to terrains that have abrasive properties caused by the nature of the soil when the track shoe crushes the material. John Deere (2007) mentioned that 50% of the largest maintenance cost on excavator is on the undercarriage. In addition, track shoe is one section of the undercarriage that needs more attention because this section is always in direct contact with the ground.

Maulana *et al*. (2017) conducted a research on the damage analysis of undercarriage components of Hitachi EX200 excavator using FMEA method. Based on the results of the research, it can be seen that the track shoe becomes one section of undercarriage which has the second highest RPN percentage of experiencing failure after sprocket.

Based on the previous research, it can be concluded that most arising problem on the excavator is on the track shoe. Therefore, the authors examine the excavator track shoe by comparing the metallic properties that have different characteristics due to heat treatment, examining the value of track shoe wear using Ogoshi high speed universal wear method and examining the value of corrosivity rate using potentiodynamic polarization method. Thus, it requires a special handling so that each element of the metal can be used as what is expected.

LITERATURE REVIEW

Definition of track shoe

Track shoe is one section of undercarriage that works beside the place of contact with the ground and is also the motor of excavator crawler. Track shoe is the section that serves to sustain and pass the load to the surface, either hard or soft surfaces, along with steering and brake systems to move the excavator. Track shoe is mounted on the excavator for the purpose of operating in a rocky area. Meanwhile, when it is operating in the sandy area, the wear rate tends to be greater. Track shoe is equipped with a rib that aims to reduce the lateral friction and is equipped with bolt guard that aims to reduce damage to the head of the bolt. The followings are the various types of excavator track, contained in Table-1.

Table-1. Kinds of excavator track shoe (Komatsu, 2009).

Kinds of track shoe	Description	Figure
Single grouser shoe	It is a type of shoe that can provide great traction, is designed for rugged and rocky operation areas and commonly used for straight dozer and angle dozer.	
Double grouser shoe	It is used to provide large traction with short turn radius.	
Triple grouser shoe	It is commonly used for dozer shovel or excavator. It provides low traction but high maneuverability and is efficient to be operated on soft soil.	
Flat shoe	It is used in the operation on asphalt road. To minimize the road damage. This shoe has no traction so that it allows for slip during the operation.	
Swamp shoe	It is the shoe with a triangle and the contact section with the ground is. It is used in muddy areas.	
Rubber shoe	It is only used when the tractor (bulldozer & dozer shovel) runs on the highway so as not to damage the surface of the asphalt road.	

Most excavators work on pavement, soft soil and so on. Therefore, based on experience, it causes problems to the track shoe. If the track shoe always works on harsh condition area, then the damage to the bottom section (track shoe) will be very soon. The best general use is “triple grouser section” type (wheel with three layers/sections) because good traction also provides minimal damage to the soil surface (Rochmanhadi, 1992). In this research, the track shoe used is the type of triple grouser shoe for 20 ton capacity.

Wear

Maulana *et al*. (2017) conducted a research on the damage analysis of undercarriage components of Hitachi EX200 excavator using FMEA method. Based on the results of the research, it can be seen that the track shoe becomes one section of undercarriage which has a fairly high percentage in terms of vulnerable damage. Therefore, the track shoe should get more attention in terms of selection, installation and maintenance.

Wear is generally defined as the progressive loss of material or the transfer of some material from a surface as a result of the relative movement between the surface and the other surface. Wear has been a practical concern for a long time but for some time it still has not gained a great scientific explanation as well as on the mechanism of damage due to tensile, impact, tipple or fatigue loading. Discussion of the wear mechanism on the material is closely related to friction and lubrication. The research of these three subjects is known as Tribology. Wear is not a material basic property but a material response to an outer system (surface contact). Any material can experience wear due to various mechanisms.

Wear testing can be done with various methods and techniques, all of which aim to simulate actual wear conditions. One of them is the Ogoshi method in which the specimen obtains the frictional load from the revolving disc. This frictional loading will result in repeated inter-surface contact which will finally take some of the material on the surface of the specimen. The magnitude of the surface traces of the frictional material is the basis for determining the level of wear on the material; the larger and deeper the wear, the higher the volume of peeling material from the specimen (Ogoshi high speed universal wear testing instruction manual).

Any type of material will experience adhesive wear, abrasive wear, erosion wear and oxidation wear. The following is a brief description of the mechanisms (Dasgubta *et al.*, 1998):

a) Adhesive wear

It occurs when the surface contact of two or more materials results in attachment to each other (adhesive) and plastic deformation which finally occurs the release of one of the materials (Dasgubta *et al*., 1998).

b) Abrasive wear

It occurs when a hard particles (asperity) of a particular material slips on the surface of another softer material resulting in penetration or cutting of the softer material (Dasgubta *et al*., 1998).

c) Erosion wear

The process of erosion is caused by gases and liquids carrying solid particles striking on the surface of the material. If the impact angle is small, the wear is analogous to the abrasive. However, if the impact angle forms a normal force angle of 90°, then wear will result in a brittle failure on its surface.

d) Oxidation/Corrosive wear

The damage process begins with a chemical change of material on the surface by environmental factors. Contact with this environment results in the formation of layers on surfaces with different properties from the parent material. As a consequence, the material will lead to interface fracture between the surface layer and the parent material and eventually the entire surface layer will be uprooted (John Deere, 2007).

RESEARCH METHOD

In this early stage, the thing to do was to prepare the tools and materials. The required preparation included cutting the raw material of track shoe (AISI 1526) into various specimens. The next stage was the process of heat treatment up to the temperature of 885°C then the process of quick cooling (quenching) using oil media. The specimens of heat treatment results were examined for whether it was feasible for the next stage. If the material was considered as feasible, there will be a laboratory testing process that is useful to know the characterization of the specimens. This laboratory testing included composition testing, hardness testing, microstructure testing, wear testing and corrosion testing.

Composition testing

Composition testing aimed to know the forming elements of the specimen. Next, knowing the percentage of carbon was useful to know the temperature of austenite during heat treatment process. In addition, the result of composition testing was used for the calculation of corrosion rate.

Hardness testing

Hardness testing aimed to determine the level of hardness in the specimen. This research used Rockwell hardness method using Rockwell hardness tester in C-scale (HRC) where the scale had 150 kgf loading with penetrator diamond cone (ASTM E18 - 3). The testing was conducted on specimen results of heat-treatment and non-heat-treatment and was tested at 3 different points.

Microstructure testing

This microstructure testing aimed to know the result of heat treatment item on track shoe. This testing used the brand of Olympus BX41M microscope with 200x magnification. The specimens for microstructure testing were firstly conducted by polishing process using sandpaper and autosol then etching with the solution of 2.5 ml HNO_3, 1ml HF, 1.5ml HCl, and 95 ml of Aquades.

Wear testing

Wear is the loss of material from a surface or transfer of material from its surface to another part or the movement of material to a surface (Almen, 1950). Wear caused by mechanical behavior is reclassified into abrasive, adhesive, flow and fatigue wear. In wear testing of this research, the wear type was abrasive wear. Abrasive wear occurs when hard particles or rough hard surfaces crush and cut off the surface resulting in the loss of the material on the surface (earth moving equipment) (ZumGahr, 1987). This process was carried out using Ogoshi universal high speed testing machine, in which the specimen was fractioned by giving a loading from the rotating ring with wear duration for 1 minute. This frictional loading will result in repetitive contact between the surfaces which will eventually take some of the material on the sample surface. The magnitude of the surface traces of the fractional material is the basis for determining the level of material wear.

The calculation of wear rate used the formula of Archad's Law (1953) but previously it is necessarily to know the abrasive specific value using the following formula:

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

Ws is the specific wear rate (mm^2/kg), B is the thickness of the disc (mm), *Bo*is the area of the abrasive material (mm), r is the radius of the disc (mm), Pois the load value (kg),*Lo*is the abrasion distance(m) (Ogoshi high speed universal wear testing machine instruction manual).

And the calculation of the rate of wear used the following Archad's Law:

$$V = K_D \text{ x } F \text{ x } s \tag{2}$$

V is the lost material volume due to wear; K_D is the wear coefficient or specific abrasion, F is the reaction force of the component or material, and s is the distance when the component is sliding against each other (sliding distance) (Dasgubta *et al.*, 1998).

Corrosion testing

The testing process was conducted using potentio dynamic polarization method in which the method for determining the corrosion behavior of metals was based on potential and anodic or cathodic currents. Metal corrosion occurred when the anodic current was equal to cathodic current although there was no current provided outside the system. It was due to the potential difference between the metal and the solution as the environment (Sunarya, 2008). The corrosion rate can be determined by this method using three-electrode potentiometer; it is the saturated calomel electrode (SCE), the auxiliary electrode in the form of platinum and the working electrode in the form of steel specimen. The data obtained from this method were anodic/cathodic polarization curve which stated the relationship between the current (μA / cm^2) as a potential function (mV).

The corrosion rate testing was conducted by observing the intensity of the corrosion current (Icorr) of the specimen in Sodium Chloride (NaCl) environment. The determination of Icorr was very important because Icorr was directly proportional to the magnitude of the corrosion rate of a metal in its environment. The calculations for determining the corrosion rate and this experiment can use a method based on the potential curve vs. intensity log of corrosion current.

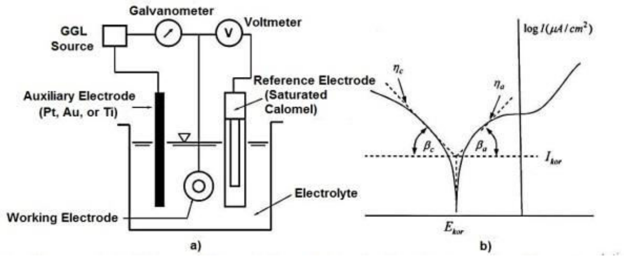

Figure-2. a) Scheme of corrosion tester with the type of three-electrode cell, b) the polarization curve (Tretheway & Chamberlain, 1991).

The corrosion current density (Icorr) is obtained from the potential curve logarithm of the current intensity curve by determining the intersection point of the reduction reaction tafel line (η_c) and the oxidation reaction tafel line (η_a) on the logarithm line of the current intensity by determining the intersection point of the reduction reaction tafel line (η_c) andthe oxidation reaction tafel line (η_a) on the corrosion potential line. The values of$\eta_c$and$\eta_a$were determined by the following equation (Jones, 1992):

$$\eta_a = \beta_a log \frac{i_a}{i_0} \tag{3}$$

$$\eta_c = \beta_c log \frac{i_c}{i_0} \tag{4}$$

$\eta_a$is the oxidation reaction tafel, $\eta_c$isthe reduction reaction tafel, $i_a$is thecurrent at the anode reaction, $i_c$is thecurrent at the cathode reaction, $i_0$is the current at the change of reduction to the oxidation reaction, $\beta_c$is the tafel gradient of cathode reaction, and$\beta_a$is the tafel gradient of anode reaction

The price of corrosion rate can be determined based on the price of the corrosion current density in which the price of corrosion rate of a metal in its environment is equal to the price of the corrosion current density. It is based on the corrosion rate equation (Jones, 1992) as follows:

$$r = 0{,}129 \frac{ai}{nD} \tag{5}$$

$r$is the corrosion rate (mpy), $a$is the atomic mass number or atomic weight, $i$is the corrosion current density $(\mu A/cm^2)$, $n$is the atomic valence, $D$is thespecimen density (gr/cm^3).

Comparison of corrosion rate to be combined is initially calculated by equivalent weight with the following equation (Möller, 2006):

$$EW = N_{EQ}^{-1} \tag{6}$$

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$$N_{EQ} = \sum\left(\frac{\omega_i}{a_i/n_i}\right) = \sum\left(\frac{\omega_i n_i}{a_i}\right) \quad (7)$$

EW is the equivalent weight, N_{EQ} is the total equivalent value, ω_i is the atomic weight fraction, a_i is the atomic mass number, n_i is the atomic valence electron. The equation of the corrosion rate becomes the following equation:

$$r = 0{,}129\,\frac{i_{corr}(EW)}{D} \quad (8)$$

The result of the above corrosion rate equations are still in mpy (mils per year). To change the unit, the following conversion of mpy to the matrix unit is required.

$$1\text{mpy} = 0{,}0254\,\frac{\text{mm}}{\text{yr}} = 25{,}4\,\frac{\mu\text{m}}{\text{yr}} = 2{,}899\,\frac{\text{nm}}{\text{hr}} = 0{,}805\,\frac{\text{pm}}{\text{sec}}$$

By looking at the comparison table of mpy with other matrix units against the corrosion rate in D. A. Jones "Principles and Prevention of Corrosion" book in 1992, we can determine the corrosion rate of the material; as shown in Table-2.

Table-2. Comparison of mpy with other matrix units against corrosion rate.

RCR	mpy	mm/yr	µm/yr	nm/h	pm/s
Outstanding	< 1	< 0.02	< 25	< 2	< 1
Excellent	1 – 5	0.02 – 0.1	25 – 100	2 – 10	1 – 5
Good	5 – 20	0.1 – 0.5	100 – 500	10 – 50	20 – 50
Fair	20 – 50	0.5 – 1	500 – 1000	50 – 150	20 – 50
Poor	50 – 200	1 – 5	1000 – 5000	150 – 500	50 – 200
Unacceptable	200+	5+	5000+	500+	200+

RESULTS AND DISCUSSIONS

Track shoe modeling

The modeling was made on a 1: 1 scale with the actual size. Dimensional data such as length, width and height were generated by reference to the size of the track shoe dimensions that were obtained from field measurements and Komatsu catalogs. The data obtained were sufficient to meet the parameters that will be the size of the track shoe using AISI 1526 steel material.

Based on the specifications, it could be made a model of track shoe using CAD software. The CAD software for modeling is Solid Works 2016 that can be seen in Figure-1.

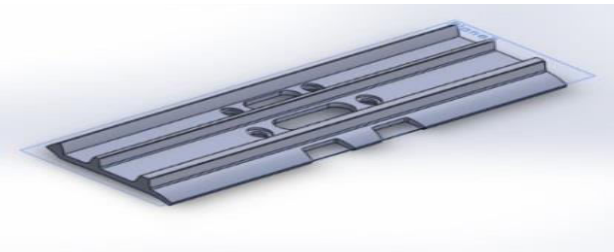
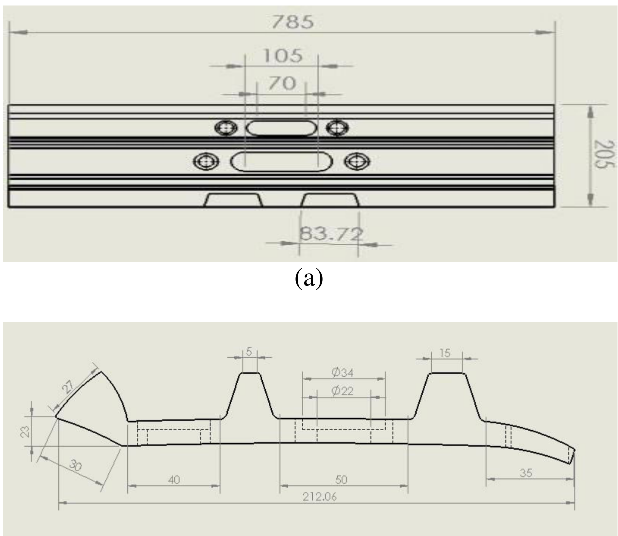


Figure-3. 3-dimensional modeling of track shoe.

The following is the size of track shoe dimensions from the top and side specifications as shown in Figure-2.



(a)

(b)

Figure-4. Size of track shoe dimensions from the top (a) and side (b) specifications.

The above material used AISI 1526 standard in which it used combination steel and was designed using Solid Works 2016 software.

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The result of chemical composition testing

Table-3. The result of chemical composition testing.

No.	Element	Percentage of content (%)	No.	Element	Percentage of content (%)
1.	C	0.2665	13.	Al	0.0011
2.	Si	0.2667	14.	Nb	0.003
3.	S	0.0115	15.	V	0.0037
4.	P	0.0164	16.	Co	0.0000
5.	Mn	1.2427	17.	Pb	0.0012
6.	Ni	0.0280	18.	Ca	0.000
7.	Cr	0.3853	19.	Zn	97.5969
8.	Mo	0.0010	20.	Fe	0.0024
9.	Cu	0.0639	21.	O	0.0150
10.	W	0.0020	22.	N	0.0039
11.	Ti	0.0463	23.	Sb	0.0011
12.	Sn	0.0006			

From chemical composition testing, bucket teeth material that went to treatment process, including medium carbon steel, had carbon content approximately 0.26%.

The result of hardness testing

Hardness testing of the research was conducted by using hardness testing tool: Rockwell Hardness Tester by using C-Scale (HRC) with 150 Kgf loading and the use diamond cone. The testing was conducted on the surface of the specimen. Each specimen had 3 (three) tests as shown in Figure-5.

Figure-5. The specimen of hardness testing

Table-4. Hardness value without heat treatment (left) and with heat treatment (right) (HRC Scale).

Point	Non-treatment specimen (HRC)	Point	Specimen of quenching with oil media
1	42	**1**	45
2	40	**2**	44
3	41	**3**	47
Average	41	Average	45.3

Based on Table-4, we can draw a comparison chart as shown in Figure-6.

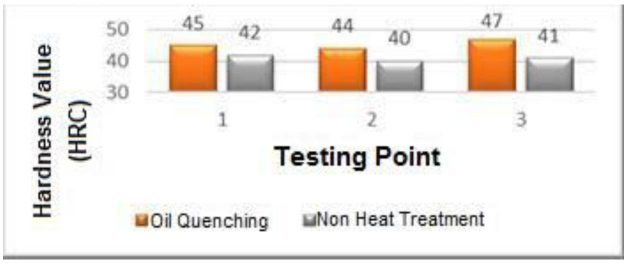

Figure-6. Chart of hardness value.

Based on the chart, it can be seen that the specimen from the result of heat treatment with oil media quenching has a higher hardness value compared with the specimen without heat treatment. This hardness value occurred only on the surface of the specimen because it was only heated on its surface. The highest hardness value is at point 3in which point 3 is the front point of the specimen with hardness value of 47 HRC, then point 1 and point 2 where the point is on the left and center side, with hardness value at point 1 of 45 HRC and at point 2 of 44 HRC. Thus, the highest hardness value is at point 3 with hardness value of 47 HRC. The difference of values from each point was due to heat treatment effect because heat treatment process was done on the surface of the material, so that the heating was uneven.

The result of microstructure testing

Microstructure testing was conducted on specimens without heat treatment process and used the water as quenching medium.

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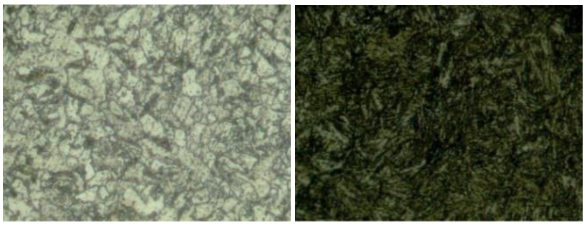


(a) (b)

Figure-7. The result of microstructure testing on the specimen (a) non treatment (b) oil quenching.

From Figure-7a, the microstructure of the material before given the treatment was in the ferrite and pearlite phases while Figure-7b shows that the microstructure of oil quenching material had formed a martensite phase. It was because a rapid cooling process with higher heating temperatures will result a martensite phase. When it was heated, the grains of pearlite and ferrite phases were grown larger.

The result of wear testing

This wear testing aimed to determine the amount of specific wear value stated in mm^2/kg. In this research, the testing used Ogoshi universal high speed testing method in which the specimen was sliding with a load of 19.08 kg from the rotating ring for 1-minute duration. This frictional loading will result in contact between repeated surfaces and will eventually take some of the material on the surface of the specimen. The magnitude of the surface traces of the sliding specimens was the basis for determining the wear rate of the material (Sarkar, 1980).

The following is the result of the data from wear testing using Ogoshi Universal High Speed Testing method.

Figure-8. The specimen of wear testing.

Table-5. Testing value of wear area without heat treatment and with heat treatment.

Treatment	Point	Number of scratches					Average area	bo (mm)
Without heat treatment	1	20	27	38	21	25	26.2	0.68947
	2	19	30	30	20	28	25.4	0.66842
	3	18	37	30	28	27	28	0.73684
With heat treatment	1	25	19	27	22	28	24.2	0.63684
	2	28	22	25	20	31	25.2	0.66315
	3	28	24	31	22	29	26.8	0.70526

The calculation sample is for determining the value of bo (mm) at point 2 of non-heat treatment in which each magnification 100x = 38 strip = 1 mm (Ogoshi High Speed Instruction Manual).

$$bo = \frac{\sum \text{area}}{38\ strip}$$

$$\text{bo} = \frac{25{,}4}{38}$$

$$\text{bo} = 0{,}66842\ \text{mm}$$

After obtaining the value of bo, the value is appropriate to be inserted into the formula to get its specific wear value; the following is the formula (Ogoshi High Speed Instruction Manual):

$$\text{Ws} = \frac{\text{B.bo}^3}{\text{8.r.Po.Lo}} \quad (9)$$

Ws = wear specific value (mm^2/kg)
B = wear disc thickness (mm)
bo = the width of the wear of the specimen (mm)
Po = load during wear testing (kg)
Lo = distance during wear process (m)

The sample calculation of one point (point 2) that has been known is:

B = 3 mm
r = 15 mm
Po = 6.36 kg
Lo = 200 m = 200000 mm

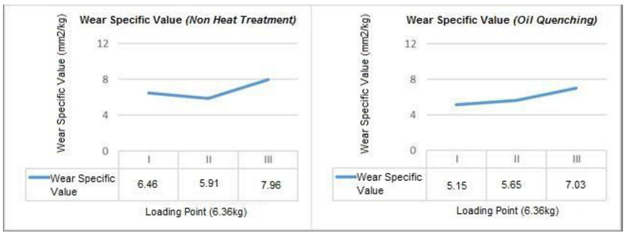
$$Ws = \frac{3\ \text{mm}\ \times\ (0.67)^3}{8\ \times 15\ \text{mm}\ \times 6{,}36\ \text{kg}\ \times 200000\ \text{mm}}$$

$$Ws = 5{,}91\ \times 10^{-9} \text{mm}^2/\text{kg}$$

Table-6. The value of wear testing without heat treatment and with heat treatment.

Treatment	**Point**	**bo** (mm)	**bo³** (mm)	**Ws** (mm²/kg)
Without heat treatment	1	0.69	0.328509	6.46×10^{-9}
	2	0.67	0.300763	5.91×10^{-9}
	3	0.74	0.405224	7.96×10^{-9}
With heat treatment	1	0.64	0.262144	5.15×10^{-9}
	2	0.66	0.287496	5.65×10^{-9}
	3	0.71	0.35791	7.03×10^{-9}

Further explanation of the data is shown in the form of chart which is shown in Figure-9.



(a) (b)

Figure-9. Chart of abrasive specific values (a) non-treatment (b) oil quenching.

To know the prediction of wear rate that occurs on the excavator track shoe Archard's law can be used:

Archard Wear Volume $V = K_D \times F \times s$

V = the lost material volume due to the wear
K_D = wear coefficient of specific abrasion
F = reaction forces on components or materials
s = the distance when the components are sliding (sliding distance)

After knowing the calculation of specific abrasion, the lowest value was taken from each specimen; non heat treatment was 5.91×10^{-9} mm²/kg and oil quenching was5.15×10^{-9}.
The calculation:

K_D =Non Heat Treatment (5.91×10^{-9} mm²/kg); Oil Quenching (5.15×10^{-9})
F = 17.300 kg *(*Traction Force*)* Source: Catalogue Hitachi
s = $12.546 \frac{m}{day} = 12.546.000 \frac{mm}{day}$
For Non Heat Treatment
V = 5.91×10^{-9} mm²/kg x 17.300 kg x 12.546.000 $\frac{mm}{day}$
V = $1.28 \frac{mm^3}{day}$
For Oil Quenching
V = 5.15×10^{-9} mm²/kg x 17.300 kg x 12.546.000 $\frac{mm}{day}$
V = $1.12 \frac{mm^3}{day}$

Table-8. The mass value of the atom.

4.6 The result of corrosion testing

This corrosion testing aimed to determine the magnitude of corrosion rate value that is stated in units of mpy (mils per year). In this research, the testing used Potentiodynamic Polarization method in which the specimen was inserted into the holder and immersed into the electrolyte solution in the reaction flask tube. The electrolyte solution was 2.98% NaCl based on the data of the NaCl solution content at Tanjung Mas Semarang port (Ispandriatno & Krisnaputra, 2015)

The following is the result of the data from corrosion rate testing using the Potentiodynamic Polarization method in Table-7.

Table-7. The value *Icorrosion* for non heat treatment and quenching air materials.

Icorrosion	
Non heat treatment	**Water quenching**
48.232 μA	32.163 μA

For the calculation of combined corrosion rate, it initially computes the equivalent weight (Equivalent Weight = EW) using the following equation:

$$EW = N_{EQ}^{-1}$$
$$N_{EQ}^{-1} = \sum \left[\frac{\omega_i}{a_i/n_i}\right] = \sum \left[\frac{\omega_i n_i}{a_i}\right] \quad (10)$$

Description:
EW = equivalent weight
N_{EQ} = the value of total equivalent
ω_i = weight fraction of atom i
a_i = mass number of atom i
n_i = valence electron of atom i

Thus, to find the weight fraction of atom, it can be seen in Table-3 which is the result of AISI 1526 composition testing. Then, to find the mass number of atom, it can be seen in the periodic table and the results can be seen in Table-8.

Fe = 55.845	**S = 32.065**	**Al = 26.982**	**C = 12.011**	**Ni = 58.693**
Nb = 92.906	Si = 28.086	Cr = 51.996	V = 50.942	Mn = 59.938
Mo = 95.94	W = 183.84	P = 30.974	Cu = 63.546	Ti = 47.867
N = 14.007	B = 10.811	So = 121.76	Ca = 40.078	Mg = 24.305
Zn = 65.38	Co = 58.933	Pb = 207.2		

Thus, the valence electron values for all elements can be seen in Table-9.

Table-9. Valence electron value.

C = 4	**Si = 4**	**Pb = 4**	**Al = 3**	**S = 6**
P = 5	N = 5	B = 3	Sb = 5	Ca = 2
Mg = 2	Fe = 2	Ni = 2	Nb = 2	Cr = 1
V = 2	Mn = 2	Mo = 2	W = 2	Cu = 1
Ti = 2	Zn = 2	Co = 2		

After obtaining the value of fraction weight of atom, atomic mass and valence electron, then we look for the value of EQ (Equivalent total) and calculation sample using Fe element (Jones, 1992).

$$N_{EQ}^{-1} = \sum \left[\frac{\omega_i}{a_i/n_i}\right] = \sum \left[\frac{\omega_i n_i}{a_i}\right]$$

$$Fe = \left(\frac{0{,}975969 \; x \; 2}{55{,}845}\right) = 0.0349527$$

Table-10. EQ value (total equivalent).

C = 0.0008875	**Si = 0.0003812**	**Pb = 0**	**Al = 0.0000375**	**S = 0.0000215**
P = 0.0000265	N = 0.0000535	B = 0.0000067	Sb = 0.0000016	Ca = 0.0000006
Mg = 0.000006	Fe = 0.0349527	Ni = 0.0000095	Nb = 0.00000023	Cr = 0.0000741
V = 0.0000012	Mn = 0.0004524	Mo = 0.0000044	W = 0.00000022	Cu = 0.00001
Ti = 0.0000193	Zn = 0.0000002	Co = 0.0000013		

$\sum EQ = 0.04036961$
$EW = N_{EQ}^{-1}$
$= 0.09036961^{-1}$
$= 24.771$

To find the value of corrosion rate, the equation becomes:

Icorr (Non Heat Treatment) = 48.232μA
Icorr (Oil Quenching) = 32.163 μA

$$r = 0.129 \; \frac{i_{corr}(EW)}{D}$$

- Non Heat Treatment = $0.129 \; x \; \frac{48.232 \; x \; (24.771)}{7.7}$ = 20.02 *mpy*
- Oil Quenching = $0.129 \; x \; \frac{32.163 \; x \; (24.771)}{7.7}$ = 13.34 *mpy*

The conversion of mils per year to matrix units:

$$1\text{mpy} = 0.0254\frac{\text{mm}}{\text{yr}} = 25.4\;\frac{\mu\text{m}}{\text{yr}} = 2.899\;\frac{\text{nm}}{\text{hr}} = 0.805\;\frac{\text{pm}}{\text{sec}}$$

Therefore,

- Non Heat Treatment whose value is 20,02 *mpy*= 0,51 $\frac{mm}{yr}$
- Water Quenching whose value is 13,34 *mpy*= 0,34 $\frac{mm}{yr}$

Thus, we can determine the material properties of the corrosion rate. AISI 1526 non treatment has a corrosion rate value of 0.51$\frac{mm}{yr}$in which it is stated in the Fair classification in the table; i.e. between 0.5 - 1$\frac{mm}{yr}$. Meanwhile, AISI 1526 of quenching results with oil medium has a corrosion rate value of 0.34$\frac{mm}{yr}$in which it is stated in the Good classification in the table; i.e. between 0.5 - 1$\frac{mm}{yr}$.It can be concluded that AISI 1526 material with oil media quenching has better corrosion resistance than AISI 1526 non-treatment material.

CONCLUSIONS

Based on the research that has been conducted, it can be drawn some conclusions as follows:

a) The result of hardness testing

Based on the results of hardness testing, non-heat-treatment material was 41 HRC, while the material of heat treatment with oil quenching was 45.3 HRC so it can be concluded that the process of heat treatment using quenching with oil media can increase the hardness value.

b) The result of microstructure testing

Based on the results of microstructure testing, non-heat-treatment material went to ferrite and pearlite phases while the material with oil quenching process went to martensite phase which meant that the material of heat treatment with oil quenching was harder than non-heat-treatment material.

c) The result of wear testing with Ogoshi universal high speed testing method

From the results of wear testing, the wear rate of non-heat-treatment material was 1.28mm^3/day and the material using heat treatment with oil quenching was 1.12mm^3/day in which the results of oil quenching was smaller than non-heat treatment results, which showed that specimen with oil quenching was more resistant to wear.

d) The result of corrosion testing using potentiodynamic polarization method

Based on the result of corrosion testing, the wear rate of heat-treatment material was 0.51 mm/yr and non-heat-treatment material was 0.34 mm/yr, so the corrosion rate for non-heat-treatment material was considered to be fair and the material with oil quenching was considered as good.

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