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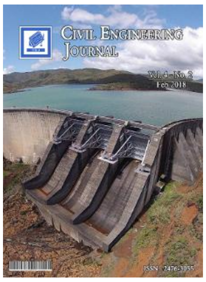

Hardness Optimization of Heat Treatment Process of Bucket Teeth Excavator

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Abstract

Excavator is heavy equipment that usually used in construction and mining works. Bucket teeth which are located in the tip of bucket excavator are used for digging works. They are easily damaged by direct contact with the media. One of the material used in bucket teeth excavator is mild carbon steel that has carbon content between 0.33% - 0.5%. However, the hardness value of this material is not yet meets the standard of bucket teeth excavator so the optimum hardness value based on its heat treatment should be known. Besides that, its tensile, impact strength, and micro structure in optimum condition will also know. Optimization method was done through Taguchi experimental design with L9 orthogonal and ANOVA (Analysis of Variance). Factors or parameters in this research were heating temperature, holding time, quenching media, and tempering temperature. In this experiment, nine specimens of mild carbon steel were tested by different heating temperatures (850 °C, 875 °C, 900 °C), different holding times (60, 90, and 120 minutes), different quenching medias (oil, water, and salt water), and different tempering temperatures (250 °C, 450 °C, 650 °C). Calculation of Taguchi method and confirmation experiment showed that the optimum parameters of hardness are 875 °C heating temperature, 60 minutes holding time, water quenching media, and 250oC tempering temperature. Meanwhile, ANOVA test showed a result that the four factors had an effect on the bucket teeth excavator hardness.

Keywords: Heat Treatment; Mild Carbon Steel; Bucket Teeth Excavator.

1. Introduction

Heavy equipment machine includes most of industrial machines used in construction, mining, forestry, cleaning, and other industrial sectors. Those machines are usually consisting of the vehicle (main body) and robotic mechanism attached to the vehicle [1]. High industrial activity growth needs high performance of heavy equipment with complex mechanism like excavator [2]. Excavator is heavy equipment with hydraulic machine used in multipurpose constructional operations such as ground flattening, load carrying and throwing, and also digging [3]. Excavator is an engineering vehicle that consists of some components such as backhoe or bucket and control room in the framework next to the base of the backhoe arm. Excavators are in various sizes and shapes [4]. The smallest one is called mini excavator or compact excavator. The heaviest model weighs 84,980 kg (187,360 lb) and have 4.5 m^3 (5.9 yd^3) size bucket. The smallest mini excavator from the same producer company weighs 1470 kg (3240 lb), and has a bucket in 0.036 m^3 (0.048 yd^3) size. Its track width can only be adjusted to 89cm (35 inch) [5]. For various purposes, bucket excavator can be replaced with another machine component. As the time goes, excavators are also equipped with loader and bulldozer so that it can perform many functions at once. There is a type of excavator that has track drive system, and there is also one that uses wheel [4].

One of the parameters affecting machine productivity is bucket teeth. Bad bucket teeth design will produce bad digging operation, high worn out, waste of time and energy, and therefore decrease overall digging operation

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productivity [6]. Generally, productivity is defined as the comparison between input and output in a particular context which is the general formula applied in industrial world. In the context of excavator, output is measured in media/material that is being worked on, such as moved media volume each hour, or bucket volumetric capacity [7]. Excavator bucket tooth must be able to receive heavy load of materials such as wet dirt and rock, and also to endure worn out caused by abrasive characteristic of dirt particle when the tooth is working to break the material. Generally, excavator bucket teeth are made of the mixture between steel and other material which has high worn out characteristic so that the usage period will prolonged [8]. High hardness value is also needed because extracted material contacts directly with the tooth [9]. One of bucket teeth material which is commonly used is mild carbon steel with carbon content of approximately 0.33%-0.5%. However, that material is not enough to endure the load and hardness of material loaded into the bucket teeth excavator [3].

Heat treatment is a method to change the physical and chemical characteristics of a material, usually metals. Heat treatments include heating and cooling in an extreme temperature, and then followed by controlled cooling so that the micro structure and characteristics can be changed and modified. It is very important to understand the heat treatment in order to achieve particular material characteristics [10].

Analysis of variance (ANOVA) can be a method to analyze the information and understand the explanation of parameter's variations among that information. The aim is to know the result of every heat treatment variations on mild carbon steel. The research technique was Taguchi method, created by Genichi Taguchi. Taguchi focused on making a simple technique or method to analyze variants. This method is often used in improvement. In this case, the method is used to understand how the variants of heat treatment affect mild carbon steel [10].

This research aimed to get material with high hardness value through heat treatment process by using hardening; the process included heating temperature, holding time, quenching and tempering. The process was conducted using a furnace by heating steel to a certain temperature above austenization temperature with 3 levels of temperature variations: 850°C, 875°C and 900°C, then it was retained at that temperature for some time to ensure the uniformity of heating and ensure that all carbon turned into austenite phase. Holding time on heating was also varied into 3 levels: holding time for 60 minutes, 90 minutes and 120 minutes. Then, the steel was cooled from the furnace and quenched by means of cooling medium which is varied into 3 media: oil, water and brine. After that, the material went to tempering process by heated it back under austenization temperature to remove residual stress. Tempering temperatures were also varied into 3 levels: 250 °C, 450 °C and 650 °C with holding time of 60 minutes. The process and variance of the stages were combined to obtain the most optimum result of hardness value. From the four stages of heat treatment in which each stage has variation of 3 levels, it required 34 equal to 81 trials, but by using Orthogonal Array of Taguchi Method, it can be reduced to 9 trials only. Thus, experimental design using Taguchi Method allows an experiment with many factors with a small number of trials but determines the optimal results instead. Meanwhile, ANOVA functions to assess the influence of independent variables on dependent variable (hardness value) and to determine the best independent variable combination in order to get the highest hardness value. In the most optimal value combination, the properties of the material were also searched for, including microstructure, tensile strength, elongation and impact value.

High hardness value is required for bucket teeth because this component will be in direct contact with soil, rock and even harder materials. Therefore, in addition to the proper material selection for bucket teeth, appropriate heat treatment is also required to obtain the most optimal hardness value. At the time when bucket teeth should be replaced after the use over a period of time, it leads to an increase in operational costs and is an important economic factor in the construction, mining or other industries. It is because the use of an excavator bucket teeth in a work will cause wear and tear which causes decrease to the performance of an excavator. Therefore, this research will conduct hardening process on the material of excavator bucket teeth with combination of heating temperature, holding time, quenching media and proper tempering to get optimal hardness value through Taguchi Statistic Method to reduce the number of experiments so that it will be more efficient and economical.

2. Materials and Methods

The steps of this research was determining the experimental combinations with heat treatment process and analyzed them with Taguchi method and ANOVA. The specimen prepared was mild carbon steel. The best combination would be retest, such as hardness test, micro structure test, tensile test, and impact test. The research method was based on the flow chart shown in Figure 1.

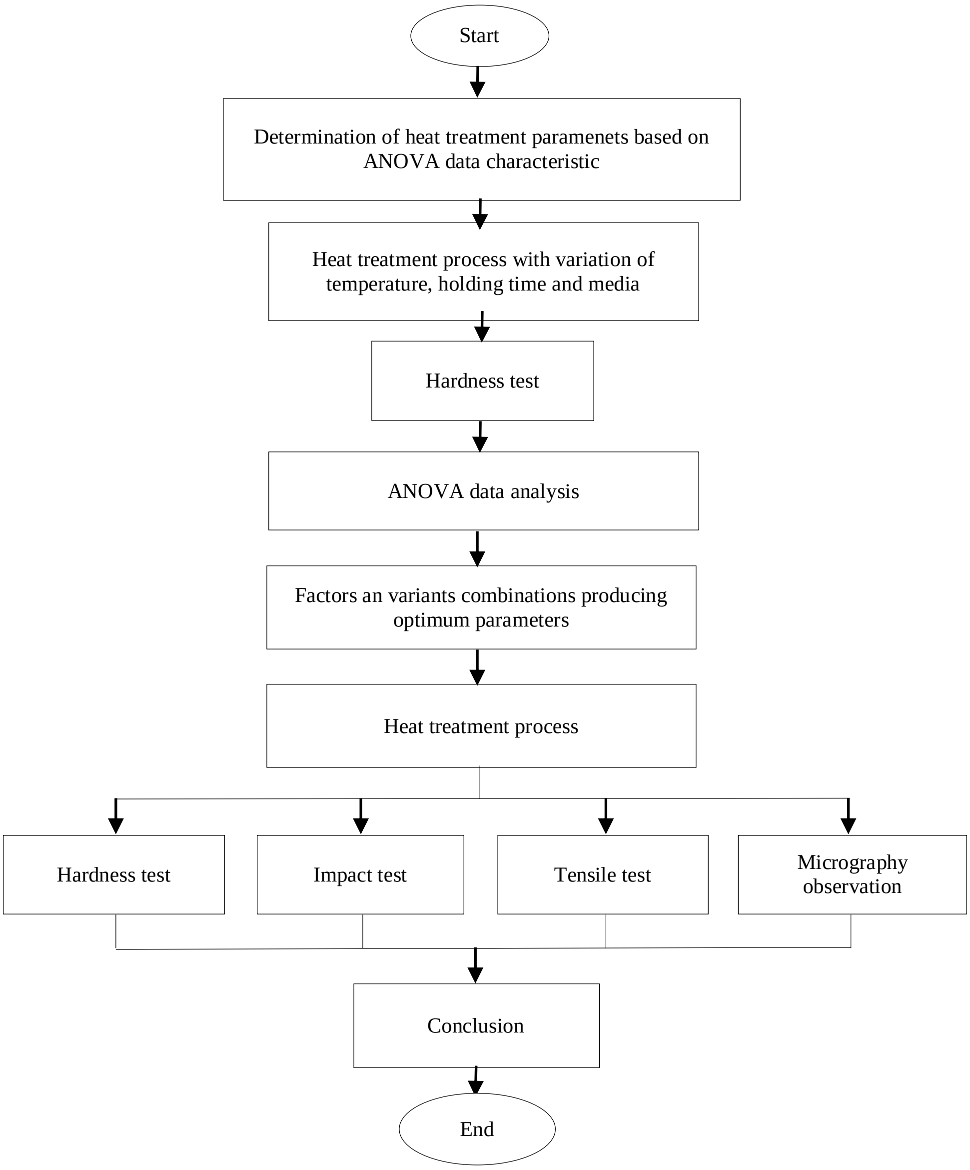


Figure 1. Research flow chart

The experimental method used in this research is Taguchi method. Two main objectives of Taguchi experiment are: (1) minimizing the various process or products, and (2) to get robust and flexible design that suitable with the environment. Two steps used in this parameter design were orthogonal array and S/N ratio. These two steps are designed to study some parameter designs at once and can be used to estimate the effect of each independent factor on the other factor. Orthogonal array's function is to provide an experimental factor that should be done. S/N ratio is a simple quality indicator, in which a researcher or designer could evaluate the change effects of every part of the product's parameters. S/N ratio is used to minimize the sensitivity of quality characteristic. S/N ratio has some advantages. If the target value is changed, the optimum condition that had been achieved by maximizing S/N ratio will still be valid. The steps of this research are as follows.

2.1. Controlled Factor and Independent Factors Selection

In this research, some independent factors or parameters chosen were heating treatment, holding time, quenching medias, and tempering temperature. The response was hardness in HRC scale. Table 1 shows the design of parameter (factor) and Taguchi level.

Table 1. Composition of mild carbon steel material

Parameter	Level			Research Result
	1	2	3	
Heating Temperature (°C)	850	875	900	Hardness (HRC)
Holding Time (Minute)	60	90	120	
Quenching Medias	Oil	Water	Salt Water	
Tempering Temperature (°C)	250	450	650	

2.2. Orthogonal Array Selection

There were four parameters in this experiment. Each of them were consists of three levels. With degree of freedom calculation from each factors, eight degree of freedoms were obtained. Therefore, orthogonal array with same or higher degree of freedom was chosen [9]. In this research, orthogonal array L9 (3^4) was chosen as shown in Table 2.

Table 2. Orthogonal array L9 experiment

Trial Number	Control Factor			
	Heating Temperature (°C)	Holding Time (Minutes)	Quenching Medias	Tempering Temperatures (°C)
1	850	60	Oil	250
2	850	90	Water	450
3	850	120	Salt Water	650
4	875	60	Water	650
5	875	90	Salt Water	250
6	875	120	Oil	450
7	900	60	Salt Water	450
8	900	90	Oil	650
9	900	120	Water	250

2.3. Material Selection

This type of steel had carbon content of 0.33%-0.5%. This type of steel is often used in parts of machine, gear, spring, and etc. Steel with low carbon content has the same properties as iron, soft but easily formed. As carbon tontent rises, the metal becomes harder and stronger but less ductile and more difficult to weld [11]. In the application, the steel should have high hardness because it will undergo friction with the other media. Mild carbon steel could be treated with heat treatments such as austenization, quenching, and tempering to increase the mechanical properties. Table 3 shows the chemical composition of material in this research.

Table 3. Composition of mild carbon steel material

%Fe	%C	%Cu	%Mn	%P	%Cr	%S	%Si
98.1971	0.3929	0.1022	0.3618	0.0233	0.2605	0.0262	0.5226

2.4. Experiment Conditions

Nine specimens were prepared to have different treatments. Specimens would undergo hardening process with temperature of 850 °C, 875 °C, 900 °C; were held for 60, 90, and 120 minutes; followed by rapid cooling or quenching process in different medias: oil, water, and salt water. After quenching process, then they were treated by tempering process with temperature of 250 °C, 450 °C, 650 °C. After heat treatment was finished, it was followed by hardness test with Rockwell Hardness Tester tool, repeated 3 times. After the experimental data was collected, the data was analyzed by ANOVA.

3. Literature Review

3.1. Heat Treatment

Heat treatment is a combination of controlled heating and cooling that is applied to metal or particular mixture in solid phase to produce particular micro structure and desired mechanical characteristics (hardness, tensile strength, melting strength, and elongation). Annealing, normalizing, hardening/quenching, and tempering are the heat treatments that are commonly used to modify the micro structure and mechanical characteristics of steel. Heat treatment process changes material's micro structure phase and crystallography. The aim of carbon steel heat treatment is to get desired mechanical characteristic, including ductility [12]. Hardening is a process of heat treatment to increase steel's hardness. This process is done in a furnace by heating the steel up to a particular temperature above austenization temperature and holds it in quite long time. This is to ensure heating uniformity and the steel changed to austenite phase. Then the steel is taken out from the furnace and undergo rapid quenching with suitable cooling method [13]. In this research, hardening process will be done to get high hardness value. Hardness is the endurance of a material from deformation, especially permanent deformation, indentation, or scratch [14].

3.2. Taguchi Method

Optimization is a key step to increase steel performance and to know optimum parameter's process based on the response. There are some optimization methods for example gradient searching method, network method, and Taguchi method [15]. Taguchi method is a technique method to engineer or improve productivity along the research and development so that high quality product can be produced quickly with low cost [16]. Experimental design with Taguchi approach can economically fulfil the need of a product or process design. By studying this technique, engineer, scientist, and researcher could significantly decrease the time needed to investigate an experiment. Experimental design with Taguchi approach is very effective to optimize product and process' design, to study the effect of some factors (such as variables, parameters, materials, etc.) on the performance, and to solve production problem in an experiment [17]. Taguchi viewed that quality improvement is a sustainable effort. He kept tried to reduce the variants surrounding the target value. Studied product may show the distribution with different average value with target value. The first step to increase quality is by approaching the population distribution as close as possible with the target value. To achieve this, Taguchi design an experiment using a special made table called Orthogonal Array (OA). By making this table, experimental design will be easier to make [18]. In choosing orthogonal array based on Taguchi experimental design, orthogonal array's degree of freedom should be higher or equal with the total degree of freedom in process parameter [16].

Degree of freedom = (number of factors) x (number of levels -1) (1)

S/N ratio (ratio signal to noise) used to choose the factors contributing to the reduction of response variants. S/N ratio is a design of data repeat transformation to a value which is variant measurement. S/N ratio used to know which factor level that affects the experimental result. S/N ratio consists of some quality characteristics, such as:

a) Smaller the better

$$\frac{S}{NR} = -10log_{10}\left[\frac{1}{n}\sum_{i=1}^{n} {y_i}^2\right] \quad (2)$$

b) Nominal the better

$$\frac{S}{NR} = 10log_{10}\frac{\mu^2}{\sigma^2} \quad (3)$$

c) Larger the better

$$\frac{S}{NR} = -10log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{{y_i}^2}\right] \quad (4)$$

In this research the optimum parameter level is the level with highest S/N ratio

Mean (Y) is an average of three experiment in each trial and $\bar{y}$ is an average of mean to calculate prediciton of hardness in optimum condition. Here is the equation that used to calculate mean. After that, the data will be analyzed statistically with ANOVA to know which parameter is statistically significant [19].

$$Y = \frac{Hardness_1 + Hardness_2 + Hardness_3}{3} \quad (5)$$

3.3. ANOVA

Analysis of Variance is a calculation technique that allows quantitative estimation of each factor's contribution to every response measurement. Analysis of variance used in parameter design can be used to identify factor's contribution, so that assumption of model's accuracy can be made [16]. When analysis of variance had been done to a data set and the sum of squares had been calculated, we can use the data to divide the sum of squares with relevant factors. By comparing this value to total sum of squares, contribution percentage of each factor will be known. From this analysis of variance, relative strength of a factor and/or the interaction in reducing the variants will also be known. SS' and contribution percentage can be calculated by Equation 5 and 6.

$$SS' = SA - VA.Ve \tag{6}$$

$$rA\frac{SA'}{St}\ x\ 100\% \tag{7}$$

3.4. Confirmation Experiment

Confirmation experiment is the final step in verifying the result based on Taguchi design approach [20]. The aim of confirmation experiment is to validate the conclusion from each analysis steps. This is necessary for examination with low resolution in form of fractional factorial. Optimum value prediction is given as the perspective of how far the value can be predicted compared to the tested value. With the presence of optimum value prediction, it could be known whether or not the tested value is within acceptable or permitted range [21]. The equation of confirmation value prediction and trust interval are shown in Equation 7 and 8.

$$\text{Prediction} = \Sigma Y_{(\text{best level})} - (Y_{\text{mean}}\ x\ (\text{Number of Factor} - 1)) \tag{8}$$

$$Cl = \sqrt{F_{\propto,v1,v2}x\ MS_{error}\ x\ \left(\frac{1}{n}\right)} \tag{9}$$

4. Results and Discussions

Analysis of research results consist of S/N ratio analysis, average response with ANOVA calculation, and mild carbon steel's mechanical characteristic testing in optimum condition. The aim of S/N ratio analysis was to know the best factor's level combination in searching optimum heat treatment so that highest hardness value will be achieved.

4.1. Hardness Test Result

Hardness value as dependent variable was determined by a test using Rockwell Hardness tester in HRC scale had cube-shaped specimen with dimensions of 30×30×30 mm. That scale has 150 kg load with diamond cone penetrator [22]. To get a good data, every experiment was replicated three times and the average value was calculated [21]. Result of each hardness values can be seen in Table 4 with mean is an average of hardness in each trial and S/N ratio used is larger the better.

Table 4. Result of Hardness Test

Trial	Heat. Temp. (°C)	Hold. Time (Minute)	Quench. Media	Temper. Temp. (°C)	Hardness (HRC)			Mean	S/N Ratio
					1	2	3		
1	850	60	Oil	250	38,5	38,9	39,2	38,9	31,7915
2	850	90	Water	450	37,9	38,1	38,4	38,1	31,6261
3	850	120	Salt Water	650	30,0	30,0	30,5	30,2	29,5905
4	875	60	Water	650	35,0	34,5	36,2	35,2	30,9391
5	875	90	Salt Water	250	41,4	41,5	42,1	41,7	32,3958
6	875	120	Oil	450	32,3	32,9	33,1	32,8	30,3086
7	900	60	Salt Water	450	38,9	39,4	39,6	39,3	31,8879
8	900	90	Oil	650	29,5	28,9	28,5	29,0	29,2380
9	900	120	Water	250	40,9	41,1	40,6	40,9	32,2274

4.2. Signal to Noise Calculation Result and Average Response

After the average value of hardness was calculated, the next step was to seek the S/N ratio (signal to noise ratio) and the mean response. The result of mean and S/N ratio calculation could be seen in Table 5 and 6 using MiniTab17 software.

Table 5. Mean response for each factor's levels

Level	Heating Temperature	Holding Time	Quenching Media	Tempering Temperature
1	35.72	37.80	33.53	40.47
2	36.56	36.26	38.08	36.73
3	36.38	34.60	37.04	31.46
Delta	0.83	3.20	4.54	9.01
Rank	4	3	2	1

Table 6. S/N ratio response for each factor's level

Level	A	B	C	D
1	31.00	31.54	30.45	32.14
2	31.21	31.09	31.60	31.27
3	31.12	30.71	31.29	29.92
Delta	0.21	0.83	1.15	2.22
Rank	4	3	2	1

The optimum condition can be obtained by selecting the level that gives the highest value for each factor. From Table 5 and 6, it is shown that the best combination to obtain optimum hardness value is heating temperature at 875ºC for 60 minutes duration with quenching media is water and tempering temperature at 250ºC. That result could also be shown in S/N ratio graphic, in Figure 2 and 3.

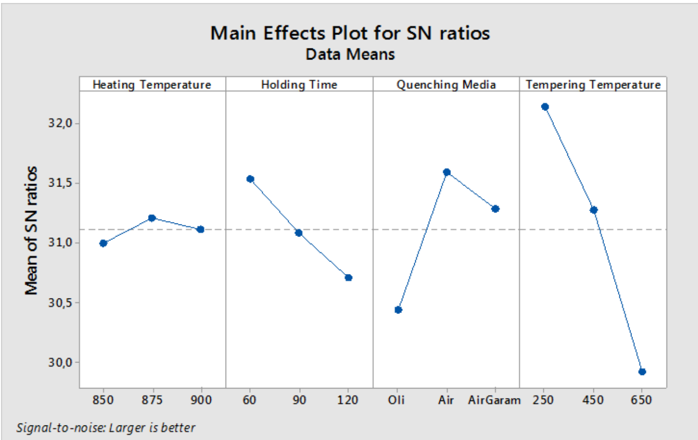


Figure 2. S/N Ratio respon graphic with MiniTab17 Software

4.3. ANOVA Test Result

Data of hardness test was analyzed with Analysis of Variance (ANOVA) to know the effect of each parameter on hardness value. Table 7. shows the result of ANOVA using MiniTab17 software with SS' and contribution percentage calculated using Equations 5 and 6.

Table 7. ANOVA test result of mild carbon steel hardness

Parameter	DF	Adj SS	Adj MS	F-Value	SS'	Contribution Percentage (%)
Heating Temperature	2	3,467	1,734	8,68	3,07	0.59
Holding Time	2	46,099	23,049	115,46	45,70	8.72
Quenching Media	2	102,143	51,071	255,83	101,74	19.41
Tempering Temperature	2	368,979	184,489	924,16	368,58	70.30
Error	18	3,593	0,200		5,19	0.99
Total	26	524,281				100.00

From the table and figure above, it could be seen that the factor affecting hardness value of mild carbon steel material in respective are tempering temperature 70.30%, quenching media 19.41%, holding time 8.72%, and the last was heating temperature 0.59%. From the table above it could be known that all factors have an effect to the hardness value where F-value > F-table ($F_{(0,05;2;18)}$= 3.55). From the results of the experiment and the calculations using ANOVA above, on the heating temperature factor, the higher the temperature of the heating temperature, the higher the hardness value would be. However, this increase in hardness would not be linear and would achieve maximum hardness at certain temperatures. This factor was not too significant because the temperature variation of this factor was still in the range of austenization temperature. The variation factor of holding time also had non-significant influence on hardness value because holding time in the hardening process basically had an influence on uniformity of heating. The factor of quenching media had a significant influence on the hardness value. It is because each media had different cooling rate. The higher the cooling rate, the higher the hardness value would be. The brine had the highest cooling rate and water had higher cooling rate than the oil. However, having too high cooling rate would cause distortion and crack so that the material would become brittle. Water was one of quenching media to get maximum hardness value but the material would become brittle. The factor of tempering temperature had big influence on hardness value because after having tempering process, it came to transformation phase from martensite to tempered martensite which causes the hardness decreases drastically but ductility and impact strength increase [11].

4.4. Prediction of Hardness Value in Optimum Condition

Based on Table 6, the highest level was chosen as the optimum condition in this case because the larger hardness characteristic, the better it will be. From the confirmation of the calculation and experiment, it would be obtained the highest hardness value of all possible combinations of factors and levels.

4.4.1. Hardness Value Prediction in Optimum Condition

Below is the prediction of the hardness value; A2 is the heating temperature factor at the level of 875 °C, B1 is the holding time factor at the level of 60 minutes, C2 is the quenching media factor of at the level of water, D1 is the tempering temperature factor at the level of 250°C and $\bar{y}$ is the total average of the average of each experiment.

$$= \bar{y} + (A_2 - \bar{y}) + (B_1 - \bar{y}) + (C_2 - \bar{y}) + (D_1 - \bar{y})$$

$$= A_2 + B_1 + C_2 + D_1 + \bar{y} - \bar{y} - \bar{y} - \bar{y} - \bar{y}$$

$$= A_2 + B_1 + C_2 + D_1 - 3\bar{y}$$

$$= 36.56 + 37.80 + 38.08 + 40.47 - 3(36.2)$$

$$= 44.31$$

Confidence Interval

$$(n_{eff}) = \frac{total\ number\ of\ experiment}{1 + jtotal\ of\ average\ degree\ of\ freedom} = \frac{9\ x\ 3}{1+8} = 3$$

$$(Cl) = \pm\sqrt{F_{(0,05;2;8)} x MS_x x \frac{1}{n_{eff}}}$$

$$Cl = \pm\sqrt{3{,}35x0{,}200x\frac{1}{3}} = \pm\ 0{,}472$$

Prediction Value = 44.31 ± 0.472

4.4.2. Hardness Test Result in Optimum Condition

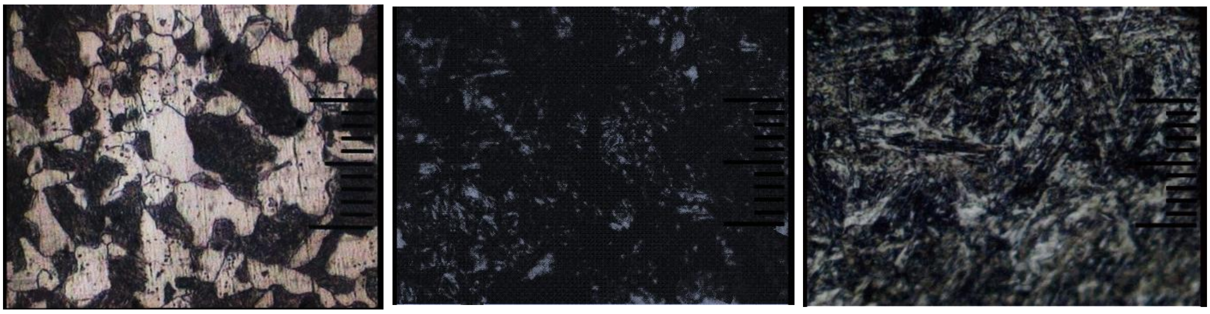
Table 8. Hardness test in optimum condition

Measurement Point			Y average
1	2	3	
43.6	43.5	43.9	43.7

4.5. Effect of Heat Treatment on Material Properties

4.5.1. Microstructure Test Result

Microstructure test result showed the presence of phase change in every process of heat treatment. Figure 3a showed raw material before heat treatment. The formed phase is pearlite and ferrite. After hardening process with temperature of 875°C and rapid cooling with water, martensite microstructure had begun to form. The formation of martensite was characterized by the result of the hardness value. This martensite was formed because the heating process given to the hardening process was above the austenization temperature which then resulted in the transformation of the initial structure of the material; namely perlite into austenite and rapid cooling by using water which has more rapid cooling rate from the critical cooling rate which caused the formation of martensite. The transformation process of austenite to martensite was classified as a transformation process without diffusion. Due to the rapid cooling, the carbon atoms did not have the time to diffuse and was trapped into the octahedral site of the BCC structure which caused the new phase of martensite with BCT structure. In the last step which is tempering with 250°C temperature, martensite had begun to be reduced. In this condition, steel's hardness and worn out is quite good already. Cooled down steel which had tempered in particular temperature has combination of impact strength, ductility, and hardness that is suitable with industrial need [12]. From the data in Table 5 and 6, the higher tempering temperature the lower the final hardness value would be. It was because the higher the tempering temperature, the more the carbon atoms from the martensite structure that became the tempered martensite so that the hardness value would decrease. In Figure 3a, the bright part indicated the ferrite while the dark part indicated the pearlite. In Figure 3b, the needle-shaped part indicated martensite while in Figure 3c martensite was transformed into tempered martensite.



(a) (b) (c)

Figure 3. Micro Structure of (a) Raw, (b) Hardening 875°C in 60 minutes with water quenching media, and (c) Hardening 875°C in 60 minutes with water quenching media followed by tempering in 250°C temperature

4.5.2. Tensile Test Result on Optimal Hardness Condition

Tensile test was done with Universal Testing Machine GD 1100-100 in Physical Metallurgy Laboratory of Mechanical Engineering, Diponegoro University. The specimen used was the type of rectangular sub-size specimen with the shape and dimension as in Figure 4 below [23].

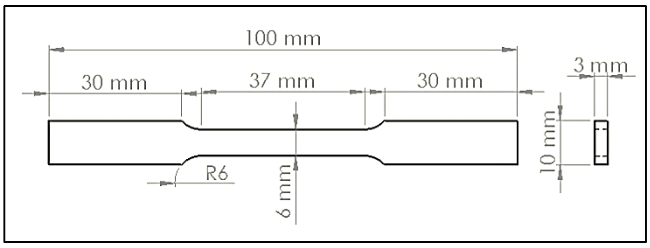


Figure 4. Tensile Test Specimen

Table 9. Tensile test result after heat treatment

Specimen	Lower Yield Strength (N/mm^2)	Upper Yield Strength (N/mm^2)	Tensile Strength (N/mm^2)	Elongation (%)
1	153,193	406,710	406,710	7.128
2	110,841	371,841	371,841	7.136
3	204,890	217,528	217,528	4.844
Average	156,308	332,026	332,026	6.364

4.5.3. Impact Test Result on Optimal Hardness Conditon

The results of Charpy impact test are presented in Table 10, in which the specimen used type A based on the metal characteristic of ferrous [24] as shown in Figure 5.

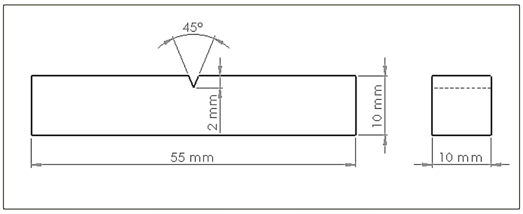


Figure 5. Impact Test Specimen

Table 10. Impact test result after heat treatment

No	Angle α (º)	Installed Energy (J)	Angle β (º)	Absorbed Energy (J)	Area (mm^2)	Impact Value (J/mm^2)
1	151.0	300	139.0	19.2	85.0	0.226
2	151.0	300	127.0	43.6	85.5	0.510
3	151.0	300	134.0	28.8	83.0	0.347
Average of Impact Value (J/mm^2)						0.361

5. Conclusion

This experiment about hardness value of mild carbon steel material with Taguchi method can be concluded as follows.

- The optimum of heating temperature is achieved on 875 ºC, holding time of 60 minutes followed by quenching in water media and tempering with 250 ºC temperature.
- By ANOVA, four factors included: tempering temperature, quenching media, holding time, and heating temperature effect on the hardness level of mild carbon steel material; where F-table > $F_{0,05;2;18}$ (3.35) with α = 5%.
- By ANOVA, the main factor which effects on the hardness level including the contribution percentage of tempering temperature (70.30%), quenching media (19.41%), holding time (8.72%), and heating temperature (0.59%).
- Based on the optimum parameters, the mechanical characteristics of mild steel specimens are 43.7 HRC in hardness level, tensile strength of 332.026 N/mm^2; elongation of 6.364%; and impact strength of 3.61 kgm/cm^2.

6. References

[1] Dadhinch, S., Bodin, U., Andersson, U., "Key Challenger in Automation of Earth-Moving Machines." Automation in Construction, Elsevier (2016). Doi: https://doi.org/10.1016/j.autcon.2016.05.009.

[2] Mehta, G. K., Iyer, V. R., and Dave, J. "Finite Element Analysis and Optimiation of an Excavator Attachments." Nirma University.

[3] Gábor, L. and István, S. "Bucket and Cutting Tooth Developments for the Bucket Wheel Excavators of Mátra Power Station LLC", Annals of the University of Petroşani, Mechanical Engineering (2012): 151-162.

[4] Ghodake, B. and More, S. "Analytical Method To Calculate Tooth Pin Failure Of Bucket Tooth Of Excavator In Shearing And Bending." International Engineering Research Journal, Issue 2 (2015): 4423-4425.

[5] Londhekar, M. S. and Bende, S. B., "A Study of Failure in Excavator Arm." International Journal of Emerging Trend in Engineering and Development, Vol. 3, Issue 4, (2014).

[6] Shaikh, B. P. and Mulla, A. M. "Analysis of Bucket Teeth of Backhoe Excavator Loader and its Weight Optimization." International Journal of Engineering Research and Technology, Vol. 4, Issue 05, (2015).

[7] Ng, Felix. Harding, J. A., and Glass, J. "An Eco-Approach to Optimise Efficiency and Productivity of Hydraulic Excavator." Journal of Cleaner Production, Elsevier, (2015). Doi: https://doi.org/10.1016/j.jclepro.2015.06.110

[8] Dagwar, K. S. and Telrandhe, R. G. "Excavator Bucket Tooth Failure Analysis." International Journal of Research in Mechanical Engineering and Technology, Vol. 5, Issue 2, (2015).

[9] Fernandes, J. E., et al. "Materials Selection to Escavator Teeth in Mining Industry" Elsevier, (2001). Doi: https://doi.org/10.1016/S0043-1648 (01)00624-X.

[10] Kumar, A. et al. "Heat Treatment Parameter Optimization Using Taguchi Technique" International Journal of Scientific Research and Education, Vol. 4, Issue 10, (2016): 5965-5974. Doi: http://dx.doi.org/10.18535/ijsre/v4i10.07.

[11] Daramola, O.O., Adewuyi, B.O., and Oladele, I.O. "Effects of Heat Treatment on the Mechanical Properties of Rolled Medium Carbon Steel." Journal of Minerals & Materials Characterization & Engineering, Vol. 9, No.8, (2010): 693-708.

[12] Verma, A. and Singh, P. K. "Influence of Heat Treatment on Mechanical Properties of AISI 1040 Steel" IOSR Journal of Mechanical and civil Engineering, Vol. 10, Issue 2, (2013).

[13] Raok, S. et al. "An Overview of Taguchi Method: Evolution Concept and Interdisciplinary Applications" International Journal of Scientific & Engineering Research, Vol. 4, Issue 10, (2013).

[14] ASTM E6 – 03, Standard Terminology Relating to Methods of Mechanical Testing.

[15] Murugan, V. K. and Mathews, P. K. "Optimization of Heat Treatment Process Using Taguchi's Parameter Design Approach" International Journal of Research in Mechanical Engineering, Vol. 1 Issue 1, (2013)

[16] Charamouli, S and Eswariah, K. "Optimization of EDM Process Parameters in Machining of 17-4 PH Steel Using Taguchi Method" 5th International Conference of Materials Processing and Characterization, Elsevier, (2016). Doi: https://doi.org/10.1016/j.matpr.2017.02.049.

[17] Madhavi, S. K., Sreeramulu, D., and Venkatesh, M., "Evaluation of Optimum Turning Process of Process Parameters Using DOE and PCA Taguchi Method" 5th International Conference of Materials Processing and Characterization, Elsevier, (2016). Doi: https://doi.org/10.1016/j.matpr.2017.02.039.

[18] Palaniradja, K., Alagumurthi, N., and Soundararajan, V., "Optimization of Process Variables in Gas Carburizing Process: A Taguchi Study with Experimental Investigation on SAE 8620 and AISI 3310 Steels" (2004).

[19] Zahid, S. K., Khan, A., and Foong, S. H. "Application of Taguchi Method in the Optimization of Injection Moulding Parameter for Manufactuirng Products from Plastic Blend" IACSIT International Journal of Engineering and Technology, Vol. 2, No. 6, (2010).

[20] Rama Rao, S. and Padmanabhan, G. "Application of Taguchi Methods and ANOVA in optimization of process parameters for metal removal rate in electrochemical machining of Al5Si Ccomposites" International Journal of Engineering Research and Applications, Vol. 2, Issue 3, (2012).

[21] Parashar, V. and Purohit, R. "Investigation of The Effect of The Machining Parameters on Material Removal Rate Using Taguchi Method in End Milling of Steel Grade EN19" 5th International Conference of Materials Processing and Characterization, Elsevier, (2016). Doi: https://doi.org/10.1016/j.matpr.2017.01.030.

[22] ASTM E18-3, Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials.

[23] ASTM E8 – 00B, Standard Test Methods for Tension Testing of Metallic Materials.

[24] ASTM E23 – - 02A, Standard Test Methods for Notched Bar Impact Testing of Metallic Materials.