Experimental Study of the Effect of Temperature Variation and Cooling Media on Reforming Resistance Seam Welding of SUS 304 Material on the Roof of the Train

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Abstract**—** *This study was prompted by the discovery of distortion in the SUS 304 material following resistance seam welding during the fabrication of Train 612's roof at PT INKA (Persero). A reforming process involving heat treatment and variations in cooling media was applied to improve joint quality. This study aims to investigate the impact of variations in reforming temperature and cooling media on the mechanical properties and microstructure of SUS 304. The research method is a quantitative experiment with ANOVA analysis. Treatment variations included non-reforming and reforming at temperatures ranging from 500 to 525 °C, 575 to 600 °C, and 650 to 675 °C, with water cooling; reforming at 575 to 600 °C with water, air, and oil cooling; and reforming at 575 to 600 °C with water cooling. The results showed that the reforming temperature and cooling medium had a significant impact on the mechanical properties. Treatment at 500–525°C with water quenching produced a fine microstructure with balanced phase distribution, the highest hardness in the weld zone, and maximum shear stress. Conversely, high temperatures and slow quenching triggered grain growth and chromium carbide precipitation, reducing hardness and shear strength. Reforming at 500–525°C with water cooling was identified as the optimal parameter for improving weld joint quality and the structural performance of SUS 304 material.*

Keywords**—** *Cooling Medium, Reforming, Seam Welding, Mechanical Properties, SUS 304, and Temperature.*

I. INTRODUCTION

In revitalising the national transportation system, railways are designated as a primary mode of transportation due to their high capacity for passenger and freight transport [1]. PT Industri Kereta Api (Persero) [PT INKA], Indonesia's national rolling stock manufacturer, is currently developing the Stainless Steel New Generation Train Project 612 as part of its efforts to enhance passenger comfort and safety. One of the critical components of this project is the train roof, constructed from austenitic stainless steel SUS 304, which is joined using the resistance seam welding process to ensure structural integrity and durability. However, field observations revealed distortion issues in welded components caused by residual stresses introduced during welding. These distortions occur due to localised heating and uneven cooling, resulting in non-uniform shrinkage in the weld zone [2], [3]. Such dimensional deviations can compromise assembly precision and delay production schedules. To address these challenges, PT INKA implements a reforming process that integrates controlled heat treatment and cooling to restore component geometry and recover the material's mechanical properties [4], [5].

Previous studies have highlighted that both heat treatment temperature and cooling media significantly influence the microstructural evolution and mechanical performance of stainless steels. Appropriate parameter selection can refine grain structure, induce martensitic transformation, and enhance hardness through rapid cooling, while excessive heat input or slow cooling may lead to grain growth and chromium carbide precipitation, reducing material strength and corrosion resistance [6], [7], [8], [9].

Based on these findings, this study investigates the effect of reforming temperature variation after resistance seam welding (500–525°C, 575–600°C, and 650–675°C with water quenching) on 0.8 mm SUS 304, as well as the influence of different cooling media (water, compressed air, and oil) at 570–600°C on 1.0 mm SUS 304. The research employs a quantitative experimental approach with ANOVA statistical analysis to evaluate the relationship between reforming parameters, microindentation Vickers hardness, tensile shear strength, and microstructural evolution. The outcomes are expected to provide optimised process parameters for distortion control and mechanical enhancement of stainless steel train roof panels in PT INKA's production line, contributing to advancements in railway manufacturing engineering..

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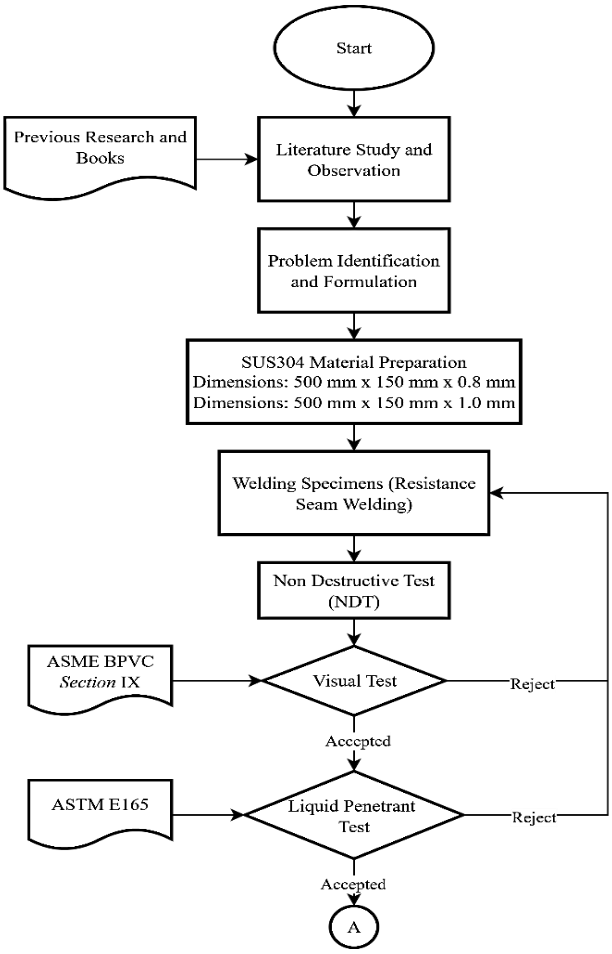
II. METHOD

This study examines the impact of reforming temperature and variation in cooling media on the SUS 304 material welded using Resistance Seam Welding (RSEW). The research employs quantitative experimental methods, with the independent variables consisting of reforming temperature variations of 500–525°C, 575–600°C, and 650–675°C, as well as cooling media variations including water, compressed air, and oil. The dependent variables include tensile shear strength, Vickers microindentation hardness, and microstructural characteristics, which were analysed to evaluate shear stress, hardness, and microstructural evolution of each specimen after reforming. Controlled variables were kept constant to ensure accurate evaluation, including the welding process (RSEW) performed on SUS 304 material with thicknesses of 0.8 mm and 1.0 mm, welding currents of 15 kA and 14 kA, respectively, welding speed of 650 mm/min, and welding time of 60 ms. Overlap joint configurations were applied for all samples, with the 1.0 mm specimens undergoing reforming at 570–600°C for cooling media variation testing. Welding was performed at PT INKA (Persero) by certified welders, specimen fabrication was carried out at the State Polytechnic of Madiun Welding Workshop, and specimen testing was conducted at the State Polytechnic of Madiun Material Testing Laboratory. Broadly speaking, the research flow carried out in this study is shown in Figure 1.



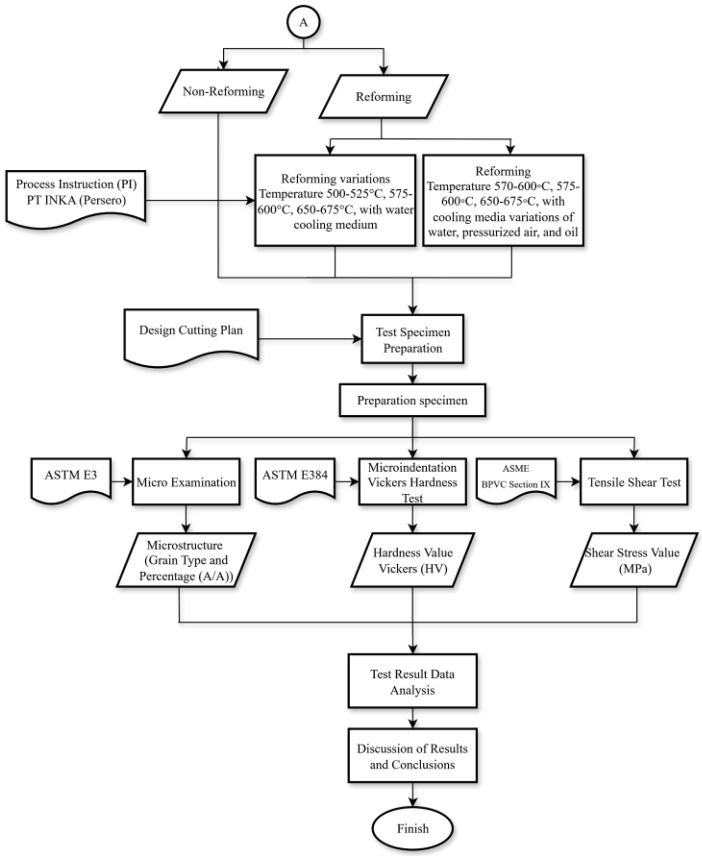


Fig. 1. Research Stages

The tools and materials used in the research "Experimental Study of the Effect of Temperature Variation and Cooling Media on Reforming Resistance Seam Welding of SUS 304 Material on the Roof of the Train" include:

TABLE I. Tools and Materials

Tools	Materials
Resistance Seam Welding Machine	SUS 304 Steel Plate Size 500×150×0,8 mm and 500×150×1 mm
Micro Examination Tools (Olympus Microscope BX53M/BXF Series)	Grinding Blade and Stone Brand: WD T41-WA60.
Tensile Shear Test Equipment (MTS Exceed E64 300kN)	HCL (Hydrocloric Acid) liquid with a concentration of 68%
Microindentation Vickers Hardness Tester (Digital Micro Vickers Hardness Tester TH715)	HNO3 (Nitric Acid) Liquid with a concentration of 33%
Gap Shear Machine	Polishing Paper Grid 240-400-600-800-1200-2000-3000-5000.
Polishing Machine tipe FTP -2MX	Autosol Metal Polish
	Cutting Wheel

A. *Stainless Steel type 304*

Stainless steel 304 (SUS 304) is an austenitic steel, meaning it is resistant to chemical corrosion and easy to shape [10]. This material is commonly used due to its corrosion resistance and flexibility. However, austenitic stainless steel has a higher thermal expansion coefficient than carbon steel. This results in excessive distortion in material joints that are welded using the resistance seam welding method. Corrosion resistance is improved by the addition of nickel and molybdenum. Some

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stainless steels may be "sensitized" during welding which makes them susceptible to intergranular corrosion [10].

B. Coupon Preparation

The welding process uses a type of Resistance Seam Welding (RSEW) with a lap joint connection carried out at PT INKA with a certified welder. The welding machine used is SIS Seam Welding Machine. The dimensions of the material being welded are 500 mm x 150 mm x 1 mm and 500 mm x 150 mm x 0,8 mm with a lap joint of 25 mm referring to the ASME Section IX standard. The material is welded with currents of 15 kA and 14 kA respectively, welding speed of 650 mm/min, and welding time of 60 ms.

After welding, a non-destructive test (NDT) is performed on the test material, including a visual test and a liquid penetrant test. Liquid penetrant tests are used to detect surface defects such as cracks and pores that are not visible to the naked eye [11]. This test is important in the industry because it evaluates the quality of the material without deteriorating its functionality, thus minimizing testing time and costs [12].

The next stage involves reforming with variations in temperature and cooling media. Once the reforming process is complete, the test specimens are cut using a gap shear machine. This process is performed according to the dimensions specified for the tensile shear test in accordance with ASME Section IX standards.

C. Resistance Seam Welding (RSEW)

Resistance Seam Welding (RSEW) is the welding process involves generating heat due to the resistance of electrical current flow at the joint area under the pressure of a circular electrode. The result is a series of overlapping weld points, or a lap joint, which are formed gradually along the joint as the electrode rotates [13]. An illustration of seam welding is shown in Figure 2. as follows.

Fig. 2. Resistance Seam Welding

D. Distortion

Distortion is a change in shape or deviation caused by heat, such as that from the welding process. The expansion of the workpiece causes the parts around the weld area to bend. The process begins with the weld joint being heated to a high temperature, which causes uneven expansion and is the main cause of distortion. The material around the joint expands more than the surrounding area, causing it to bend or change shape. During cooling, uneven shrinkage also occurs; the parts that expanded more shrink more, which distorts the material [14].

Fig. 3. Distortion

E. Reforming

Reforming is a controlled heating process that restores a material's shape without altering its mechanical properties. It is influenced by heating manufacturing processes, such as welding and metal forming. For austenitic stainless steel (SUS304), the recommended temperature range for reforming is 500–700°C, depending on the degree of distortion and the material's sensitivity to carbide precipitation [15].

Fig. 4. Reforming

F. Micro Examination

Micro-examination aims to see the grain crystal structure of the metal being tested so that its properties and structure can be determined [16]. Micro examination is used to identify the structure using aqua regia etching solution (liquid HCL and HNO_3). The results of the micro examination are in the form of images containing information on the type of phase, size and shape of crystal grains, defects, and chemical element content [17]. Micro examination using ASTM E3 specimen preparation standard and ISO 17639 testing standard and Microindentation vickers hardness test using ASTM E384 standard. Specimens were cut, then mounting, grinding, polishing, and etching aqua regia to determine the diameter of the nugget, microstructure, and hardness value of the material [18].

G. Microindentation Vickers Hardness Test

The Microindentation Vickers Hardness Test analyzes a material's hardness value and measures its resistance to deformation. In this test, a square-based diamond indenter is pressed into the surface of the specimen under a predetermined load using a digital microindntation Vickers hardness tester. The diagonals of the resulting square impression are measured and averaged to determine the hardness value [19].

H. Tensile Shear Test

The tensile shear test analyses the mechanical properties of a material's shear strength, specifically the shear stress generated by seam welding, using the ultimate tensile strength (MPa). Shear strength describes a material's ability to withstand tensile and shear forces simultaneously [20], [21].

III. Result and Discussion

The results and discussion of the research describe the analysis of the results of the effect of variations in reforming temperature and cooling media on the mechanical properties and microstructure of SUS 304 material, namely microstructure, hardness and shear stress. Therefore, the tests carried out are micro examination, microindentation vickers hardness test and tensile shear test.

A. Micro Examination Results and Analysis

A microstructural examination was conducted to analyse the effects of varying reforming temperatures and cooling media on the weld nugget of SUS 304 material. The observations were carried out at a magnification of 1000× to evaluate the grain morphology, phase distribution, and microstructural changes resulting from the heat treatment process [2]. Microstructural analysis plays a crucial role in understanding the material's metallurgical behaviour, assessing mechanical performance, and optimising manufacturing parameters for improved quality and reliability. Figures present the microstructures of specimens subjected to reforming at temperatures of non reforming, 500–525°C, 575–600°C, and 650–675°C with water cooling, as well as reforming at 570–600°C with water, compressed air, and oil cooling.

TABLE II. Results of Micro Examination of Temperature Variation Reforming

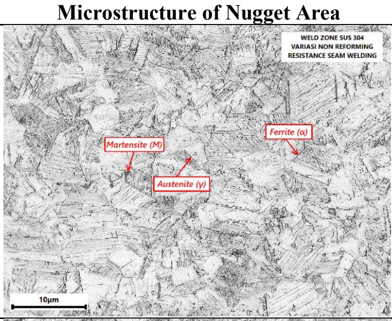
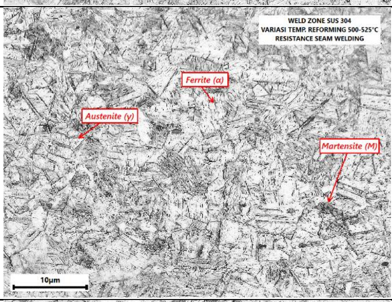
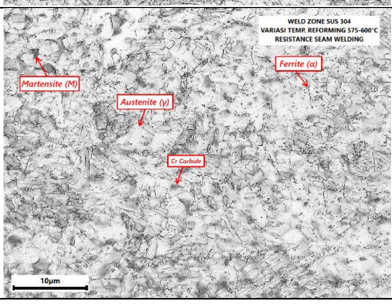
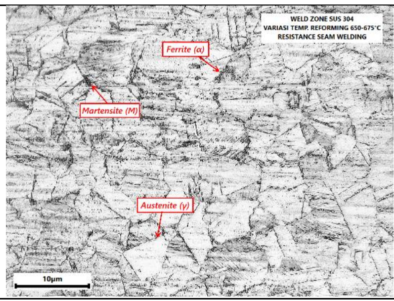
No	Variation	Microstructure of Nugget Area
1.	Non Reforming	
2	500–525°C	
3	575–600°C	
4	650–675°C	

TABLE III. Results of Micro Examination of Cooling Media Variation Reforming

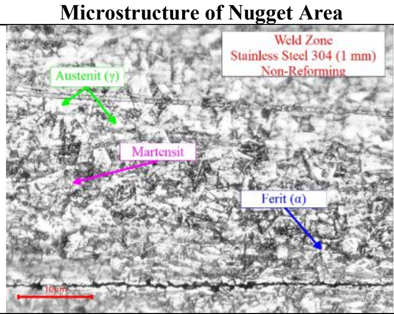
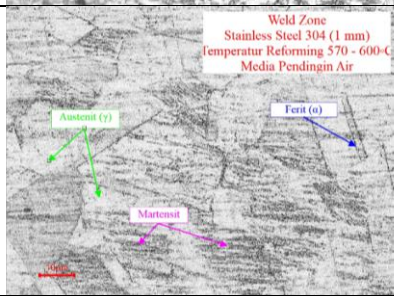
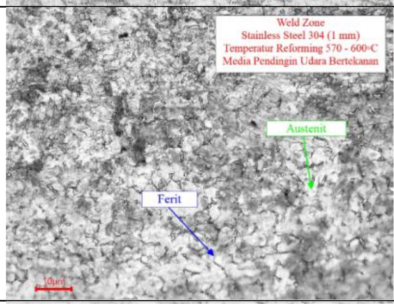
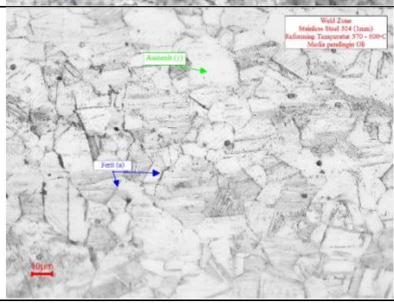
No	Variation	Microstructure of Nugget Area
1.	Non Reforming	
2	Water	
3	Compressed Air	
4	Oil	

Figure 5 shows that the microstructure percentages of SUS 304 material that underwent resistance seam welding and reforming treatment at various temperature ranges (500–525°C, 575–600°C, and 650–675°C) vary significantly. Without reforming, the microstructure is dominated by 60,52% austenite, 38,3% ferrite, and 1,18% martensite. This

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composition is a common characteristic of austenitic stainless steel that undergoes thermal deformation due to welding; limited martensite formation occurs due to rapid local cooling in the weld zone.

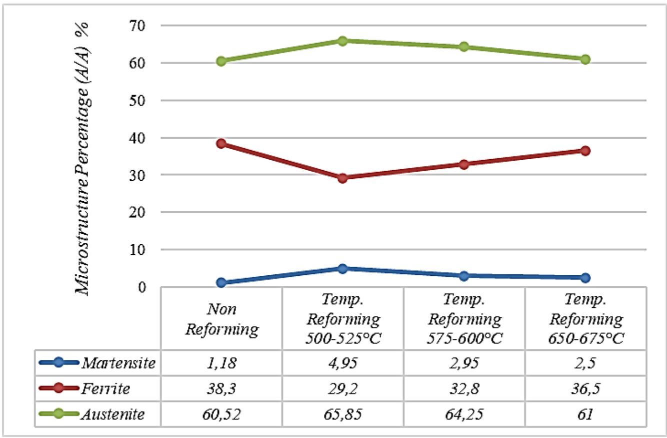

Fig. 5. Data Graph of Comparison of Microstructure Percentage of Temperature Variation Reforming

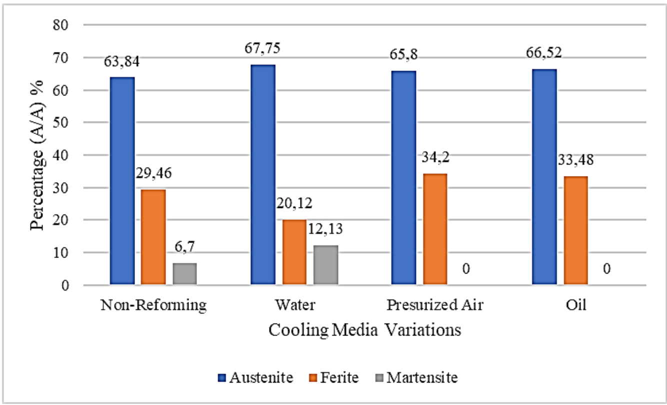

Fig. 6. Data Graph of Comparison of Microstructure Percentage of Cooling Media Variation Reforming

Reforming treatment at 500–525°C resulted in significant changes: an increase in austenite to 65,85%, an increase in martensite to 4,95%, and a decrease in ferrite to 29,2%. These changes suggest that reforming at this temperature range can optimise phase transformation, refine the microstructure, and homogenise the distribution of alloying elements via residual stress relaxation. Morphologically, the microstructure appears denser and more uniform, reflecting good phase stabilisation. The moderate increase in martensite contributes to an increase in hardness and local strength around the weld zone [22].

Conversely, reforming treatment at 575–600°C resulted in a decrease in austenite to 64,25% and martensite to 2,95%, as well as an increase in ferrite to 32,8%. The decrease in martensite is believed to be associated with overaging or recovery, processes that encourage the formation of chromium carbide (Cr_xC_y) at grain boundaries, particularly within the sensitisation temperature range [23]. This results in microstructural instability and decreased hardness and mechanical properties due to excessive residual stress release.

At a reforming treatment temperature of 650–675°C, austenite decreased significantly to 61%, while martensite decreased to 2,5%. Ferrite increased sharply to 36,5%. This condition exhibits larger microstructure grains due to overheating, which reduces the number of grain boundaries that function as barriers to dislocation movement. Consequently, the material becomes softer and more susceptible to plastic deformation, resulting in a significant decrease in strength [24].

A reforming temperature of 500–525°C is optimal for improving welding results because it produces a finer, more homogeneous microstructure with a phase distribution that increases hardness and shear stress. Conversely, treatment above 600°C negatively affects the material by causing grain enlargement, undesirable carbide precipitation, and a decrease in corrosion resistance and mechanical properties.

Figure 6 shows that the SUS 304 material's microstructure differs after welding due to cooling variations. In non-reforming welding, 63,84% austenite, 29,46% ferrite, and 6,7% martensite are seen. This is normal for SUS 304, an austenitic stainless steel that's stable at room temperature, but a small amount of martensite forms due to cooling in the weld area.

Water cooling increases martensite, reaching 12,13% in the weld zone and 8,21% in the base metal. This is because the rapid cooling rate doesn't allow atoms to diffuse, trapping some austenite and converting it to martensite. This explains the increase in hardness and shear stress, as martensite is hard but brittle [19]. In pressurised air cooling, the microstructure is mostly austenite 65,89% with some ferrite 34,2%, no martensite. This is due to a moderate cooling rate, which allows atoms to diffuse without undergoing martensite transformation. This structure produces a ductile material with a lower hardness than water quenching. Oil cooling had the slowest cooling rate, with the most austenite 66,52% and the least ferrite, no martensite. This gives soft mechanical properties, as seen in the hardness and tensile shear test results, which had the lowest values compared to the other variations [10].

The cooling rate significantly affects the material's final microstructure. Water-cooled samples form martensite, increasing hardness and shear stress. Pressurised air-cooled samples maintain a stable austenite-ferrite balance. Oil-cooled samples maintain austenite, resulting in softer mechanical properties. These results align with phase transformation theory in austenitic stainless steel, where atomic diffusion during cooling determines phase stability and mechanical properties.

B. Microindentation Vickers Hardness Test Results and Analysis

The Microindentation Vickers hardness test is used to determine the hardness of a material's surface. The resulting data is Vickers hardness (HV). Figure 7 and Figure 8 show graphs of surface hardness in the base metal area and nugget seam welding with varying reforming temperatures and cooling media.

Figure 7 shows that Vickers hardness testing (HV) on SUS 304 material that underwent post-seam welding reforming treatment reveals that temperature variation significantly affects hardness values in two main areas: the weld zone (WZ) and the base metal (BM). At temperatures between 500–525 °C, WZ hardness increased from 226,24 HV to 242,06 HV, indicating the optimisation of mechanical strength through residual stress relaxation and the formation of fine precipitates [25]. However, increasing the temperature to 575–600°C or 650–675°C decreased WZ hardness to 230,36 HV or 227.26 HV, respectively, due to recovery and grain growth processes that weakened the microstructure [26]. A similar trend was observed in BM: the highest hardness 228,63 HV occurred at 500–525°C, and there was a gradual decrease at higher temperatures. Linear regression analysis supports the trend of decreasing hardness, with a negative slope in WZ (y = -0,864x + 233,64) and a stable trend in BM (y = 0,2383x + 222,58). Overall, a reforming temperature of 500–525°C produces an optimal combination of high hardness and a fine microstructure. However, temperatures above 600°C trigger grain growth and a decrease in mechanical properties [22], [27], [28].

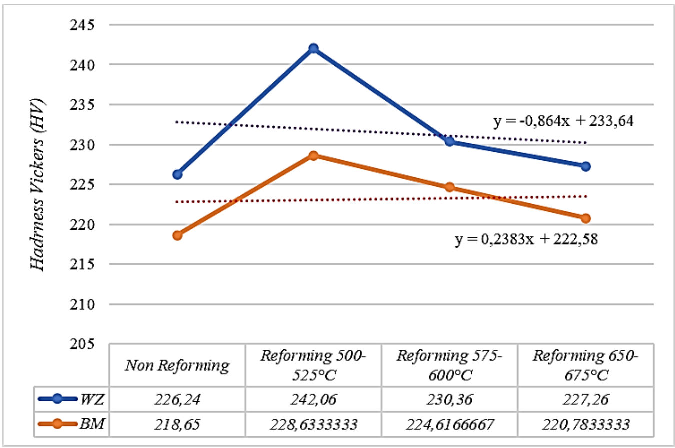

Fig. 7. Comparison Graph of Non-Reforming Hardness (HV) Values and Reforming Temperature Variations in Seam Welding of the Weld Zone and Base Metal

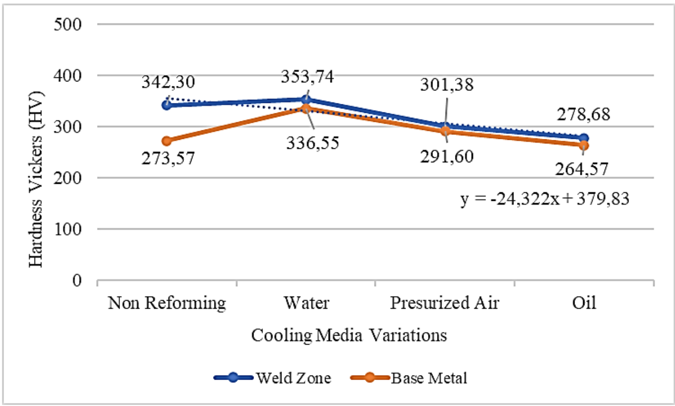

Fig. 8. Comparison Graph of Non-Reforming Hardness (HV) Values and Reforming Cooling Media Variations in Seam Welding of the Weld Zone and Base Metal

Figure 8 shows the test results and a graph comparing non-reforming hardness values and variations in cooling media (water, pressurised air, and oil). The graph indicates the average hardness values. Water cooling media produced the highest values in both the weld zone area 353,74 and the base metal area 336,55. Water cooling media can quickly absorb heat from the material, resulting in high hardness values. Meanwhile, oil and compressed air release heat more slowly due to their thermal properties [29].

Pujiliyanto (2024) states that used oil produces the highest hardness value because it contains more carbon than new oil. This carbon content comes from the combustion process. This results in a faster cooling rate compared to new oil. The rapid cooling process promotes the formation of a martensitic structure in 304 stainless steel, producing high hardness values [30]. The cooling medium affects the cooling rate. Pressurised air and oil cooling media tend to have slower rates and can affect the hardness and strength of the material [31]. Cooling media have higher hardness values than oil media because water quickly absorbs passing heat and cools it quickly [32]. Using water as a cooling medium produces higher hardness values than using pressurised air or oil because it promotes the formation of martensite, which makes 304 stainless steel harder and more brittle [30].

C. Tensile Shear Test Results and Analysis

Tensile shear tests were conducted on SUS 304 material to evaluate the effect of variations in post-resistance seam welding reforming temperature and cooling media on joint strength. These tests produced maximum shear stress data (MPa), which was obtained from the highest tensile force that caused specimen failure. The effect of each variation in reforming temperature (500–525°C, 575–600°C, and 650–675°C) and cooling medium (water, compressed air, and oil) on joint strength was tested by averaging the shear stress from several specimens. The results were presented in a graph comparing the increasing and decreasing trends in joint strength based on these parameter combinations. These findings were used to identify optimal reforming parameters that could improve the mechanical performance of resistance seam-welded joints in SUS 304 material.

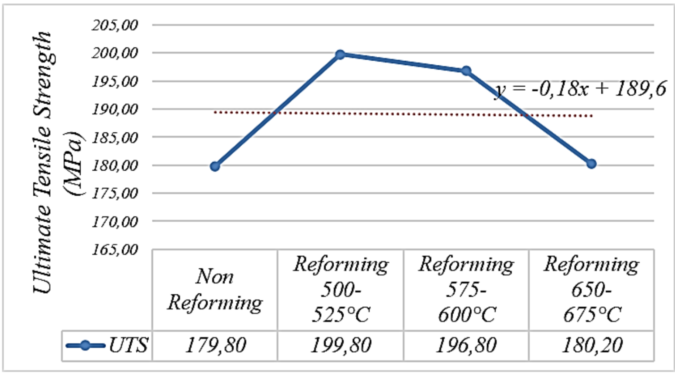

Fig. 9. Graph of the Relationship between Seam Welding Reforming Temperature Variation and Shear Stress (MPa)

Figure 9 shows the linear regression equation trend (y = -0,18x + 189,6), indicating a decrease in shear stress with increasing reforming temperature. This finding is consistent with the observation that using high reforming temperatures tends to degrade the shear strength of the joint. Generally, post-seam welding reforming treatments at temperatures ranging from 500–525°C, 575–600°C, and 650–675°C produce higher shear stress values than specimens without reforming treatment. This is due to internal stress relaxation and the formation of a more homogeneous microstructure, which results in improved mechanical properties of the material [25].

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

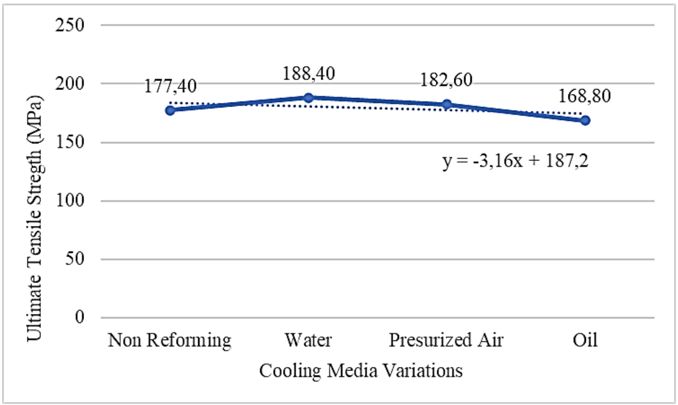

Fig. 10. Graph of the Relationship between Seam Welding Reforming Cooling Media Variation and Shear Stress (MPa)

The optimal reforming temperature was found to be in the range of 500–525°C, yielding a shear stress value of 199.80 MPa. This value was higher than those of specimens reformed at temperatures of 575–600°C and 650–675°C and of non-reformed specimens. However, increasing the temperature beyond the optimal range decreased shear stress. This phenomenon is associated with overheating, which triggers excessive grain growth and oxidation. These processes reduce the material's ability to withstand shear loads [33], [34]. Therefore, controlling the reforming temperature is important for maximising the strength of the seam welding process.

Figure 10 shows the tensile shear test results for non-reforming and reforming specimens with different cooling media: water, compressed air, and oil. The results indicate that water produced the highest ultimate tensile strength (UTS) value of 188.40 MPa. Water's rapid cooling ability accelerates heat dissipation, refining the grain size and speeding up the martensitic transformation process in the material. This increases the dislocation density, improving the material's mechanical properties, especially its shear stress [10].

Conversely, oil and pressurised air cooling media have slower cooling rates. This causes the material's microstructure to become softer and less dense, thereby reducing shear strength. Slow cooling can trigger grain growth and reduce the material's resistance to plastic deformation. Thus, water cooling media have been proven to be the optimal parameter in the post-seam welding reforming process for increasing shear stress in joints [35].

D. Analysis Statistic – ANOVA (Analysis of Variance One Way)

One-way analysis of variance (ANOVA) is a statistical technique used to test the means of treatments in experiments with a single factor and three or more groups. This study is based on two main hypotheses that are tested through statistical analysis. The null hypothesis (H_0) states that variations in temperature and reforming seam welding cooling media on SUS 304 material do not significantly affect the material's mechanical properties, nor do they significantly contribute to the development of the railway manufacturing process. In other words, all variations in applied reforming temperature are considered not to cause significant differences in the mechanical strength of the welded joint. Conversely, the alternative hypothesis (H_a) states that variations in temperature and cooling medium during seam welding reforming significantly affect the mechanical properties of SUS 304 material. This suggests that temperature and cooling medium settings for reforming could be critical parameters in developing railway manufacturing processes, especially in enhancing the quality of welded joints and the performance of stainless steel components in the railway industry. Through testing and analysis, this study aims to determine whether variations in temperature and reforming cooling media significantly affect shear stress and hardness, as well as their relevance in manufacturing practices. The test was conducted by examining the P-value in the ANOVA table. The initial hypothesis was that if the p-value was less than 0,05, then there was a statistically significant difference between the means; if the p-value was greater than 0,05, then there was no statistically significant difference between the means [36]. The following are the results of the one-way analysis of variance (ANOVA) from the tensile shear test data shown in Table IV and Table V.

TABLE IV. Results of One-Way Analysis of Variance of Shear Stress Testing of Welded Joints at Variation Temperatures on Ultimate Tensile Strength

Source	*DF*	*Adj SS*	*Adj MS*	*F-Value*	*P-Value*
Factor	3	1697,3	565,78	29,28	0,000
Error	16	309,2	19,32		
Total	19	2006,5			

TABLE V. Results of One-Way Analysis of Variance of Shear Stress Testing of Welded Joints at Variation Cooling Media on Ultimate Tensile Strength

Source	*DF*	*Adj SS*	*Adj MS*	*F-Value*	*P-Value*
Factor	3	1038	345,9	3,30	0,047
Error	16	1676	104,8		
Total	19	2714			

Table IV shows that the results of the one-way analysis of variance (ANOVA) on the tensile shear test data of SUS 304 material resulting from seam welding with temperature variation (non-reforming at 500–525°C, 575–600°C, and 650–675°C) indicate a calculated F-value of 29,28. The F-table value is 3,23 at a significance level of 0,05 (α = 5%). Since F_{count} is greater than F_{table}, the null hypothesis (H_0) is rejected. Therefore, it can be concluded that there is a significant difference in shear stress of the welded joint between the reforming temperature treatment groups. The p-value of 0,000, much smaller than the significance level of 0,05, reinforces the decision to reject the null hypothesis. The temperature treatment factor contributes 84,59% to the total variation in the data, while 15,41% comes from random or error variation. Comparing the adjusted mean square (Adj MS) of 565,78 for the treatment factor and 19,32 for the error confirms that the variation between the treatment groups is much greater than the variation within the groups. Thus, the reforming temperature has a statistically significant effect on the mechanical properties of SUS 304 welded joints. Furthermore, Table V shows the results of a one-way ANOVA for cooling medium variation in the tensile shear test. This test shows a p-value of 0,047 (<0,05). This indicates that H_0 is rejected, meaning there is a significant

Indarto Yuwono, Deby Ika Hariani, Noorsakti Wahyudi, et al., “Experimental Study of the Effect of Temperature Variation and Cooling Media on Reforming Resistance Seam Welding of SUS 304 Material on the Roof of the Train,” *International Research Journal of Advanced Engineering and Science*, Volume 10, Issue 4, pp. 127-135, 2025.

difference between cooling medium types. In other words, variation in cooling media after the reforming process significantly affects the shear strength of welded joints.

The following are the results of the one-way analysis of variance (ANOVA) from the tensile shear test data shown in Table VI and Table VII.

TABLE VI. Results of One-Way Analysis of Variance Microindentation Vickers Hardness Test Temperature Variation Reforming Seam Welding on Hardness Values in the Weld Zone and Base Metal

Source	*DF*	*Adj SS*	*Adj MS*	*F-Value*	*P-Value*
Factor	7	1893,9	270,55	35,78	0,000
Error	36	272,2	7,56		
Total	43	2166,1			

TABLE VII. Results of One-Way Analysis of Variance Microindentation Vickers Hardness Test Cooling Media Variation Reforming Seam Welding on Hardness Values in the Weld Zone and Base Metal

Source	*DF*	*Adj SS*	*Adj MS*	*F-Value*	*P-Value*
Factor	7	45111,1	6444,45	1381,70	0,000
Error	36	167,9	4,66		
Total	43	45279,0			

According to Table VI, the results of the one-way ANOVA test on the Vickers microindentation hardness values in the weld zone (WZ) and base metal (BM) areas reveal a calculated F-value of 35,78. This value is considerably higher than the table F-value of 2,27 at a significance level of $\alpha = 0,05$. These results confirm the rejection of the null hypothesis (H_0), indicating a significant difference in material hardness due to reforming temperature treatments. This finding is reinforced by a p-value of 0,000 (less than 0,05), indicating that the differences are not due to chance but are directly influenced by variation in treatment temperature. Contribution analysis shows that the temperature treatment factor contributes 87,43% to the total variation in the data, while the random factor (error) contributes only 12,57%. This makes the reforming temperature the dominant factor in controlling the hardness of SUS 304 material resulting from seam welding. Additionally, the significant difference in the adjusted mean square (adj MS) value of the factor 270,554 compared to the error 7,562 further supports the conclusion that variation between treatmPent groups is greater than variation within groups. Meanwhile, Table VII shows the results of a one-way ANOVA test on the Vickers microindentation hardness test with variation in the cooling medium, which produced a p-value of 0,000 (<0,05). This indicates that variations in the cooling medium also significantly affect material hardness. Rapid cooling (quenching) using water increases hardness by refining the grain and accelerating the martensitic phase transformation. In contrast, slow cooling using oil or pressurised air decreases hardness because it triggers grain growth and the homogenization of a softer phase.

The results of the ANOVA analysis reinforce the conclusion that varying the temperature and cooling medium significantly affects material hardness. This is an important basis for controlling the quality of resistance seam welding joints in SUS 304 material applications in the railway industry.

IV. Conclusion

It is shown by this study that the mechanical properties and microstructure of SUS 304 material are significantly affected by variation in reforming temperature and post-resistance seam welding (RSEW) cooling media. Reforming treatment at temperatures between 500 and 525°C followed by rapid cooling with water yields the optimal microstructure. This microstructure is characterised by fine, homogeneous grains; austenite dominance; moderate martensite; and low ferrite. These features contribute to increased hardness and shear stress of the joint. Conversely, higher temperatures (575–600°C and 650–675°C) and slow cooling using pressurised air or oil trigger grain growth and chromium carbide precipitation. This causes the microstructure to soften and the mechanical properties to deteriorate. Vickers hardness and tensile shear tests reinforce these findings. The highest hardness 199,80 MPa and maximum shear stress were achieved with the optimal combination of temperature and cooling. ANOVA analysis confirmed the significant influence of temperature treatment and cooling medium on mechanical properties. Temperature variation contributed 87,43% to hardness and 84,59% to shear stress. In conclusion, reforming at 500–525°C with water cooling is recommended to improve the quality of RSEW joints in SUS 304 material. This is important for ensuring the dimensional precision, structural reliability, and production efficiency of stainless steel-based railway components.

Acknowledgment

We would like to thank the funders of the Internal Competitive Research Activity, specifically the DIPA Fund (Number: 023.18.2.677632/2025), as well as the Madiun State Polytechnic for their support of the Laboratory and Workshop Manufacturing. Their contributions have been instrumental in ensuring the sustainability of our event, providing support both morally and materially.

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