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Analysis of Characteristics of S45C Steel Changes due to the Quenching and Tempering Process

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ABSTRACT

S45C steel has a carbon content of 0.50% and its classified as medium carbon steel. The main element content of S45C is carbon (C) is 0.50%, sulphur (S) is 0.035%, and manganese (Mn) is 0.80%. Tempering is a heat treatment process in which the hardening or normalizing process was previously carried out on steel. The research method was carried out where the steel was heated below the critical temperature and cooled. Quenching is a process of rapidly cooling the material from austenitizing from a temperature range of 815 °C to 870 °C for steel. S45C steel was quenched at 950 °C for 120 minutes, then tempered at 700 °C, and 500 °C for 120 minutes. The raw material sample (without heat treatment) is the initial reference standard among the samples undergoing the heat treatment process. They are then analyzed, and the influence and changes in the characteristics after that. In addition, changes in mechanical properties due to the heat treatment process experienced by S45C steel use tensile tests, Charpy impact tests, hardness tests and microstructures. The research results on the quenching process sample were tempered at a temperature of 500 °C and held for 120 minutes, increasing tensile strength by 17.1% and yield strength of 56.82%.

Keywords: *characteristic changes, mechanical properties, quenching, tempering*

1. INTRODUCTION

Steel is a material that is easy to change its shape and at a relatively affordable price; therefore, steel is the most widely used. Different types of steel differ according to strength, hardness, elasticity, toughness, weldability, cold and hot formability and corrosion resistance. Construction steel accounts for 90% of all steelmaking; construction steel is used to manufacture steel bars and profile steel. For all types of construction such as bridges, towers, tall buildings, etc. (Jasman, Official, & State, 2018).

Construction steel is also used at high and low temperatures. All metals generally do not lose their stress, stiffness and even increase ductility with an increased room temperature (Candra & Puspitasari, 2014). Temperature treatment can be defined as a combination of hot and cold operating temperatures on metals and their alloys. This temperature treatment is given to metals or alloys to obtain specific properties. In the temperature treatment process on medium carbon steel, grain changes will be produced, and the mechanical properties of the material in this study will be studied changes in the mechanical properties of the test metal treated with a temperature of 700 °C & 500 °C. (Handoyo, 2015).

S45C steel is steel with a carbon content of about 0.50% and is classified as medium carbon steel; S45C steel is widely used to manufacture machinery, mechanical components to make mechanical components, including base plates, springs, milling cutters, gears, studs shafts. tension bar, standard punch head, roller, shaft, spindle load, particular punch head and thread rolling tool requiring high precision, long service and abrasion resistance of various machining tools.

S45C steel is a standardized product from Japan which is commonly abbreviated as JIS (Japan Industrial Standard). S45C steel contains the main elements in the form of carbon (C) at 0.50%, sulphur (S) at 0.035%, and manganese (Mn) at 0.80%. This steel has the property of being able to carry out a heat treatment process to obtain better mechanical properties. A steel of this specification is widely used as gear shafts, saw blades, razor blades and bearings.

1.1. Heat Treatment

Tempering

Tempering is a heat treatment process in which the hardening or normalizing process was previously carried out on steel. Steel is heated below the eutectoid temperature (critical temperature) and cooled. The things that need to be considered in the tempering process are the tempering temperature, tempering time, cooling rate, and the composition of the steel to be tempered.

The tempering process aims to increase the ductility, toughness, and grain size of the matrix. Generally, steel is tempered (reheated) after the hardening process to obtain the desired mechanical properties and reduce stress resulting from the quenching, welding, and machining processes.

Quenching

Quenching is a process of rapidly cooling the material from austenitizing from a temperature range of 815 °C to 870 °C for steel. The choice of quenching media depends on the material's hardenability and thickness, including the material's shape and the cooling period to achieve the desired microstructure. The quenching medium used is usually in the form of a solution or gas. The quenchant media in the solution used are Oil which can consist of various additives, such as Water. Polymer solution. Water containing salt or other additives. The gaseous quenching medium usually consists of helium, argon, and nitrogen. (ASM Vol 4, 1991).

This quenching process is carried out by rapid cooling to produce the desired structure. If the quenching process occurs quickly, distortion and cracking can occur. 283 / 5,000.

Therefore, the quenching media must be considered to produce a satisfactory product. One of these media is Water which provides a quenching rate three (3) times faster than Oil and is easier to clean from Oil (Iman, Haryadi, Zahrawani, & Adjiantoro, 2018)

2. RESEARCH METHODOLOGY

Detailed research methodology is shown in Figure 1. The material used in this research is an S45C steel round bar with a length of 200 mm, and a diameter of 19 mm, the shape of the sample; seen in Figure 2 is the microstructure test sample, Figure 3 for the Tensile test sample, Figure 4 test sample for the Charpy impact test (Type V-Notch) and Figure 5 for the hardness test sample.

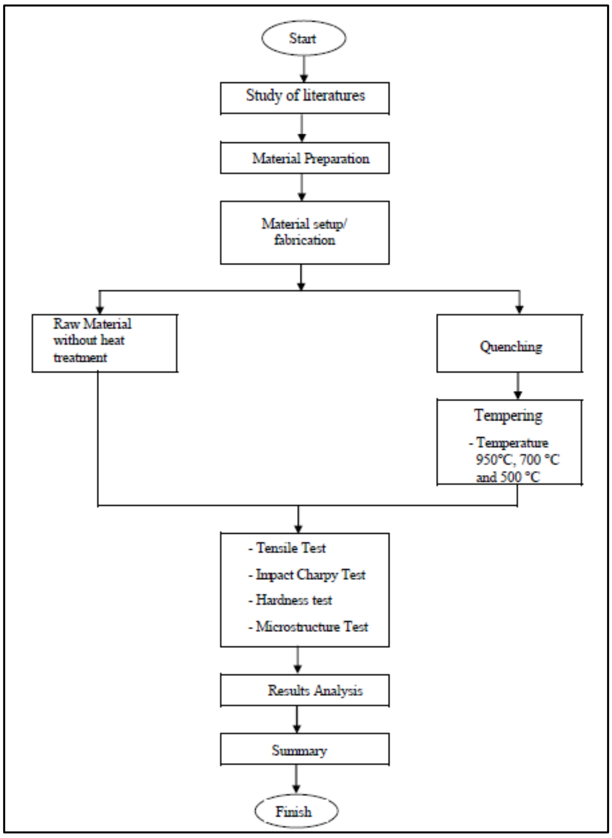

Fig. 1. Flowchart

Table 1. Test structure of S45C. steel material

No & Code Sample	Treatment					
	Quenching (°C)	Tempering (°C)	Holding Time (edit)	Tensile Test (pc)	Charpy Impact Test (pc)	Hardness Test (pc)
A	-	-	-	2	3	One pc (3 points)
B	950	-	120	2	3	One pc (3 points)
C	950	700	120	2	3	One pc (3 points)
D	950	500	120	2	3	One pc (3 points)

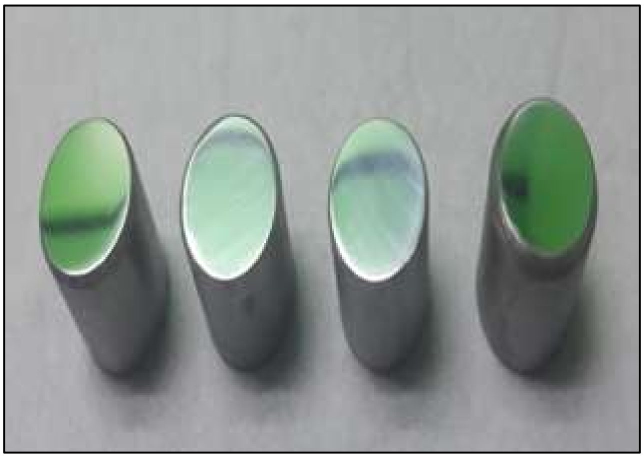

Fig. 2. Sample microstructure specimen

Fig. 3. Tensile test specimen sample

Fig. 4. Charpy impact test sample (Type V-Notch)

Fig. 5. Sample hardness test

3. PURPOSE OF OUTCOMES AND DISCUSSION

3.1. Effect of Temperature Changes on Mechanical Properties

a. Tensile Test

The results of the tensile test are in Table 2 and Figure 6 and Figure 7. The results of the tensile test of S45C steel without and with variations in heat treatment temperature. This tensile test is carried out on S45C steel, whether it is experiencing temperature changes.

Table 2. Tensile test results of S45C steel without and with variations in heat treatment temperature (*raw material*). Methods for Tension Testing of Metallic Material

No. / Sample Code	Treatment	Tensile Strength (Mpa)	Yield Strength (Mpa)	Elongation (%)	Reduction of Area (%)
A	Raw Material without heat treatment	744.88	421.89	20.99	49.56
B	Quenching 950°C	906.16	603.81	10.35	30.83
C	Quenching 950 °C & Tempering 700°C	676.05	473.53	31.10	68.10
D	Quenching 950 °C & Tempering 500°C	898.50	661.6	15.30	45.35

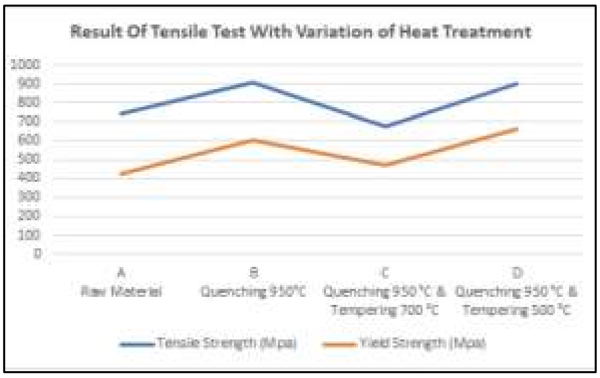

Fig. 6. Graph of the effect of heat treatment (quenching and tempering) of S45C steel on tensile strength and yield strength

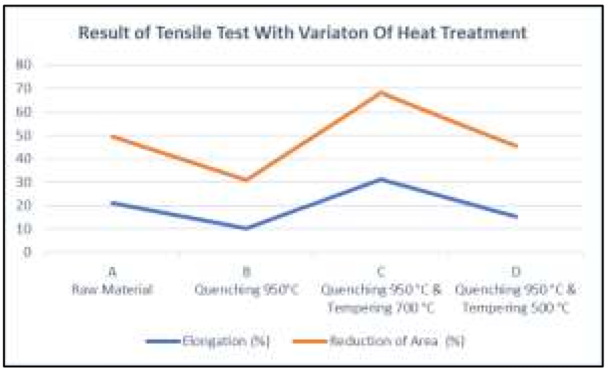

Fig. 7. Graph of the effect of heat treatment (quenching and tempering) of S45C steel on elongation and reduction area

b. Impact Charpy Test

The Charpy impact test was carried out at the Indonesian Classification Bureau (Persero) Laboratory of the Energy & Industry SBU Unit. This Charpy impact test is carried out on S45C steel. The results of charpy impact test are in Table 3.

Table 3. Data on the results of the Charpy impact test of S45C steel due to the influence of heat treatment

No. / Sample Code	Treatment	Impact Energy (Joule)			Average (Joule)
		Impact 1 (Joule)	Impact 2 (Joule)	Impact 3 (Joule)	
A	Raw Material without heat treatment	79.41	83.39	80.23	**79.82**
B	Quenching 950 °C	238.36	339.99	215.2	**226.78**
C	Quenching 950 °C & Tempering 700 °C	278.95	270.23	267.78	**273.37**
D	Quenching 950 °C & Tempering 500 °C	278.12	282.69	289.57	**283.85**

Fig. 8. Hardness testing process – Vickers HV 10

c. Microstructure Test

Microstructural testing starting from the preparation of test samples, the etching process to grin size analysis, was carried out according to ASTM standards as follows: Preparation of test samples was carried out according to ASTM E3:2001 Standard Guide for Preparation of Metallographic Specimens.

1. The etching process is carried out by ASTM E 407: 2007 Standard Practice for Microetching Metals and Alloys.
2. Grain size measurement and analysis by ASTM E112: 20012 Standard.

d. Test Methods for Determining Average Grain Size

For the microstructural test, here we will see/measure and calculate the grain size/grain size of each S45C steel, both heat treated and heat treated. The sample was etched with metal with a composition of 100 ml Alcohol + 5 ml HNO_3 with 100X magnification. The microstructure test in this study used 2 (two) grain size measurement methods, namely the comparison method and the planimetric method.

Table 4. Big data and the number of grains

No. / Sample Code	Treatment	Grain Size no.	Diameter. d (µm)	Number of Grains
A	Raw material without Heat treatment	5.5	53.4	141
B	Quenching 950 °C	11.0	7.9	4310
C	Quenching 950 °C and Tempering 700 °C	10.5	9.4	3308
D	Quenching 950 °C and Tempering 500 °C	9.0	15.9	1934

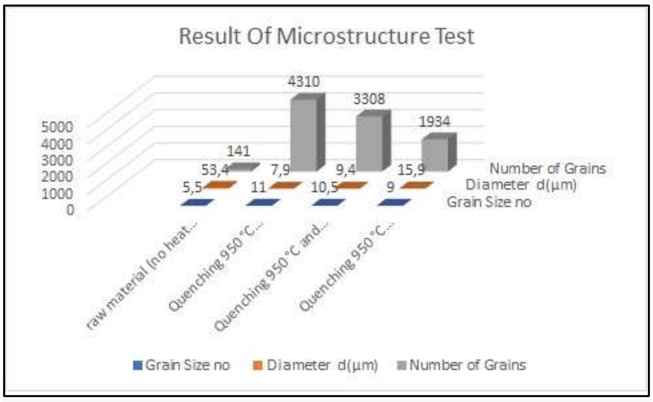

Fig. 9. Graph of the effect of heat treatment (Quenching and tempering) S45C steel against microstructure

e. Microstructural Data Analysis

1. The results of the observation of the microstructure on the grain size test of the code A sample (raw material/material that has not undergone heat treatment) obtained No. Grain 5.5, grain size 53.4 m with 141 grains.
2. The results of the microstructural test for the code B sample, namely the material that underwent a quenching process at a temperature of 950 °C and was held for 120 minutes in obtaining No. Grain 11.0 with 4310 grains.
3. The results of microstructural testing for the code C sample, namely the material that underwent a quenching process at a temperature of 950 °C and distempered at a temperature of 700 °C, was held for 120 minutes at a holding time of 120 minutes—grain 10.5 with 3308 grains.
4. The results of the microstructural test for the code D sample are materials that have undergone a quenching process at a temperature of 950 °C and tempered at a temperature of 500 °C in a holding time of 120 minutes in obtaining No. Grain 9.0 with a grain count of 193.

From the results of the microstructure test of the grain size in the code B sample, there was a reduction in the grain diameter of the raw material from 53.4 m to 7.9 m. For sample C, after the sample was quenched and then tempered at 700 °C, there was a decrease in grain size to 9.4 m., and for sample D, after the sample was quenched and then tempered at a temperature of 500 C, there was a decrease in grain size to 15.9 m.

Analysis of the results of the microstructure test on samples quenched at 950 °C then tempered at 500 °C there was no significant change in grain size because tempering at 500 °C was not close to the austenite + ferrite phase (723 °C). This is under R Widodo's theory/research.

4. CONCLUSION

From the research that has been done from mechanical testing and micro-structure testing, the data and conclusions are obtained as follows:

1. The effect of temperature changes on the mechanical properties of S45C steel after going through the quenching process at a temperature of 950 °C and holding time for 120 minutes. Then the sample is cooled suddenly by immersing it in Oil, and the mechanical properties change as follows:
   a) There was an increase in tensile strength of 21.80% and yield strength of 43.12% from the initial value without heat treatment/raw material, namely a tensile strength of 744.88 MPa and yield strength of 421.89 MPa increased to a tensile strength of 906.16 MPa and yield strength of 603.81 MPa.
   b) There was an increase in the hardness value of 69%, from the original raw material value of 200.55 HV to 340.4 HV and an increase in the energy impact value of 184.11% from the initial value of 79.82 joules to 226.78 joules.
   c) After going through the quenching process, the samples were tempered at a temperature of 700 °C and held for 120 minutes; there was a decrease in tensile strength of 10% but an increase in yield strength of 12.24%.
   d) After the quenching process, the sample was tempered at a temperature of 500 °C and held for 120 minutes; there was an increase in tensile strength of 17.1% and yield strength of 56.82%.
2. The relationship between quenching and tempering treatments in this study was:
   a) There is an increase in strain and reduction in the area if the steel that has gone through the quenching process is tempered at a temperature close to 700 °C. (austenite and martensite phases).
   b) There is an increase in the value of impact/toughness for steel that has been quenched then the tempering process is carried out.

5. REFERENCES

ASTM 112. (2012). *Standard Test Methods for Determining Average Grain Size1*.

ASTM A370. (2016). Standard Test Methods and Definitions for Mechanical Testing of Steel Products. *ASTM International*, *155*(23), 739–744. https://doi.org/10.1520/A0370.

ASTM E 407. (2007). *Standard Practice for Microetching Metals and Alloys1*.

ASTM E3. (2001). *Standard Guide for Preparation of Metallographic Specimens1*.

ASTM E8. (2016). *Standard Test Methods for Tension Testing of Metallic Materials1*.

Candra, W., & Puspitasari, R. P. (2014). *Pengaruh Kadar Dromus Oil Dalam Media Pendingin Terhadap Kekuatan Tarik Dan Struktur Mikro Baja St 60 Yang Mengalami Proses Hardening Tempering*. (2).

Handoyo, Y. (2015). Pengaruh Quenching Dan Tempering Pada Baja Jis Grade S45C Terhadap Sifat Mekanis Dan Struktur Mikro Crankshaft. *Jurnal Ilmiah Teknik Mesin Unisma "45" Bekasi*, *3*(2), 102–115.

Iman, S., Haryadi, Zahrawani, A., & Adjiantoro, B. (2018). Pengaruh Proses Quenching Dan Tempering Terhadap Sifat Mekanik Dan Struktur Mikro Baja Karbon Rendah Dengan Paduan Laterit. *Jurnal Teknik Mesin*, *4*(1), 56–64.

ISO-6507-1. (2018). *Metallic materials— Vickers hardness test*.

ISO 148-1. (2016). *BSI Standards Publication Metallic materials — Charpy pendulum impact test Part 1 : Test method*.

Jasman, J., Resmi, S., & Negeri, U. (2018). *Analisis Sifat Mekanik Dan Struktur Mikro Baja Aisi 4140 Akibat*. (October).

Kelautan, F. T. (2016). *Final Project – Mn141581 Temperature And Quenching On Its Toughness Value*.

Mahbegi, D. (2017). *Analisa Pengaruh Temperatur Tempering pada Perlakuan Panas Terhadap Perubahan Struktur Mikro dan Sifat Mekanik Coupler Yoke Rotary (AAR-M201 Grade E)*. Retrieved from http://repository.its.ac.id/1361/

Mizhar, S., & Tampubolon, B. (2015). *Analisa Kekerasa Dan Struktur Mikro Terhadap Variasi Temperatur Tempering Pada Baja Aisi 4140*. *1*(2), 98–104.

Nurjayanti, D., & Ginting, E. (2013). Pengaruh Lama Pemanasan , Pendinginan secara Cepat , dan Tempering 600 o C terhadap Sifat Ketangguhan pada Baja Pegas. *Jurnal Teori Dan Aplikasi Fisika*, *01*(02), 113–120.

Widiyawati, F. M. Achyarsyah. E. Hidayat. (2014). Analisis Sifat Mekanik Pada Material Aisi 4140 Dan Creusabro 8000 Untuk Aplikasi Gigi Bucket Produksi Pt. Polman Swadaya.

Muhamad Fitri, Poempida Hidayatullah, Kusnanto Mukti Wibowo, Agung Setyo Darmawan. 2o21. The Effect of Smaw Welding Currents on Mechanical Properties and Micro Structures of Low Carbon Steels. Materials Science Forum Submitted: 2020-12-06 ISSN: 1662-9752, Vol. 1029, pp 15-23

Dafit Feriyanto, Maizlinda Izwana Idris, DARWIN Sebayang. 2015. The Effect of Ultrasonic Treatment on the Oxidation Resistance and Microstructure of $Fe_{80}Cr_{20}$ Alloy Powder at High Temperature Oxidation Process. Advanced Materials Research (Volume 1087**)**

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