International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

Mechanical Engineering Experimental Study for Clip Rail in VCN 150 and S45C Materials with Heat Treatment

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Abstract— *The research problem is that clip rail often experiences problems related to rail widening, rail dropping, and loss of rail fastening due to low mechanical properties. The purpose of the research is to improve mechanical properties by using VCN 150 and S45C materials and then comparing the results. The research method is quantitative experimentation, with heat treatment of VCN 150 and S45C materials in the process of 830°C hardening, oil quenching, and 300-500°C tempering variations carried out micro examination, rockwell hardness test, and tensile test. The results of the study are VCN 150 and S45C materials before and after heat treatment affect the microstructure, hardness level, and tensile strength. Heat treatment on micro examination produced ferrite, pearlite, and tempered martensite structures. The test results showed that the VCN 150 material experienced a significant increase in mechanical properties as evidenced by the highest rockwell hardness test value at 300°C tempering variation on VCN 150 worth 47.58 HRC and on S45C material hardness value worth 17.20 HRC. The highest tensile test value at 300°C tempering is at VCN 150 worth 1,455 MPa and at S45C worth 926 MPa. The conclusion of the research is that heat treatment on VCN 150 produces higher mechanical properties than S45C.*

Keywords— *VCN 150, S45C, heat treatment, micro examination, rockwell hardness test, tensile test.*

I. INTRODUCTION

National Transportation Safety Committee of the Republic of Indonesia in 2016 revealed that rail fasteners suffered structural failures of 408 pieces due to derailment, fractures due to forced widening and frequent loss of rail fasteners. LawNo. 3 of 2014 concerning Industry contains the role of the government in the progress of the industrial sector to be carried out in a planned and systematic manner, so that improving the quality of rail fastening bolts must be carried out by taking into account material retention, It's not easy to corrode, and the hard surface avoids not being easily worn out due to continuous friction.

Based on the ASTM A183 standard which discusses the specifications of bolts for connecting rails on railroad tracks using grade 2 or general use, namely using medium alloy steel which requires heat-treated for general line use [1]. Types of alloy steel that comply with the specifications for the manufacture of rail fasteners are VCN 150 (Vanadium Carbon Nickel 150) or AISI 4340 (American Iron and Steel Institute 4340) and S45C materials. The selection of VCN 150 and S45C is a martensitic medium alloy steel that has a chrome (Cr) content of 0.6% with an initial hardness of only 19 HRC and 16 HRC material which has high enough strength properties in hot conditions, so it requires a treatment process to increase hardness [2]. S45C is a type of medium carbon steel with a carbon content of 0.3 to 0.5% carbon which must be improved in mechanical properties to improve the mechanical properties of the material treated.

The level of hardness is carried out with a rockwell hardness test which states that the maximum hardnessproduced in VCN 150 material to produce high-quality products in the manufacture of bolts on rail fastening is a minimum of 45 HRC [2]. Proof of mechanical properties is tested to determine changes in the mechanical properties of the material after undergoing a heat treatment process with hardening and tempering methods, micro-testing is carried out with ASTM E3 standards [3]. The hardening and tempering process, there is a holding time on the material that aims to maintain the temperature at a certain time so that the temperature and structural changes become evenly distributed [4]. This research is supported by research conducted by [5] hardening and tempering with tempering temperaturevariations of 200 °C, 250 °C, 300 °C, 400 °C, 500 °C, 650 °C to increase the strength and hardness of VCN 150 and S45C with results that show tempering has an effect in improving mechanical properties.

II. LITERATURE REVIEW

There have been several previous studies conducted by several researches regarding the increase in hardness and mechanical properties of AISI/SAE 4340 steel after heat treatment because when the specimen after 800°C hardening and 300°C tempering temperature [6].

Another research as a reference is regarding "*A New Step Heat Treatment For Steel* AISI 4340" which explains the development of heat treatment for AISI 4340 combined specimen strength. The recommended heat treatment mode is applied to all types and stainless steels. The study compares the mechanical properties of steel after different treatments and

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suggests that a mixture of precipitated martensite and lower bainite gives a good combination of strength and ductility [7].

Another study is regarding "Holding Time Optimization to obtain S45C Steel Hardness" which concludes that the highest hardness value is produced at a holding time of 30 minutes with a temperature of 850 ℃. Because at the lowest holding time the heat transfer rate is faster which results in the lowest hardness value [8].

Research on "the Effect of Tempering Time on the Character of S45C Steel After Quenching at 950 ℃ and Tempering at 500 ℃" which concludes that the microstructure of S45C steel in post-quenching and tempering, it has martemper and ferrite phases. The heat treatment process applied to the tensile testing of S45C steel increases the toughness of S45C steel which is characterized by an increase in tensile strength and ductility [9].

III. METHODOLOGY RESEARCH

The research method used in this study is the experimental method. The experimental method is a systematic method by taking a quantitative approach that aims to determine the causal effect of giving treatment or treatment on the behavior of the research subject under study.

1. *Flowchart Design*

Research methods are carried out gradually. These stages include literature studies, specimen making, welding processes and testing schemes, discussion andconclusions. Seen in the figure of the research flow diagram in Fig. 1.

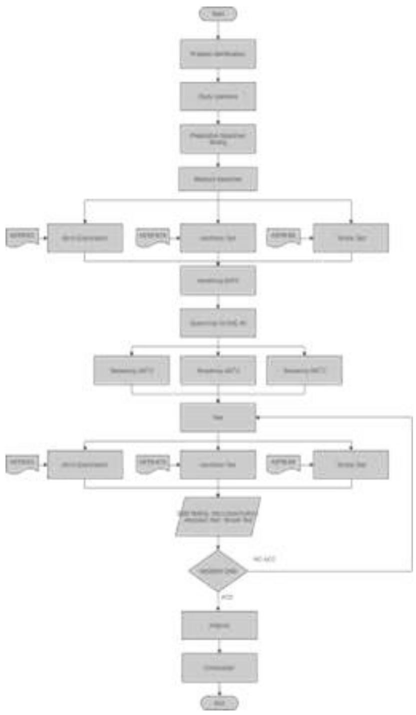

Fig. 1. Flowchart Methodology

2. *Preparation of Testing Specimen*

a. *Tensile Test Specimen*

Specimens carried out tensile tests in accordance with ASTM E8 standards with an overall length of 170 mm, outer dimension Ø20 mm, inner dimension Ø12.5 mm with a radius of 10 mm as in Fig. 2 with the specimen preparation process using a lathe [10].

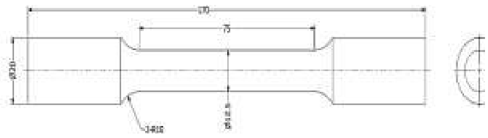

Fig. 2. Tensile Test Specimen Design

b. *Micro Examination Specimen*

Micro examination testing using ASTM E3 standards with a size of Ø22 mm [11].

c. *Rockwell Hardness Test Specimen*

Rockwell hardness test specimens that use ASTM E18 standards with a specimen size of Ø22 mm. The testing process took 13 test points as shown in Fig. 3 [12].

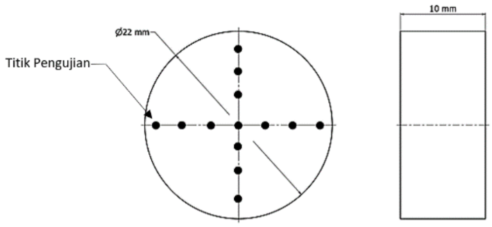

Fig. 3. Hardness Specimen Testing Point Design

3. *Heat Treatment*

Raw materials after the machining process to become specimens are put into the heating machine with the heating process and temperature as in TABLE 1.

TABLE 1. Heat Treatment Process on Specimen

No	Specimen	Process
1.	Specimen 1-3	Raw material specimen without heattreatment
2.	Specimen 4-12	Specimens are hardened to 830^{0}C temperature with a holding time of 26minutes.
3.	Specimen 4-6	Specimens were tempered at 500^{0}Cfor 90 minutes.
4.	Specimen 7-9	Specimens were tempered at 400^{0}Cdegrees for 90 minutes.
5.	Specimen 10-12	Specimens were tempered at 300^{0}Cdegrees for 90 minutes.

4. *Rockwell Hardness Test*

Rockwell hardness test is the most effective test in determining the mechanical properties of a material because this test serves to easily determine the description of the mechanical properties of the material, even though in this test measurements are only made at one point or a certain area . The Rockwell hardness test produces a valid value of the hardness of a material so that it easily classifies ductile materials or brittle materials. Hardness test is done by pressing the test specimen using a diamond indenter with a compressive force of 150 kgf. This test uses the rockwell method based on ASTM E18 standards in this test using 13 points with the result of the hardness value in units (HRC).

5. *Tensile Test*

Tensile tests were conducted to determine the mechanical properties of the VCN 150 steel test material before heat treatment until after heat treatment. The mechanical properties reviewed are ultimate tensile strength, yield strength, and elongation. The test was conducted with ASTM E8 standard. The tensile strength value includes both the hardness and fatigue strength of the material. When two samples of the same material with identical microstructure but with different compositions are considered, it is observed that fatigue strength and hardness have a direct relationship with tensile strength.

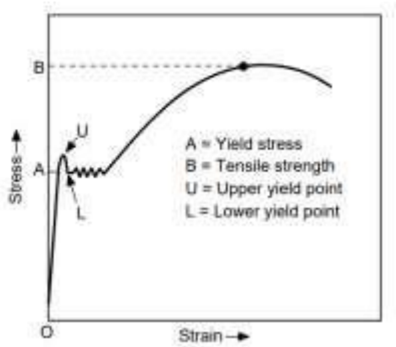

Fig. 4. Stress-Strain Curve for Mild Steel

6. Micro Examination

Micro examination aims to determine the difference in microstructure between the two different carbon steel materials that occur heat treatment process. Micro examination is done by cutting the end of the tensile test specimen or by making a 1 cm long specimen and then leveling and smoothing the surface until it meets the specimen requirements using sandpaper sizes 240, 600, and 1000. Then cleaned with a fine cloth and the use of 2% Nital etching liquid which produces shiny specimens.

7. Tools and Material

The materials used are VCN 150 steel and S45C steel round bar. Tools used by hardening machine, lathe machine, tensile test, rockwell hardness test, microscope test and polishing machine.

IV. Result and Discussion

A. Micro Examination

Micro examination is a test to determine changes in grain boundaries of the material after heat treatment with tempering temperature variations of 300°C, 400°C, and 500°C. Micro examination is done with 1000x magnification and 2% nital.

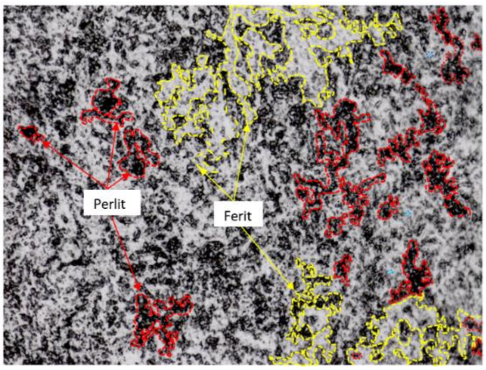

Fig. 5. Raw Material VCN 150, 1000x

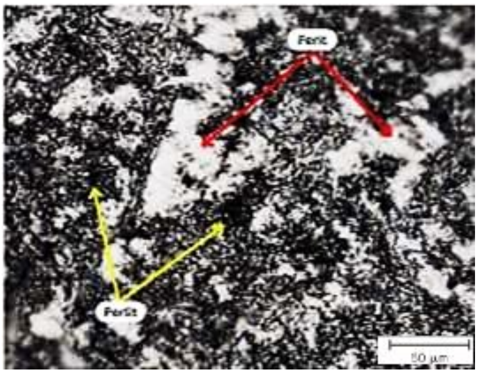

Fig. 6. Raw Material S45C, 1000x

The results of micro examination of base metal or without treatment of VCN 150 and S45C materials resulted in structures formed only ferrite and pearlite structures. Ferrite structure is characterized by bright white color which has soft properties. The pearlite structure is characterized by dark color colony grains which have harder properties than the ferrite structure [13].

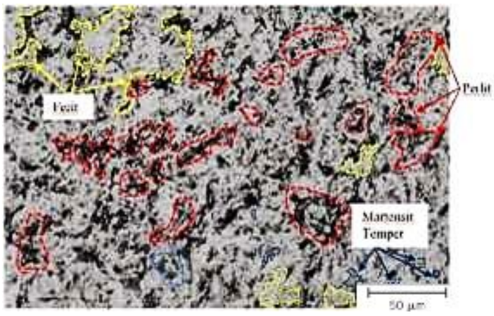

Fig. 7. Tempering 300°C VCN 150, 1000x

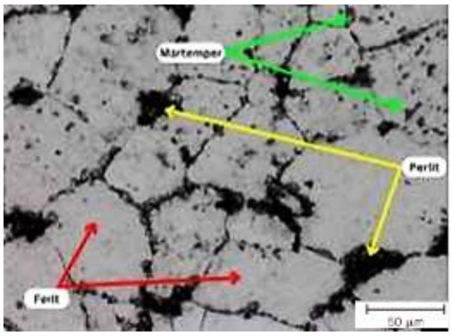

Fig. 8. Tempering 300°C S45C, 1000x

Fig. 7 and Fig. 8 is the result of micro examination after heat treatment with 830 °C hardening process followed by oil quenching and continued tempering variation of 300 °C. After heat treatment, a new structure is formed, namely tempered martensite. Quenching martensite has very high strength but very low fracture resistance so that almost all steel hardening to martensite is tempered or reheated below A1 temperature to increase toughness so as to produce a tempered martensite structure that provides strengthening and restores ductility [14]. The tempered martensite structure is more dominant in VCN 150 material than S45C.

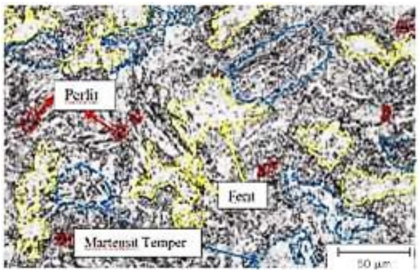

Fig. 9. Tempering 400°C VCN 150, 1000x

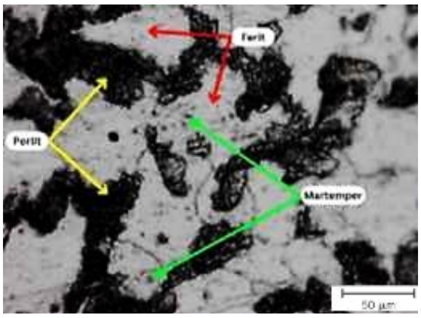

Fig. 10. Tempering 400°C S45C, 1000x

Fig. 9 and Fig. 10 are the results of the micro examination of the 400°C tempering variation with the results of tempering martensite appearing increasingly fine lines in white and pearlite appearing black spots with a martensite tempering matrix [15].

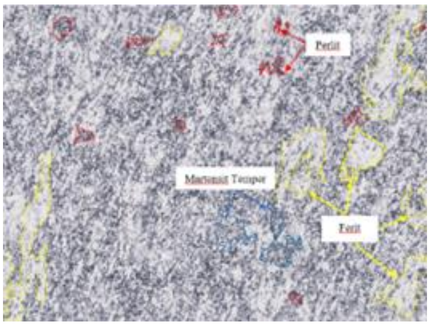

Fig. 11. Tempering 500°C VCN 150, 1000x

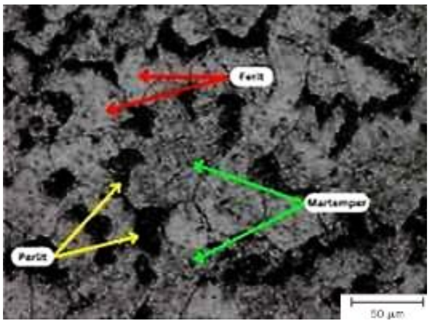

Fig. 12. Tempering 500°C S45C, 1000x

Tempering temperature 500°C tempered martensite structure looks increasingly fine-grained uniform, ferrite formed more and more stable with pearlite structure such as dark-colored rough spots, and uniform results from residual austenite is completely lost [16]. Tempering temperature higher martensite tempering structure formed increasingly smooth and partially pearlite spread in the form of fine spots [17].

B. Rockwell Hardness Test

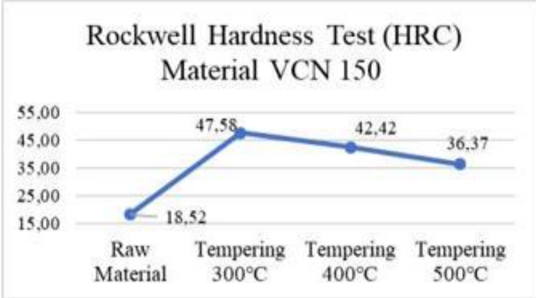

Fig. 13. Rockwell Hardness Test VCN 150

VCN 150 material produced a hardness value of 18.52 HRC. The resulting hardness value is still low so heat treatment is carried out to increase the level of hardness. Heat treatment hardening process serves to increase the hardness and strength of the material, but produces brittle properties. Therefore, the tempering process is carried out to increase the ductility of the material [18]. The results of 300°C tempering specimens produce very high hardness values because the low temperature in tempering causes a decrease in hardness from the hardening process only slightly compared to higher temperatures. The graph shows that the higher the temperature of tempering, the lower the hardness value. This is because during tempering, the martensite structure cooled after the quenching process turns into tempered martensite [18].

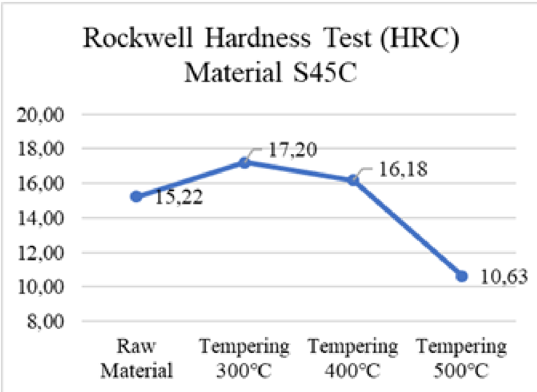

Fig. 14. Rockwell Hardness Test S45C

S45C material without treatment produces a hardness of 15.22 HRC and for heat treatment produces the highest average result value produced at a tempering temperature of 300oC worth 17.20 HRC. In hardness testing all specimens show a decrease in hardness results from the lowest temperature to the highest temperature.

C. Tensile Test

The ultimate tensile strength graph in Fig. 15 shows different values for each variation. The highest ultimate tensile strength value is at tempering temperature variation 300°C worth 1455 MPa while the lowest value at temperature 500°C is 1188.67 MPa.

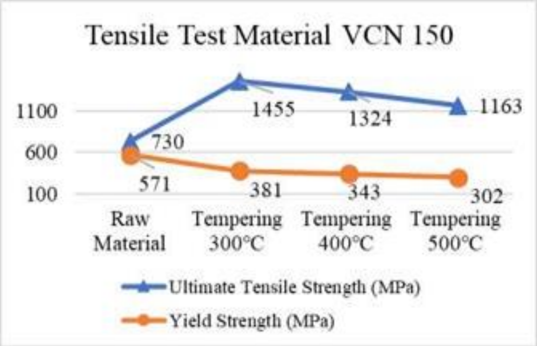

Fig. 15. Result Tensile Test VCN 150

At tempering temperature 500°C has thelowest ultimate tensile strength value compared to tempering temperatures 300°C and 400°C because tempering with high temperatures causes cementite particles to grow and ferrite begins to appear austenite transformation into pearlite and cooling becomes the slowest because the tempering temperature at 500°C the resulting metal grains become smooth. The ultimate tensile strength value is inversely proportional to the yield strength value. Yield strength is the maximum stress tolerated by a material before the specimen undergoes plastic deformation. The 500°C tempering specimen has the highest value of 473.33 MPa while the lowest value is located in the 300°C tempering specimen which is 380.47 MPa. Based on the data and graphs, yield strength shows the phenomenon of heat treatment in tempering variations increases as the tempering temperature increases. The yield strength value decreases as the tempering temperature increases, resulting in atoms diffusing to form a stable phase, namely ferrite, so that the strength of the steel decreases [19].

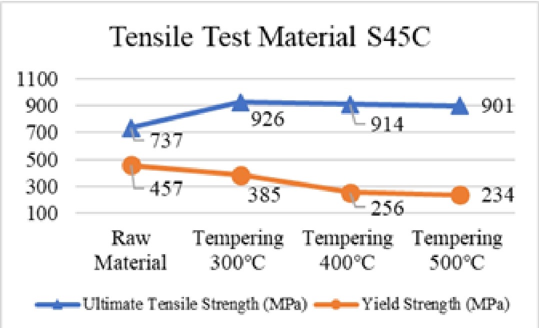

Fig. 16. Result Tensile Test S45C

The ultimate tensile strength graph shows different values for each tempering temperature variable. The results of the ultimate tensile strength value of 300°C, 400°C and 500°C tempering temperature heat treatment materials decreased. The results of the ultimate tensile strength value are linear with the results of the elongation value and yield strength value, the ultimate tensile strength value is influenced by the level of material hardness. In the results of tempering temperature material hardness 500°C is the lowest level of hardness and these results are linear with the results of the ultimate tensile strength value.In the graph of the yield strength value, it is shown that the heat treatment specimens from the tempering temperature of 300°C, 400°C and 500°C decreased below the yield strength value of the raw material which is worth 457 MPa. Heating the material causes a decrease in the yield strength value, when the temperature increases the thermal energy increases which results in atomic movement in the crystal structure of the material so as to reduce the yield strength value of the material [20].

V. Conclusion

From the results of the research on the experimental study of mechanical engineering of clip rail with VCN 150 And S45C Materials through heat treatment. it is concluded as follows:

a. To improve the mechanical properties of the material in the use of bolts in rail fastening, heat treatment is carried out with a hardening process followed by quenching and tempering to produce hardness and toughness of the material.
b. Based on micro testing, hardness, and tensile, it is known that the higher the tempering temperature, the higher the hardness and toughness values so that the tempering recommendation is at 300°C.
c. Based on micro testing, hardness, and tensile it isconcluded that before and after the heat treatment process has increased the level of hardness and strength.
d. The strength of the material is able to accept the highest load on VCN 150 with a tempering variation of 300°C worth 1455 MPa.
e. In the use of rail fastening between VCN 150 and S45C material, it is recommended that VCN 150 material with 300°C tempering variation because it has high hardness and strength values.

Acknowledgment

This research was financed with DIPA funds Number DIPA 023.18.2.677632/2023 dated July 7, 2023, Madiun State Polytechnic.

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