The Hardness and Microstructure of The Modified 13Cr Steam Turbine Blade Steel in Tempered Conditions

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***Abstract*—Martensitic stainless steels were usually used for turbine blade. Their properties can be improved in various ways, such as by heat treatment. This paper reports the influences of tempering temperature on hardness and microstructure of the modified 13Cr martensitic stainless steels. Samples were austenitized at 1050°C and tempered at 300, 400, 500, 550, 600, 650, and 700ºC. Hardness measurement was conducted by Rockwell C indentation and metallographic observation was conducted by scanning electron microscope (SEM). The results show that increasing tempering temperature until 500°C can improve hardness. The microstructure formed consists of tempered martensite containing carbides $M_{23}C_6$. The presence of carbides can also increasing hardness. Increasing tempering temperaturefrom 500°C to 650°C can decrease Cr content of carbide.**

Keyword-Steam turbine blade, Martensitic stainless steel, Carbide

I. INTRODUCTION

Martensitic stainless steels were commonly used for manufacturing component due to their high mechanical properties and moderate corrosion resistance, operating at either high or low temperature. Due to their properties could be improved by heat treatment, these steels are suitable for various application such as turbine blade [1]–[3]. However, the failure of the blade frequently found in service due to mechanical and environmental interaction which operated in turbine system. Furthermore, almost 50% the failures of turbine blade are related to fatigue, pitting corrosion, stress corrosion cracking, and corrosion fatigue [4].

The mechanical properties and corrosion resistance of martensitic stainless steels depend on chemical composition and heat treatment. Heat treatment process of these steels commonly involved solid-solution treatment (ausenitizing) to form an austenite structure, and dissolving carbides, followed by cooling or quenching to transform austenite into martensite structure, and then followed by tempering to obtain carbide precipitation [5]. The amount of carbide can affect mechanical properties and corrosion resistance in this material. The presence of retained austenite may affect wear resistance, fatigue properties, and ductility [6].

The addition of small increase Molybdenum (Mo) and Nickel (Ni) in stainless steel can contribute to increase corrosion resistance. Mo is particularly effective to increase corrosion resistance, but only in presence of Chromium (Cr). Various explanations have been reported for the effect of Mo to increase corrosion resistance [7, 8]. The modified 13Cr martensitic stainless steel containing Ni and Mo are being developed in our laboratory [9]. This study reports on the hardness and microstructure of the modified 13Cr3Ni3Mo martensitic stainless steel with respect to tempering temperature.

II. EXPERIMENTAL PROCEDURE

The modified 13Cr martensitic stainless steel ingot was prepared in electric induction furnace. The ingots of 5x5x10 cm in dimension were hot forged at around 900-1100°C until the dimension of the ingots decreased to about 12x6x2 cm. The square specimens of 1 cm^2 in thickness were cut from forged alloys for chemical composition test using Optical Emission Spectrometer (OES). The chemical composition of the alloys is presented in Table 1. The specimens were austenitized at 1050°C for 1 hour followed by oil quench to obtain martensite structure. Then, specimens were tempered at 300, 400, 500, 550, 600, 650, and 700°C for 1 hour. Rockwell hardness measured on all heat treated samples using hardness Rockwell C scale with load 150 kgf at room temperature. For metallographic test samples were polished and etched using kalling's reagent, then examined using scanning electron microscope (SEM). Energy dispersive X-ray spectroscopy (EDS) analysis was utilized to identify carbides during tempering.

TABLE I. Chemical composition in %wt of the modified 13Cr martensitic stainless steel in this study

Steel Type	C	S	P	Mn	Si	Cr	Mo	Ni	Fe
13Cr3Mo3Ni	0.10	0.005	0.02	0.61	0.24	12.73	2.52	2.93	Bal.

III. RESULTS AND DISCUSSION

The effect of tempering temperature of the 13Cr modified martensitic stainless steel on hardness value is shown in Fig.1. As seen, hardness decreased from as-quenched until tempering temperature at 400°C. The initial drop in hardness is due to precipitation of M3C which causes softening of the martensite because of the carbon depletion [10]. Hardness was almost constant for tempering temperature 500 to 600°C. It can be observed from Fig.1 that the highest hardness of 13Cr3Ni3Mo martensitic stainless steel in temper condition is 50.6 HRC at 500°C. Hardness increase in the range of tempering temperature 400 to 500°C. The increasing of hardness in the range of 400 to 500°C can be attributed to secondary hardening phenomenon. This phenomenon can be related to formation of M_7C_3 carbides within the martensite lath. It can be also seen in Fig.1 that hardness decrease with the increase at tempering temperature in range 500 to 700°C. It can occur due to the M_7C_3 carbides started to coarsen and partially transform to $M_{23}C_6$ carbides [1]. The reason for variation in properties can be attributed to combined effect of (i) hardening: due to transformation of retained austenite and formation of fine precipitates; and (ii) softening: due to reduction in internal stresses, decrease in dislocation density within martensite lath, and formation of reversed austenite as described in other report [11]. The increase hardness of the modified 13Cr stainless steel is also due to presence of tempered martensite. While tempering at higher temperatures, quenched martensite formed while solution annealing starts softening which leads to elimination of internal stresses, decrease in dislocation density, and occurrence of retained austenite [12].

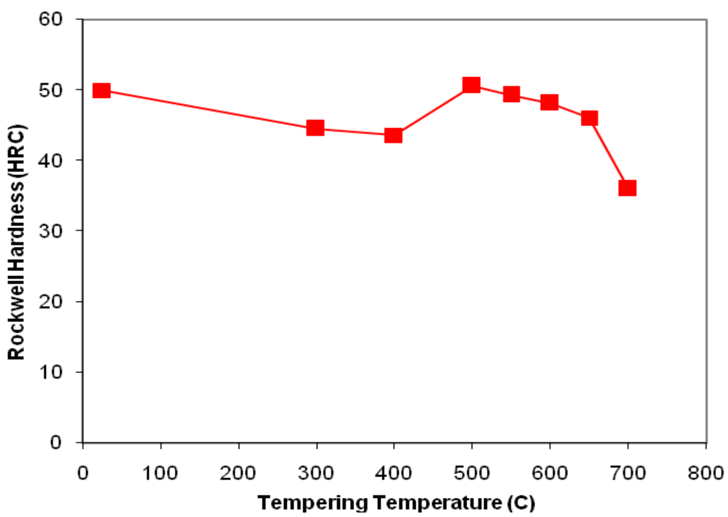

Fig 1. The hardness of the modified 13Cr martensitic stainless steel at various tempering temperature.

Fig. 2 shows SEM microstructure of various tempering temperature at as-quenched, 400, 500, and 650°C. It can be observed that the microstructure of tempered stainless steel generally contain martensite lath, and carbide. Carbide formed at tempering temperature of 400°C is not so clear to see. However, when tempering temperature reach 500 and 650°C carbide are so clear. The EDS analysis of carbide on the modified 13Cr martensitic stainless steel shows the dominant peak of Cr and Fe. For Mo show small peak compared with the others, but higher than the steel matrix (Fig. 3). Table 2 shows chromium content for both tempering temperature is about 30-34% Cr that can be defined as $M_{23}C_6$ carbide. The formation of carbide $M_{23}C_6$ at tempering temperature 500°C has been investigated [13]. At low tempering temperature, the formation of carbide is unstable M_3C that will be transformed into stable carbide M_7C_3 and $M_{23}C_6$ at higher temperatures. These transformations could contribute to the secondary hardening, before the final softening produced by the coarsening of the most stable carbides [10].

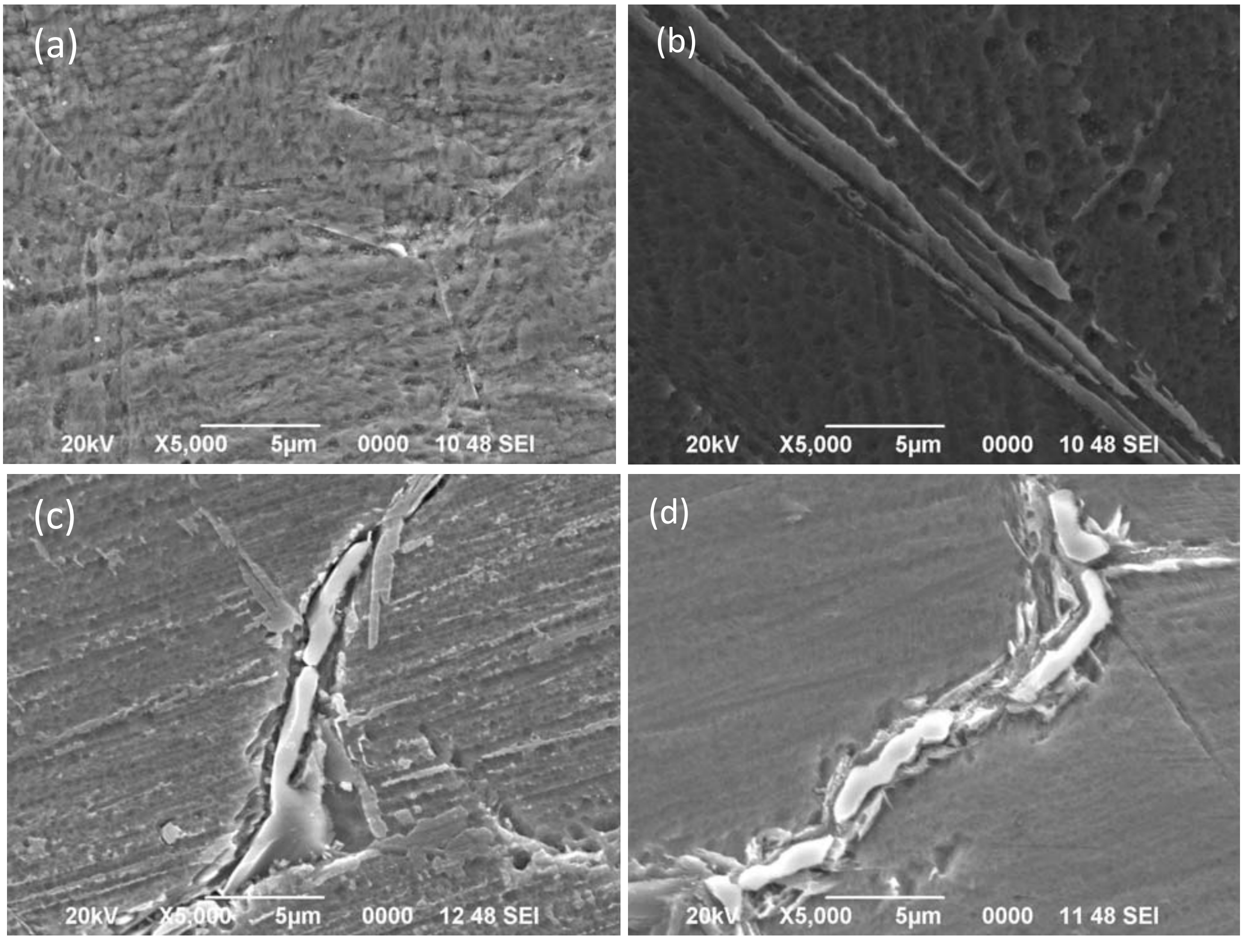

Fig. 2 SEM micrograph of specimens tempered at (a) as-quenched, (b) 400°C, (c) 500°C, and (d) 650°C.

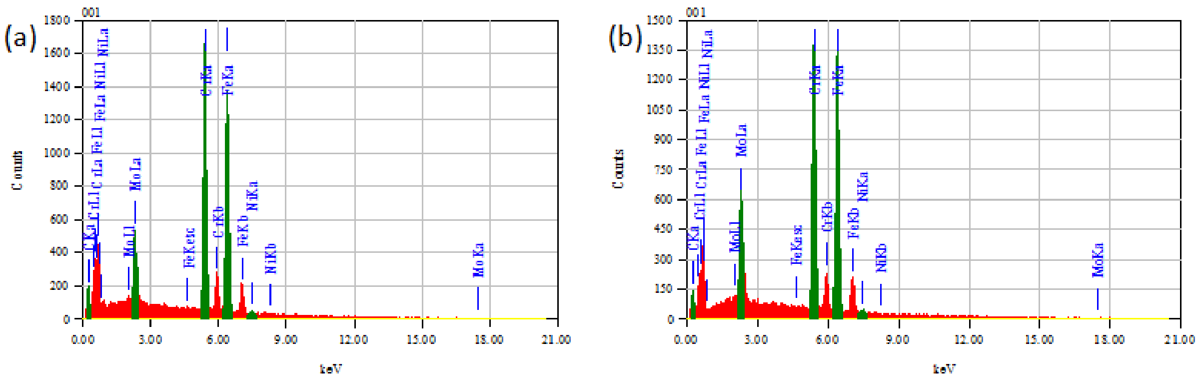

Fig. 3 EDS analysis of specimens tempered at (a) 500°C, (b) 650°C.

The addition of Mo in the modified 13Cr martensitic stainless steel can be attributed to increase δ-ferrite phase content into microstructure. However, δ-ferrite phase content can be decreased by the addition of Ni into the steel. The formation of δ-ferrite in the 13Cr modified martensitic stainless steel have been investigated in previous report [14].

TABLE II. Chemical compositions of carbide in the modified 13Cr martensitic stainless steel at various tempering temperature

Temperature (°C)	C	Cr	Mo	Ni	Fe
500	5.8	34.90	9.23	1.45	48.62
650	4.93	30.95	11.04	0.73	52.34

IV. CONCLUSION

The tempering temperature could strongly affect the hardness and microstructure of the modified 13Cr martensitic stainless steel. Increasing tempering temperature can improve the hardness of modified 13Cr martensitic stainless steel. The highest hardness obtained at 500°C. Increase hardness can be attribute to formation of precipitation carbide $M_{23}C_6$ into microstructure. Increasing tempering temperature from 500 to 650°C can decreased Cr content on carbide and increase Mo content on carbide.

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