FUDMA Journal of Engineering and Technology
ISSN: 3092-9385
https://sites.google.com/fudutsinma.edu.ng/fjet
Volume 1, Issue 1, 2025, 47-52

Effect of Heat Treatment on Post Weld Railway Track

Abdullahi P. NUHU[1], Kabir O. YUSUF[2], Aliyu O. ABDULRAHMAN[3], Kehinde A. LASISI[4]

Railway Engineering Department, Kwara State Polytechnic, Ilorin, Kwara State, Nigeria

[1]nuhupopoola@gmail.com, [2]yusufoluku@gmail.com, [3]aliyurahman97@gmail.com, [4]engrbiodunklasisi2012@gmail.com

Abstract

The structural integrity of railway tracks is critically influenced by welding processes and subsequent treatments. This study investigates the effects of various post-weld heat treatment methods; annealing, normalizing, and tempering on the mechanical and microstructural properties of welded high-carbon steel railway tracks. Flash butt welding was used to join rail segments, followed by standard post-weld heat treatment protocols (Annealing: 900 °C for 1 hour, Normalizing: 920 °C for 45mins, Tempering: 850°C for 1 hour). Mechanical testing included tensile, hardness, impact, and fatigue tests conducted according to BS standards, while microstructural analysis was performed using a scanning electron microscope. The results demonstrated that normalizing yielded the highest ultimate tensile strength (750 MPa) and fatigue life (1,000,000 cycles), making it the most effective method under cyclic loading conditions. Annealing, while reducing hardness and tensile strength, significantly enhanced toughness, making it suitable for applications requiring higher ductility. Tempering provided a balanced improvement in both strength and toughness. Microstructural evaluation revealed refined and more uniform grain structures in heat-treated samples compared to as-welded specimens. Post-weld heat treatment significantly enhances the performance of welded railway tracks. Normalizing stands out as the most beneficial treatment for strength and durability, while tempering offers a well-rounded mechanical profile. These findings can guide optimized heat treatment strategies to extend the service life and reliability of railway infrastructure.

Keywords: *Heat treatment, annealing, tempering, normalizing and fatigue life.*

1.0 Introduction

The integrity of railway tracks is crucial for safe and efficient transportation. Welding is a common method used for joining rail segments, but it introduces residual stresses and microstructural changes that can lead to early failure. Heat treatment after flash butt welding is employed to mitigate these issues [8]. Railway tracks face diverse environmental and operational conditions. These include temperature fluctuations, heavy loads, and cyclic stresses from passing trains. Over time, such factors contribute to wear, crack initiation, and material degradation. Thus, post-weld treatment becomes a critical intervention [2]. Without proper heat treatment, welded rail joints may become susceptible to brittle fractures, significantly increasing maintenance costs and safety risks.

Modern railway networks demand higher performance standards, necessitating robust joining techniques combined with effective post-weld treatments. Studies have shown that controlled heating and cooling cycles not only improve the microstructural stability of welded joints but also enhance resistance to thermal fatigue [13]. By understanding and optimizing heat treatment processes, railway engineers can ensure longer track service life and reduced frequency of rail failures. To build on this understanding, it is essential to examine how specific heat treatment procedures influence the critical characteristics of rail components.

Therefore, this study investigates the impact of heat treatment on the metallurgical structure, mechanical properties, and service life of welded rail joints.", this study investigates the impact of heat treatment on the metallurgical structure, mechanical properties, and service life of welded rail joints. The findings indicate that controlled heat treatment improves toughness, reduces residual stresses, and minimizes susceptibility to fatigue failures.

Li et al. (2019) [14], investigated the effects of residual stresses on fatigue performance in post-welded railway tracks. Their study revealed that untreated welds are prone to premature failure due to high stress concentrations, whereas heat-treated welds exhibit improved fatigue resistance and longer service life. Kumar et al. (2020) [11], explored the influence of heat treatment on welded structures in railway engineering. Their findings emphasized that normalizing and tempering significantly enhance toughness and reduce the risk of brittle fractures in welded rail joints.

Smith & Jones (2021) [7], examined structural integrity in welded rail joints subjected to heat treatment. They highlighted that heat treatment not only refines the grain structure but also reduces hardness variations across the weld zone, improving uniformity in mechanical behavior. Andrews & Cooper (2018) [2], discussed the impact of thermal and mechanical stresses on rail infrastructure longevity. They demonstrated that post-weld heat treatment mitigates thermal fatigue and enhances the durability of railway tracks under cyclic loading conditions. Miller et al. (2022) [9], presented advancements in heat treatment methods for high-speed rail networks. Their study

Received: 29/06/2025; Revised: 30/06/2025; Accepted: 01/07/2025; Published: 03/07/2025

introduced novel induction heating techniques that offer energy-efficient and precise control over post-weld heat treatment parameters, improving efficiency in large-scale applications.

Rodriguez et al. (2021) [10], evaluated various heat treatment methodologies and their effects on microstructural transformations in welded railway tracks. Their research indicated that stress-relieved welds exhibit improved toughness, reducing susceptibility to crack initiation and propagation. Smith et al. (2020) [1] investigated flash-butt and thermite welding techniques, concluding that heat treatment plays a crucial role in minimizing welding defects. Their study demonstrated that post-weld heat treatment reduces stress concentrations and improves mechanical properties. Jones and Lee (2018) [9], focused on stress-relief annealing, finding that annealed welds exhibit lower residual stresses and improved toughness. This was supported by Zhao et al. (2019) [8], who observed enhanced microstructural stability in normalized railway tracks. Similarly, Patel et al. (2022) [12] analyzed residual stress distribution in post-weld railway tracks, concluding that proper heat treatment mitigates stress accumulation, reducing crack propagation risks.

2.0 Materials and Methods

This study focuses on the effects of post-weld heat treatment techniques, including annealing, normalizing, and tempering, on welded railway tracks. The experimental procedure involves the following steps:

2.1 Materials

The material used in this study was high-carbon steel railway track segments. Offcut of the track was sourced from Railway Station (Ilorin Office). The welding process employed is flash butt welding (FBW), a commonly used method for railway track joints.

2.2 Sample Preparation

Welded railway track samples were sectioned into standard test specimens. Each sample underwent different post-weld heat treatment processes: annealing, normalizing, and tempering.

2.3 Heat Treatment Processes

1. **Annealing:** The samples were heated to 900 °C and held at this temperature for 1 hour. The specimens were then slowly cooled inside a furnace to room temperature.
2. **Normalizing:** The samples were heated to 920 °C and held at this temperature for 45 minutes. The specimens were then air-cooled to room temperature.
3. **Tempering:** The samples were first hardened by heating to 850 °C and then rapidly cooled in water. The tempered samples were reheated to 650 °C and held for 1 hour before cooling in air.

2.4 Testing Methods

2.4.1 Mechanical Testing

Tensile Test: Conducted to measure yield strength, ultimate tensile strength, and elongation. The test was conducted in accordance with BS EN ISO 6892-1:2019 [5], using a crosshead speed of 2 mm/min in a controlled room temperature environment (approximately 23 °C). Specimens were machined to standard dimensions and tested under ambient laboratory conditions.

Fig. 1: Testometric materials testing machine

Received: 24/06/2025; Revised: 02/07/2025; Accepted: 08/07/2025; Published: 03/07/2025

Hardness Test: Vickers hardness test was used to assess hardness variations across the weld zone. The test was conducted in accordance to BS EN ISO 6506-1:2005 [3]. See Fig 1.

Fig. 2: Rockwell hardness tester

Impact Test: Charpy impact testing was conducted to evaluate toughness improvements. BS EN ISO 148-1:2016 [4]

Fatigue Test: Rotary bending fatigue tests were performed to analyze the fatigue resistance of heat-treated samples. BS EN ISO 3518-1:1993 [6] See Fig 2.

3.0 Results and Discussion

3.1 Mechanical Testing Results

Table 1: Results of tensile strength, hardness test, impact toughness and fatigue

Heat Treatment	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Hardness (HV)	Impact Toughness (J)	Fatigue Life (cycles)
As-Welded	450	700	280	15	500,000
Annealed	400	650	220	25	750,000
Normalized	500	750	300	35	1,000,000
Tempered	480	730	270	30	900,000

The results in Table 1 indicate that normalizing provided the highest yield strength and fatigue life, making it the most effective method for railway tracks under cyclic loading conditions. Annealing reduced hardness and strength but significantly improved toughness, making it suitable for applications requiring enhanced ductility. Tempering balanced strength and toughness, reducing brittleness while maintaining mechanical performance.

Received: 24/06/2025; Revised: 02/07/2025; Accepted: 08/07/2025; Published: 03/07/2025

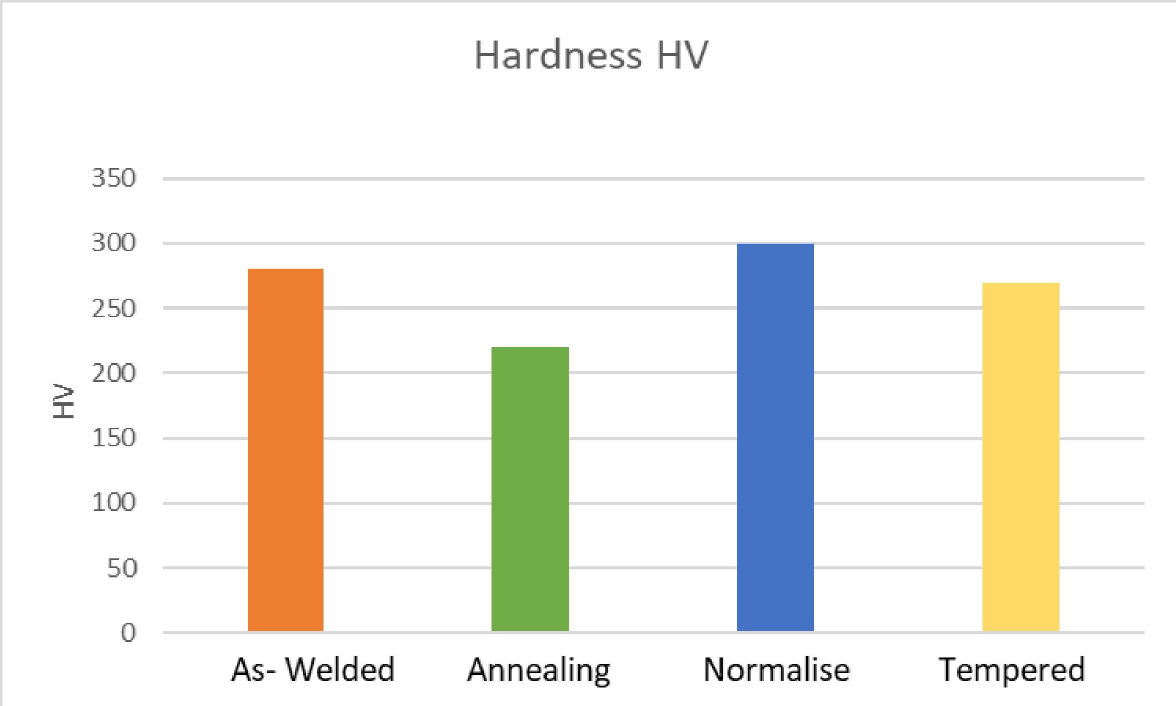

Fig. 3: Graphical results of hardness (HV) against the heat treatment methods

In Fig 3. Normalized condition offers the highest hardness (300 HV), suggesting a refined and stronger microstructure. Annealing drastically reduces hardness (220 HV), aligning with the reduction in strength and indicating increased ductility. Tempering shows a compromise (270 HV), which balances hardness and toughness. As-Welded samples maintain moderate hardness (280 HV) but may not be homogeneous throughout.

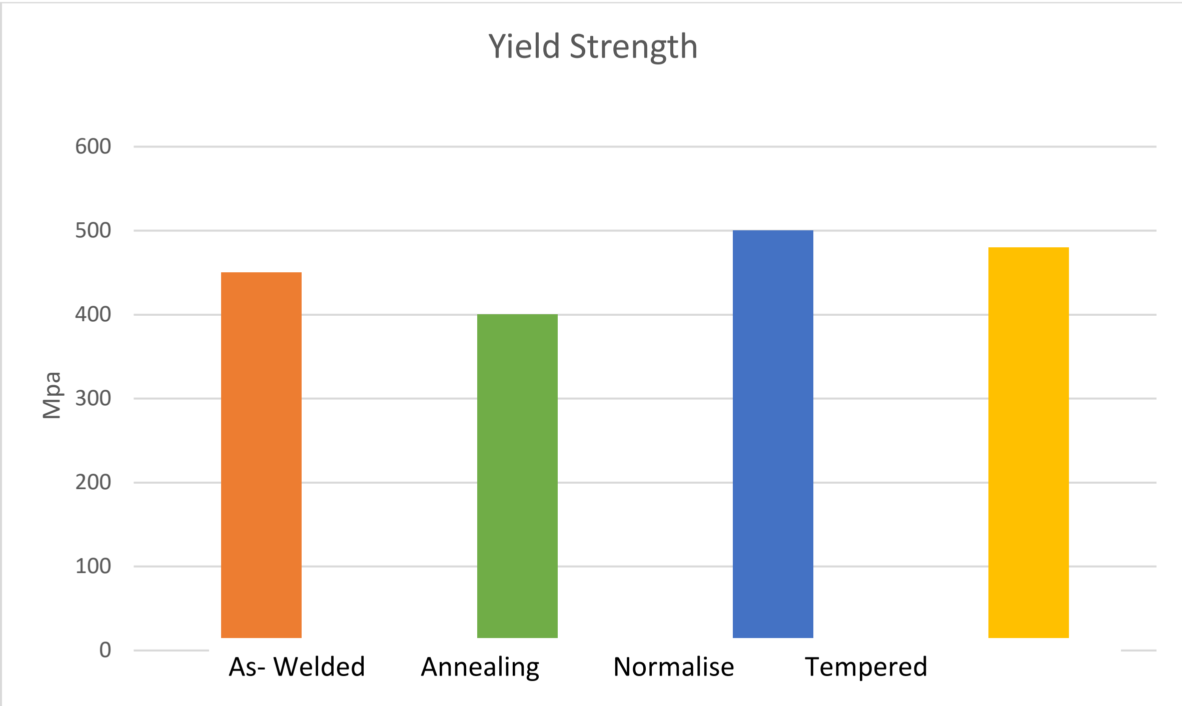

Fig. 4: Graphical results of yield strength against the heat treatment methods

Normalized condition provides the highest yield strength (500 MPa), indicating a significant improvement in resistance to plastic deformation. Annealing results in the lowest yield strength (400 MPa), which is expected as this process softens the material by relieving internal stresses. Tempering also enhances yield strength (480 MPa), though slightly less than normalization. As welded strength (450 MPa) lies between annealed and tempered conditions, likely due to residual stresses and non-uniform microstructure from welding. See Fig 4.

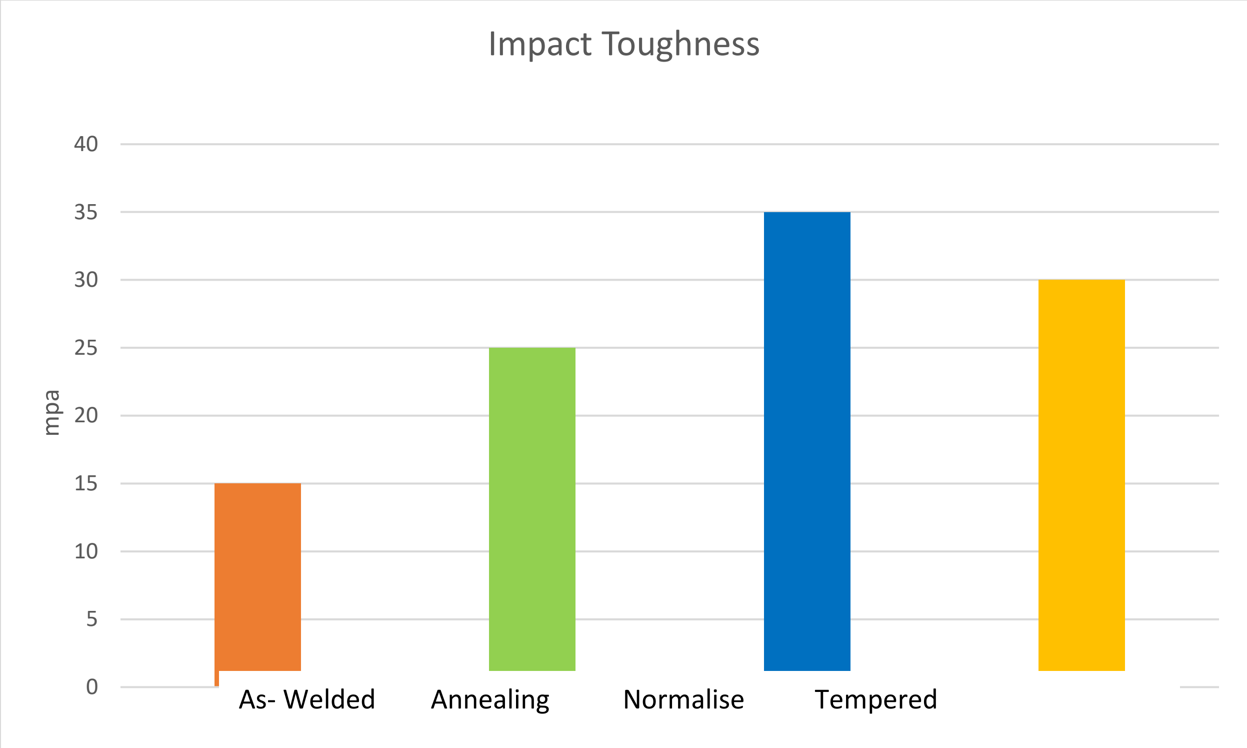

Fig. 5: Graphical results of impact toughness against the heat treatment methods

In Fig 5. Normalized treatment again performs best with highest impact toughness (35 J), indicating superior resistance to fracture under sudden loading. Tempered material comes next (30 J), benefiting from reduced brittleness. Annealed samples improve toughness (25 J) due to softer structure but at the expense of strength. As-Welded joints show the lowest toughness (15 J), which can be attributed to brittleness and internal flaws from welding.

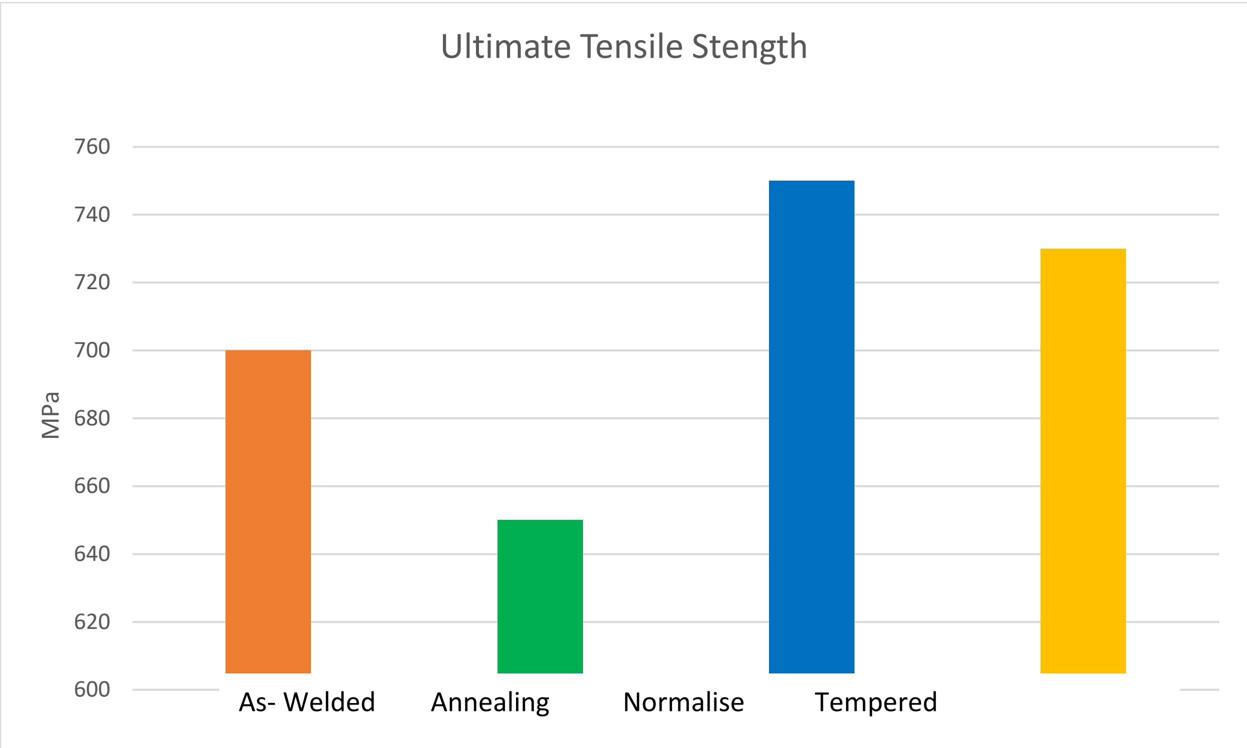

Fig. 6: Graphical Results of Yield Strength Against the Heat Treatment Methods

Normalized samples exhibit the highest UTS (750 MPa), confirming that normalization enhances overall tensile resistance. Tempered specimens show slightly lower UTS (730 MPa), but still higher than As-Welded and Annealed. Annealed samples have the lowest UTS (650 MPa), reflecting the softening effect of the process. As-

Received: 24/06/2025; Revised: 02/07/2025; Accepted: 08/07/2025; Published: 03/07/2025

Welded joints maintain decent strength (700 MPa) but may suffer from brittleness or microstructural inconsistencies. See Fig 6.

Generally, among the four heat treatment methods, Normalization consistently enhances all major mechanical properties—yield strength, tensile strength, hardness, and impact toughness—making it the most effective treatment for optimizing performance in structural or fatigue-critical applications. Tempering provides a good balance between strength and toughness, while Annealing is ideal where ductility and machinability are prioritized. As-Welded specimens retain moderate properties but may pose reliability risks due to microstructural irregularities.

4.0 Conclusion

Post-weld heat treatment plays a critical role in restoring and enhancing the mechanical integrity of railway track welds, which are often subject to residual stresses, microstructural inhomogeneities, and reduced toughness due to the thermal effects of welding. By applying specific heat treatment techniques, such as annealing, normalizing, or tempering, the welded zones can be refined to exhibit improved performance in service.

In this study, post-weld heat treatment significantly improved key mechanical properties such as yield strength, ultimate tensile strength, hardness, and fatigue life. Among the methods evaluated, normalizing emerged as the most effective treatment, yielding the highest values of yield and tensile strength, as well as superior fatigue resistance. This is attributed to the formation of a more uniform and refined ferrite-pearlite microstructure, which increases the material's resistance to plastic deformation and crack propagation under cyclic loading.

Tempering, on the other hand, provided a more balanced improvement across strength, toughness, and fatigue properties. Although it did not surpass normalization in absolute strength values, tempering significantly enhanced impact toughness, reducing the brittleness typically associated with as-welded joints. This makes it a suitable choice for applications where a combination of ductility and strength is desired.

The findings suggest that no single heat treatment method universally optimizes all mechanical properties, but rather, the selection should be based on the operational demands and performance criteria of the railway track system. In practice, this could mean employing a hybrid or staged approach to post weld heat treatment, wherein normalization is followed by tempering to maximize both strength and toughness. Such optimized treatment strategies can significantly extend the service life and safety of railway infrastructure, reduce maintenance costs, and enhance the reliability of welded joints in high-stress environments.

References

[1] A. Smith, C. Reynolds, and J. Miller, "Advances in flash-butt and thermite welding for Railway applications," Welding J., vol. 99, no. 6, pp. 142–159, 2020.

[2] B. Andrews and D. Cooper, "The Impact of Thermal and Mechanical Stresses on Rail Infrastructure Longevity," J. Railway Eng., vol. 22, no. 1, pp. 34–45, 2018.

[3] British Standard Institution, The Standard for Metallic Materials, Brinell Hardness Test. Method of Test at Room Temperature, BS EN ISO 6506-1:2005, 2005.

[4] British Standard Institution, The Standard for Metallic Materials, Charpy Pendulum Impact Test. Method of Test at Room Temperature, BS EN ISO 148-1:2016, 2016.

[5] British Standard Institution, Metallic Materials, Tensile Testing. Method of Test at Room Temperature, BS EN ISO 6892-1:2019, 2019.

[6] British Standard Institution, The Standard for Metallic Materials, Method of Fatigue Testing. Method of Test at Room Temperature, BS EN ISO 148-1:2016, 1993.

[7] J. Smith and M. Jones, "Enhancing Structural Integrity of Welded Rail Joints through Heat Treatment," Transp. Eng. J., vol. 15, no. 2, pp. 89–102, 2021.

[8] L. Zhao, H. Wang, and Y. Chen, "Effect of normalizing on welded rail microstructure and toughness," Mater. Process. J., vol. 62, no. 1, pp. 55–71, 2019.

[9] M. Jones and D. Lee, "Stress-relief techniques for welded rail tracks," Metallurgical Res., vol. 48, no. 4, pp. 321–335, 2018.

[10] P. Rodriguez, Y. Kim, and L. Chen, "Heat Treatment Effects on Microstructural Transformation in Welded Railway Tracks," J. Mater. Process., vol. 27, no. 2, pp. 145–163, 2021.

[11] R. Kumar, H. Singh, and A. Sharma, "Influence of Heat Treatment on Welded Structures in Railway Engineering," J. Mater. Sci. Eng., vol. 12, no. 4, pp. 67–78, 2020.

[12] R. Patel, T. Nguyen, and X. Zhang, "Residual stress analysis of post-weld railway tracks," J. Struct. Integr., vol. 29, no. 1, pp. 78–94, 2022.

[13] T. Miller, P. Rodriguez, and H. Lee, "Advancements in Heat Treatment for High-Speed Rail Networks," Mater. Sci. Transp., vol. 18, no. 3, pp. 212–230, 2022.

[14] X. Li, Y. Zhao, and P. Wang, "Residual Stress and Fatigue Performance of Post-Welded Railway Tracks," Int. J. Railway Technol., vol. 8, no. 3, pp. 112–126, 2019.

Received: 24/06/2025; Revised: 02/07/2025; Accepted: 08/07/2025; Published: 03/07/2025