Optimizing Heat Treatment Process of Fe-13Cr-3Mo-3Ni Martensitic Stainless of Steel

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Abstract. The Fe-13Cr-3Mo-3Ni stainless steels are modified into martensitic stainless steels for steam turbine blades application. The working temperature of steam turbine was around 600 – 700 °C. The improvement properties of turbine blade material is necessary to maintain steam turbine work. The previous research revealed that it has corrosion resistance of Fe-13Cr-3Mo-3Ni which is better than 13Cr stainless steels in the chloride environment. In this work, the effect of heat treatment on microstructure and hardness of Fe-13Cr-3Mo-3Ni stainless steels has been studied. The steel was prepared by induction melting followed by hot forging. The steels were austenitized at 1000, 1050, and 1100 °C for 1 hour and were tempered at 600, 650, and 700 °C for 1 hour. The steels were then subjected to metallographic observation and hardness test of Rockwell C. The optimal heat treatment of Fe-13Cr-3Mo-3Ni was carried out austenitized in 1050 °C and tempered in 600 – 700 °C.

Keywords: Fe-13Cr-3Mo-3Ni, martensitic, stainless steel, turbine blade, heat treatment.

1. Introduction

The development of materials for steam turbine blade is still a concern for the researcher. They need the best mechanical and physical development to achieve high-efficiency turbine work to result in electrical power. The resistance to wear, fatigue, and corrosion is a property that has to be available in the steam turbine blade materials. However, the failure phenomenon still occurs on the steam turbine blade caused by lack of their properties [1-4]. Some of the efforts to minimize failure of turbine blade materials are the alloying process followed by heat treatment, maintaining service condition in the normal stage without fluctuating loads, low corrosive environment, and temperature stabilization [5].

The martensitic stainless steel is preferred to steam turbine blade application because it is hardenable by heat treatment. Since the first patent claim in 1912 [6], the several studies for martensitic stainless steel are still conducted until present. Liu Yu-Rong et al. [7] and Bojack A et al. [8] have been studying the influence of heat treatment of 13Cr super martensitic stainless steel on the austenite formation with a nickel content of 4 – 6 wt% and molybdenum content of 2 wt%. Liu Y. et al. [9] have been studying the effect of heat treatment of AISI 431 martensitic stainless steel on the microstructure and tensile properties. Refer to these previous studies, the heat treatment process on the martensitic stainless steel can rise retained austenite that disperses in the martensitic microstructure. It can enhance the mechanical and physical properties of this steel. However, the increasing temperature of heat treatment also can decrease the hardness of blade materials [10]. In this study, the optimizing heat treatment process of 13Cr martensitic stainless steel containing 3 wt% Ni and Mo has been investigated.
2. Experimental Method
In the study, the material was Fe-13Cr-3Mo-3Ni martensitic stainless steel prepared in an electric induction furnace to carry out melting process. Then, the liquid metal was cast in the mold of 5 x 5 x 10 cm. Liquid metal became ingot in the solid phase in the several times. The ingot was carried out hot forged at the initial temperature of 1125 °C to achieve ingot cross section size around 3 x 3 cm². After the forging process, the specimen was cut into 1 cm in thickness for chemical composition test by using OES (optical emission spectrometer) instrument. The chemical composition of Fe-13Cr-3Mo-3Ni steel (in weight percent) is 0.1 C, 0.61 Mn, 0.24 Si, 12.73 Cr, 2.93 Ni, 2.52 Mo and balance Fe.

The specimen was conducted austenitizing process at 1000, 1050, 1100 °C for 60 min and quenching in the oil. Then, austenitizing alloy steel was tempered at 600, 650, 700 °C for 60 min and followed by air cooling to room temperature. The heat treated alloy steel was prepared to metallographic test by using optical microscopy, which Kalling reagent as an etchant solution. Hardness was measured with a Rockwell C hardness (HRC) tester with a load of 150 kgf and a diamond of 120° in angle as an indentor. HRC hardness test was measured six times and averaged.

3. Results and discussion
3.1. Microstructure analysis
3.1.1. Tempering at 600 °C. Figure 1a – c shows the microstructure of Fe-13Cr-3Mo-3Ni steel austenitizing at 1000, 1050, and 1100 °C followed by tempering at 600 °C.

![Microstructure images](image-url)

Figure 1. Microstructure of Fe-13Cr-3Mo-3Ni austenitizing at (a) 1000 °C, (b) 1050 °C, (c) 1100 °C followed by tempering at 600 °C, in magnification of 200X
The tempered martensite and carbide are found in the microstructure. After tempering at 600 °C, the Fe-13Cr-3Mo-3Ni steel of the austenitizing of 1100 °C has a lower growth of tempered martensite and much reversed austenite formed in the microstructure when compared with Fe-13Cr-3Mo-3Ni steel in the austenitizing of 1000 and 1050 °C. Refer to the previous study [9], the shape of carbide of Fe-13Cr-3Mo-3Ni steel shows irregular circle that precipitates in the martensitic microstructure. The tempered martensite and carbide were also found in the previous study [11].

3.1.2. Tempering at 650 °C. Figure 2a – c shows the microstructure of Fe-13Cr-3Mo-3Ni steel austenitizing at 1000, 1050, and 1100 °C followed by tempering at 650 °C. The tempered martensite is found almost fully in the microstructure. It means that the transformation of the reverse austenite easily becomes martensite after tempering at 650 °C in the various austenitizing temperature. The carbide also precipitates in the martensitic microstructure.

![Microstructure of Fe-13Cr-3Mo-3Ni steel](image1)

3.1.3. Tempering at 700 °C. Figure 3a– c shows the microstructure of Fe-13Cr-3Mo-3Ni steel austenitizing at 1000, 1050, and 1100 °C followed by tempering at 700 °C. After tempering at 700 °C, the Fe-13Cr-3Mo-3Ni steel in the austenitizing of 1050 °C has a higher growth of tempered martensite when compared with Fe-13Cr-3Mo-3Ni steel in the austenitizing of 1000 and 1100 °C. It means that the transformation of the reverse austenite is more easily become martensite after tempering at 700 °C followed by cooling in the austenitizing of 1050 °C. The microstructure of Fe-13Cr-3Mo-3Ni steel austenitizing at 1050 °C followed by tempering at 700 °C in the Figure 3b is different with the others. The growth of their tempered martensite is more coarse when compared with the microstructure of Fe-13Cr-3Mo-3Ni steel austenitizing at 1000, and 1100 °C. It is probably the higher temperature tempering applied in the Fe-13Cr-3Mo-3Ni steel.
3.2. **HRC hardness analysis**

Figure 4 shows the change of HRC hardness at various austenitized and tempering temperatures. The HRC hardness decreases at all austenitized and tempering temperatures. It notices that the higher temperature of tempering process can decrease fragile nature of Fe-13Cr-3Mo-3Ni steel, but increase their ductility and toughness [12]. This steel becomes softener because the carbide starts coarsen and martensite becomes less tetragonal [13]. It is confirmed in the Figure 1–3.
Figure 4. HRC hardness at various austenitized and tempering temperatures

Table 1 shows the HRC hardness loss percentage. The lowest HRC hardness loss percentage was found on the Fe-13Cr-3Mo-3Ni steel when it carried out austenitized in the temperature of 1050 °C and tempering in the temperature of 650 – 700 °C. It means that this steel can be used as turbine blade material in the steam turbine’s work in the temperature of 600 – 700 °C; their hardness will be almost stable. Also, the wear and fatigue resistance properties of this steel are better when compared with Fe-13Cr-3Mo-3Ni steel austenitized in 1000 and 1100 °C and tempered in 600 – 700 °C. It implies that the optimal heat treatment of Fe-13Cr-3Mo-3Ni was carried out austenitized in 1050 °C and tempered in 600 – 700 °C.

| Tempering Temperature (°C) | Austenitized Temperature (°C) |
|---------------------------|-------------------------------|
| 600                       | 1000                          | 1050  | 1100          |
|                           | 0                             | 0     | 0              |
| 650                       | 7.81                          | 2.8   | 13.81          |
| 700                       | 22.82                         | 4.44  | 21.9           |

4. Conclusion
Refer to results and discussion, the conclusions comprise that the 13Cr martensitic stainless steel containing 3 wt% Ni and Mo (Fe-13Cr-3Mo-3Ni) can be used as turbine blade material in the steam turbine’s work in the temperature of 600 – 700 °C. The heat treatment process of Fe-13Cr-3Mo-3Ni exhibits tempered martensite and carbide in the microstructure. The increment of tempering temperature at the various austenitization temperature can effect on the coarser of tempered martensite microstructure and hardness Rockwell C (HRC) of the Fe-13Cr-3Mo-3Ni steel. The lowest HRC hardness loss percentage was found on the Fe-13Cr-3Mo-3Ni steel when austenitized temperature was 1050 °C at tempering temperature of 650 – 700 °C. The optimal heat treatment of Fe-13Cr-3Mo-3Ni was carried out austenitized in 1050 °C and tempered in 600 – 700 °C.

5. References
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