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DESIGNING AND WEAR TESTING OF EXCAVATOR BUCKET TEETH FOR THE NEED OF INDONESIAN MINING

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ABSTRACT

The Excavator bucket tooth can be damaged due to abrasive wear and impact load after it has been operated in the field. This paper deals with a review of wear analysis of excavator bucket tooth. Excavators examined in the present study was made up of alloy steel from two branded products (ND and X). The purpose of the present work was to make a quality analysis of those bucket teeth products. Results of field test for two bucket teeth product provided the actual wear volume of 31.25 cm3 /day and 36.88 cm3 /day for ND and X tooth tested respectively. Similar to Ogoshi wear test, the X bucket teeth have a value of wear volume loss higher than that of ND bucket teeth. In this test, the specific abrasion value (K1) can be used for indicating the abrasive material hardness. The comparison of the value of specific abrasion (K1) bucket teeth on the application in the field and the Ogoshi wear test is 67 %. This suggested that the X bucket teeth can still compete with ND bucket teeth products on the marketplace.

Keywords: bucket teeth, wear, ogoshi test, field test, abrasion value.

INTRODUCTION

Wear can be suffered on excavator bucket teeth as a result of the prolonged frictional interaction between its surfaces contacting with soil in relative motion during mining processes which subsequently control its life span (Patel and Prajapati, 2012). Also, this condition may include impact, abrasion, fretting, and chemical action. Wear has become a critical issue in mining industries because it can make the premature failure of the bucket teeth and needs a replacement with new component (Diaz Lankenau *et al*., 2012; Fernández *et al*., 2001; Patel and Prajapati, 2012; Wulpi, 2013). When replacement of this component has been very often due to wear, it can make a reduction in productivity. Accordingly, the friction and wear of bucket teeth have received much attention through a fundamental understanding of mechanism wear on the tooth surface (Chattopadhyay, 2001). In this way, the use of material characterization of the tooth surfaces during and after wear test can understand a transitional wear behavior of the final state.

Further, the excavator bucket teeth commonly undergo the dynamic of wear processes on which material characteristics of bucket teeth should have good strength and surface hardness. Accordingly, the teeth are often made of steel, which has a good hardness and toughness, and also it can work under the influence of complex process with loading and unloading periods (Cires and Nani, 2016; Peurifoy and Ledbetter, 1985). In order to withstand abrasive elements, steel can be improved by surface coating since it has good weldability on which the good choice of the base tooth material is for easy coating application (Sarkar *et al*., 2015; Singla *et al*., 2014). For example, steel alloys containing Cr, V and Nb could be welded onto the steel surface. Additionally, a ferrite matrix with tungsten carbide is weldable and can be employed a coating material with varying forms and sizes of a tooth. Nevertheless, under load, the teeth coated with hardened materials may be subjected to cracks propagating through the thickness of the coating or interfacial de-cohesion which leads to failures. Thus, a low cost of an excavator's tooth has been proposed to employ a medium carbon steel casting in a sand mold and could be subsequently heat treated to modify microstructures and mechanical properties (Singla *et al*., 2014).

In particular, the heat treatment in steel can play an important role in modifying the microstructure. Steel could be treated through applying phase transformation during heating and cooling, which eventually make the change of a microstructure in the solid state. Correspondingly, two processing approaches of heat treatment could be adopted, namely (i) thermo-mechanical treatments for improving the mechanical property and microstructure, and (ii) thermochemical treatments for tailoring the chemistry and microstructure of the surface material. In traditional thermo-mechanical treatments, steel is initially heated to reach an austenitizing temperature and hold it for a certain time and then cooled by water or oil quenching. The austenitizing temperature of the heating matrix could be in the range of 750 to 950 ^{O}C depending on the carbon content of the steel. In this way, heating of the sample must be performed slowly to prevent cracking or cracking temperature (Diaz Lankenau *et al*., 2012; Fernández *et al*., 2001; Patel and Prajapati, 2012; Wulpi, 2013; Singla *et al*., 2014). Whereas, cooling should be undertaken by quenching for minimizing the carbides. Here the heat treatment on casting product of excavator teeth requires the right selection of surface treatment which could provide a good wear performance with the least expensive method. Hereby optimizing heat treatment parameters ensures the surface hardness to meet the standard of component performance, which eventually provides the competitive costs of the products (Bayer, 2004).

Since the bucket teeth are frequently exposed to heavy wear, it needs an evaluation of wear properties in term of laboratory and field test to avoid costly downtime and reduce the cost of the product. Correspondingly, laboratory wear experiments of the bucket teeth could be

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carried out by a pin-on-disk and a topographical microscope. In this way, frictional loads are initially imposed on the specimens and the resulting surface topography can be subsequently examined by a topographical microscope using 3D profilometry, scanning electron microscopy (SEM). In this work, a laboratory and field test was proposed to enable in-situ monitoring and evaluation of wear under dry conditions. The present research was undertaken to study the wear behavior for as heat treated bucket teeth subjected to laboratory and field trial. The obtained wear rate from both laboratory and field test could help to predict the service life of the bucket teeth, which made to enhance the life span of the product. The lab tests were taken because of considering a low cost method to limit the wear performance of the hardened part similar to the real working conditions, while Ogoshi test was done in the laboratory according to a standard testing procedure (ASTM G105-89) (Bayer, 2004).

MATERIALS AND METHOD

Samples of bucket teeth for testing

In this study, our owned products of bucket teeth (X) were prepared from the design and casting process at the laboratory, on which the product should meet chemical compositions according to SNI 8050: 2014. After finishing the casting, every product was examined by atomic spectrometry for the chemical composition determination. The results of the composition determination are presented in Table-1. Subsequently, the bucket teeth were heat treated to improve the value of hardness. The heat treatment of the product consisted of heating up it to an austenitization temperature of about 800 ^{O}C, holding for 1 h and then quenching with water, and finally followed by tempering. Two types of bucket teeth (products of X_1-X_2 and as-manufactured products of ND_1-ND_2) were examined for their wear properties and operation under real field conditions. Conversely, the as-manufactured product was purchased from the Indonesian market for excavator component. The purpose is to compare our product with another product to ensure the quality and meet the requirement of the SNI Standard (Figure-1).

Figure-1. Excavator bucket teeth product; a) as-cast product (X1, X2), b) as-manufactured product (ND1, 2).

Table-1. The composition of bucket teeth material selected for this experiments.

Element	Our owned products-blue (X_1-X_2)	Branded products-yellow (ND_1-ND_2)	Indonesian Standard (SNI 8050:2014)
C	0.30	0.185	0.28-0.35
Si	0.53	1.001	0.30-0.80
Mn	0.80	1.007	0.70-1.40
P	0.01	0.038	≤ 0.035
S	0.02	0.013	≤ 0.035
Others	0.21	1.5902	≤ 0.30

Prior to the Ogoshi wear tests, the material characterization experiments were performed for measuring the hardness, on which tests were performed by microhardness setting-up the Rockwell C scale (load 150 kg) (Table-2). To get the accurate measurement was made by five measurements in each the surface of the samples, while the microstructure of the samples was studied with optical microscopy. The results of the test are presented in Table-5 and Figure-2. Whereas the microstructures of both types for the bucket teeth are shown in Figure-3. The X-bucket tooth has mainly martensite structure, while the bainite and some perlite are present in the ND tooth between discs and the surface of the specimen would produce traces of friction marks which can be used as the basis for determination wear value.

Table-2. Hardness of bucket teeth (HRC).

Point	X-bucket teeth (HRC)	ND-bucket teeth (HRC)
1	49	50
2	51	52
3	51	52
4	50	53
5	51	52.5
Average	50.4	51.9

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Figure-2. The bucket samples selected for measuring the hardness.

(a)

(b)

Figure-3. Microstructure of a) X bucket teeth (b) ND bucket teeth.

Laboratory test

The laboratory test of the bucket teeth specimen was carried out using Ogoshi wear testing machine (Type OAT-U) (Instruction Manual). On this experiment, the specimen was prepared with dimensions of 30 mm long and 10 mm thick. Subsequently, inter-surface contact between discs and the surface of the specimen would produce traces of friction marks which can be used as the basis for determination wear value. Here specimen was tested in a 38 mm diameter rotating disk (revolving disc) under the friction load for 1 minute. The specimen was loaded with 62.85 N against the rotating disc using a pneumatic jack. Then surface specimens to be observed with abrasive wear were helped using an optical microscope. Correspondingly the wear rate could be determined as a volume ratio abrasive with the sliding distance (Archard and Hirst, 1956);

$$Ws = B.b^3 / (8.r.po.lo)\ (mm^2/\text{kg}) \quad (1)$$

$$W = K_1 \times P \times s \quad (2)$$

Where,

Ws	= specific wear rate (mm^2/ kg)
B	= width of the revolving disk (mm)
Bo	= width of the worn indentation (mm)
r	= radius of the revolving disk (mm)
Po	= normal force on the disk (kg)
lo	= distance of the worn material (mm)

Field test

Field wear test of bucket teeth was performed by mounting them on an excavator (Komatsu PC 200), on which the X bucket teeth product was fixed on the left edge, while ND product was on the right edge (Figure-4a). Conversely, the second excavator has been mounted with the ND bucket teeth on the right edge and bucket teeth ND on the left edge (Figure-4b). During their surface contact with the working environment, the metal surface was lost yielding to the worn material. Moreover, this wear of material did not consider the change of dimension due to plastic deformation, although, for all practical methods, wear may be experienced to the material without material removal. In this study, the materials to be excavated may involve clays, sands and brown lignite, as well as Palaeozoic materials containing lime and quartz rocks. In particular, the diggers have problems with clays which can result in a hard or very hard basement. Here from 0.05 to 1.8 MPa of compression strength may be subjected to the floor, but this may frequently reach up to 3.3 MPa, while the tensile force in the range of from 0.08 to 0.35 MPa may be subjected to the teeth.

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(a)

(b)

Figure-4. Installation of bucket teeth (a) on the first excavator; (b) on the second excavator.

RESULTS AND DISCUSSIONS

Laboratory results with Ogoshi wear testing

The results of the wear tests provided the specific abrasive wear which was calculated using the formula in Equation 1. Specific abrasive values were used in calculations with Archard's Law (equation 2) in which the wear volume loss could be obtained (Archard and Hirst, 1956). Figure-5 shows the estimated wear volume loss of X bucket teeth and ND bucket teeth for 4 days of operation. Generally, the volume loss of all bucket teeth increases rapidly with the day of operation. Apparently, the trend of the volume loss corresponding to the abrasive material which controlled the wear loss, whereas the highest wear volume loss could be experienced by the X1 bucket teeth. The lower wear resistance of the tooth may be caused by the lower hardness of the metal. Results of wear volume loss for all samples are shown in Table-3. Generally, the wear occurred on the metal surface, on which worn material may be developed corresponding to plowing and/or cutting mechanism. Also, the cavities were observed in the surface area of the metal having a lower hardness. The finding of cavities in the localized areas of wear may be caused by the contact load between the biggest abrasive particles and metal surface, thereby yielding the worn material. Correspondingly, a large hole of a loosened carbide particle could be observed. It is suggested that a softer particle coming from the harder material was removed, whereas the softer matrix material was lost and abraded. This outcome is in agreement with the finding of several authors (Maciejewski et al., 2004; Sare and Constantin, 1997).

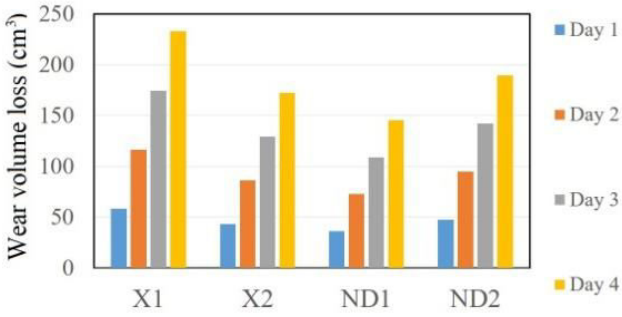

Figure-5. Average wear volume based on Ogoshi wear testing.

Table-3. Results of the calculation of the wear volume with Archard's Law.

No.	Product Code	Specific Abrasion (k_1)	Volume loss of Wear (W)
1	X1	6.48 x 10^{-8} mm^2/kg	58.277 cm^3/day
2	X2	4.79 x 10^{-8} mm^2/kg	43.031 cm^3/day
3	ND1	4.04 x 10^{-8} mm^2/kg	36.292 cm^3/day
4	ND2	5.27 x 10^{-8} mm^2/kg	47.360 cm^3/day

Field test results of the bucket teeth

Wear performance of bucket teeth was examined by applying it directly to the excavator for mining. During the field test, the bucket teeth frequently contacted with abrasive particles from rocks and sand. The wear volume loss was determined by direct measurements based on Archimedes' law, on which the sample was dipped entirely into a beaker containing water and an increase in water volume is reflected the volume of the object. Results of the volume loss for the worn bucket tooth are presented in Figure-6. It shows the comparison of actual wear volume between X and ND-bucket teeth against the duration of the test.

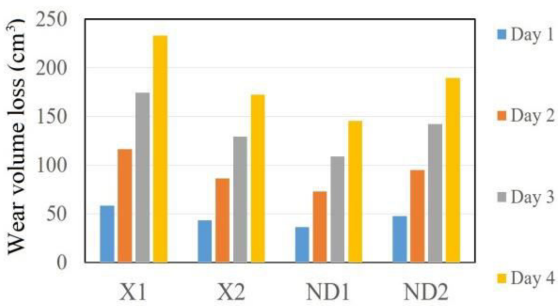

Figure-6. Chart of actual bucket teeth wear volume.

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The wear volume loss of all teeth increased with the duration of the field test (1- 4 days). The ND1 tooth indicates the superiority of the wear resistance in comparison with the X1 tooth for 4 days, whereas wear for teeth with X2 is better than that with ND2 for 2 days of the test. Moreover, the actual wear volume loss of the tested teeth are presented in Table-4. Presumably, the outcome of the field test per day suggested that the manufactured product (ND1, 2) have better wear resistance than X1 teeth product, which may correspond to their high hardness and fracture toughness. The quick view of failure analysis of each tested tooth is shown in Figure-7.

Table-4. The calculation results of actual wear volume loss.

No.	Product Code	Volume (ΔV)	Time (t)	Volume of Wear (W)
1	X1	150 cm^3	4 day	37.50 cm^3/day
2	X2	50 cm^3	2 day	25.00 cm^3/day
3	ND1	95 cm^3	4 day	23.75 cm^3/day
4	ND2	100 cm^3	2 day	50.00 cm^3/day

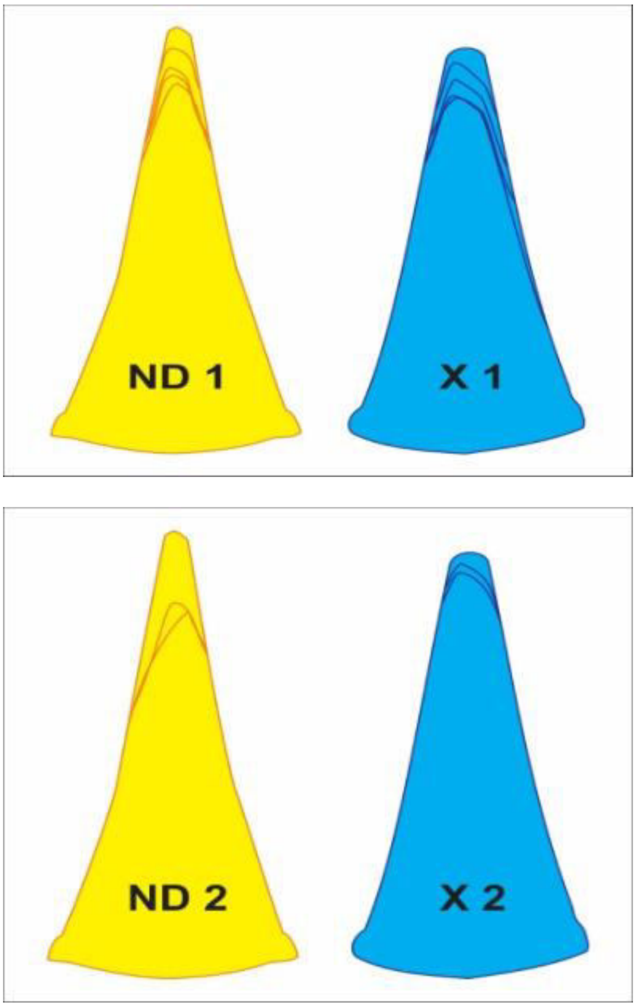

Figure-7. Schematic wear loss of ND1, 2 and X1, 2 bucket teeth.

The first worn product of X1 and ND1 could be analyzed at the foremost edge and each side of the leading edge. Obviously, the ND1 teeth show very little wear damage after the field test. Apparently, the ND1 tooth tip was partially abraded by the abrasive character of the land. The X1 tooth experienced higher wear damage around the tooth tip. After testing, the other facing on the tooth was completely abraded because of the abrasive property of land. Seemingly, the tooth dimension and curvature at the outer end changed related to the wear occurred at the leading edge, directing to the significant weight loss of the tooth. Conversely, the ND_2 tooth experienced severe wear damage. Here wear occurred mostly on the leading edge on which most wear damages could be observed.

Further, the surface with a low hardness on the leading edge was totally removed under dynamic loading, due to the extreme abrasive wear (Penkov *et al.*, 2017). There is evidence of soft-faced alloy present on the tooth surface after the field test. This surface provided less abrasive resistance compared to the X1 tooth. The shape of bucket teeth also influences the performance of the excavator when used to dig the ground. Sharper bucket teeth can penetrate deeper when digging the ground. This condition makes the bucket teeth to be more durable and can increase productivity (Jamal *et al.*, 2016; Zhang *et al.*, 2013).

CONCLUSIONS

It can be concluded that established along with the lab tests, the average wear volume loss of X bucket teeth is 45,643 cm^3 / day and 45.050 cm^3/ day for ND tooth. While the field test provided the actual wear volume of 31.25 cm^3 / day and 36.88 cm^3 / day for ND and X tooth tested respectively. Moreover, the X bucket teeth have a value of wear volume loss higher than that of ND bucket teeth with the difference in the volume of ogoshi testing by 0.594 cm3 / day and the actual wear volume of 13.75 cm3 / day. In the Ogoshi wear test there is a specific abrasion value (K1) indicating the abrasive material hardness? The comparison of the value of specific abrasion (K1) bucket teeth on the application in the field and the ogoshi wear test is 67%. This suggested that the X bucket teeth can still compete with ND bucket teeth products when it would be sold in the market.

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