IJEES

International Journal of Electrical Engineering and Sustainability (IJEES)

ISSN (online): 2959-9229

https://ijees.org/index.php/ijees/index

ISI 2023-2024: (0.557) Arab Impact Factor: 1.51 SJIF 2024 = 5.274

Volume 3 | Number 2 | April-June 2025 | Pages 47-57

Article

The Impact of Heat Treatment on Hardness and Corrosion Resistance of Medium Carbon Steel

Eman Miftah[1*]

[1]Mechanical Engineering Department, Bright Star University, El–Brega, Libya

[*]Corresponding author: **eman.alsharif@bsu.edu.ly**

Received: February 05, 2025 Accepted: April 07, 2025 Published: April 08, 2025

Abstract: The primary aim of this project is to examine the impact of heat treatment processes on the hardness and corrosion resistance of medium carbon steel. In the current study, an experiment is conducted utilizing various devices and materials to assess the impact of heat treatment on the mechanical properties and corrosion resistance of medium carbon steels. The specimens are subjected to tempering at temperatures of 200°C and 400°C for a duration of 1 hour. Following the heat treatment, the samples underwent mechanical testing for hardness (Rockwell), and the corrosion of steel was also examined. The findings indicated a high hardness of 52 HRD as a result of quenching, in contrast to the annealed sample, which exhibited the lowest hardness among all specimens across all types of steel. The outcomes that were achieved indicate that the heat treatment procedure considerably diminished the corrosion behavior of carbon steel during the quenching process, with a weight reduction of merely 0.0322 g.

Keywords: Medium carbon alloy steel, Annealing, Normalizing, Quenching, Tempering, Hardness, Corrosion resistance.

1. Introduction

Medium carbon steel, with its moderate carbon content typically ranging between 0.3% and 0.6%, occupies a vital position in the hierarchy of engineering materials due to its balanced combination of strength, hardness, and ductility [1,2]. This steel category is widely employed in the manufacturing of automotive components, machinery parts, and structural applications where both toughness and mechanical robustness are essential. However, the intrinsic properties of medium carbon steel can be further optimized through heat treatment processes, which are deliberately designed to modify its internal microstructure [3,4]. Processes such as annealing, normalizing, quenching, and tempering are commonly employed to manipulate phase transformations, grain size, and dislocation density, thereby enhancing the material's hardness and overall performance [5,6].

Heat treatment profoundly influences the hardness of medium carbon steel by altering its microstructure, particularly through the formation of martensitic, bainitic, or pearlitic phases. Quenching, for instance, rapidly cools the steel from high temperatures, trapping carbon atoms within the iron lattice and resulting in a hard but brittle martensitic structure [7,8]. Subsequent tempering can reduce brittleness while maintaining an elevated hardness level suitable for engineering applications. The relationship between heat treatment parameters—such as heating rate, soaking time, and cooling medium—and the resultant hardness is critical to achieving the desired mechanical properties. A thorough understanding of these parameters allows for precision engineering of steel components to meet specific load-bearing and wear-resistance requirements.

In addition to mechanical strength, corrosion resistance is another crucial factor influencing the longevity and reliability of medium carbon steel in service environments. Heat treatment can modify the steel's corrosion behavior either positively or negatively, depending on the phases formed and the residual stresses introduced during the process [9,10]. For instance, the presence of certain microstructures, like tempered martensite, can improve corrosion resistance compared to as-quenched martensite, which may have a higher susceptibility to localized corrosion due to internal stresses. Furthermore, surface oxidation and decarburization during heat treatment must be carefully controlled, as they can compromise the protective oxide layers and accelerate corrosion rates, particularly in humid or chemically aggressive environments. Several studies have investigated the impact of heat treatment on the hardness and corrosion resistance of medium carbon steel. Table 1 presents a summary of recent findings regarding the effects of heat treatment on hardness.

Table 1. A summary of recent findings regarding the effects of heat treatment on hardness.

Ref.	Publisher	Highlighted	Target
[11]	Elsevier	▪ Heat treatment is employed to critically modify the mechanical behavior of steel specimens, targeting enhancements in ductility, hardness, yield strength, tensile strength, impact resistance, and corrosion resistance, thereby expanding their applicability for diverse engineering functions. ▪ Selected specimens are subjected to thermal cycles at temperatures exceeding the austenitic transformation region, followed by quenching, in order to elucidate the resultant modifications in mechanical properties and microstructural morphology relative to untreated counterparts. ▪ The results demonstrate that heat treatment significantly alters the mechanical behavior of medium carbon steels; hardened samples exhibiting a martensitic structure achieved superior tensile strength and hardness but lower ductility and toughness, whereas annealed samples dominated by ferrite phases displayed inverse trends.	Heat treatment
[12]	Elsevier	▪ Extended spheroidization heat treatment of CK45 medium carbon steel led to a progressive reduction in strength and hardness due to the softening of the martensitic structure, while simultaneously enhancing tensile ductility and improving corrosion resistance. ▪ Short-term intercritical annealing of spheroidized steels promoted the partial dissolution of cementite particles and the formation of austenite, resulting in the development of a dual-phase microstructure composed of ferrite and martensite following water quenching. ▪ Increasing the holding time at intercritical annealing temperatures significantly augmented the martensitic volume fraction, which, while increasing strength, adversely affected the ductility and corrosion resistance of the material due to the dominance of brittle martensitic networks.	Heat treatment
[13]	Springer Nature	▪ The present study focuses on the development of a novel grade of Hadfield steel, classified under ASTM-A128 grade B-2, aiming to minimize carbide formation during casting through both conventional heat treatment and an innovative steelmaking approach that eliminates the need for post-casting thermal processing. ▪ Microstructural characterization was conducted utilizing optical microscopy, scanning electron microscopy (SEM), and X-ray diffraction (XRD) techniques, while mechanical properties were evaluated through uniaxial tensile testing, Charpy impact testing, and Vickers microhardness measurements; additionally, tribological and electrochemical assessments were performed to analyze wear and corrosion resistance, respectively. ▪ Samples subjected to heat treatment at 1050 °C for 2 hours and 30 minutes demonstrated superior ductility, enhanced tensile strength, and improved	Heat treatment

		impact resistance, attributed to the dissolution of detrimental carbide phases within the microstructure.	
[14]	Elsevier	▪ The study systematically investigates the effects of annealing and hardening heat treatments on the mechanical and microstructural properties of medium carbon steel welds with varying carbon content, specifically focusing on EN 8 and EN 24 steel grades. ▪ Specimens of EN 8 and EN 24 were prepared through groove welding and normal welding techniques, followed by annealing and hardening at various temperature ranges. Brinell hardness testing, tensile testing, and optical microstructural analyses were conducted to evaluate property changes across the parent metal, heat-affected zone (HAZ), and weld zone. ▪ The results demonstrated significant differences in tensile strength between heat-treated and non-heat-treated specimens, attributed to microstructural modifications induced by thermal cycles during welding and subsequent heat treatment.	Heat treatment
[15]	Springer Nature	▪ Dual electroless plating baths incorporating Al_2O_3 and SiC nanoparticles were employed to fabricate duplex Ni-P coatings. Microstructural and compositional analyses were performed using scanning electron microscopy (SEM), energy-dispersive spectrometry (EDS), and X-ray diffraction (XRD), while mechanical properties were evaluated via Vickers microhardness testing and corrosion resistance was assessed through potentiodynamic polarization studies in a 3.5% NaCl environment. ▪ Among the coatings developed, the bilayer configuration featuring Ni-P-SiC as the external layer exhibited the highest microhardness values, highlighting the reinforcing effect of SiC nanoparticles in improving surface mechanical performance. ▪ The duplex coating with Ni-P-Al_2O_3 as the external layer demonstrated superior corrosion resistance, attributed to the enhanced electrochemical stability imparted by the Al_2O_3 particles within the coating matrix.	Heat treatment

In this direction, Yu [16] systematically investigated the effects of heat treatment on the microstructural evolution, residual stress relaxation, nano-indentation performance, corrosion resistance, and cavitation erosion (CE) behavior of 17-4PH stainless steel (SS) subjected to laser surface melting (LSM). Post-heat treatment, the LSM-processed samples predominantly consisted of a martensitic matrix with uniformly distributed niobium carbide (NbC) precipitates, particularly in the S3 sample, which underwent solution treatment at 1040 °C for 3 hours followed by aging at 480 °C for 3 hours; heat treatment also induced an increase in grain size. The applied heat treatment effectively mitigated the high residual stresses introduced by LSM and enhanced the nano-indentation behavior of the samples, indicating improvements in localized mechanical properties compared to untreated LSM specimens.

A recent study by [17] critically examines the influence of various heat treatment protocols and continuous cooling rates on the mechanical properties and microstructural characteristics of 0.18%-carbon steel, using controlled heating at 925 °C for 1 hour across multiple sample sets, alongside an 'as-received' reference for comparative analysis. Tensile strength, hardness, toughness, and shear strength were systematically measured for each sample, revealing that heat treatment generally led to a notable reduction in tensile and shear strengths, coupled with significant enhancements in ductility and toughness, particularly in sand-cooled and furnace-cooled specimens. Optical microscopy analyses identified the predominance of coarse and fine pearlite structures accompanied by proeutectoid ferrite regions, while fracture surface examinations via field emission scanning electron microscopy (FE-SEM) indicated a combination of ductile and brittle fracture modes.

This study makes a significant contribution to the understanding of how different heat treatment processes influence the mechanical and corrosion properties of medium carbon steel. By systematically analyzing the effects of annealing, normalizing, quenching, and tempering at various temperatures, the research elucidates the direct relationship between heat-induced microstructural transformations and performance characteristics. The findings demonstrate that quenching not only markedly enhances hardness but also substantially improves corrosion resistance through the formation of a martensitic microstructure, which limits corrosive degradation in saline environments. Moreover, the work highlights the critical balance between hardness and ductility achieved through tempering at elevated temperatures, providing valuable insights for tailoring mechanical properties according to application-specific requirements. Overall, this study advances the strategic application of heat treatment techniques to optimize the structural integrity and environmental durability of medium carbon steels, offering practical guidance for industries reliant on high-performance steel components.

2. Materials and methodology

This section outlines the strategy for executing the experiment utilizing various devices and materials employed to assess the impact of heat treatment on the mechanical properties and corrosion resistance of medium carbon steel.

A. Material

The material studied in this work is a medium carbon steel (0.25-0.65% carbon) steel intended for heat treatment. The chemical composition is shown in Table 1.

Table 1. Chemical composition of medium carbon steel alloy in wt.%.

Content (%)	C	Si	Mn	Cr	Ni	Mo	P	S	Fe
Element	0.42-0.5	Max. 0.4	0.5-0.8	0- 0.4	0- 0.4	0- 0.1	0- 0.045	0- 0.045	Balance

B. Sample Preparation

This project commenced with the preparation of specimens made from medium carbon steel, totaling approximately 5 samples. The samples underwent various heat treatment sequences, including annealing, hardening, water quenching, and tempering at two distinct temperatures: 200°C and 400°C. The heat-treated specimens were subjected to mechanical testing for hardness properties, as well as corrosion testing. All specimens of medium carbon steel, measuring 2. 5 × 1. 5 cm, were cut using a cutting machine as illustrated in Figure 1.

C. Heat treatment processes

The heat treatment procedures chosen to examine the influence of heat treatment methods on microstructure, hardness, and corrosion resistance of medium carbon steel is annealing, normalizing, quenching, and quenching followed by tempering. The furnace utilized in this study operates from 600 C° to 1000 C° for the hardening of hot work steel and high-speed steel. This furnace type is vectstar 498000 km, with a maximum operating temperature of 1200 C°, as illustrated in Figure 2.

Figure 1. Samples cutting machine.

Figure 2. The furnace.

- 2.3.1 Annealing process

A full annealing process was conducted on the specimen by gradually heating the metal to 800C°. It is maintained at this temperature for an adequate duration (approximately one hour) to ensure that all the material converts into austenite as shown in Figure 3. Subsequently, it is gradually cooled within the furnace to room temperature.

- 2.3.2 Normalizing process

Each sample of the medium carbon steel intended for normalization was positioned in the furnace and raised to a temperature of 800 C° over a duration (approximately one hour) and was subsequently taken out of the furnace and allowed to cool in the air.

- 2.3.3 Hardening process

The specimens intended for hardening were positioned inside the furnace and heated to 800 C°. At this temperature, a transformation occurs in the steel to austenite. The samples were held at this temperature for a duration of one hour during which the transformation should have been finalized, after which they were subsequently taken out of the furnace and placed into various containers of water for quick cooling to room temperature as illustrated in Figure 4.

Figure 3. The samples of annealing in the furnace.

Figure 4. The samples after cooling by water.

- 2.3.4 Tempering process

Load the samples into the furnace as soon as they have cooled down to room temperature for water-quenched samples. Adjust the furnace to the intended tempering temperature. The samples undergo tempering at 200°C and 400°C for 1 hour as illustrated in Figure 5.

Figure 5. The samples of tempering at 200°C.

D. Grinding and polishing

The samples are grinded and polished utilizing the grinding machine as depicted in Figure 6. These samples are polished with 160, 500, 800, and 1200 SiC papers to achieve the grinded samples as shown in Figure 7.

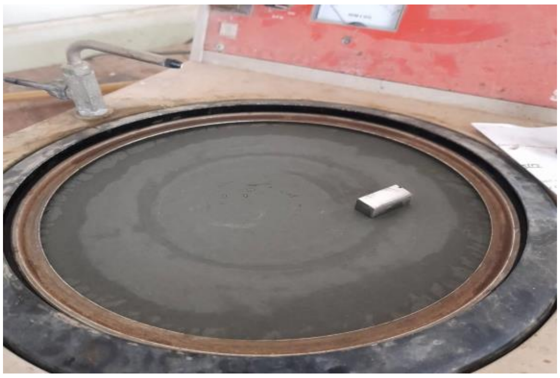

Figure 6. Grinding and polishing machine.

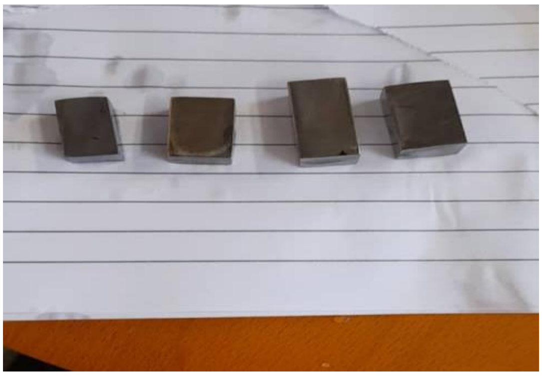

Figure 7. Specimen after grinding.

E. Hardness test

Hardness is a mechanical property of metal that manifests when a load is applied, allowing the material to resist permanent deformation. Figure 8 depicts the HR_150 Rockwell hardness testing machine used for measuring hardness values HRD, where the average of seven readings was taken at various positions on the samples as illustrated in Figure 9. The type of hardness test conducted here is the Rockwell hardness test.

The Rockwell hardness testing method involves indenting the test material using a diamond cone or a hardened steel ball indenter. The indenter is pressed into the test material under a preliminary minor load $F0$, typically 10 kg. Once equilibrium is achieved, an indicating device that tracks the indenter's movements and responds to depth changes in the indenter's penetration is set to a reference position. While maintaining the preliminary minor load, an additional major load is applied, resulting in increased penetration. After equilibrium is once more attained, the additional major load is removed while the preliminary minor load remains. The removal of the additional major load permits a partial recovery, thus decreasing the depth of penetration; the permanent increase in the depth of penetration, caused by the application and removal of the additional major load, is utilized to compute the Rockwell hardness number.

Figure 8. Hardness testing machine.

Figure 9. Sample for hardness test.

F. Corrosion test

Corrosion testing using the immersion test method with a 3. 5% sodium chloride solution was carried out to evaluate the influence of various carbon contents and distinct heat treatments on the corrosion rate of carbon steels, employing the weight loss approach. Figure 10 illustrates the apparatus used to weigh samples prior to and following the corrosion process to assess corrosion resistance based on weight loss. Figure 11 depicts the container containing a 3. 5% sodium chloride solution for the corrosion process.

Figure 10. Device for measuring the weight of samples.

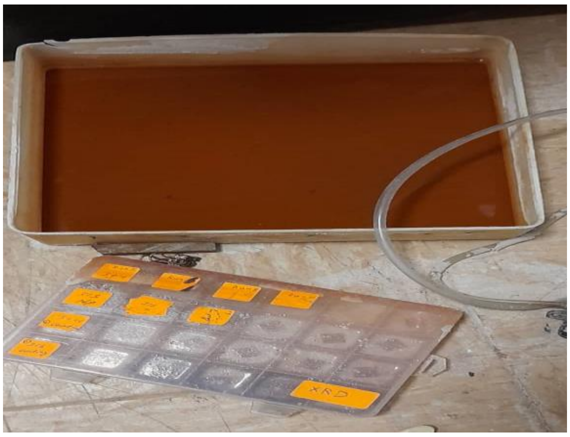

Figure 11. Sodium chloride solution container.

3. Results and Discussion

The results that were achieved after the four varieties of heat treatment sequences: annealing, normalizing, quenching, and tempering are as follows.

A. Hardness results

The hardness tests were conducted at seven distinct points on the sample surface, and the mean was subsequently determined from the three measurements. Table 2 illustrates the outcome of the hardness assessment following heat treatment. The fluctuation of hardness of medium carbon steel at different temperatures.

Table 2. Result of hardness after heat treatment processes.

Heat treatment processes	Temperature, C°	Hardness, HRD (C)
Annealing	800	22
Normalizing	800	27
Quenching	800	52
Tempering	200	51
Tempering	400	46

The presented results illustrate the significant influence of different heat treatment processes on the hardness of the tested material. Annealing at 800 °C produced the lowest hardness value (22 HRD C), as expected, due to the formation of coarse ferrite and pearlite structures that enhance ductility while substantially reducing hardness. Normalizing at the same temperature slightly increased the hardness to 27 HRD C, attributed to a finer grain structure resulting from air cooling. In contrast, quenching at 800 °C dramatically elevated the hardness to 52 HRD C by producing a predominantly martensitic microstructure, although this came at the cost of reduced toughness. Subsequent tempering at 200 °C slightly lowered the hardness to 51 HRD C, maintaining much of the quenched martensite's hardness while marginally improving toughness. When the tempering temperature was raised to 400 °C, the hardness further decreased to 46 HRD C, indicating increased carbide precipitation and partial recovery of the martensitic structure, which considerably improved the material’s toughness and ductility. Overall, the data reveal a clear trade-off between hardness and toughness, where lower temperature tempering retains high hardness, while higher temperature tempering offers a more balanced combination of mechanical properties suitable for structural applications. Figure 12 illustrates Hardness, HRB vs heat treatment processes.

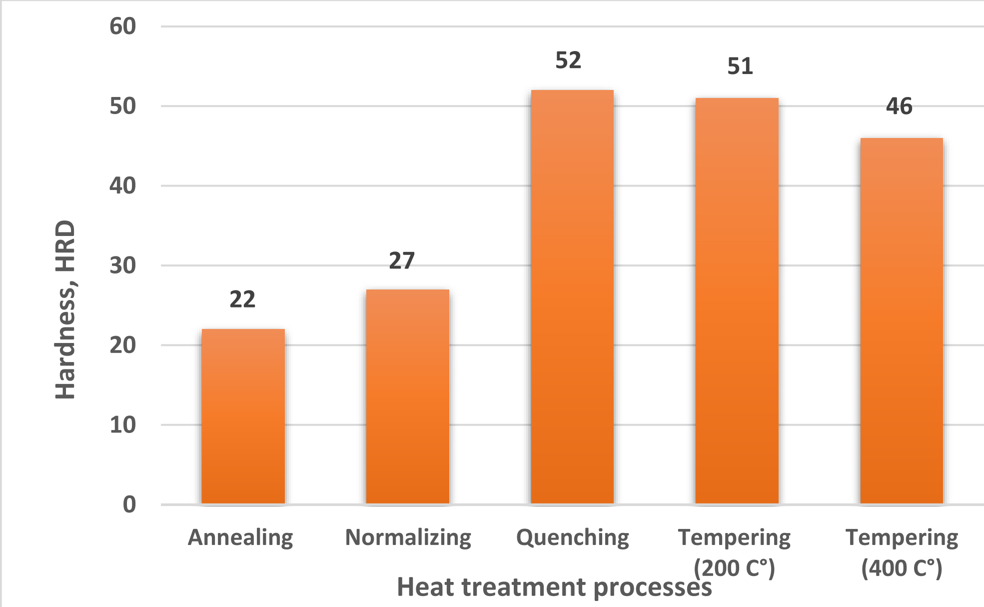

Figure 12. Hardness, HRD vs heat treatment processes.

The hardness values displayed in Figure 12 illustrates that quenched samples exhibit the greatest hardness because of the creation of a hard martensite structure, while quench and temper treatment follow, and the annealed sample shows the least hardness among all samples. This is attributed to the development of a softer structure consisting of large ferrite and pearlite following the annealing process. The hardness tends to increase considerably after the quenching heat treatment, reaching a value of 52 HRD. This increase is primarily due to the development of a structure following rapid in water. The martensitic structure is recognized for providing high hardness as a consequence of the quenching process, during which the face-centred cubic austenite changes into a highly strained body-centered tetragonal variant that becomes supersaturated with carbon. Conversely, the shear deformations that occur generate a significant quantity of dislocations, which is a crucial strengthening mechanism in steels; thus, the maximum hardness was achieved in high carbon steel because martensite can readily form following quenching's the carbon content rises accordingly. Nevertheless, the presence of ferrite diminishes the hardness of the matrix while simultaneously increasing ductility, which consequently leads to an enhancement in elongation.

B. Corrosion results

Table 3 illustrates the outcomes of the corrosion test conducted prior to and following the immersion test in a 3. 5% sodium chloride solution for a duration of two weeks.

Table 3. Weight loss after corrosion test of the steel specimens.

Heat treatment processes	Weight loss, g
As received	0.0451
Annealing	0.0516
Normalizing	0.0515
Quenching	0.0322
Tempering (200 C°)	0.0329
Tempering (400 C°)	0.0334

The corrosion behavior of medium carbon steel specimens subjected to different heat treatment processes was evaluated through weight loss measurements after immersion testing, with results clearly indicating that the heat treatment route significantly influences corrosion resistance. The as-received specimen exhibited a weight loss of 0.0451 g, while annealed and normalized specimens showed slightly higher weight losses of 0.0516 g and 0.0515 g, respectively, suggesting that these treatments, associated with coarse-grained ferritic-pearlitic structures, reduce corrosion resistance. In contrast, the quenched specimen demonstrated the lowest weight loss (0.0322 g), indicating superior corrosion resistance due to the formation of a martensitic microstructure, which offers fewer preferential corrosion pathways compared to ferrite and pearlite. Tempering after quenching slightly increased the weight loss, with values of 0.0329 g for tempering at 200 °C and 0.0334 g at 400 °C, though still remaining substantially lower than the as-received and annealed counterparts. This slight increase is attributed to partial recovery and carbide precipitation during tempering, which may introduce localized galvanic sites but do not significantly compromise overall corrosion performance. These results confirm that quenching, followed by appropriate tempering, effectively enhances the corrosion resistance of medium carbon steel by refining the microstructure and reducing the susceptibility to chloride-induced degradation.

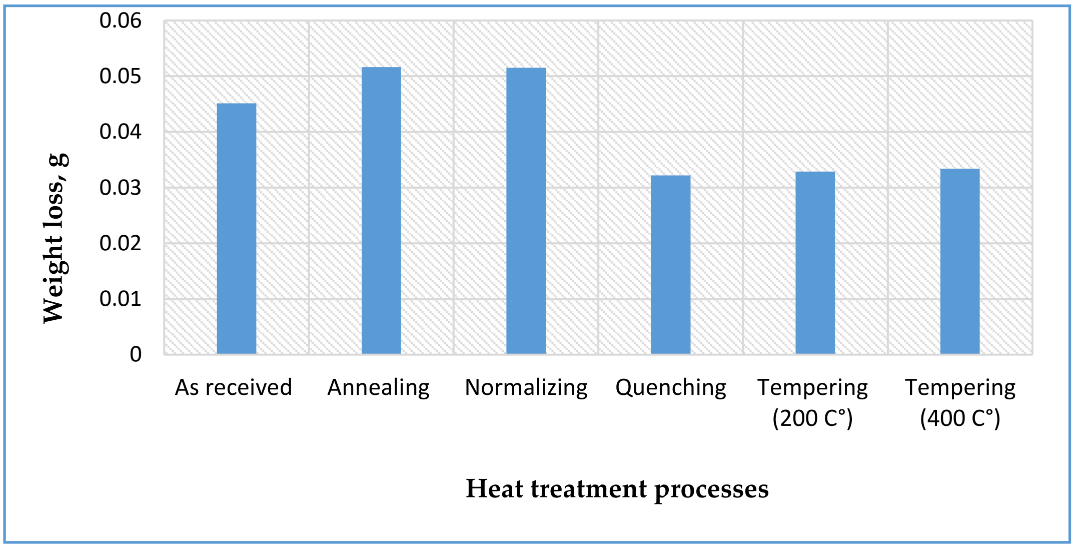

Figure 13. Weight loss after corrosion test vs heat treatment processes.

Figure 13 illustrates the weight loss observed after a two-week immersion period for samples that underwent no treatment (as received) and those that were heat-treated through annealing, normalizing, quenching, and tempering at temperatures of 200 °C and 400 °C for medium carbon steel alloy. According to the graph, the annealed samples exhibit the greatest weight loss (0. 0516 g). This is succeeded by the normalizing sample (0. 0515 g), the as-received samples (0. 451 g), and the quenched and tempered samples, which display weight losses of 0. 0322 g, 0. 0329 g, and 0. 0334 g, respectively. In contrast, it has been observed that the samples subjected to quenching demonstrate the least weight loss when compared to the tempering process. It has been determined that the quenching process facilitated the formation of martensite, consequently reducing the corrosion rate.

The process of heat treatment impacts the corrosion behavior of carbon steel. This is attributed to the alteration in microstructure induced by the heat treatment process, which can result in either improved or diminished corrosion performance of carbon steel. It has been demonstrated that annealed carbon steel exhibits a weight loss of 0. 0516 g. The annealing process enlarges the grain size of the carbon steel and concentrates the carbon within the grain boundaries, thereby increasing the surface area of the susceptible attacking site, ferrite. This results in the ferrite being more readily corroded by a 3. 5% sodium chloride solution, consequently elevating the corrosion rate.

Quenching was the thermal treatment that significantly reduced the corrosion characteristics of carbon steel, resulting in a weight loss of only 0. 0322 grams. Upon quenching, the microstructure of carbon steel changes into martensite, a needle-like, carbon-dense microstructure. Martensite generally exhibits a high resistance to corrosion. Consequently, tempered martensite, resulting from the quench and temper process, shows a slightly elevated corrosion rate compared to untempered martensite, with a peak of 0. 0329 g. This occurs due to the carbon being released from the unstable structure of martensite, which creates a ferrite structure and exposes a greater amount of ferrite surfaces to corrosion in a 3. 5% sodium chloride solution. Thus, the immersion test's results demonstrate that the heat treatment process affects the corrosion behavior of carbon steel through microstructural alterations. The presence of the martensite structure further lowers the overall corrosion rate of carbon steel.

4. Conclusions

This study systematically investigated the effects of various heat treatment schedules, including annealing, normalizing, quenching, and tempering at different temperatures, on the mechanical and corrosion properties of medium carbon steel. It was observed that the quenching process resulted in a substantial increase in hardness, achieving a maximum value of 52 HRD. However, with increasing tempering temperatures, a gradual reduction in hardness was noted, accompanied by a corresponding enhancement in the ductility of the steel. Among the heat treatments studied, quenching significantly improved the corrosion resistance of the material, evidenced by a minimal weight loss of only 0.0322 g during immersion tests in a 3.5% sodium chloride solution. The corrosion behavior of carbon steel was found to be highly dependent on the heat treatment process, primarily due to microstructural transformations. In particular, the formation of a martensitic structure contributed notably to the reduction of the corrosion rate, underscoring the critical role of microstructural refinement in enhancing both mechanical performance and environmental durability of medium carbon steels.

Author Contributions: Author has contributed significantly to the development and completion of this article.

Funding: This article received no external funding.

Data Availability Statement: Not applicable.

Acknowledgments: The author would likes to express their sincere gratitude to Bright Star University, Libya for their invaluable support and resources throughout the course of this research.

Conflicts of Interest: The author(s) declare no conflict of interest.

ORCID

Eman Miftah https://orcid.org/0009-0007-0230-2490

References

[1] L. Wu, K. Zhang, R. Yu, G. Wang, Z. Zhou, and X. Zhang, "Discrepancy evaluation in mechanics and corrosion resistance of reactive plasma sprayed TiN coatings fabricated under different heat treatment," *Constr. Build. Mater.*, vol. 446, no. 138087, p. 138087, 2024.

[2] B. M. Edun, O. O. Ajayi, P. O. Babalola, and O. O. Joseph, "The impact of selected bio-based carburising agents on mechanical and tribocorrosion behaviour of medium carbon steel," *J. Bio-Tribo-Corros.*, vol. 10, no. 4, 2024.

[3] K. Du, Z. Lv, W. Fan, R. Zhang, X. Li, and L. Xu, "Effect of heat treatment process on microstructure and mechanical properties of high-carbon H13 steel," *Processes (Basel)*, vol. 11, no. 11, p. 3239, 2023.

[4] A. Apelfeld *et al.*, "Enhancement of medium-carbon steel corrosion and wear resistance by plasma electrolytic nitriding and polishing," *Metals (Basel)*, vol. 11, no. 10, p. 1599, 2021.

[5] I. Aichouch, A. El Magri, and B. Hammouti, "Influence of laser power and scan speed on porosity, microhardness, and corrosion resistance in HCl medium of additively manufactured H13 tool steel," *Prog. Addit. Manuf.*, 2025.

[6] M. Ravindran, M. Aswatha, N. Santhosh, G. Ravichandran, and M. Madhusudhan, "Effect of heat treatment on fatigue characteristics of En8 steel," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1013, p. 012009, 2021.

[7] J. N. Ndumia, J. Zhu, B. V. Gbenontin, M. Kang, X. Liu, and S. M. Nyambura, "Effect of heat treatment on the microstructure and corrosion behavior of arc-sprayed FeCrAl/Al coating," *J. Mater. Eng. Perform.*, 2022.

[8] H. Dong, P.-F. Guo, Y. Han, R.-X. Bai, Z.-C. Yang, and S.-Q. Zhang, "Enhanced corrosion resistance of high speed laser-cladded Ni/316L alloy coating by heat treatment," *J. Mater. Res. Technol.*, vol. 24, pp. 952–962, 2023.

[9] J. S. Siqueira, M. R. Abreu Alves, T. Marcial Luiz, and R. A. Renzetti, "Effect of heat treatment on the chromium-depleted zones of a high carbon martensitic stainless steel," *Mater. Corros.*, vol. 72, no. 11, pp. 1752–1761, 2021.

[10] K. Kishore, S. Chhangani, M. J. N. V. Prasad, and K. Bhanumurthy, "Microstructure evolution and hardness of hot dip aluminized coating on pure iron and EUROFER 97 steel: Effect of substrate chemistry and heat treatment," *Surf. Coat. Technol.*, vol. 409, no. 126783, p. 126783, 2021.

[11] B. Chandra Kandpal *et al.*, "Effect of heat treatment on properties and microstructure of steels," *Mater. Today*, vol. 44, pp. 199–205, 2021.

[12] M. Soleimani, H. Mirzadeh, and C. Dehghanian, "Effects of spheroidization heat treatment and intercritical annealing on mechanical properties and corrosion resistance of medium carbon dual phase steel," *Mater. Chem. Phys.*, vol. 257, no. 123721, p. 123721, 2021.

[13] R. Zellagui *et al.*, "Effect of heat treatments on the microstructure, mechanical, wear and corrosion resistance of casted Hadfield steel," *Int. J. Met.*, vol. 16, no. 4, pp. 2050–2064, 2022.

[14] S. Murmu, S. K. Chaudhary, and A. K. Rajak, "Effect of heat treatment on mechanical properties of medium carbon steel welds," *Mater. Today*, vol. 56, pp. 964–970, 2022.

[15] S. Uppada, R. Koona, V. B. Chintada, and R. Koutavarapu, "Influence of heat treatment on crystal structure, microhardness and corrosion resistance of bilayer electroless Ni-P-SiC/Ni-P-Al2O3 coatings," *Silicon*, vol. 15, no. 2, pp. 793–803, 2023.

[16] D. T. Yu, C. L. Wu, S. Zhang, C. H. Zhang, H. T. Chen, and X. P. Tao, "Effects of heat treatment on the nano-indentation, corrosion and cavitation erosion behavior of 17-4PH stainless steel by laser surface melting," *Surf. Coat. Technol.*, vol. 484, no. 130821, p. 130821, 2024.

[17] A. R. Kulkarni, P. V. Raju, P. P. Sarma, S. Dewangan, and S. K. Selvaraj, "Microstructure and mechanical properties of 0.18%-C steel samples processed through five different heat treatment techniques," *J. Inst. Eng. (India) Ser. D*, vol. 105, no. 3, pp. 1945–1960, 2024.