Study of Factors Affecting Quenching of High-Speed Steel M2

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Abstract

The objective of this research was to study the factors in the Quenching process that affects the hardness and structure of the metal. With hardening and tempering the material at different temperatures and times. The material used in the experiment was High Speed Steel M2. The agent used to harden the metal were water, oil, and air. The experimental factors consisted of temperature for Quenching which was divided into 7 levels, namely, 1,000 °C, 1,050 °C, 1,100 °C, 1,150 °C, 1,200 °C, 1,250 °C and 1,300 °C. The time required for quenching was 3 minutes, 3.5 minutes, 4 minutes, 4.5 minutes, 5 minutes, 5.5 minutes and 6 minutes. Based on the experimental study, it was found that temperature and time have a significant effect on the hardness of High-Speed Steel M2 at the significant level of 0.05. The most suitable factor is the use of an oil-based Coolant at a temperature of 1,150 °C for 4.5 minutes which gives the highest hardness than other Coolant with the hardness of 55.62 HRC and a martensite interior structure

Keywords : quenching, heat recovery, high speed steel

Introduction

Heat Quenching process of the metal is required in order to make the steel after Quenching becomes harder and resistant to friction during use [1,2] Quenching is the process that results in the final steel structure being martensite or bentonite depending on the hardness required for the use. Sometime, if the appropriate type of steel and the use are not considered in the heat treatment process, the steel will be in poor quality, not hard, brittle, and not good when using. Heat Quenching of steel in some cases may cause the steel to be softened for easy forming [3] Heat Quenching of steel by is to heat the metal and then cooling it at a critical cooling rate to create a martensite structure using the Coolant. Heat Quenching of steel is therefore an important process and widely used in the industry for making machinery parts, engines, tools and materials.

The Coolant is solid, liquid and gas [4] It acts as an intermediary during the Quenching process. Liquid that is commonly used in Quenching. Most of them are liquid, such as water, oil or air. Coolant in the form of solids such as sand. Coolant will cool the steel after burning to make the metal harder. Therefore, Coolant is one of the factors affecting the hardness, toughness and abrasion resistance. Steel is undergone the Quenching process in order to meet the qualifications required for maximum efficiency.

This research is to study the determination of suitable factors for Quenching and tempering high speed steel (M2) and study of the properties of steel in the Quenching process by studying the temperature, time, and Coolant. These factors are an important condition for steel Quenching. The results of the study of high-speed steel (M2) will be used for the development of tool, materials and equipment used in the machining process for the part manufacturing industry and for the benefit of the research and further research process.

Objective

1. To Study of Factors Affecting Quenching of High-Speed Steel M2.
2. To Study Quenching process that affects the hardness and structure of the metal.

Methodology and Materials

The properties of mixture of high-speed steel (M2), temperature and time suitable for Quenching and tempering was studied. Differences of each Coolants on the different results and the characteristics of each Coolant were also studied in order to be used in the design of the experiment for finding the most suitable factor for Quenching and tempering to increase the hardness of High-Speed Steel M2.

1. Preparation of Experiment Equipment

1.1 High-speed steel (M2)

1.2 Quenching Furnace

1.3 Coolantat at room temperature

Water: 10 liter of tap water

Oil: 10 liter of oil

Air: Use air at room temperature for cooling at 27 degrees.

1.4 Polishing equipment for illuminating structures.

Sandpaper numbers 220, 320, 400, 600 and 1,000

TIGER Belt Sander BD-46N

Al2O3 fine polishing powder mixed with distilled water Heat dryer

Nitric acid (HNO3) Nitol (2-4%)

1.5 Rockwell Hardness Tester

1.6 Microscope

Tools and materials used in the experiment, Figure 1

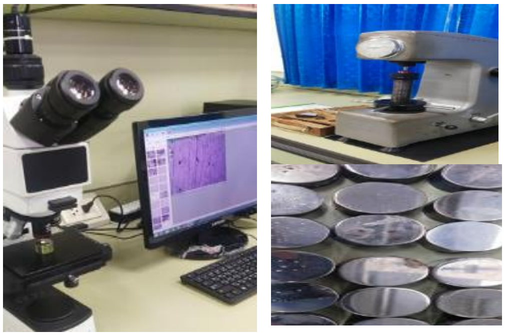


Figure 1. Tools and equipment

2. Experiment and Data Collection

2. 1 Prepare high- speed steel M2, Dimension 25 mm. In the amount of 7 x 21 = 147 pieces,3 coolant 147 x 3 = 441 pieces.

2. 2 Quenching by using an electric oven at room temperature 27 oC and heat it up to 850oC to warm the workpiece for 20 minutes. The process begins with heating the steel to reach the temperature where the structure changes to austenite.[5] Leave it in the oven for a set period of time until a steady austenite structure is created. Then cool it down at a sufficient speed to create a martensite structure. The temperature used for heat treatment test is 1,000 °C, 1,050 °C, 1,100 °C, 1,150 °C, 1,200 °C, 1,250 °C and 1,300 °C.

2. 3 Time used for quenching is 3 minutes, 3 minutes 30 seconds, 4 minutes, 4 minutes 30 seconds, 5 minutes, 5 minutes 30 seconds and 6 minutes.

2. 4 Then let it cool in the various plating, namely water, oil and air.

2. 5 When the workpiece cools down, conduct tempering for 2 times, 2 hours each time. The first tempering is conducted at 540 °C for 2 hours, then let the workpiece cools down in the air. Then conduct another tempering at the temperature of 540 °C for 2 hours. from Figure 2.

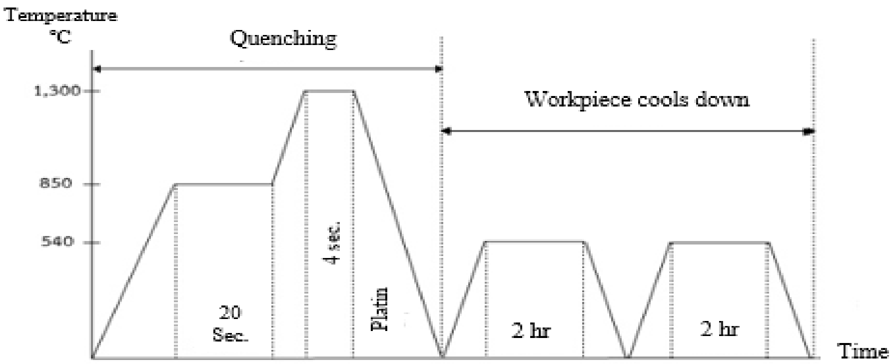


Figure 2. Example graph showing time of metal quenching at different temperatures

2.6 Undergo the workpiece through the Rockwell Hardness measured on the C scale (HRC) and record values in the results recording table. [6]

3. Experiment Table Design

Table for recording the Rockwell Hardness measured on the C scale (HRC) fter quenching, experiment design and data analysis using data variance test. There are 3 factors that are used to determine the hardness value, namely, coolant, quenching temperature (°C) quenching time (minutes). [7]

Table 1. The determination of the level of factors in the quenching of high-speed steel M2 using 3 types of coolant, namely, water, oil and air.

Quenching Temperature (°C)	Quenching Time (minutes)	Coolant	Tempering Temperature (°C)
1,000 1,050 1,100 1,150 1,200 1,250 1,300	3 3.3 4 4.3 5 5.3 6	Water Oil Air	540

After quenching of high-speed steel with different time, temperature and tempering at 540°C for 2 hours, 2 times, according to the experimental factors that have been set, the[8] Rockwell Hardness measured on the C scale (HRC) will be conducted at 3 points on the workpiece per piece and then record the hardness in the results table classified by type of coolant, i.e. a table to record the hardness of steel that has been quenched by using water, oil and air as coolant.

4. Data Analysis

The experimental results are analyzed to find the optimum conditions using the Minitab Version 16 statistical program. The General Linear Model function is used and the confidence level at 95% (α = 0.05) is set in order to analyze the experimental results, where the following hypothesizes are determined. [9]

4.1 The hypothesizes are:

H0i: xi1 = xi2 = xi3 = 0

H1i: xi1 = xi2 = xi3 = 0

H0j: xj1 = xj2 = xj3 = xj4 = xj5 = xj6 = xj7 = 0

H1j: xj1 = xj2 = xj3 = xj4 = xj5 = xj6 = xj7 = 0

H0k: xk1 = xk2 = xk3 = xk4 = xk5 = xk6 = xk7 = 0

H1k: xk1 = xk2 = xk3 = xk4 = xk5 = xk6 = xk7 = 0

X_i is the effect of the coolant water, oil and air (A).

Xj is the effect of the quenching temperature of 1,000oC, 1,050oC, 1,100oC, 1,150oC, 1,200oC, 1,250oC and 1,300oC (B).

X_k is the effect of the quenching time of 3 minutes, 3 minutes 30 seconds, 4 minutes, 4 minutes 30 seconds, 5 minutes, 5 minutes 30 seconds and 6 minutes (C).

4.2 Experimental Hypothesis

Main hypothesis (H0i): The effect of the coolant does not affect the steel hardness.

Secondary hypothesis (H1i): The effect of the coolant affects the steel hardness.

Main hypothesis (H0j): The effect of the quenching temperature does not affect the steel hardness.

Secondary hypothesis (H1j): The effect of the quenching temperature affects the hardness of the steel.

Main hypothesis (H0k): The effect of the quenching time does not affect the steel hardness.

Secondary hypothesis (H1k): The effect of the quenching time affects the steel hardness.

Main hypothesis (H0ij): The combined effect of the coolant and the temperature does not affect the steel hardness.

Secondary hypothesis (H1ij): The combined effect of the coolant and the temperature affects the steel hardness.

Main hypothesis (H0ik): The combined effect of the coolant and time does not affect the steel hardness.

Secondary hypothesis (H1ik): The combined effect of the coolant and time affects the steel hardness.

Main hypothesis (H0jk): The combined effect of temperature and time does not affect the steel hardness.

Secondary hypothesis (H1 jk): The combined effect of temperature and time affects the steel hardness.

Main hypothesis (H0ijk): The combined effect of the coolant, temperature and time does not affect the steel hardness.

Secondary hypothesis (H1ijk): The combined effect of the coolant, temperature and time affects the steel hardness.

4.3 Check the accuracy of the data obtained from the experiment. Present the results by creating a graph from the Minitab program to check the accuracy and analyze the results to find the most appropriate parameters that affect the quenching process.

Results and Discussion

From the experiment, the size of the workpiece is determined within the scope specified which is 12x12x3 mm, 2 times tempering at 540 °C for 2 hours. The experimental variables are quenching time, temperature, and coolant, in which the hardness of the workpiece of each level of factors is different. The test results were the Rockwell Hardness measured on the C scale (HRC) at 3 points on the workpiece per piece in each trial. The amount of 3 workpieces are used per each experiment. The hardness value is recorded in the hardness record table to find the average hardness of each workpiece. The average hardness will reveal the most hardness parameter as shown in Table 2:

Table 2. Represents the quenching parameters that give the highest hardness

Coolant	Temperature (°C)	Time (minute)	Rockwell Hardness measured on the C scale (HRC)			
			Workpiece1	Workpiece2	Workpiece3	Average
Oil	1,050	4.30	55.43	55.17	56.27	55.62
Water	1,000	3	55.00	54.23	54.60	54.61
Air	1,050	5	50.20	53.10	51.20	51.50

Based on the quenching process of steel and the average hardness, it is found that the experiment with the highest hardness is the quenching at the temperature of 1,050 °C for 4.30 minutes by cooling in the oil. Analysis of Variance (ANOVA) of the quenching was performed and the analysis of the variance of factorial data [9] can be displayed by using Minitab statistical program to analyze the results of the experiment to study all factors by determining the level of confidence of 95% or (α = 0.05) to validate the results. Based on residual analysis using the function ANOVA> General Linear Model, the results are as follows.

1) There is a normal distribution of residuals which is used in the Normal Probability Plot. Considering from Figure 3, it is found that the residuals are distributed along a straight line. The X-axis is the residuals and the Y-axis is the normal distribution percentage, thus it can be estimated that the residuals have a normal distribution.

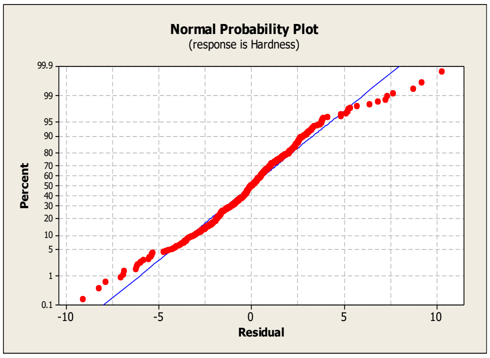


Figure 3. Normal Distribution

2) Residuals are independent from one another. When plotting the residues in the graph, the X axis is the order of the experiment and the Y axis is the residues. Considering Figure 4, it is found that the residuals are independent and there is no exact pattern or the exact pattern cannot be estimated, showing that the residuals are independent.

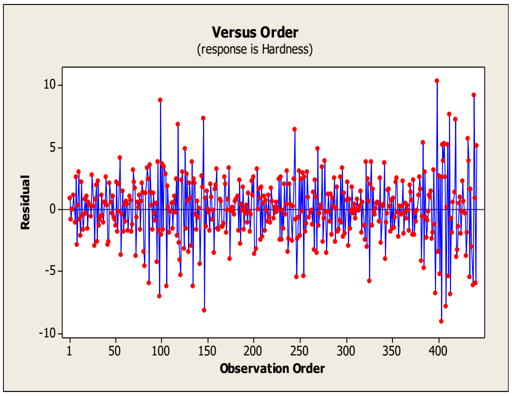


Figure 4. The distribution of residuals versus the order of the experiments.

3) Data is stable in variance. When the residue is plotted in the graph, the X axis is the experimental mean and the Y axis is the residues. Considering figure 5, it is found that the variance of residuals in each position is closed to each other and there is no tendency for the residual distribution pattern to be found. Therefore, it is concluded that the data is stable of variances.

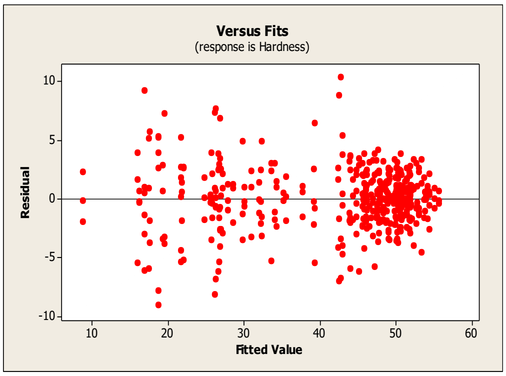


Figure 5 The distribution of residues versus the experimental mean

Analysis of variance (ANOVA) of metal quenching can present the variance analysis of 2k Factorial design by using Minitab statistical program to analyze the results of the experiment to study all factors by setting the confidence level at 95% or (α = 0.05).

Table 3. Results of experimental data analysis in general linear model

Analysis of variance for Hardness						
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Coolant	2	2833.35	2833.35	1416.67	142.25	0.000
Temperature	6	52562.29	52562.29	8760.38	879.65	0.000
Time	6	132.72	132.72	22.12	2.22	0.041
Coolant* Temperature	12	1209.08	1209.08	100.76	10.12	0.000
Temperature* Time	36	871.14	871.14	24.20	2.43	0.000
Coolant*Time	12	211.15	211.15	17.60	1.77	0.053
Coolant*Temperature*Time	72	1125.67	1125.67	15.63	1.57	0.005
Error	294	2927.93	2927.93	9.96		
Total	440	61873.33				
S = 3.15578	R-Sq = 95.27%		R-Sq (adj) = 92.92%			

From Table 3, based on the data analysis using Minitab Version 16, it is found that R2 = 95.27% and R2adj = 92.92% are good coefficient of decision making.

3.1 Based on the main hypothesis (H0i), The effect of the coolant does not affect the steel hardness, it can be seen that P-Value of the coolant is 0.000 <α (which the researcher specified α = 0.05). It shows that the regression variables of the coolant significantly affect the hardness. We therefore reject the main hypothesis (H0i), and accept the secondary hypothesis (H1i). The effect of the coolant affects the steel hardness.

3.2 Based on the main hypothesis (H0j), the effect of the quenching temperature does not affect the steel hardness, it can be seen that P-Value of the temperature is 0.000 <α (which the researcher specified α = 0.05). It shows that the temperature regression variable affects the hardness value significantly. We therefore reject the main hypothesis H0j and accept the secondary hypothesis (H1j). The effect of the quenching temperature affects the steel hardness.

3.3 Based on the main hypothesis (H0k), the effect of the quenching time does not affect the steel hardness, it can be seen that P-Value of the time factor is 0.041 <α (which the researcher specified α = 0.05). It shows that time regression variables affect the hardness value significantly. We therefore reject the main hypothesis H0k and accept the secondary hypothesis (H1k). The effect of the quenching time affects the steel hardness.

3.4 Based on the main hypothesis (H0ij), the combined effect of the coolant and the temperature does not affect the steel hardness, it can be seen that P-Value of the co-factor of coolant and temperature is 0.000 <α (which the researcher specified α = 0.05). It shows that the combined effect of the two factors affects the hardness value significantly. We therefore reject the main hypothesis H0ij and accept the secondary hypothesis (H1ij). The combined effect of the coolant and the temperature affects the stell hardness.

3.5 Based on the main hypothesis (H0jk), the combined effect of temperature and time does not affect the steel hardness, it can be seen that P-Value of the combined effect of temperature and time is 0.000 <α (which the researcher specified α = 0.0). It shows that the combined effect of the two factors affects the hardness value significantly. We therefore reject the main hypothesis H0jk and accept the secondary hypothesis (H1jk). The combined effect of the temperature and the time affects the steel hardness.

3.6 Based on the main hypothesis (H0ik): The combined effect of the coolant and time does not affect the steel hardness, it can be seen that P-Value of the combined effect of coolant and time is 0.000 <α (which the researcher specified α = 0.05). It shows that the combined effect of the two factors does not affect the hardness value significantly. We therefore cannot reject the main hypothesis H0ik. The combined effect of the coolant and the time does not affect the steel hardness.

3.7 Based on the main hypothesis (H0ijk), the combined effect of the coolant, temperature and time does not affect the steel hardness, it can be seen that P-Value of the combined effect of coolant, temperature and time is 0.000 <α (which the researcher specified α = 0.05). It shows that the combined effect of the three factors affects the hardness value significantly. We therefore reject the main hypothesis H0ijk and accept the secondary hypothesis (H1ijk): The combined effect of the coolant, temperature and time affects the steel hardness.

Graph Data Analysis Results

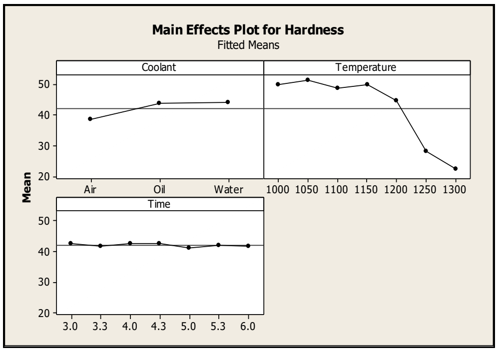


Figure 6. Relationship of the Effect from the Main 3 Factors

From Fig.6, it is found that the effect of the coolant, temperature and time has a significant effect on the average hardness, which is the oil, temperature of 1050 oC, and the time of 4.30 minutes lead to more value of hardness than other coolant, temperature and time which can be observed from the graph tendency.

In the coolant graph, it can be seen that oil and water have a higher hardness than air. The temperature graph shows that the higher the temperature will lead to less hardness values. In addition, the time graph shows the graph lines which are quite straight but with a slight difference because the P-Value of the time factor is 0.041 <α (which the researcher specified α = 0.05). The results are not very different.

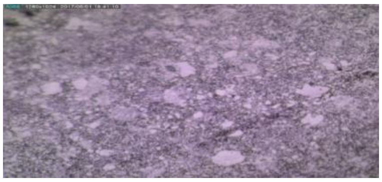
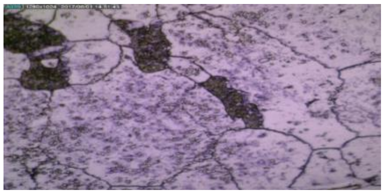
Conclusions and Discussion

The study to find the suitable factors for quenching and tempering of high-speed steel (M2) by studying the factors of temperature, time, and coolant shows that the high-speed steel (M2) with quality that can be used in the production of machining equipment and material is the quenching parameters at the temperature of 1050oC, 4 minutes and 30 seconds and oil coolant, which results in the highest hardness of 55.62 HRC. From Table 4.

Table 4. Conclusions the suitable factor

Hardness Value	Coolant	Temperature (°C)	Time (minute)	Rockwell Hardness measured on the C scale (HRC)
Experiment Result	Oil	1,050	4.30	55.62

Table 5. The comparison of the steel structure

High-speed steel, M2	Microstructure
Before quenching	
After quenching at the temperature of 1,050 °C for 4.30 minutes using oil coolant	

From Table 5 The comparison of the steel structure before quenching and tempering of high-speed steel M2 before being quenched into austenite. When the steel has undergone [10] the quenching process, cooled by oil coolant and 2-time tempering at 540-degree temperature for 2 hours, the steel structure has been changed to martensite. The oil coolant will cause the workpiece to become relative less cracked from the division of grains than the use of other coolant. Therefore, when choosing to use the quenching process of high-speed steel, M2, the temperature should be 1050oC for 4 minutes and 30 seconds and oil should be used as the coolant. The benefits from this experiment can be used as basic data for the development of tools, materials and equipment by increasing the hardness value with PVD or CVD coating. It can also be used in the production of machinery parts including mold manufacturing industry.

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