Jurnal Polimesin
Department of Mechanical Engineering
State Polytechnic of Lhokseumawe
http://e-jurnal.pnl.ac.id/polimesin

e-ISSN	: 2549-1999	No.	: 3	Month	: June
p-ISSN	: 1693-5462	Volume	: 21	Year	: 2023

Article Processing Dates: Received on 2023-02-01, Reviewed on 2023-03-07, Revised on 2023-05-08, Accepted on 2023-05-09, and Available online on 2023-06-30

Hardening of bucket teeth made from creusabro 8000 steel by using the induction hardening method

Darma Firmansyah Undayat*, Cecep Ruskandi, Ari Siswanto
Department of Metal Casting Engineering, Politeknik Manufaktur Bandung, Bandung 40135, Indonesia
*Corresponding author: darmafirm@gmail.com

Abstract

Excavators are often used in mining projects such as for penetrating, excavating, dredging, gouging, and crushing mineral rocks. Bucket teeth are an excavator component that is often being replaced due to failure. The most common failure mode that occurred in bucket teeth was wear on the tip or front section of it. To reduce the wear of the bucket teeth material then its hardness should be increased. As the hardness value increases, the resistance to wear increases. The bucket teeth were made of Creusabro 8000 steel and a hardening process was then carried out on the front section of the bucket teeth components by using an induction furnace. The power used in the induction furnace varies from 28, 35, 42 and 49 kW (kilowatts) and the holding time varies between 3 and 5 minutes. The heat treatment process used oil as a cooling medium. The analysis was carried out to determine the area that experienced an increase in hardness and its occurred microstructure. Microstructure examination was carried out with an optical microscope, and hardness test by using a Vickers microscopy. It can be concluded from the result of the analysis that the large area experienced an hardness increase is directly proportional to the electric current magnitude and holding time. The microstructure has changed from fine pearlite to martensite thus hardness of Bucket Teeth can be increased up to 100% of the initial hardness.

Keywords: bucket teeth, induction furnace, Creusabro 8000, hardness, microstructure

1 Introduction

Bucket Wheel Excavator (BWE) is a heavy equipment used in the mining process. BWE is a type of digging tool that continuously operates on a large scale. One of the main components of BWE is the axle wheel which functions as a digging tool. Buckets is mounted at the edge of the axle wheel around the wheel axle. The bucket serves as a place for excavated material. Each part of the bucket is paired with several bucket teeth which are used to penetrate, dig, dredge, gouge, and crush minerals [1][2] Today's bucket teeth consist of a welded adapter or a locking system that makes it easy to replace when needed [3].

According to a study conducted by Fauzi Widyawati (2014) that the more appropriate material used for bucket teeth was Creusabro 8000 (C8000) steel than AISI 4140 steel. It was due to Creusabro 8000 steel has better mechanical properties when it was processed by the same heat treatment and has better hardness value than AISI 4140. Hardness of Creusabro 8000 steel was higher than AISI 4140 steel but Creusabro 8000 material has a lower impact value than AISI 4140 steel [4].

The hardness within each part of bucket teeth should be different i.e. the front section (sharp end) of bucket teeth should be hard whereas at the middle and lock (ear) section must be soft and ductile (Fig. 1). In its application, the front section of bucket teeth receive frictional load from the excavated material so that hardness is very important in order to increase its life time. Bucket teeth is attached and locked to its holder called adaptor by hammering process, thus the middle and lock section of bucket teeth must be ductile enough to prevent fracture while hammering. Fracture at those part can not be accepted because the bucket teeth become unused. Wear of bucket teeth at the front section during its application can't be hindered, it is still allowable as long as the wear rate is low [3] and hardness value of 36 – 40 HRC or 354 – 392 HV[5][4][6].

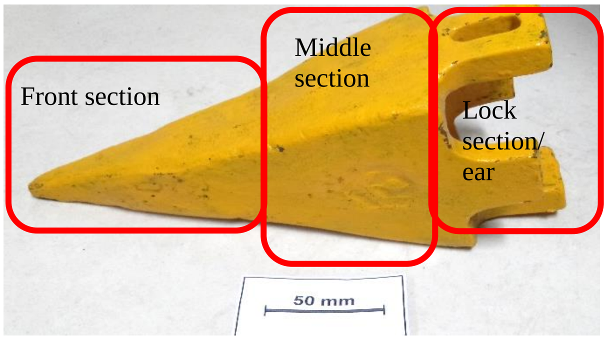

Fig. 1. Bucket teeth and its section

Achyarsyah and Fauzi Widyawati (2014) had worked to compare the mechanical properties of two types of steel applied for bucket teeth which were AISI 4140 and Creusabro 8000. The result concluded that Creusabro 8000 steel had better mechanical properties than another. The other work conducted by Sigit Ngalambang (2013) that studied the effect of spray quenching on the mechanical properties of those two steels applied for bucket teeth [7]. The result showed that the mechanical properties in term of hardness value were different on each section of the bucket teeth. However the drawback of this research was that the hardening process of bucket teeth carried out one by one so that the method is relatively difficult to apply because it require specific equipment in order to obtain a homogenous mechanical properties of every bucket teeth processed in each batch.

Induction hardening method can produce different hardness on each section of part or product by adjusting the position of the part to be hardened. The induction hardening process can produce consistent hardness values in a batch of product because the equipment used in this method contains software that can be programmed by entering certain parameters [8][9]. Any parameters of the software can be changed in order to get the expected result. Such parameters are the diameter of coil, scan rate, holding time, electrical power, frequency and cooling medium. The result of research by M. Onan et.al on AISI 1040 steel explained that those parameters affected the depth of hardness and hardenability of each section of the part [10][11]. Varying power magnitude and holding time will result in temperature variety [12].

In order to improve hardness on the front section of bucket teeth, this research used the induction hardening method then followed by oil quenching.

The geometry of bucket teeth is mentioned in Fig. 2, which the front section (sharp edge) of it is thicker than other section. Each section of bucket teeth have the differences in cross sectional area. Some variables involved in this research were the power of induction furnace and holding time which were termed free variables; and the diameter of coil, frequency and the coil position relative to bucket teeth were termed fixed variables.

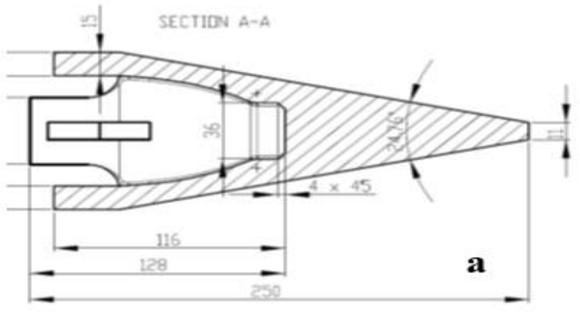

Fig. 2. Sectional view and dimension of Bucket Teeth.

2 Research Methods/ Materials and Methods

Four stages have been conducted in this research i.e. casting process, heat-treatment, microstructural observation and testing of mechanical properties.

2.1 Casting process

Bucket teeth were made of Creusabro 8000 steel with the chemical composition as shown in table 1 [13]. In producing bucket teeth, sandcasting method have been chosen and by using medium frequency induction furnace with the capacity of 250 kg for melting process of this steel. The chemical composition of steel was checked using optical emission spectrometry (OES)[14] instrument of ARL type 3460and the result was shown in the far right of table 1.

Table 1. Chemical composition of Creusabro 8000 steel

Elements	Standard composition (wt.%)	Actual composition (wt.%)
Carbon (C)	≤ 0,28	0,23
Sulfur (S)	≤ 0,005	0,009
Phosphor (P)	≤ 0,018	0,012
Mangan (Mn)	≤ 1,6	0,99
Nickel (Ni)	≤ 1,0	0,53
Chromium (Cr)	≤ 1,6	1,2
Molybdenum (Mo)	≤ 0,4	0,13

2.2 Heat-treatment Process

Cast bucket teeth were then heat treated using induction hardening method. During heating process, the bucket teeth was hanged and the coil distance from the edge of bucket teeth is of 50 mm. The single coil of GY-70AB induction heater with the inner diameter and the outer diameter of coil 80 mm and 120 mm respectively and the current frequency of 60 kHz was used for heating process.

On each heating process, the heating power was varied from 28, 35, 42 and 49 kW (Kilo Watt) with holding time 3 and 5 minutes. From its heating temperatures the samples of bucket teeth were then oil quenched to room temperature. Table 2 showed the samples with its variation in heating power and holding time that was applied.

Table 2. Variation in induction heating process

Sample Name	Power (kW)	Holding time (minute)
Sample 1	28	3
Sample 2	28	5
Sample 3	35	3
Sample 4	35	5
Sample 5	42	3
Sample 6	42	5
Sample 7	49	5

All of the samples were then cut by using wire cutting process. The cross sectional view is shown in Fig. 2.

2.3 Microstructure observation

Microstructure observation were conducted on as cast and heat-treated samples of bucket teeth. The observation involved some steps started with grinding, polishing and etching processes of samples. All of the samples were etched with 2% concentration of Nital. The microstructure was observed by using optical microscope of Olympus GX-FSL [15].

2.4 Mechanical properties test

Hardness test was conducted on the sample which has been induction hardened by varying power and holding time. Hardness test were conducted on both as cast and heat treated bucket teeth samples.

Micro Vickers hardness test with the test load of 1 kg and dwell time of 10 seconds was carried out on samples using universal hardness tester Zwick/Roell ZHU[14].

The hardness test on each sample was conducted at 20 different spots with each 5 mm apart started from the sharp end of bucket teeth shown in Fig. 3.

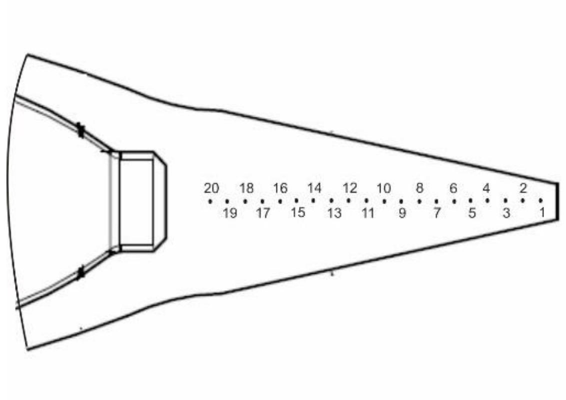

Fig. 3. Location of hardness test on samples

3 Results and Discussion

Hardness of bucket teeth is presented graphically in Fig. 4. According to the graphic shown in the Fig., there was no change in hardness and microstructure of sample 1 which was hardened by using the power of 28 kWh and held for 3 minutes. That was because the available power and time were not sufficient to reach the transformation temperature, so that the microstructure that occurs was relatively the same as the condition of the as cast sample, that was consist of ferrite and pearlite (Fig. 5). Its hardness value was in the range of 223-233 HV.

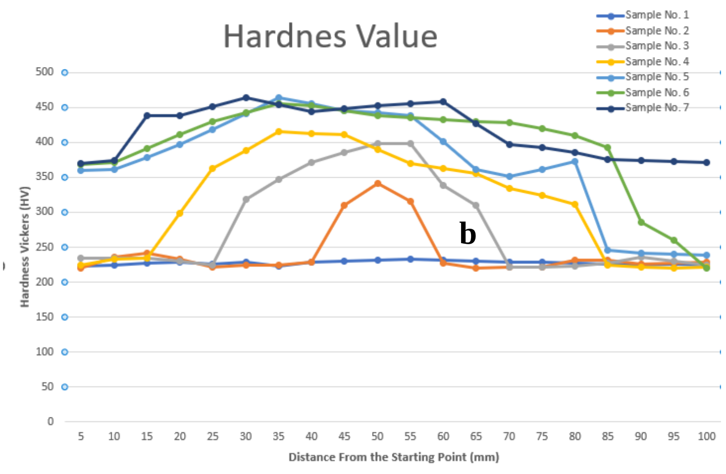

Fig. 4. Hardness value of induction hardened bucket teeth with the variation of power magnitude and holding time.

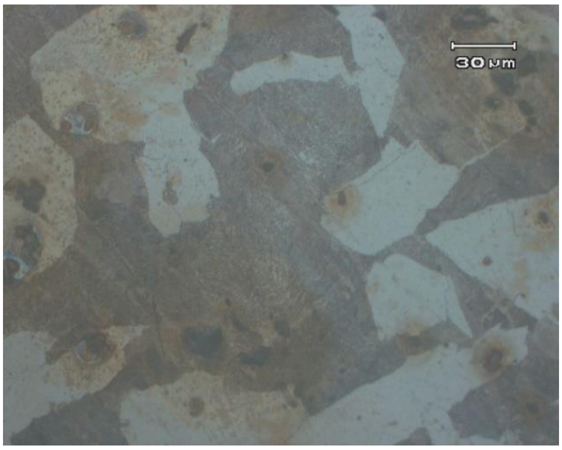

Fig. 5. Ferrite and Pearlite phase on the microstructure of as cast bucket teeth, 200 – 300 HV.

In sample 2, the changes in hardness has occured at a distance of 45 - 55 mm from the front end of bucket teeth. As known coil was located at the distance of 50 mm from the front end so that the area becomes the center of heat. However, due to the low power used (28 kWh) even though the holding time was quite long (for 5 minutes), it can only increased the hardness value to 310-342 HV. The microstructure of sample has changed from ferrite & coarse pearlite to ferrite and fine pearlite as shown in Fig. 6. Within the fine pearlite, the distances between carbides is much closer thus increasing hardness.

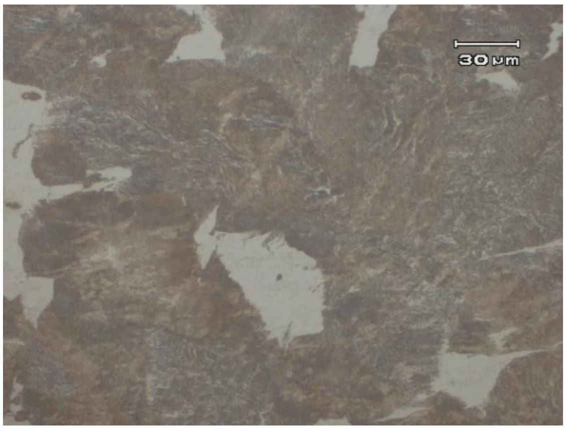

Fig. 6. Ferrite and fine pearlit existed on the microstructure of bucket teeth after heattreatment process on part having a hardness value of 300 – 350 HV.

On the heattreatment process of sample 3, the power of 35 kWh was applied for 3 minutes on holding time can changed hardness on parts which the distance is of 30-65 mm from the front end of bucket teeth. Along this distance, the minimum and the maximum hardness value is 319 and 399 HV respectively. The increase in hardness was due to the dual phase microstructural changes ferrite and pearlite became three phases i.e ferrite, pearlite and bainite. As shown in Fig. 7, the fraction of each of those microstructure is 30% bainite, 30% pearlite and 40% ferrite approximately. The change in the number of ferrite and pearlite fractions that become bainite was directly proportional to the hardness value. The more bainite fraction, the higher the hardness value.

Bainite is a fine non-lamellar structure and is formed at a higher cooling rate than the transformation of austenite into pearlite so that bainite contains more dislocations, although bainite and pearlite consist of the same microstructure, namely cementite and ferrite, but the microstructure morphology of bainite and pearlite is different due to cooling rate. The difference between perlit and bainite is that perlite contains alternating layers of ferrite and cementite whereas bainite has a plate-like microstructure [16], so that their mechanical properties were also different. Bainite has a higher hardness than pearlite.

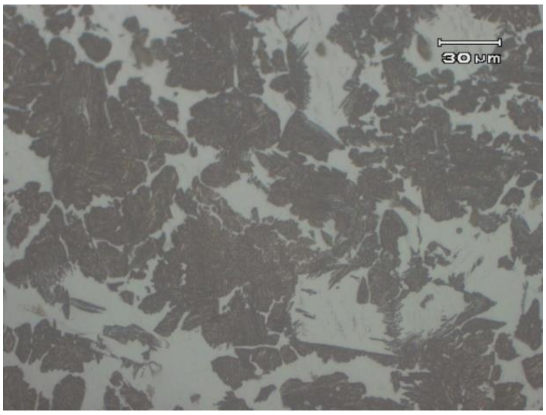

Fig. 7. Ferrite, Pearlite and Bainite phase in the microstructure of heattreated bucket teeth using the power of 35 kWh and holding time for 3 minutes.

In the experiment of sample 4 that using 42 kWh of power and holding time for 5 minutes there was a change in hardness in the part that the distance was 20-80 mm from the front end, in that part the hardness value increased to a minimum and a maximum of 362 and 415 HV respectively.

This increased in hardness to a 415 HV maximum was due to the increased amount of bainit fraction formed and decreased of ferrite.

The difference in the microstructure in Fig. 7 and 8 was the decrease in the amount of ferrite fraction, otherwise bainit fraction increased to a more than ± 50% and the decrease of ferrite was ± 20% and also pearlite ± 30% as shown in Fig. 8. Therefore, the hardness of sample increased to 350 – 400 HV.

Fig. 8. Bainit fraction is much more than ferrite in the microstructure of bucket teeth

The hardness change ocuured on sample 5 that used power of 35 kWh and holding time of 3 minutes at 0 – 80 mm from the front end of bucket teeth. The hardness was up to 351 HV – 450 HV. The maximum hardness of 450 HV located at the center of heating. The front end of this bucket teeth has a hardness of 360 HV. It showed that the heat resulted from the induction heater has not reached that section because the distance is too far from the center of coil. Theoretically, the increase in hardness value should tend to increase toward a small cross-section of parts. The part of the sample that has a small cross-section heated up faster and quickly reached the austenite temperature and the heat distribution becomes wider [5][8]. However, due to the long distance from the center point of the coil to the front end, this section has a low temperature so it was possible that some of the ferrite and pearlite phases have not been transformed into the austenite phase during the induction heating process.

The microstructure in section that has a hardness of ± 450 HV consists of ferrite, bainit and martensit. As it was noted that martensite has formed in this sample. The increase in the hardness value was indicated by the increasing number of changes in the ferrite & pearlite phase to bainite or martensite. As shown in Fig. 8 the number of martensite fractions + 50%, bainite + 30% and ferrite + 20%.

This microstructure occurred in the area around the center of the coil. Microstructural changes occurred due to the presence of ferrite & pearlite phases which then transformed into austenite that occurred more quickly because the power used was quite large. Even though the hold time was 3 minutes. The hard martensite phase originated from the transformation of the pearlite & ferrite phases due to rapid cooling. The martensitic phase in carbon steel was formed by rapid cooling (quenching) of austenite at such a high rate that the carbon atoms did not have time to diffuse out of the crystal structure in large enough quantities to form cementite (Fe3C). Austenit is a gamma phase iron (γ-Fe), solid solution of iron and alloying elements. As a result of cooling, the austenite which has a face centered cubic (FCC) unit cell transforms into a very strong body-centered tetragonal (BCT) form called martensite. The resulting shear deformation results in a large number of dislocations, which are the primary strengthening mechanism for steel. The transformation from austenite to martensite takes place as the temperature is lowered below Ms until the final martensite temperature (Mf) is reached, at which point 100% martensite is expected.[8]

The microstructure of bucket teeth after heat-treatment process on the section that has a hardness of 400 – 450 HV with ferrite, bainit and martensite phases is shown in the fig. 9.

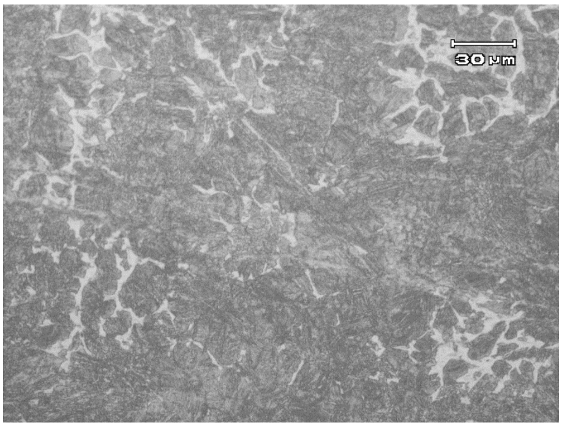

Fig. 9. The microstructure of bucket teeth after heat-treatment process on the section that has a hardness of 400 – 450 HV with ferrite, bainit and martensite phases.

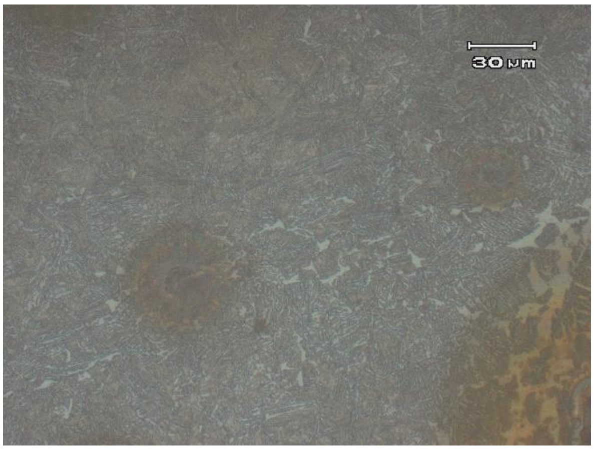

Fig. 10. Microstructure of ferrite, bainit and martensite phase.

Sample 6 which was heated with a power of 42 kWh and a holding time of 5 minutes showed that the part which experienced an increase in hardness value had a length of 0 – 85 mm with a minimum hardness value of 369 HV located on the front and a maximum of 456 HV was located around the heating center. It appeared that the microstructure formed in this section is almost the same as in sample 5 but with a total fraction of +60% martensite, +30% bainite and +10% ferrite (Fig. 10). There is a difference in the number of phase fractions in the microstructure samples that affect the hardness value.

Sample 7 was heated with a power of 49 kWh and a holding time of 5 minute, it showed the length of the part that experienced an increase in hardness value from point 0 – 100 mm with a minimum hardness value of 370 HV and a maximum of 464 HV which was located near the front end. The entire front section of bucket teeth has experienced an increase in hardness so that it is more friction resistant than the other sections. The higher the given heating power the higher the temperature of the samples.

Then with a relatively longer heating time, it will provide an opportunity for the front of the bucket teeth which has a smaller dimension to experienced a rapid increase in temperature thus accelerating the transformation of ferrite & pearlite into austenite which then in the rapid cooling process transformed into martensite [17][18]. In areas that have a hardness of 464 HV, martensite occurs with a fraction of 100% (Fig. 11).

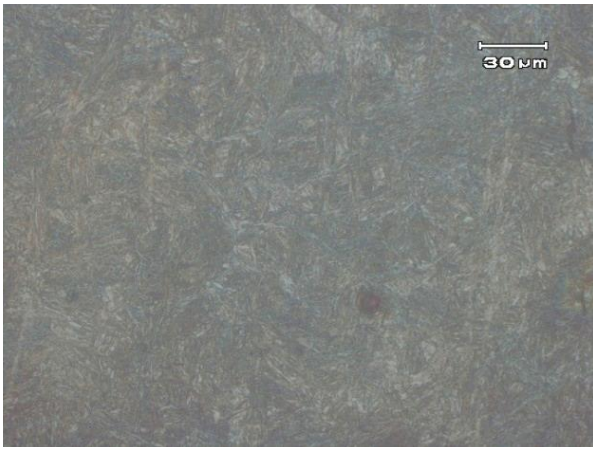

Fig. 11. Microstructure of 100% martensite in bucket teeth occurred at section with hardness exceed 450 HV.

4 Conclusions

The conclusion to the research about the induction hardening effect on the hardness of bucket teeth made of Creusabro 8000 steel is the strength of the induction furnace, heating time and distance from the heating center point affect the achievement and temperature distribution as well as changes in the microstructure of the workpiece. In the induction hardening process, the front of the bucket teeth shows that the greater the power and the longer the holding time then the hardness value and the range of the parts that become hard will increases, although the tendency in the front area is relatively lower than the area close to the center of the coil location. With an electric power of 49 kWh and a holding time of 5 minutes it produces an increase in the maximum hardness value in the longest range of areas, namely 0-100 mm. There was a change in the microstructure from the ferrite and pearlite phases to bainite and martensite phases. The demand for a product hardness value of 354-392 HV can be achieved in sample 5 with a power of 35 kWh and a holding time of 3 minutes, but only this occurs at a length of 0 – 80 mm from the front of the bucket teeth. To get a longer hard area, the parameters on sample 7 are recommended to be used.

References.

[1] Tyssenkrupp, “Continuous mining systems.”

[2] A. P. Bayuseno and D. A. Negoro, “Peningkatan Nilai Kekerasan pada Bucket Teeth Excavator dengan Metode Pack Carburizing dan Media Quenching Oli SAE 20W-50 Serta Cangkang Kerang sebagai Energizer,” *Rotasi*, vol. 20, no. 4, p. 195, 2019.

[3] A. Tasevski and C. Hedlund, “Design of bucket teeth,” 2016.

[4] E. H. Fauzi Widyawati, M. Achyarsyah, “Analisis Sifat Mekanik Pada Material AISI 4140 dan CREUSABRO 8000 Untuk Aplikasi Gigi Bucket Produksi PT. Polman Swadaya,” vol. 01, no. 1, 2014.

[5] J. E. Fernández, R. Vijande, R. Tucho, J. Rodríguez, and A. Martín, “Materials selection to excavator teeth in mining industry,” *Wear*, vol. 250, no. 1–12, pp. 11–18, 2001.

[6] ASTM E 140-02, “E140-07 Standard hardness conversion tables for metals relationship among brinell hardness, vickers hardness, rockwell hardness, superficial hardness, knoop hardness, and scleroscope hardness,” *Astm*, pp. 1–21, 2007.

[7] S. N. S. Tr, “Pengaruh Proses Spray Quenching Terhadap Nilai Kekerasan Dan Laju Keausan Material Creusabro 8000 Dan Aisi 4140 Pada Komponen Bucket Teeth.”

[8] “Induction Heating Principles.” .

[9] A. H. Committee, *ASM VOL 4 Heat Treating*, ASM Handbo. 1991.

[10] K. B. & H. İ. Ü. M Onan, “Determining the influence of process parameters on the induction hardening of AISI 1040 steel by an experimental design method,” vol. 22, no. October, pp. 513–520, 2015.

[11] D. R. Agnieszka Szczotok,Radek Norbert, “Effect of Induction Hardening on Microstuctures of Selected Steel,” *Met. 2018*, vol. 14, no. 2, pp. 95–106, 2002.

[12] A. Vieweg *et al.*, “Induction hardening: Differences to a conventional heat treatment process and optimization of its parameters,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 119, no. 1, 2016.

[13] ArcelorMittal, “Industeel ® Industeel Trademark - Creusabro ® Creusabro® 8000,” vol. 44, no. 32, pp. 1–6, 2016.

[14] *ASM Vol 10 Material Characterization*, Fifth. 1967.

[15] ASM Handbook vol 9, *Metallography and Microstructures 2004 ASM*, vol. 9. 2004.

[16] H. K. D. H. Bhadeshia, “Bainite in steels, second edition,” vol. 21A, pp. 1–454, 2001.

[17] G. E. Totten, “Dieter, Steel Heat Treatment,” pp. 1–12, 2006.

[18] I. Magnabosco, P. Ferro, A. Tiziani, and F. Bonollo, “Induction heat treatment of a ISO C45 steel bar: Experimental and numerical analysis,” *Comput. Mater. Sci.*, vol. 35, no. 2, pp. 98–106, 2006.