IMPACTS OF HEAT TREATMENT ON THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF 15%Cr-5%Ni-2%Cu MARTENSITIC STAINLESS STEEL

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Abstract

This study examines how the heat treatment parameters affect the strength and microstructures of 15%Cr-5%Ni-2%Cu martensitic stainless steel. A tempering range of 300-650°C in air cooling and quenching at 1050°C in oil cooling produced the tested specimens. Following heat treatments, optical and scanning electron microscopes, X-ray diffraction analyses, hardness measurements, and tensile testing were used to examine mechanical properties and microstructure. The findings demonstrated that the impact of heat treatment, particularly tempering temperature, on the microstructure and mechanical properties of martensitic stainless steel has been studied. As the tempering temperature rose, the steel's hardness and tensile strength declined. The ductility may be significantly enhanced by raising the tempering temperature. The property was thought to be associated with the microstructure of reversed austenite and tempered lath martensite. A more incredible reversed austenite amount facilitates the increased ductility of martensitic stainless steel.

Keywords: *Martensite stainless steels; reversed austenite; phase transformation; heat treatment.*

1. Introduction

The mechanical, weldable, hot workable, and corrosion-resistant qualities of martensitic stainless steel are all well-represented [1]-[4]. As a result, it has found extensive use in the petrochemical, hydroelectric, and offshore oil and gas sectors [1], [5], [6]. After heat treatments like quenching and tempering, the distinctive composite microstructure of martensitic stainless steel determines its exceptional comprehensive mechanical characteristics [6], [7]. Their process usually entails quenching the austenite field to produce a martensitic structure, followed by a tempering treatment where precipitation takes place to provide them great strength, excellent toughness, and corrosion resistance [8]-[11].

Heat treatment of martensitic stainless steel has been the topic of several research [1], [3], [5]. The impact of the heat treatment regime on the structure and

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properties of Fe-16%Cr-5%Ni super martensite stainless steel was investigated by Song *et al.* [1]. The super martensite stainless steels were tempered at 480°C and 700°C for 60 minutes, then allowed to cool to room temperature by air before being oil-quenched after being held at 1100°C for 60 minutes in a muffle furnace. The findings demonstrate that the heat treatment conditions significantly impact steel's structural and mechanical characteristics. While tempering at 620°C produced the finest plasticity of the samples, tempering at 540°C gave a good mix of strength and toughness. Zou *et al.* looked at how the heat treatment method affected the mechanical characteristics and microstructural changes of 00Cr13Ni4Mo super martensitic stainless steel [5]. After a one-hour solution treatment at 1040°C, the specimens were left to cool to ambient temperature. After three hours of tempering in the 520-720°C range, the specimens were allowed to cool naturally. An ideal tempering temperature was then selected to extend the holding duration from three to twelve hours. The findings showed that quenching at 1040°C for one hour in water cooling and tempering at 600°C for three hours in air cooling produced the best mechanical properties. Increasing the isothermal tempering time may significantly increase the toughness.

This study investigated the impacts of heat treatment on the mechanical properties and microstructure of 15%Cr-5%Ni-2%Cu martensitic stainless steel. The link between microstructure and mechanical characteristics and the effect of tempering temperature on microstructure evolution were covered in detail.

2. Experimental methods

After melting from pure metals with purity above 99.9% in a vacuum induction furnace with high-quality argon, the 15%Cr-5%Ni-2%Cu martensitic stainless steel is cast into rods. Table 1 lists its chemical composition.

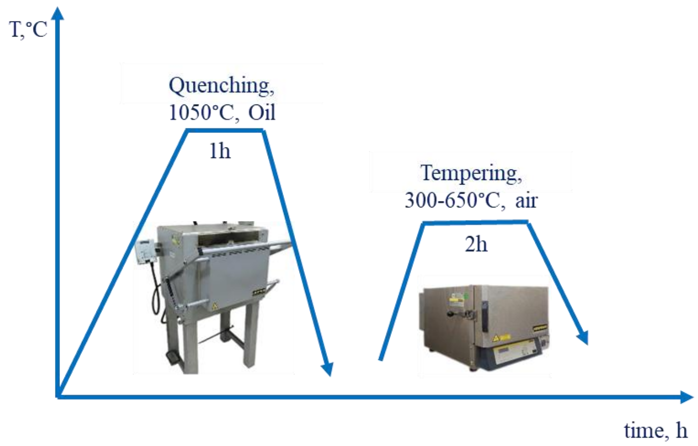

Fig. 1. Schematic diagram of heat treatment of 15%Cr-5%Ni martensitic stainless steel.

Figure 1 has previously detailed the heat treatment processing procedure of 10 × 8 × 10 mm rods [1], [6], [11]. Following an oil quenching process at 1050°C, the samples were heat-treated by tempering them between 300°C and 650°C. The steel microstructure is examined using the Axiovert 25ca microscope at Le Quy Don Technical University's Department of Materials Science and Engineering, while their hardness is measured using the Vicker Wilson Werlport hardness tester. At the Institute of Technology's Mechanics Laboratory, the Devotrans tensile testing machine tests the tensile test samples. The tensile test samples have standard dimensions, as shown in Fig. 2. The microstructures of martensitic stainless steel were further examined using a field-emission electron microscope (FESEM Hitachi S-4800, Japan). The steel structural characterization was investigated using X-ray diffraction (XRD, Bruker, D5005, USA).

Tab. 1. Chemical composition of experimental 15%Cr-5%Ni-2%Cu martensitic stainless steel

Name	**Chemical composition**							
	C	**Cr**	**Ni**	**Cu**	**Al**	**P**	**S**	**Fe**
Sample	0.087	14.85	5.07	1.79	0.0198	< 0.002	< 0.001	Bal.

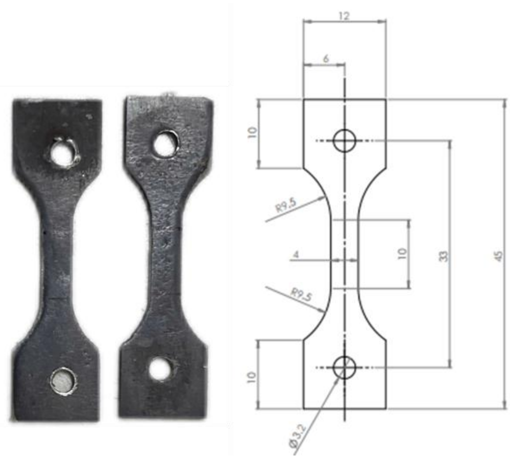

Fig. 2. Tensile test samples.

3. Results and discussion

3.1. The impact of heat treatment processing on microstructure and phase structure

Figure 3 displayed optical microscopy images of samples under various heat treatment processing conditions. In the quenching sample (Fig. 3a), the microstructure of martensitic stainless steels is composed of retained austenite, carbides, and lath martensite. Austenite contrasts brighter with martensite in the micrographs. Retained austenite, reversed austenite, carbides, and lath martensite are the microstructure components of martensitic stainless steels in the tempering sample (Fig. 3b). Varying sizes and densities of lath were present in the martensite. Lath size and density are more significant at the quenching state because the martensite proportion rises, and the austenite grains scattered throughout the microstructure decrease [12].

The XRD patterns of the samples following quenching and tempering are shown in Fig. 4. Since only BCC peaks were seen, it is clear that complete martensite was produced in the quenching sample. One possible explanation for the lack of peaks in the other phases is that the concentration was too low to show a peak. On the other hand, when tempered at 600°C, significant FCC peaks are seen, confirming that some reversed austenite has developed below the A_{c1} temperature and remained at ambient temperature. These findings were entirely in line with previous studies [1], [3].

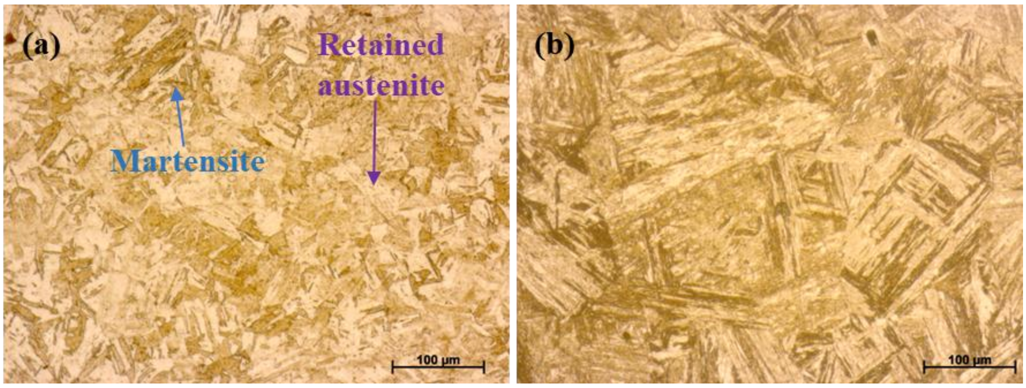

Fig. 3. Optical microscopy image of samples:
a) Quenching at 1050°C, b) tempering at 600°C.

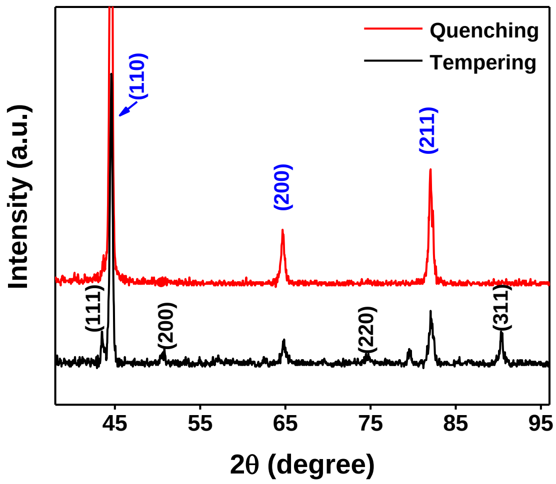

Fig. 4. XRD results of samples at various conditions of heat treatment processing.

3.2. The impact of tempering temperature on microstructure and mechanical properties

Figure 5 shows the microstructure optical microscope images of the tempered steel samples. Martensitic stainless steels often have a tempered microstructure of residual austenite, carbides, and tempered martensite. Austenite may be retained in the space between the martensite laths. The size of the lath martensite increases as the tempering temperature rises.

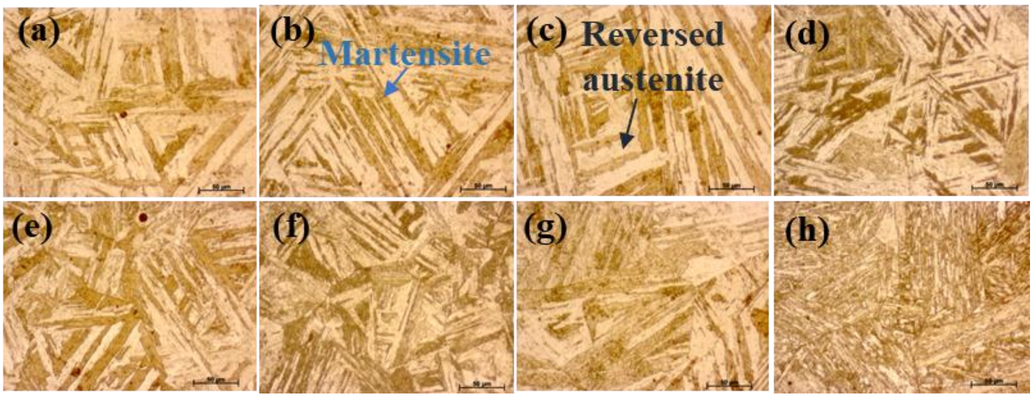

Fig. 5. Optical microscopy image of samples at different tempering temperatures: a) 300°C, b) 350°C, c) 400°C, d) 450°C, e) 500°C, f) 550°C, g) 600°C, h) 650°C.

The SEM is used to observe the carbides in the martensite steel, and the results are presented in Fig. 6. Small white particles characterize the carbides. The formation of stable carbide $M_{23}C_6$ in the high-temperature tempering seen in this study is consistent with findings from previous studies [10].

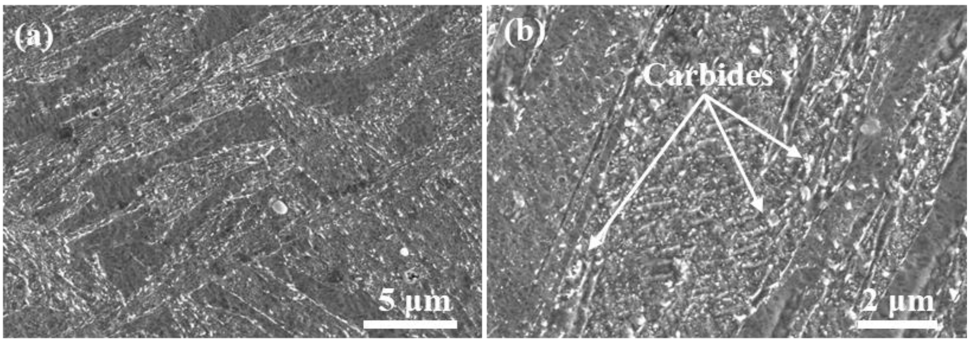

Fig. 6. SEM image of samples at the tempering temperature of 600°C.

The correlation between tempering temperature and average Vickers hardness was displayed in Fig. 7. As the tempering temperature increased from 300°C to 600°C, the corresponding hardness decreased gradually from 353 HV to at least 280 HV. The hardness progressively recovered to 283 HV when the sample was tempered at 650°C. It is commonly known that the purpose of tempering martensitic stainless steel is to promote the precipitation of carbides and relax as-quenched hard martensite.

The diffusion of the elements, which depends on temperature and time, is closely linked to these processes. High temperatures can cause the martensite to relax more quickly, the carbides to change into stable $M_{23}C_6$, and the structures to coarsen, which lowers the steel's hardness to a low value. The retransformation of reversed austenite into fresh martensite at 650°C causes a little increase in hardness.

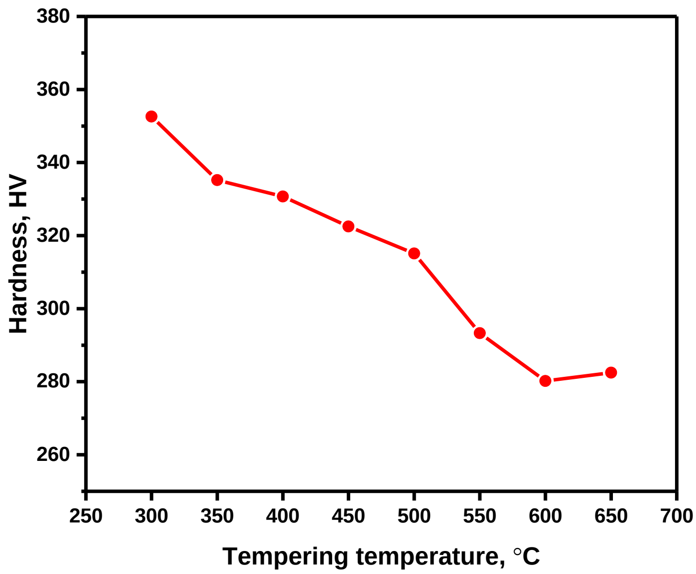

Fig. 7. Hardness of samples as a function of tempering temperatures.

Tab. 2. Tensile strength results of samples tempered at 400°C and 600°C

Sample	**Tensile strength, MPa**	**Yield strength, MPa**	**Elongation, %**
400°C	902	762	20
600°C	752	692	28

Table 2 shows the results of the tensile tests performed on samples that were tempered at 400°C and 600°C. The elongation reached a high value of 20% at the tempering temperature of 400°C, while the yield strength and ultimate tensile strength were around 762 MPa and 902 MPa, respectively. However, the elongation increased when the tempering temperature rose, but the YS and UTS declined. The elongation reached a high value of 28% at the tempering temperature of 600°C, while the yield strength and ultimate tensile strength were around 692 MPa and 752 MPa, respectively. These findings are pretty comparable to those reported in [3], which demonstrated that the Fe–13%Cr–4%Ni–Mo steel had a yield strength of 650 MPa, a tensile strength of 750 MPa, and an elongation of 20% following tempering at 600°C. This indicates that while the steel retains its high strength, reversed austenite at high-tempering temperatures positively affects ductility. The observed coarsening of the carbides and the growth in lath martensite size may be related to the martensitic stainless steel's diminishing strength as the tempering temperature rises [10].

4. Conclusion

The impact of heat treatment, particularly tempering temperature, on the microstructure and mechanical characteristics of martensitic stainless steel has been studied. The steel's tensile strength and hardness declined as the tempering temperature rose. The steels' hardness levels varied from 353 HV for tempering at 300°C to 280 HV for tempering at 600°C. The tensile characteristics varied from 902 MPa of tensile strength and 20% elongation at 400°C to 752 MPa of tensile strength and 28% elongation at 600°C. While the presence of reversed austenite at high tempering temperatures has a positive impact on ductility, the observed coarsening of the carbides and increasing size of the lath martensite may be related to the decreasing strength of martensitic stainless steels as the tempering temperature rises. This study provides important insights for industrial applications by highlighting how crucial it is to regulate heat treatment conditions to maximize the mechanical characteristics of martensitic stainless steel.

Acknowledgment

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ẢNH HƯỞNG CỦA CHẾ ĐỘ XỬ LÝ NHIỆT TỚI TỔ CHỨC VÀ CƠ TÍNH CỦA THÉP KHÔNG GỈ MACTENXIT 15%Cr-5%Ni-2%Cu

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Tóm tắt: Bài báo trình bày việc nghiên cứu ảnh hưởng của chế độ nhiệt luyện đến tổ chức và cơ tính của thép không gỉ mactenxit 15%Cr-5%Ni. Mẫu thép không gỉ được tôi ở 1050°C trong dầu và sau đó được ram từ 300-650°C trong không khí. Mẫu sau khi xử lý nhiệt được tiến hành kiểm tra tổ chức và cơ tính trên các thiết bị kính hiển vi quang học và điện tử quét, phân tích nhiễu xạ tia X, đo độ cứng và thử nghiệm kéo. Kết quả cho thấy rằng chế độ xử lý nhiệt, đặc biệt là nhiệt độ ram, ảnh hưởng mạnh tới tổ chức và cơ tính của thép không gỉ mactenxit. Khi nhiệt độ ram tăng, độ cứng và độ bền kéo của thép giảm. Độ dẻo có thể được cải thiện đáng kể bằng cách nâng cao nhiệt độ ram. Đặc điểm này liên quan đến tổ chức austenit chuyển biến ngược và mactenxit ram. Số lượng austenit chuyển biến ngược càng nhiều thì càng làm tăng độ dẻo của thép không gỉ mactenxit sau ram.

Từ khóa: *Thép không gỉ mactenxit; austenit chuyển biến ngược; chuyển pha; nhiệt luyện.*

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