Analysis of Hardness Test and Microstructure Test of R.54 Type Railway Rail with Variations in *Heat Treatment Cooling Media*

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Abstract

Rail steel R.54 is a steel that is included in high carbon steel. Rail steel R.54 has a carbon element of 0.60-0.80% allowing the hardening process to be carried out with appropriate heat treatment
. This type of research is an experimental laboratory study. The study aims to determine the effect of variations in cooling media on the observation of microstructure and hardness values in the hardening process of rail steel R.54. The Vickers method with a load of 500 gf is one of the important aspects in hardness testing. The results showed that the hardness value without heat treatment was
383.93 HV and the hardness value after heat treatment with three variations of cooling media, namely soapy water of 669.13 HV, 35% table salt (NaCl) of 689.14 HV, and new oil of 835.50 HV. The three cooling media can be concluded that the highest level of steel hardness is achieved in specimens that are hardened and cooled with new oil cooling media. The viscosity of new oil affects the hardness level of R-54 rail steel. The hardness level of R-54 rail steel will increase along with the increasing viscosity of the oil that is inserted into the cooling medium of R-54 rail steel after the quenching process. The results of observations of the microstructure of R-54 rail steel samples show that there is a phase change without heat treatment that is formed is ferrite and pearlite to form ferrite , austenite and martensite phases due to the heating process of austenite which is cooled rapidly in the cooling medium.

Keywords: *Railway, R.54 Rail Steel, Heat Treatment, Microstructure, Hardness of R-54 Rail*

I. INTRODUCTION

Lampung in Indonesia is located at the southern tip of the island of Sumatra. The Bandar Lampung area is the main city and center of government of the Lampung province. To help the development and progress of the economy and improve governance, the province of Lampung has a variety of superior transportation characteristics, one of which is the Train.
trains to carry passengers or goods in large numbers are guided by *guided vehicles* with various characteristics. In facing the increasing need for train services, complexity in the field is still a challenge, one of which is in the field of railway infrastructure. The railway track is divided

into two longitudinal steels that connect directly, useful for directing and supporting the movement of train wheels consistently, as well as the presence of *rail pads* to receive and distribute train loads. Railway tracks also play a role as a binding structure for a sturdy railway line.

One of the problems in the field that often occurs is rapid rail wear. Rail wear can occur on the Babaranjang train that transports coal from the Regional Division (DIVRE) III South Sumatra to the coal unloading station in Tarahan. Regional Division (DIVRE) IV Tanjung Karang, PT. KAI (Persero) because of direct contact between the train wheels and the rails. Rails can be said to wear out quickly if *the Passing Tonnage* is high.

Replacement of worn rails is carried out when the rail head is reduced from the standard, this usually occurs on small radius curves, at level crossings, before entry and exit signals, and entering and exiting bridges. For the DIVRE IV Tanjung Karang area, rail replacement is carried out periodically, usually a six-monthly period of replacement or waiting for the arrival of new rails.

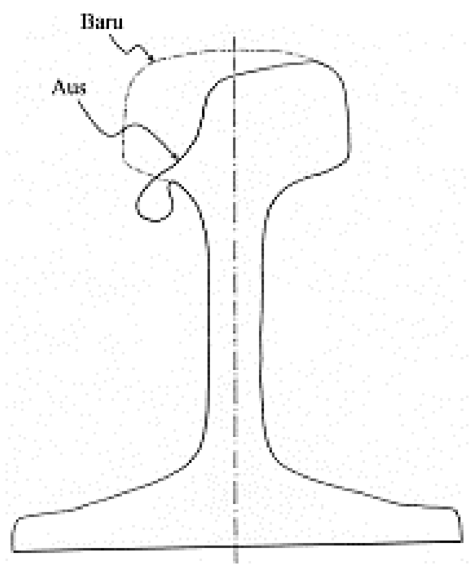

Figure 1Railway Track Design
Source: Dahlan, 2017

The wear of the rails can occur precisely on the inner outer rails that are in the curve. Excessive wear of the rails can cause high maintenance costs, decreased reliability and availability *of* the infrastructure, or if not replaced periodically, a *derailment event can occur* .

The Babaranjang train on the Tanjung Karang-Tarahan route consists of 26 sets weighing up to 50 tons per carriage. Each set consists of 60 carriages and 2 locomotives. The railway from Tarahan to Tanjung Karang has several curves with small radii and *gradients* large enough for a freight train size of no more than 10/mile.

The wear that occurs on the rail can also come from the material caused by experiencing several different mechanisms such as from the condition of the material, the geometry of the surface of the object, the environment. Low carbon steel materials are commonly used for railway rail materials, especially the R-54 type at PT. Kereta Api Indonesia (KAI) in the Tanjung Karang Regional Division IV. Therefore, it is necessary to conduct testing using:

- *Heat treatment* process (heat treatment)
- *hardness* testing (hardness of R.54 rail steel)
- microstructure analysis testing; and
- chemical composition testing.

From the above test, the author is interested in obtaining data on " Analysis of Hardness Test and Microstructure of R-54 Type Rails with Variations in *Heat Treatment Cooling Media* ".

II. RESEARCH METHODS

Flowchart is *a* versatile tool to express all the contents of existing ideas in detail when conducting research from the initial stage to the final stage which is expressed in the form of graphic symbols for different types and functions and their sequences are connected by arrows [1]. The other objectives are:

a. To be a guideline in mapping every research process.
b. Documenting the research process.
c. Shorten and visualise the flow of impementation of complex research.
d. Track the progress of ongoing research.
e. Explain the relationship between one step and another in different processes.
f. Identifying and preventing the occurrence of a research problem.
g. Create and present the results of a study.
h. Provide an overview for a new process design.

Research Flow Chart

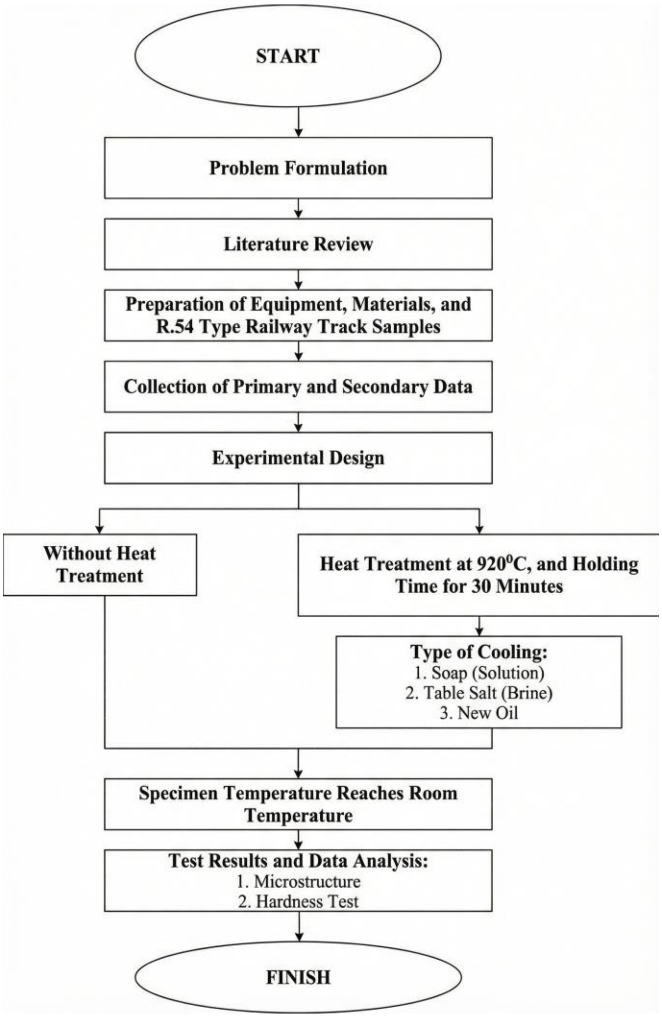

Figure 2. Research Flow Diagram
Source: Personal

Location and Time of Research

The time and location of the hardness and microstructure testing of type R.54 railway rails were carried out as follows:

a. The implementation of cutting of R.54 type railway rail samples, *heat treatment process,* and hardness testing were carried out in the Laboratory located in the campus area of the Sumatra Institute of Technology (ITERA), specifically in the Manufacturing Laboratory and Material Engineering Laboratory, Faculty of Technology and Industry (FTI).
b. The implementation of microstructure testing was carried out in the Functional Materials Laboratory.
c. The research implementation period was carried out from early April to June 2024.

Types of research

Microstructure testing and hardness testing of R.54 type railway rails are quantitative research with a laboratory experimental approach. This research is a type of research that is carried out directly related to the causes and effects of the treatment given to the research object being observed in the laboratory. Laboratory experimental research is chosen because the sample and treatment are mutually controlled, measurable and the effect of the treatment is more accurate.

Research Variables

The variables in the research on R.54 type railway steel are divided into 3 parts, including:

1. Control Variables:
   a. Railway rail steel type R.54
2. Independent variables include
   a. Without Treatment
   b. Cooling Media: Soap, Table Salt, and New Oil
3. Dependent variables include:
   a. Room Temperature 31-33 degrees Celsius
   b. Hardness and Microstructure

Data collection technique

Several techniques are used to formulate research ideas so that all data can be obtained, including:

I. Literature study
This research involves reading materials in collecting data from several trusted written sources such as books, journals, previous research and others. Literature studies are very helpful for authors in studying, supporting, or as a guideline in studying related to the title being researched.

II. Preparation of Research Tools and Materials
When conducting research, research tools and materials are needed to support testing the hardness and microstructure of R.54 type railway rails so that they run smoothly.

III. Research Materials

When conducting research, materials are needed to support the Final Assignment research so that it runs well. These materials consist of:

1) R.54 rail steel
   The main material used during the research. The R.54 type railway rail is used by PT. KAI for the rail line in the Tanjung Karang Regional Division IV.

Figure 3. Type R.54 Railway Track
Source: PT. KAI DIVRE IV Tanjung Karang

2) HNO_3 solution and *Ethanol solution*
   This solution is useful for each surface of the rail sample after *polishing*. *HNO_3* solution and *Ethanol solution* are also useful to see the phase boundaries of each rail sample during the microstructure test.

Figure 4. Etching Solution
Source: Personal Documentation

3) Resin and catalyst
   Viscous fluid is used to harden R.54 type railway rail specimens.

Figure 5. Resin Liquid and Catalyst
Source: Personal Documentation

4) *Autosol Metal Polish*
   Autosol is used to polish and smooth the surface of R.54 type railway steel rail specimens.

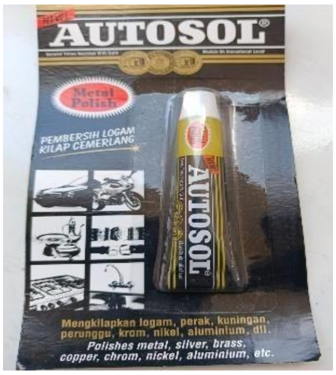

Figure 5 . *Autosol Metal Polish*
Source: Personal Documentation

5) Table salt 40%
   The chemical compound that has a 1:1 ratio between sodium and chloride ions is called table salt or commonly known as sodium chloride (NaCl). The respective molar masses are 22.99 and 35.45 grams/mol.

Figure 6. Table Salt
Source: Personal Documentation

6) Water and Soap
   Water and soap are commonly used as skin cleansers in solid or liquid form made from soap-based ingredients without causing skin irritation.

Figure 7. Liquid Soap
Source: Personal Documentation

7) New oil
   The type of oil used during this study was MPX2 10W30 SL 0.8L IDE type oil.

Figure 2 New MPX 2 Oil
Source: Personal Documentation

Research Tools

The tools used when testing the microstructure and hardness of R.54 type railway rails are as follows:

1. R.54 rail sample cutting machine (KNUTH *Bandsaw Machine*)

Figure 9. Etching Solution
Source: Personal Documentation

2. *Heat treatment* equipment (Laboratory Chamber Furnace Carbolite CWF 1300)

Figure 10 . R.54 Rail Steel Heat Treatment Tool
Source: Personal Documentation

3. Railway rail hardness tester type R.54 rail (*Zwick Roell ZHU 250 CL Models).*

Figure 11. R.54 Rail Steel Hardness Tester
Source: Personal Documentation

4. Microstructure Tool (*Trinocular Metallurgical Microscope* +14MP USB 3.0 *Camera.*

Figure 12. Optical Microscope Tool
Source: Personal Documentation

Test Equipment Specifications

Each The tools have different specifications, the tool specifications include:

1. *Band Saw* Machine for cutting R.54 type rail samples.

Table 1. *Band Saw* Specifications

***Band Saw* Specifications**	
Long	2360
Wide	19
Thick	0.9
Size	5/8

Source: ITERA Manufacturing Lab

2. *Heat* Treatment Machine

The machine used to heat R.54 type railway rail specimens with a variety of cooling media is known as *the Laboratory Chamber Furnace Carbolite CWF* 1300 [2].

Table 2. *Carbolite Chamber Furnance* Tool Specifications

TOOL SPECIFICATIONS	
Name	*Carbolite Gero CWF 1300*
Type	CWF 13/13 220-240 V 1 PH
Serial No.	21-902498
Max Temperature	1300°C
Electricity	230 V, 1 *Phase,* 50-60 Hz
	2872 ts and 12.5 A

Source: www.carbolite-gero.com

3. Hardness Testing Tool

The hardness tester is known as *the Universal Hardness Tester* with the brand and type *Zwick Roell ZHU 250 CL Models.* The R.54 rail sample testing method used is the *vickers method* [3].

Table 3. *Universal Hardness Tester* Tool Specifications *Zwick Roell ZHU 250 CL Models.*

Item no	*024484*
Load Test, Min	*1*
Load Test, Max	*250*
Included In The Scope Of Delivery	*Holding Down Clamp*
Optical Indentation Measuring Device	*Focusing Screen*
Test Method	*1.) Vickers: HV1, HV2, HV3, HV5,HV10, HV20, HV30, HV50, HV60, HV100,HVT Knoop: HK1* *2.) Knoop: HK1* *3.) Brinnel: HBW 1/1…1/30 – HBW 2.5/6.25…2.5/187.5 – HBW 5/25…5/250 – HBW 10/100…10/250 And HBT* *4.) Rockwell: HR Scales A, B, C, D, E, F, G, H, K, 15N, 30N, 45N, 15T, 30T, 45T* *5.) Ball Indentation Hardness: H-49.03 N / 132.39N / 357.9N / 961.0N*
Voltage	*Adjustable, 100…250*
Dimensions	
Height, Approx	*1200*
Width, Approx	*270*
Depth, Approx	*870*
Weight, Approx	*300*

Source: https://www.zwickroell.com

The specifications of the *universal hardness tester Zwick Roell ZHU 250 CL Models* for R.54 rail steel using the *Vickers method* are as follows:

Table 5. *Vickers* Method Specifications .

Type	*Indenter as per hardness test method*	*Included In Delivery*	*Item No*
Indenter	*Vickers, with pyramidal diamond point 136°*	*Official Test Certificate*	*318061*

Source: https://www.zwickroell.com

4. Microstructure Testing Equipment

The hardness testing tool is known as *the Universal Hardness Tester* with the brand and type *Zwick Roell ZHU 250 CL Models* .

Table 6. Microstructure Test Equipment Specifications

Trinocular Metallurgical Microscope +14 MP USB 3.0 *Camera*	
1. Unit Specs	
Nosepiece	*Triple*
Focusing Range	1-9/16" (40 mm)
Interpupillary Adjustment	2-3/16 " – 3 - 0" (55-75 mm)
Mechanical Tube Length	6-5/16" (160 mm)
Head	30 *degree inclined trinocular*
Trinocular port	23 mm *universal or standard photo tube*
Eyepieces	WF10X(18mm *field of view*)
Widefield	25 X
Objectives	PL 4X (0.1 NA) , 10X (0.25NA), 40X, 100X (Spring 0.65 NA)
Stage Dimensions	5-1/8"x4-13/16" (130x122 mm)
Stage Traveling Range	1-3/16"x2-3/4" (30x70 mm)
Vernier Division	0.004" (0.1 mm)
Illumination	20W *halogen*
Power Supply	220V
Camera Specs	*Sensor: ON Semi (color)*

Sensor type	CMOS
Sensor Size	6,138 x 4,603 mm
Pixel size	1.4 µm
Resolution	14 MP
Frame Rate	54 fps @1024 x 822, 21 fps @2048 x 1644, 6.2 fps @4096 x 3286
Sensitivity	0.724 V/ *Lux-Sec* (550 nm)
2. Software specifications	
OS Requirements	*Windows (32/64 bit) XP/Vista/7/8/10, Mac OS X, Linux Kernel 3.13+;*
Hardware Requirements	*Intel Core2 2.8 GHz or comparable processor, 2GB RAM*
3. Packing List	*One Trinocular Metallurgy Microscope With Episcopic Illumination System; One pair of widefield 10 X Eyepieces; One pair of widefield 25X eyepieces; Three Plan Objectives: 4X, 10X, 40 Four Filters: Yellow, Blue, Green and Frosted (built-in already); One 14 Mp USB 3.0 Digital Camera; one reduction lens two sizing adapters; One USB cable;*
4. Include	*PC + 24" LED monitor, printer, Windows OS, Desk, Chair*

Source: Functional Materials Laboratory

Testing Procedure

Sample cutting to testing the microstructure and hardness of R.54 type railway rails has several testing procedures including:

1. Specimen Cutting

The following are the steps used in cutting specimens:

a) Before use.

1. Check the condition of *the band saw machine*
2. Mark the sample (R.R4 rail) to be cut.
3. Position the workpiece (align the R.54 rail specimen cutting point with the *Blade eye*), and use supports if necessary.
4. Clamp the sample (rail R.54) using *a vise* , and ensure it is locked properly (press the locking lever down).

b). When using.

1. *band saw* machine by pressing *the switch on button.*
2. Press *the coolant pump on button,* and wait for the *coolant fluid* to be in good condition.
3. *band saw* arm by adjusting the hydraulic valve so that the *band saw arm* lowers slowly.
4. Continue the cutting process, as long as there are no problems (if there is a problem, then press *the off switch* and raise the *band saw machine arm*)
5. Anticipate and cut the R.54 rail sample so that it does not fall.
6. *band saw* machine when it is finished using it.
7. Lift *the band saw machine arm* slowly.
8. Removing the R.54 rail sample from *the vise* or vise.

c.) After use

1. Place, store, and tidy up samples and tools and supporting facilities in the designated place.
2. *band saw* machine and the environment are clean from *coolant fluid* and remaining *chips* .

2. Heat Treatment Testing (*Heat Treatment)*

Some of the steps in conducting *Heat Treatment testing* include:

a. Ensure *grounding* (max 1 *volt*) and the cable is connected to electricity.
b. Use work safety equipment in the form of two gloves.
c. Provide a container in the form of a cup in intact condition.
d. *Crucible* pliers to make it easier to insert and remove the cup.
e. Press the ON button to turn on *the furnace.*
f. Press the Menu button, then select *Arrow Keys* , then select SP°C to set the desired temperature, then press the arrow keys up or down to set the desired temperature.
g. The light on *the heater* will turn on when the temperature has been set.
h. The speed of temperature increase by pressing SPrr, then pressing Menu, selecting *Arrow keys* and then selecting SPrr. The value is pressed up or down.
i. If the mode is *ON* then select a temperature of 920°C, and the heater light will flash according to the level of temperature increase.
j. Select the t1 method to be used for 30 minutes on the Menu button.
k. Inserting the heated R.54 rail specimen with several cooling media of new oil, salt water, soapy water, and without treatment.
l. The time will immediately run backwards when it reaches *the setpoint,* and the *heater lamp turns*

off. The reading 'End' appears on the home *display menu.*

m. Each specimen is cold, so it is given the following code:

Table 7. Sample Cooling Code

Code	Specimen
A	Without Treatment
B	Soap
C	Table Salt
D	New oil

Source: Private Code

n. Clean the surface of the rail specimen smoothly and evenly.

o. Make sure the power connection is unplugged.

3. Etching preparation procedure
   a. Prepare samples of R.54 rail without heat treatment and heat treatment respectively.
   b. Cutting the pipe based on the sample size of the R.54 rail
   c. Inserting the R.54 rail sample into the cut pipe.
   d. For 30 seconds, apply etching solution to each R.54 rail sample with two mixtures, namely *HNO_3* and *ethanol.*
   e. Smooth and level each surface of the R.54 rail sample with 200 to 2000 grit sandpaper.
   f. Apply *Autosol* to the surface of the R.54 rail sample to make the surface clean and smooth.
   g. Once the research is complete, the tools and materials that have been used are tidied up, cleaned and returned.

4. *Hardness Test* (Hardness)

The following are the stages in the *hardness test,* including:

a.) Prepare each surface of the R.54 rail specimen along with computer equipment and *Universal Hardness Testing bese hardness test equipment.*

b.) Prepare and turn on the computer, then turn on the *Universal Hardness Testing tool,* then select the *Zwick Roell HD Indentec ZHμ.HD-S application.*

c.) Clicking on the *Option menu* at the top of the application interface and then selecting *Preferences* to open the settings window, then testing the R.54 specimen with the method used is *Vickers (HV)* .

d.) The tools and computers are ready to use.

e.) Place each surface of the R.54 rail sample, then rotate the specimen table to make it more focused.

f.) Once focused, press the Run menu then select *Free Test* , by waiting for 10 *seconds* , the hardness results will appear, then repeat the test for each R.54 rail sample.

g.) Taking the average value of the hardness on each R.54 rail sample.

5. Optical Microscope Procedures and *Power Supply*

The following are the stages used when testing microstructure using a *Trinocular Metallurgical Microscope machine.* + 14MP USB 3.0 *Camera* includes:

   a. *plug* cable is connected to electricity and press the on button.
   b. Each R.54 rail test sample was placed in a specimen holder.
   c. The image uses an objective lens with the smallest magnification to make it look more focused.
   d. Adjust the position of the condenser lamp and set the illumination lamp unit properly.
   e. The light intensity of the lamp is adjusted as needed.
   f. Rotate the *fine adjusting handle menu* to better focus the position of the specimen with the objective lens.
   g. Press the *light-path changeover lever menu* for observation.
   h. There is no vibration that occurs when you want to save an image.

The optical microscope is connected to a computer and *power supply* . The stages in using a 10 Volt 100 *Watt Power Supply are* as follows:

a. Make sure the switch is on (*On*) or off (*Off*)
b. Confirming *the Potentiometer*
c. Verify Pilot Light for *remote control operation* (external)
d. Ensure the ready condition for *the Reflected Lamp* (RL) Switch and *Transmitted Lamp* (TL) Switch.
e. Turn the switch on or off by pressing the *on* or off *button* .
f. Turn on the microscope according to applicable procedures.
g. Turn the desired illumination system on or off alternatively using the Reflected or Transmitted

Light Selector Switch in the RL and TL positions respectively.

h. Adjust the lighting intensity of the switch lamp by rotating *the Potentiometer* .
i. When necessary, switching between illumination systems has no effect on the adjusted lamp brightness. The brightness must be readjusted after each switch.

IV. RESULTS AND DISCUSSION

According to the results of the *experimental* laboratory tests that have been carried out, data on observations of microstructure and average hardness values were obtained in the form of microstructure images, numbers and graphs from R.54 rail specimens without any treatment or given heating *(Heat Treatment)* with variations in cooling with soapy water, salt water, new oil at a temperature of 920 °C and a time of 30 minutes.

Figure 13. Cutting Dimensions of R.54 Rail Sample
Source: Personal Documentation

The data of each sample image of R.54 rail was obtained from an optical microscope using a lens magnification of 20 times. In analyzing the results of the microstructure images, it is also necessary to understand the *Continuous Cooling Transformation* (CCT) and *Isothermal Transformation Diagram* (TTT) diagrams to be able to determine the reading of each phase. Each microstructure image and hardness test were taken from the same part, namely the upper head of the R.54 rail. When cutting the R.54 rail, the part that was cut was the upper rail head measuring length x width x height, namely 6.6 X 1.5 x 1.8 cm.

The upper part of the rail has a higher hardness value than the lower part so that the rail can be harder. This happens because the railroad tracks are often passed by trains. While the lower the railroad tracks, the harder they are.

The R.54 rail cutting was divided into four samples to be used for microstructure and hardness testing. A total of three R.54 rail samples were cut into cubes of the same size, namely length x width x height of 1.0 cm x 1.0 cm x 1.0 cm for samples without treatment, table salt and new oil. While one sample of salt in the form of a quarter circle has a radius of 1.0 cm.

I. Microstructure Test

Characterization of microstructure observation (metallography) to identify changes in physical properties that occur in the head of the R.54 rail before and after the heating process *(heat treatment).* The material for testing is classified as high carbon steel with the UIC R.54 rail type.

A. Microstructure Test of R.54 Rail Steel Without Heat Treatment

The metal composition that has a maximum solubility limit of 0.025% *Carbon* at a temperature of 723 °Celsius, its crystal structure *is body center cubic* (BCC) and room temperature has a solubility limit of 0.008% C *carbon is called the ferrite phase* (Iron α). While *the Euutectoid mixture* of *ferrite* and *cementite* (α + Fe_3C) at a temperature of 723 ° C contains 0.836% carbon called *pearlite.* The mechanical properties of the *ferrite phase* are ductile and soft, while the *pearlite phase* is hard and ductile. This railroad rail material is classified as *fully pearlitic steel* .

Fully pearlitic steel is a type of steel material that has a microstructure consisting of the *pearlite phase* as a whole. Usually occurs for *carbon* (C) content of 0.836% including in high carbon steel alloys (*High Carbon Steel*).

The characterization of *fully pearlitic steel* for locomotives and carriages is that it has great structural strength in withstanding compressive loads, good friction resistance, but is not too tough. In accordance with the chemical elements of carbon materials that have been determined by the government referring to [4]Ministerial Regulation 60 of 2012 concerning the technical requirements of railway lines, around 0.60-0.80 percent has been applied by PT. Kereta Api Indonesia (PT. KAI).

Picture 14. The results of testing the microstructure of R.54 type steel rails without heat treatment (*Non Heat Treatment*) show that the R.54 rails have a phase that is formed like a lighter colored crystal structure *(Ferrite)* and a blackish color (fine *Pearlite*).

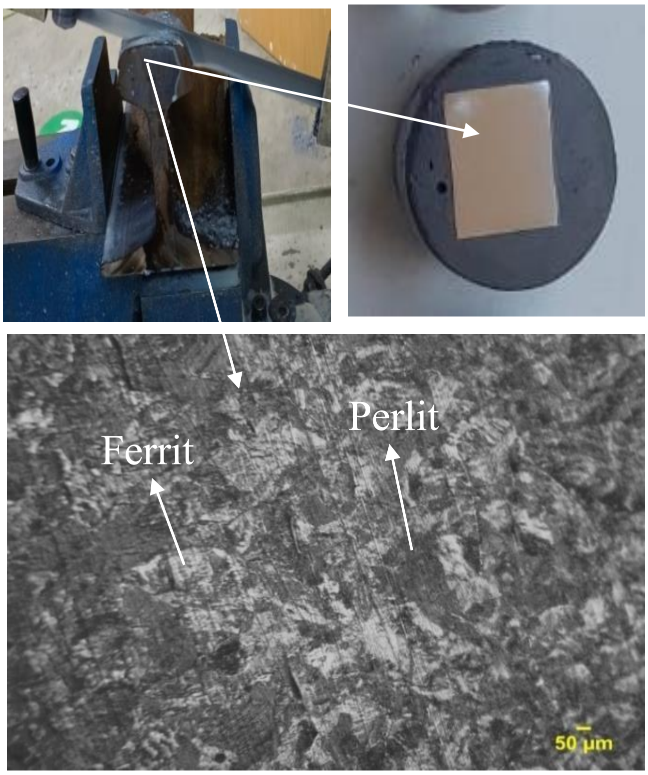

Figure 14. Latest Research on Microstructure of Untreated R.54 Rail Head
Source: Personal Documentation

B. Microstructure Test of R.54 Rail with Cooling Media

Based on the results of the R.54 rail sample after the heating process (*Heat Treatment*) it is seen that heat treatment affects each hardness value of various types of cooling. Cooling variations are various types of cooling that play a role in determining the cooling rate of R.54 rail steel material that has been tested with a heating process (*heat treatment*). The cooling is soap, table salt, and new oil.

1.) Microstructure With Soap Media

Figure 16 shows the results of the microstructure of the mixture using soap cooling media. After being given heat treatment using soap cooling media, it shows the presence of a *martensite phase, ferrite* and *austenite.* The transformation time of *martensite* phase formed in the carbon steel alloy after being cooled with soapy water is at a temperature of 250 ^{o} C. This *martensite phase is shaped like a short line of solid black color and is very hard. This heat treatment process begins with the ferrite* phase transforming into the *austenite phase* on heating and then returning to *martensite* .

These phases are important phase components in carbon steel alloys because their stability is affected by the very rapid cooling rate during the heat treatment process. With increasing *austenite carbon content* , the *martensite structure* becomes longer and brittle. The ferrite phase is dark black due to the large carbon content in the rail, and the remaining *austenite* that has not had time to transform into the *martensite phase* can reduce its hardness.

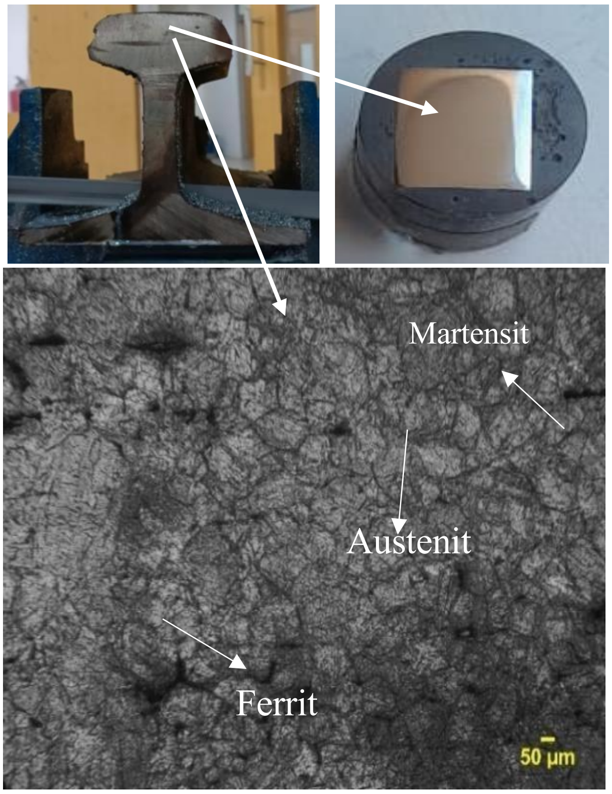

Figure 16. Microstructure Image of R.54 Rail Head with Soap Media
Source: Personal Document

2.) Microstructure with Table Salt Media

Figure 17 shows the results of water and salt cooling which have a *martensite phase* that is shaped like a short needle with a solid black color, a *ferrite phase* like a white solid crystal structure and a residual *austenite phase* that is shaped like a solid plate with an identical bright gray color. This *austenite phase* exists because when hardening the steel is unable to change shape into *martensite* so that it will reduce the hardness.

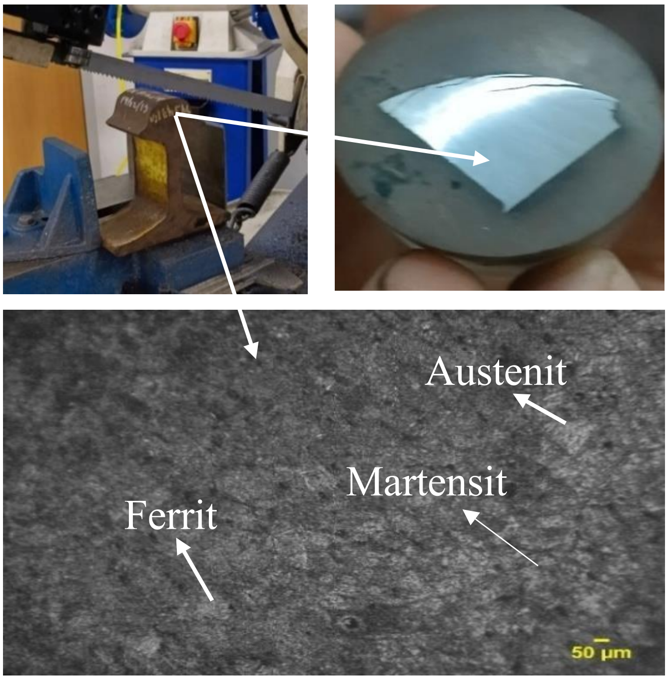

Figure 17. Microstructure Image of R.54 Rail Head with Table Salt Media
Source: Personal Document

3.) Microstructure With New Oil Media

Oil is a type of oil that is usually used in machines or vehicles as a lubricant. In the context of scientific research or applications, the viscosity and base material of the oil do have a very important role in the cooling process.

Figure 18 shows the results of the microstructure, it can be seen that the new oil cooling media is mostly filled with the *martensite phase. This phase is formed when austenite* iron is cooled very quickly to a low temperature, approaching room temperature. This process causes *austenite* , which initially has an FCC (*face-centered cubic*) crystal structure, to act quickly and without diffusion, then change to a BCT (*body-centered tetragonal*) crystal structure.

The change occurs directly without atomic movement (diffusion), so it is called a non-diffusion transformation. The *martensite structure* is characterized by grains that have a needle-like or *plate- like shape* and are very hard but *brittle. Although the transformation into martensite* occurs , the *ferrite* and *austenite structures* (dark in color) do not have time to transform and can still be seen.

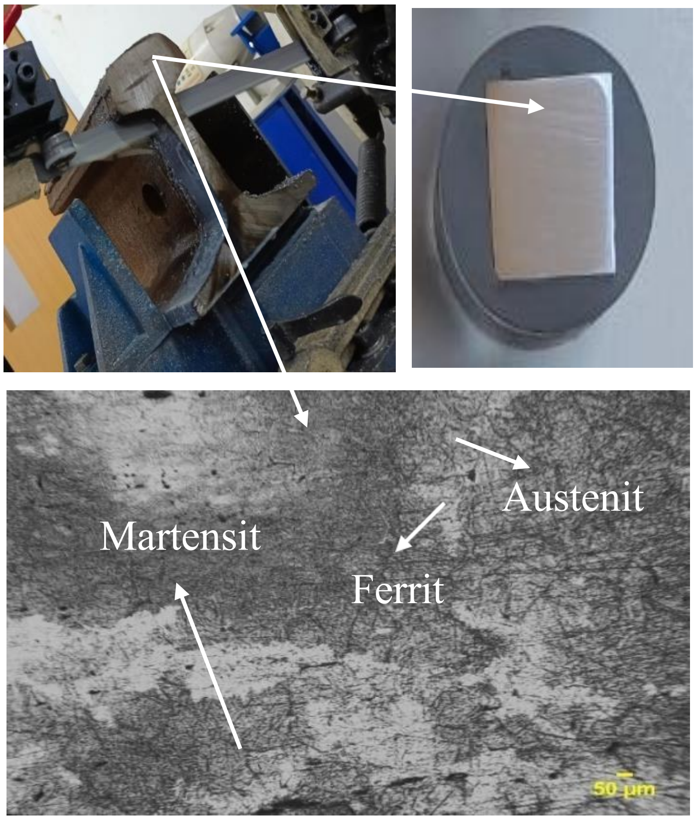

Figure 18. Microstructure Image of R.54 Rail Head With New Oil Media
Source: Personal Document

II. Hardness Testing

The hardness value of R.54 rail steel material without treatment and after receiving heat treatment *using* a variety of cooling media will produce various values. The *Vickers method* has a diamond pyramid-shaped indenter with an angle of 136 º and the loading standard available on the laboratory computer, namely 500 *grams of force* (gf) for 10 seconds, is used in this study.

In 2019, the hardness test results of the *Universal Hardness Test* ZHU 250 have been calibrated. Each R.54 rail specimen was tested at three points on the R.54 rail head to be able to represent the hardness value of each specimen, then the three hardness value points were averaged to determine the final hardness result based on the variation of the coolant used. Various types of coolants were used in this study such as soap, table salt, and new oil.

The R.54 rail steel sample was heated, after which the hardness value of the R.54 rail steel sample increased. The depth of the pressure marks affects the high and low hardness values tested on the R.54 rail steel research sample. Smaller pressure marks indicate that the hardness value of the R.54 rail steel is getting harder. Likewise, the hardness between one sample of cooling media is different due to heat loss when collecting R.54 steel samples to be cooled, due to the distance between the heating furnace and the cooling media being quite far. **Figure 19** shows the hardness test point of the R.54 rail steel.

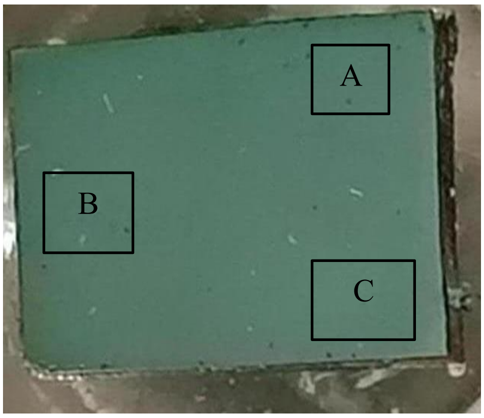

Figure 19. Random Test Points of R-54 Rail Steel
Source: Personal Documentation

Information:
A = Test Location 1
B = Test Location 2
C = Test Location 3

From the three-point test, **Table 5** shows the test results of the R.54 rail specimen before and after the heating process *(heat treatment).*

Table 8. Hardness Test Calculation Using the *Vickers Method*

Variables		**Cooling Media Variations**			
		Without *Heat Treatment*	**Soap**	**Salt**	**New Oil**
Rail Specimen Code R.54		A	B	C	D
Temperature (°C)		920°C			
Hold Time		30 minutes			
P or Load (gf)		500			
Diagonal X *(microns)*	**1**	49.70	37.68	36.59	32.77
	2	48.61	36.59	36.05	32.77
	3	47.52	36.59	37.14	33.86
Diagonal Y *(microns)*	**1**	50.25	37.68	37.14	33.86
	2	49.15	37.14	36.59	33.32
	3	49.70	37.68	36.59	33.32
Test Point	**1**	371.29	652.91	682.25	835.39
	2	388.06	682.25	702.92	849.26
	3	392.44	672.25	682.25	821.86
Average *Vickers Hardness Value* (HV)		383.93	669.14	689.14	835.50
***Brinnel* Hardness Test Value Conversion**		364.73	635.68	654.68	793.72

Source: Personal Documentation

From the hardness test results table above, it can be calculated based on the *Vickers method* with the following equation:

$$HVN = 4\,x\,\frac{1}{2}\,d\,\sqrt{2}\,x\,\frac{1}{2}\left(\frac{d\sqrt{2}}{4\,sin\frac{\alpha}{2}}\right)$$

$$A = \frac{d^2}{2\,sin\frac{136^\circ}{2}}$$

$$HV = \frac{P}{\frac{d^2}{2\,sin\frac{136^\circ}{2}}}$$

$$= \frac{2\,P\,x\,0927}{D^2}$$

$$HVN = 1.854\frac{P}{D^2}$$

Information :
HV = HV Hardness
P = Load
D = Footprint Diagonal

According to the Regulation of the Minister of Transportation 60 of 2012 concerning the technical requirements of railway lines for railway rail hardness standards of not less than 320 HB [4]. Meanwhile, according to the Regulation of the Minister of Transportation No. 175 of 2015 concerning standards, procedures for testing and certification of the suitability of self-propelled trains, the hardness of the train wheels must be below the hardness of the rails so as not to damage the rail track [5]. The following is the AAR standard for train wheel hardness.

Table 9. AAR Standard Railway Wheel Hardness

Class	**Minimum *Hardness***	**Maximum *Hardness***
L (light rail lorry or truck)	197 HBW	277 HBW
A (Passenger Train)	255 HBW	321 HBW
B (Train and Carriage)	302 HBW	341 HBW
C (Locomotive)	321 HBW	363 HBW
D (Locomotives with axle loads of more than 25 tons, or other heavy vehicles)	341 HBW	415 HBW

Source: PT. KAI Center

Figure 20. Shows a graph of the average hardness value of the R.54 rail specimen without heating (*non-heat treatment*) and after heating with different variations of cooling media.

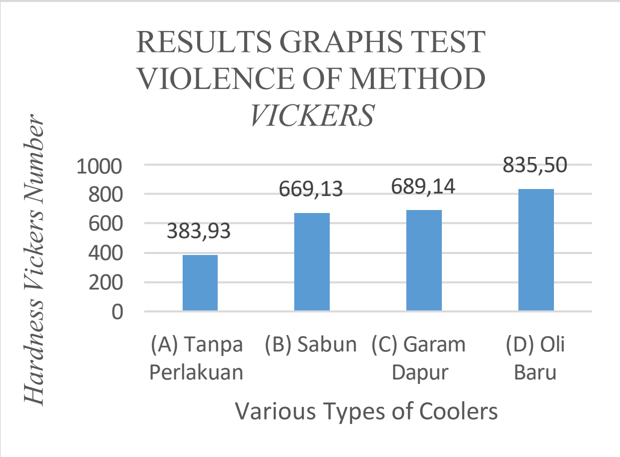

Figure 20. Graph of the Middle Value of Hardness Test Using the *Vickers Method*
Source: Author's Research Results Documentation

From the graph, the *Vickers test results* of the R.54 rail specimen are converted into the *Brinel test form* based on the established standard, namely ASTM E 140 " *Standard Hardness Conversion Tables For Metal ". The Vickers* to *Brinel* conversion formula is as follows:

HB = HV X 0.95

Where:
HB = *Brinell Hardness*
HV = *Vickers Hardness*
0.95 = *Vickers to Brinell constant*

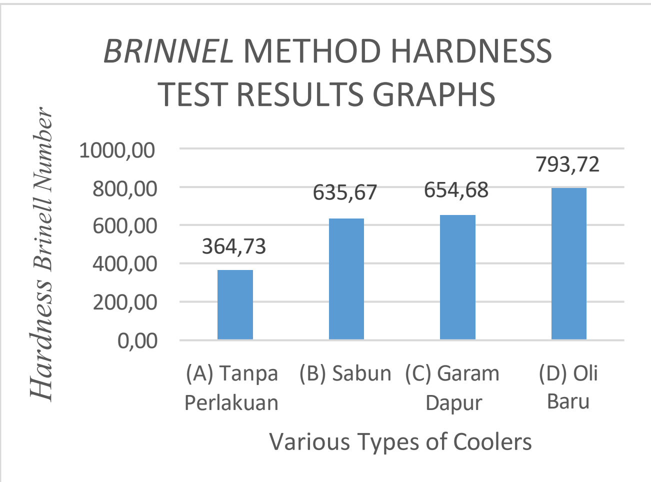

Figure 3. Hardness *Value* Graph Using the *Brinnel Method*
Source: Author's Research Results Documentation

Seen from the graph, sequentially there is an increase in hardness from untreated R.54 rail steel worth 383.93 HV, to soap worth 669,136 HV, table salt worth 689.14 HV, and new oil worth 835,503 HV. The effect of *non-heat treatment* (without treatment) and variations in cooling media on the hardness of the R.54 rail material, including:

(A). Hardness of R.54 Rail Steel Material Without Heat Treatment (*Non Heat Treatment*).

Based on the average results of the hardness test of the R.54 rail specimen without heat treatment, 383.93 HV (364.73 HB) was obtained. The hardness value has met several existing provisions such as:

1. The standard hardness value that has been set by the government refers to the 2012 ministerial regulation regarding the technical requirements for railway lines for rail head hardness which must not be less than 320 HB.
2. The AAR standard for [5]maximum locomotive wheel hardness is 363 HB.
3. The technical specifications used by PT. KAI in 2013 are rail heads with the lowest tensile strength of 1200 N/m^{2}and the hardness level of the rail body to the rail head is 360-418 HB.

Comparison of the difference between the results of the hardness of the railroad tracks obtained with the maximum standard of hardness of locomotive railroad wheels, which is 0.005. According to [5]the hardness value, the railroad tracks must be above the hardness of the railroad wheels. This aims to ensure that if there is contact between the wheels and the railroad tracks, the railroad wheels will wear out faster. This approach is applied because replacing railroad tracks costs more than replacing railroad wheels.

(B). Hardness of Rail Steel Material After Heat Treatment With Soap Quenching.

The average hardness value of the rail material after being given soapy water cooling media is 669.136 HV (635.67 HB). The comparison of the difference between the results of the hardness of the railroad rail and the maximum standard of wheel hardness is 0.751. Where the hardness value of the rail experiences an increase in hardness when it has been given heat treatment . *If the soap* *content is higher and the steel cooling process takes place faster, the hardness of the soap cooling media will increase. This happens because of the* *austenite* and *martensite* phases so that the material will become hard.

(C). Hardness of Rail Steel Material After Heat Treatment With Salt Quenching.

The average hardness value of Sodium Chloride (NaCl) or known as table salt obtained a hardness value of around 689.14 HV (654.68 HB). The comparison of the difference between the maximum standard of locomotive wheels and the hardness of the rail obtained was very significant, namely 0.804. By dipping the R.54 rail steel into the salt water cooling medium, the steel construction still had a residual *austenite phase* because it did not succeed in completely transforming into *martensite* during the steel hardening process.

If the railroad uses heating with table salt cooling media and other cooling media heat treatment, then the hardness will be much harder. If applied in the field, it can cause the train wheels to wear out quickly. Eroded train wheels can also cause faster wear on the wheels, shorten the life of the wheels, and increase maintenance needs.

In general, there is an inverse relationship between hardness and toughness and toughness of rail steel material after being heat treated *with* rapid cooling media. The higher the concentration of salt dissolved in water, the higher the hardness value achieved, but the toughness and toughness of carbon steel material decreases.

(D). Hardness of R.54 Rail Steel Material After Heating and Cooling with New Oil.

The mean value of the new oil hardness is 835.503 HV (793.72 HB) indicating that after the heat treatment process with new oil cooling media, its hardness has a significant effect on the hardness of the R.54 rail specimen compared to the hardness value of other cooling media. The comparison of the difference between the hardness test results of the R.54 type steel rail and the maximum train wheel is 1.187. This is due to the viscosity of the new oil against the rapid cooling rate of the R.54 rail steel material.

Oil viscosity is the level of thickness and the ability of the oil to flow. When high viscosity oil is used as a cooling medium, the cooling process becomes faster. Rapid cooling, the majority of the phases obtained from the microstructure are very hard *martensite.* If it occurs with high oil viscosity, it can produce a more brittle microstructure. This can reduce the toughness of the rail material because the brittle structure is more easily broken than the material that gets a slower cooling process. Therefore, increased hardness is often associated with decreased toughness of a rail material.

IV. CONCLUSION

Based on the results of laboratory experimental tests entitled analysis of hardness tests and microstructure tests of R.54 type railway rails with variations in *heat treatment media,* it can be concluded that:

a. The results of observations of the microstructure of R54 rail steel show differences in the microstructure of each type of cooling used, namely soap, table salt, and new oil. R.54 rail steel without heat treatment, the phases formed are *pearlite* and *ferrite.* While the cooling media soap, table salt, and new oil, the phases formed are *ferrite, austenite, and martensite.* The hardest microstructural phase of R.54 type railway rail is obtained from the *Martensite phase.*
b. The results of the hardness test in the study showed that there was an increase in the average hardness test value of the R.54 rail before heat treatment and after being mixed with variations in the type of coolant. The results of the study obtained a hardness value for the R.54 rail steel material without heat treatment of 383.93 HV (364.73 HB), soap media of 669.13 HV (635.67 HB), table salt of 689.14 HV (654.68 HB), and new oil of 835.50 HV (793.72 HB). The highest hardness value was achieved by the new oil cooling media. This occurs because of the influence of the high viscosity of the oil on the increase in the hardness value of an R.54 rail steel material. Railway rails using heat treatment with table salt cooling media or other cooling media will make the hardness of the railway rail much harder. Heat treatment for R.54 type railway steel with variations in soap, table salt, and new oil cooling media has never been applied in the field. If applied in the field,

it will have an impact on the train wheels wearing out more quickly.

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