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Determination of synergistic effects of austempering + cryogenic heat treatments applied to r260 rail steel

R260 ray çeliğine uygulanan ostemperleme + kriyojenik ısıl işlemlerin sinerjik etkilerinin belirlenmesi

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Determination of Synergistic Effects of Austempering + Cryogenic Heat Treatments Applied to R260 Rail Steel

Highlights

- *Austempering and cryogenic treatments have improved the microstructure of R260 rail steels and increased their hardness.*
- *The hardness of the A180C sample increased by 226% compared to the initial value, reaching 607 HV1.*

Graphical Abstract

The diagram shows the heat treatment of R260 steel: austenitizing, austempering, and cryogenic processing with time-temperature relations

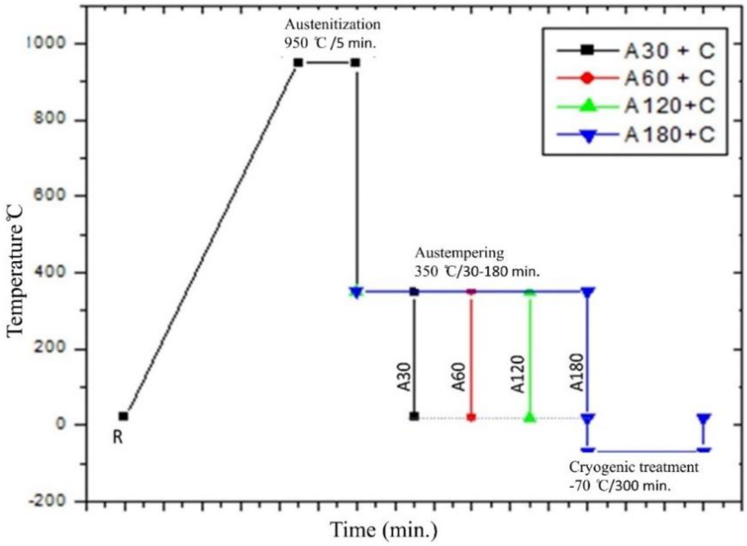

Figure. Schematic Representation of Heat Treatments Applied to R260 Steel

Aim

This study aimed to determine the appropriate temperature and time to improve the microstructural and mechanical properties of austempering and cryogenic treatments applied to R260 rail steels.

Design & Methodology

Austempering and cryogenic treatments were applied to R260 steel samples, and their microstructural were analysed using SEM, XRD, and Vickers hardness testing

Originality

The study offers a unique contribution by examining the combined effects of austempering and cryogenic treatments

Findings

Austempering and cryogenic treatments resulted in a 226% increase in hardness and microstructural improvements

Conclusion

Austempering and cryogenic treatments significantly improved the hardness properties and microstructure of R260 steel.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Determination of Synergistic Effects of Austempering + Cryogenic Heat Treatments Applied to R260 Rail Steel

Research Article

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ABSTRACT

In this study, commercially obtained R260 grade rail steels were subjected to cryogenic treatment after isothermal holding at different austempering times. The effects of cryogenic treatment applied to the test specimens for five hours at -70 °C after austenitisation at 950 °C for five minutes, followed by austempering heat treatment at 350 °C in a neutral salt bath with different isothermal holding times (30-180 min) on microstructure, mechanics and crystallography were investigated. When the SEM microstructures of the alloy were examined, it was observed that with increasing isothermal retention times, significant subbainite transformation was completed, and hardnesses increased. While the untreated sample had a hardness value of 269 HV1, the hardness was measured as 607 HV1 with an increase of 226% after 180 min austempering and cryogenic processes. As a result of XRD measurements, it was determined that the amount of intermediate carbides and residual austenite decreased with increasing heat treatment time and improved mechanical properties.

Keywords: R260 steel, microstructure, cryogenic treatment, austempering, hardness

R260 Ray Çeliğine Uygulanan Östemperleme + Kriyojenik Isıl İşlemlerin Sinerjik Etkilerinin Belirlenmesi

ÖZ

Bu çalışmada, ticari olarak temin edilen R260 kalite ray çelikleri, farklı östemperleme sürelerinde izotermal tutma işleminin ardından kriyojenik işleme tabi tutulmuştur. Deney numunelerine 950 °C'de beş dakika östenitlemenin ardından -70 °C'de beş saat uygulanan kriyojenik işlemin, ardından farklı izotermal tutma süreleriyle (30-180 dk) nötr tuz banyosunda 350 °C'de östemperleme ısıl işleminin mikroyapı, mekanik ve kristalografi üzerindeki etkileri incelenmiştir. Alaşımın SEM mikro yapıları incelendiğinde, artan izotermal tutma süreleri ile önemli subbainit dönüşümünün tamamlandığı ve sertliklerin arttığı gözlenmiştir. İşlem görmemiş numunenin sertlik değeri 269 HV1 iken, sertlik 180 dk östemperleme ve kriyojenik işlemler sonrasında %226 artışla 607 HV1 olarak ölçülmüştür. XRD ölçümleri sonucunda, ara karbür ve kalıntı ostenit miktarının artan ısıl işlem süresiyle azaldığı ve mekanik özelliklerin iyileştiği belirlendi.

Anahtar Kelimeler: R260 çeliği, mikroyapı, kriyojenik işlem, östemperleme, sertlik

1. INTRODUCTION

Rails, which play an essential role in determining the safety and reliability of railway transport, are expected to have sustainable stiffness [1]. Rail steels exposed to repeated loads deteriorate structurally over time [2]. The main damage that occurs on the rail surface can be counted as various plastic deformations, especially fatigue problems due to wear and rolling contact [3]. Although the depth of deformation in the rail depends on the material, load, and environment, it can occur up to a distance of 1-2 millimeters [4]. Today, the most widely used alloy in the manufacture of rails is mainly steels with pearlitic microstructure. Pearlite is a phase mixture of cementite lamellae embedded in a soft ferritic matrix that exhibits superior tribological properties [5,6]. Nowadays, in order to improve the mechanical and microstructural properties of railway wheel alloys, studies have been carried out on cerebritic [7], carbide-free cerebritic [8] and complex phase structure [9-10] steel alloys. Therefore, various heat treatments are applied to develop rail steels [11]. Cryogenic treatment is frequently applied to steel alloys due to its contribution to mechanical and crystallographic properties, such as elimination of residual austenite, improvement of yield strength, and improvement of tribological properties [12,13]. In a study investigating the effects of austempering of rail steels at different times between 190-230℃ on microstructure and mechanical properties, it was observed that yield strength decreased, and elongation ratio values increased with increasing austempering temperature [14]. Hasan et al. determined

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that the ultra-thin bainitic structure formed at low austempering temperatures has higher wear resistance than pearlitic rail steel and that wear resistance increases with increasing residual austenite content as well as decreasing bainitic ferrite lath thickness [15]. Zhao et al. determined that in rail steels austempered at different temperatures, the elongation and coarsening of the bainite plates started to increase with the increase in austempering temperature; thus, the mechanical properties decreased after an optimum value [16].

In this study, the effects of austempering and cryogenic heat treatments on the structural properties of R260 rail steels were investigated. When the literature studies are examined, it is known that independent heat treatments are applied to rail steels, but multiple heat treatment procedures are not sufficiently studied. With this motivation, the originality of the study is aimed to be a guide for future studies.

2. MATERIAL and METHOD

Commercially purchased 6 mm diameter R260 quality rail steel was used in the experimental studies. The chemical composition of R260 alloy used as the starting sample was determined by optical spectrometry (Q4 Tasman) and is presented in Table 1. R260 alloy used as starting material in the experimental studies is coded as "R". For the austempering heat treatment, all specimens were firstly converted into austenite phase with a face-centred cubic lattice structure by holding in an Ar atmosphere-controlled heat treatment furnace at 950 °C for 5 minutes. Then, the austempering process was carried out isothermally in a neutral salt bath at 350 °C for periods ranging from 30,60,120,180 minutes. The austempered samples were subjected to cryogenic treatment by holding at -70°C for 300 min. The samples subjected to cryogenic treatment were coded as A30C, A60C, A120C, A180C. The information about the heat treatment routes applied to the samples is presented schematically in Figure 1.

The HV1 Vickers macro hardness values of the samples were determined by using a 1 kg (9.807 N) tip for 15 seconds and QNESS 60 M EVO Hardness Tester according to ASTM E384. The samples were prepared for optical, Scanning Electron Microscope (SEM), and XRD analyses by etching with 3% Nital solution (3 ml HNO_3, 97 ml ethanol). Microstructural investigations were carried out using JEOL JSM-6060LV SEM and Leica optical microscope, and crystallographic analyses were carried out using Bruker D8 Advanced instrument using CuKα (λ=0.154 nm) target and step size 0.06 °/s. A

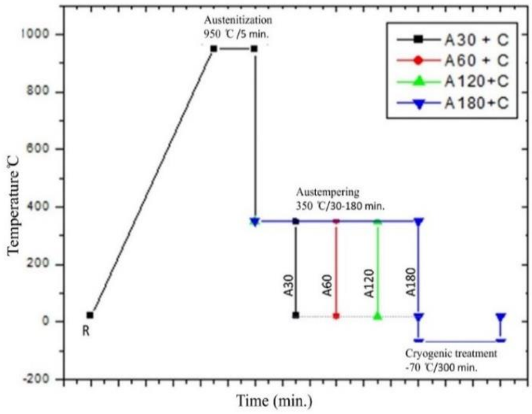

Figure 1. Schematic Representation of Heat Treatments Applied to R260 Steel

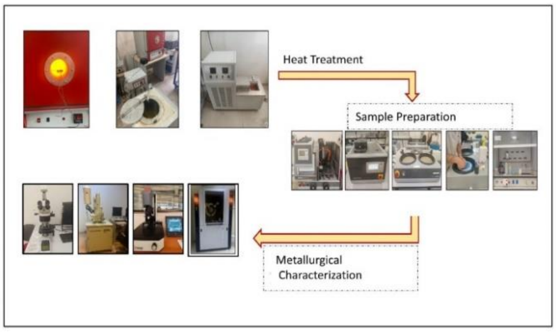

Figure 2. Schematic Representation of Experimental Processes

graphical summary of the experimental studies is presented in Figure 2.

3. RESULTS AND DISCUSSION

SEM microstructures of pearlitic and brainitic steels are presented in Figure 3. Figure 3(a) shows a typical pearlitic microstructure with thin lamellae formed by soft and ductile ferrite and very hard cementite. The lamellae are formed in the same orientation in each grain. The mechanical properties of pearlitic steels are mainly determined by the distance between the ferrite-cementite lamellae [17]. The A30C and A60C specimens presented in Figure 3(b-c) show a bainite microstructure resembling a mixture of tempered martensite and ferrite. Bainite microstructure is different from pearlite and martensite microstructures due to its wide cooling rate range and depending on the austempering temperature and time variables. In this context, A120C and A180C specimens, which were austempered for a longer time, have a traditional hairy bainite microstructure. It is known that the increase in the volume of bainite in the

Table 1. Chemical Composition of R260 Alloy (Weight %)

	Elements (wt. %)							
Standard	C	Si	Mn	Cr	N	Cu	P	S
(*TS EN 13674-4*)	0.72	0.31	1.03	0.02	0.06	0.01	0.006	0.01

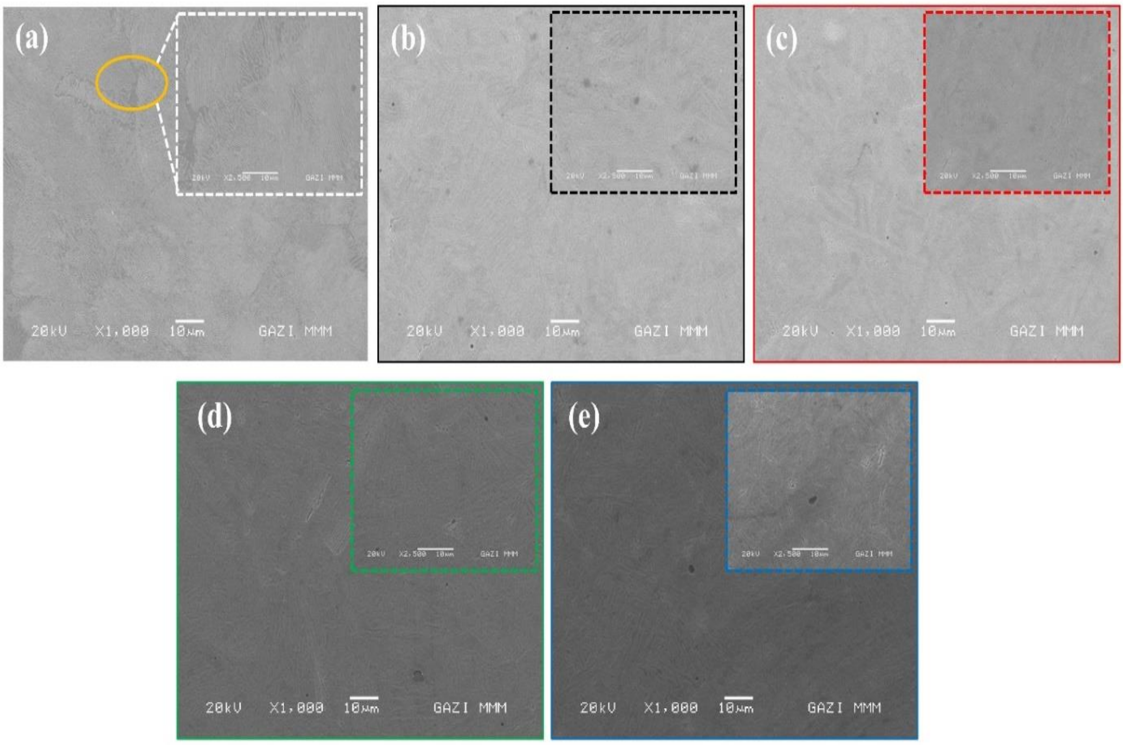

Figure 3. SEM microstructure images of specimens; (a) R260, (b) A30C, (c) A60C, (d) A120C, (e) A180C

microstructure has a positive effect on the impact toughness of the material and increases its hardness with sudden loading [18,19]. In addition, the effect of cryogenic treatment on the bainitic structure was also investigated in this study. In the optimum treatment group determined in this study, a balanced distribution of bainitic structures was obtained. This comprehensive approach contributed to an overall improvement in the mechanical properties of the material.

In Figure 4, the microhardness (HV1) measurement results of the samples are presented graphically. Sample R260, which is formed in dense perlite lamellae, has a hardness value of 269 HV1. The hardness values generally increased with the cryogenic treatment applied for 5 hours after austempering. The maximum hardness of A180C specimen was measured as 607 HV1, with an increase of 226% compared to R specimen. The hardness of A30C and A60C samples were measured as 579 and 575 HV1, respectively. It is thought that the short 30 and 60 minutes isothermal holding time and the residual austenite in the structure caused the hardness to be low [20]. The hardness of A120C and A180C specimens was measured higher than all other specimens due to their fine austenite structure with increasing austempering time [21]. The growth of carbides and better dispersion of carbon atoms with increasing austempering time increases the overall stability of the microstructure of the material. A homogeneous and balanced microstructure improves the mechanical properties of the material [22,23].Careful control of these processes has a major influence on the production of rail steels with the desired properties. Optimal austempering times and temperatures aim to optimally balance both the hardness and toughness properties of the material.

It is known that this situation is directly related to the increase in bainite volume fractions with increasing austempering times [24].

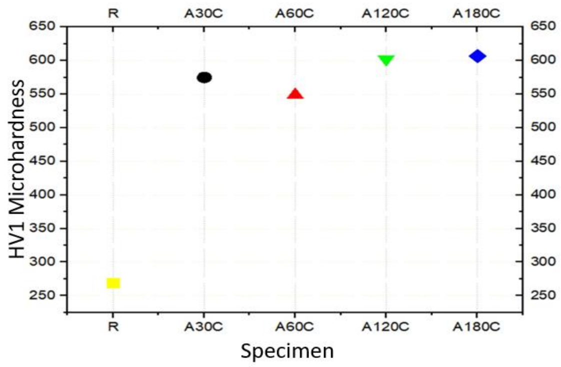

Figure 4. Microhardness (HV1) Values of the Samples

Figure 5 shows the XRD diffraction patterns of the samples. The diffraction pattern of the raw (R) sample shows α-ferrite main iron peaks and orthorhombic cementite peaks supporting the presence of dense pearlite colonies (Figure 3a). Due to the austempering heat treatment of the samples, some residual austenite is also present in their structures during the solid state austenite transformation. Especially A30C and A60C specimens contain (200) and (220) austenite peaks. It is known that chemical, mechanical, or thermal treatment variables applied to steels affect the amount of residual austenite, which is one of the effects on crystallography [25,26]. In the A120 and A180 specimens, where the austempering time was longer, residual austenite was not detected, and ferrite and cementite peaks, which are the products of the traditional bainite phase mixture, were detected. In addition, martensitic transformation did not occur in all samples due to the formation of the proeutectoid phase and the slow cooling rate [27]. The growth and coalescence of carbides are controlled by the recrystallisation of α-Fe matrix grains. The recrystallisation of α-Fe causes the movement of grains and the aggregation of θ-Fe_3C particles located at the twinning boundaries [28,29].

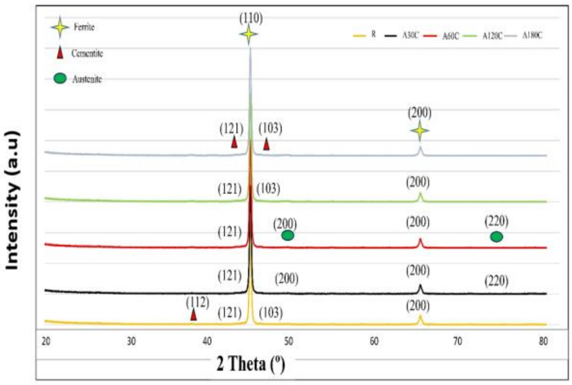

Figure 5. XRD Diffraction Patterns of the Samples

6. CONCLUSION

In this study, cryogenic treatment was applied to the bainitic microstructures obtained by isothermal holding of R260 rail steels at different austempering times, and the following results were obtained.

1. While the R sample had a hardness value of 269 HV1, the highest hardness after austempering and cryogenic treatment was measured in the A180C sample with a value of 607 HV1 with an increase of 226%.

2. It was determined by XRD analysis that the presence of residual austenite after cryogenic treatment of the samples decreased with increasing austempering time.

3. It was observed as a result of SEM analyses that the R sample, which has a lamellar pearlitic microstructure, transformed into a bainitic structure with austempering heat treatments.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods they used in their work do not require ethics committee approval or legal-special permission.

AUTHORS' CONTRIBUTIONS

Mehmet Gülsün: He conducted experiments and analyzed the results.

Uğur Arabacı: : He conducted experiments and analyzed the results.

Mustafa Boz: : He conducted experiments and analyzed the results.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

REFERENCES

[1] Wang W. J., Jiang W. J., Wang H. Y., Liu Q. Y., Zhu M. H., & Jin X. S., "Experimental study on the wear and damage behavior of different wheel/rail materials", ***Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit***, 230: 3-14, (2016).

[2] Ekberg A., & Kabo E., "Fatigue of railway wheels and rails under rolling contact and thermal loading—an overview", ***Wea***r, 258: 1288-1300, (2005).

[3] Ma L., He C. G., Zhao X. J., Guo J., Zhu Y., Wang W. J., & Jin X. S., "Study on wear and rolling contact fatigue behaviors of wheel/rail materials under different slip ratio conditions", ***Wear***, 366: 13-26, (2016).

[4] Bower A. F., & Johnson K. L., "Shakedown, residual stress and plastic flow in repeated wheel-rail contact", Rail Quality and Maintenance for Modern Railway Operation: ***International Conference on Rail Quality and Maintenance for Modern Railway Operation Delft June 1992, Springer Netherlands***, 239-249, (1993).

[5] Nikas D., Zhang X., & Ahlström J., "Evaluation of local strength via microstructural quantification in a pearlitic rail steel deformed by simultaneous compression and torsion", ***Materials Science and Engineering: A,*** 737: 341-347, (2018).

[6] Altuntaş O., Güral A., & Tekeli S., "Microstructure engineering for superior wear and impact toughness strength of hypereutectoid powder metallurgy steel", ***Powder Metallurgy***, 65: 101-111, (2022).

[7] Adamczyk-Cieślak B., "Low-cycle fatigue behaviour and microstructural evolution of pearlitic and bainitic steels", ***Materials Science and Engineering: A***, 747: 144-153, (2019).

[8] Muniz-Mangas M., "Welding of carbide-free bainitic steels for railway applications", ***Doctoral dissertation, University of Sheffield***, (2021).

[9] Pacyna J., "The microstructure and properties of the new bainitic rail steels", ***Journal of Achievements in Materials and Manufacturing Engineering***, 28: 19-22, (2008).

[10] Messaadi M., Oomen M., & Kumar A., "Friction modifiers effects on tribological behaviour of bainitic rail steels", ***Tribology International***, 140: 105857, (2019).

[11] Jabłońska M., Lewandowski F., Chmiela B., & Gronostajski Z., "Advanced heat treatment of pearlitic rail steel", ***Materials***, 16: 6430, (2023).

[12] Altuntaş G., Altuntaş O., & Bostan B., "Evaluation of the Effect of Shallow Cryogenic Treatment on Tribological Properties and Microstructure of High Manganese Steel", ***International Journal of Metalcasting***, 18: 1523-1534, (2024).

[13] Wang K. K., Gu K. X., Miao J. H., Weng Z. J., Wang J. J., Tan Z. L., & Bai B. Z., "Toughening optimization on a low carbon steel by a novel quenching-partitioning-cryogenic-tempering treatment", ***Materials Science and Engineering: A***, 743: 259-264, (2019).

[14] Liu, W., Jiang, Y. H., Guo, H., Zhang, Y., Zhao, A. M., & Huang, Y., "Mechanical properties and wear resistance

of ultrafine bainitic steel under low austempering temperature." ***International Journal of Minerals, Metallurgy and Materials***, 27, 483-493., (2020).

[15] Hasan, S. M., Chakrabarti, D., & Singh, S. B., "Dry rolling/sliding wear behaviour of pearlitic rail and newly developed carbide-free bainitic rail steels." ***Wear***, 408, 151-159., (2018).

[16] Zhao, J., Lv, B., Zhang, F., Yang, Z., Qian, L., Chen, C., & Long, X., "Effects of austempering temperature on bainitic microstructure and mechanical properties of a high-C high-Si steel." ***Materials Science and Engineering: A***, 742, 179-189. (2019).

[17] Aglan H. A., et al., "Mechanical and fracture behavior of bainitic rail steel", ***Journal of Materials Processing Technology,*** 151: 268-274, (2004).

[18] Wang Y., Zhang Y., Song R., Huang L., & Pei Y., "Effect of the austenitizing temperature on microstructure evolution and impact toughness of a novel bainite ductile iron", ***Metals and Materials International***, 27: 4014-4022, (2021).

[19] Zhang T., et al., "Effects of deep cryogenic treatment on the microstructure and mechanical properties of an ultrahigh-strength TRIP-aided bainitic steel"***, Materials Characterization,*** 178: 111247, (2021).

[20] Hasan S. M., et al., "Development of continuously cooled low-carbon, low-alloy, high strength carbide-free bainitic rail steels", ***Materials Science and Engineering: A***, 771: 138590, (2020).

[21] Wang Y., et al., "A new effect of retained austenite on ductility enhancement in high strength bainitic steel", ***Materials Science and Engineering: A***, 552: 288-294, (2012).

[22] Arabaci, U., & Turan, Ş., "Weldability of austempered rail steel using the flash-butt process." ***Materials Testing***, 63(7), 662-667., (2021).

[23] Yang, J., Wang, T. S., Zhang, B., & Zhang, F. C. "Microstructure and mechanical properties of high-carbon Si–Al-rich steel by low-temperature austempering." ***Materials & Design***, 35, 170-174., (2012).

[24] Zhang, F. C., Wang, T. S., Zhang, P., Zheng, C. L., Lv, B., Zhang, M., & Zheng, Y. Z. "A novel method for the development of a low-temperature bainitic microstructure in the surface layer of low-carbon steel." ***Scripta Materialia***, 59(3), 294-296., (2008).

[25] Altuntaş O., et al., "Investigation of the microstructure, hardness and electrical conductivity properties of Fe/Graphene compacts", ***Materials Science and Technology***, 39: 2670-2679, (2023).

[26] Podder A. S., & Bhadeshia H. K. D. H., "Thermal stability of austenite retained in bainitic steels", ***Materials Science and Engineering: A***, 527: 2121-2128, (2010).

[27] Srijampan, W., Wiengmoon, A., Wanalerkngam, A., Boonmee, S., Yotkaew, T., Tosangthum, N., & Tongsri, R., "Identification of carbides and phase transformations in sintered Fe–Mo–Mn–C alloys produced under a slow continuous cooling." ***ISIJ International***, 62(11), 2366-2373., (2022).

[28] Liu, X., Man, T. H., Yin, J., Lu, X., Guo, S. Q., Ohmura, T., & Ping, D. H., "In situ heating TEM observations on carbide formation and α-Fe recrystallization in twinned martensite. ***Scientific Reports***, 8(1), 14454., (2018).

[29] Ping, D. H., Xiang, H. P., Chen, H., Guo, L. L., Gao, K., & Lu, X., "A transition of ω-Fe3C→ ω′-Fe3C→ θ′-Fe3C in Fe-C martensite. ***Scientific Reports***, 10(1), 6081., (2020).