Investigation of corrosion rate on the modified 410 martensitic stainless steel in tempered condition

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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 and holding time in various concentration and temperature of NaCl solution on corrosion rate of the modified 13Cr martensitic stainless steels. Samples were austenitized at 1050°C for 1 hour followed by oil quenching. The austenitized sample were tempered at 600°C, 650°C, and 700°C for 1, 3, and 6 hours. All tempered specimens were immersed in 20% NaCl concentration for 120 hours and tempered specimen at 700°C for 6h was prepared for another corrosion test. Samples were immersed in different concentration of NaCl solution 3.5%; 10%; and 20% at room temperature, 60°C, and 80°C. Increasing temperature and concentration of solution will lead to corrosion rate increased. However, corrosion rate slightly decreases at higher temperature due to dissolved oxygen was decreased.

1. Introduction

Low pressure steam turbines (LPSTs) are used as the terminal energy extraction devices in steam cycle systems, such as those that exist in thermal power plants (nuclear and fossil fuelled). The steels used in fabricating the disks/rotors and the turbine blades are commonly AISI Type 403 SS (Fe13Cr martensitic stainless steel), with the latter being chosen primarily because of its advantageous vibrational mechanical damping characteristics [1,2]. However, it is often found failure due to mechanical combination with corrosion due to turbine blades working at high rotation and corrosive environment of the main mechanism of pitting corrosion, corrosion fatigue (CF) and corrosion cracking (stress corrosion cracking / SCC) [3,4].

Martensitic stainless steels are generally heat treated to provide moderate corrosion resistance and a good combination of mechanical properties. This often involves an austenitizing heat treatment followed by air or fan quenching. It is well known that tempering of the as-quenched martensitic steel can bring about secondary hardening when the softening effect due to annealing is offset by the precipitation of alloy carbides in the material [5]. The precipitation and coarsening of secondary phases during heat treatment including austenitizing, quenching and tempering, are then a key point to obtain the desirable microstructure and, hence, to achieve high temperature properties under such serious severe condition [6]. Depending on the composition and processing history, the microstructure of martensitic stainless
steel consists of martensite, undissolved carbides as well as precipitated carbides, retained austenite and δ-ferrite. It is well-known that properties obtained in these steels are strongly influenced by such treatments [7].

In recent years, new types of martensitic stainless steels can increase toughness and corrosion resistance for certain applications with the addition of minor alloys. The most widely used alloying elements consist of nitrogen (N) [8,9], nickel (Ni) [10], and molybdenum (Mo) [11,12]. Mo is particularly effective, but only in the presence of Cr. It was suggested that Mo acts by adsorbing on the surface as molybdate or by blocking active sites during active dissolution [13]. Previous research has been explained about the effect of addition Mo and Ni elements on mechanical properties and corrosion resistance [14–16]. The effects of austenization and tempering temperatures may also affect the mechanical properties and corrosion resistance of this type of stainless steel [17–19]. However, there has been no research on the corrosion rate in different temperature of the modified 13Cr3Mo3Ni martensitic stainless steels. Therefore, the aim of this study is to determine the corrosion rate after tempering that occurs in various concentrations and temperature of the solution.

2. Materials and method

2.1. Preparation and heat treatment

Material used in this study is stainless steel 13Cr3Mo3Ni ingot. The chemical composition is shown in Table 1. The material is then hot forged at a temperature range of 900 – 1100°C. Then, the sample was austenized at 1050ºC for 1 hour, followed by oil quenched. The austenized samples were then tempered at temperatures of 600ºC, 650ºC, and 700ºC with holding time for 1, 3, and 6 hours.

2.2. Corrosion Test

All tempered specimens were immersed in 20% NaCl for 120 hours. And tempered specimen at 700ºC with a holding time of 6 hours, were selected for corrosion test at various NaCl concentration and immersion time. The test specimen was immersed for 120 hours at a concentration variation of 3.5% NaCl solution; 10%; and 20% with temperature variations 60ºC, 80ºC, and room temperature.

Corrosion rate was calculated by weight loss method according to ASTM G1, with the following formula

\[ CR \text{ (mmpy)} = \frac{\Delta W \times K}{D \times A \times T} \]  

where \( \Delta W \) is the weight loss in grams, \( K \) is the constant (8.76x10^4), \( D \) is the metal density (g/cm^3), \( A \) is the area of the specimen (cm^2), and \( t \) is the exposure time (days).

3. Results and discussion

3.1. Corrosion Rate

Figure 1 shows the corrosion rate of the modified 410 martensitic stainless at various temperature and holding time. Figure 1 shows that corrosion rate decreases with increasing of tempering temperature and holding time.

Table 1. Chemical composition (% wt) the modified 410 martensitic stainless steel.

|        | C   | S  | P   | Mn  | Si  | Cr  | Mo  | Ni  |
|--------|-----|----|-----|-----|-----|-----|-----|-----|
|        | 0.10| 0.001 | 0.01 | 0.69 | 0.24 | 12.50 | 2.72 | 2.89 |

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Figure 1. Corrosion rate of the modified 410 martensitic stainless steel at various tempering temperatures and holding time.

Figure 2. Optical micrograph of pitting corrosion on the modified 410 martensitic stainless steel tempered at 600°C for 1 hour after immersion in 20% NaCl for 120 hours (magnification 500x).

The highest corrosion rate was obtained at tempering 600°C for 1 hour and the lowest corrosion rate was obtained at tempering 700°C for 6 hours. The decreasing corrosion rate could be attributed to chromium carbide precipitation. Dissolution of carbides in the matrix causing in more homogenous microstructure is an important factor in reduction of corrosion rate [20]. The dissolution of chromium carbide precipitation increases the contents of Cr and Mo, therefore the corrosion resistance enhanced [21]. The current density in both active and passive regions will decreases significantly with addition of Mo [22]. Figure 2 shows the microstructure on the modified 410 martensitic stainless steel tempered at
600°C for 1 hour after immersion in 20% NaCl for 120 hours. Visible pitting corrosion on the surface appears in dark contrast or contrast due to high oxygen content and there is a tendency to inter-granular corrosion. It is suggested that the chromium level in the affected area is reduced to below the critical value which is necessary for passivation, then the steel becomes sensitized to inter-granular corrosion [23].

Corrosion rate of the modified 410 martensitic stainless steel in various NaCl concentration and temperature is shown in Figure 3. The modified of tempered 410 martensitic stainless steel tempered at 700°C for 6 hours was chosen for corrosion test. As seen in Figure 3, the curve showed that corrosion rate increases as increasing NaCl concentration and temperature operation. The minimum value of corrosion rate is 0.198 mmpy that was obtained in 3.5% NaCl concentration at room temperature and the maximum is 1.335 mmpy that was obtained in 20% NaCl concentration at 80°C.

![Figure 3. Corrosion rate of the modified 410 martensitic stainless steel tempered sample at 700°C for 6 hours in various NaCl concentration and temperature.](image-url)

Temperature of the process plays an important role to accelerate corrosion rate of metals. Increasing temperature will lead to higher corrosion rate. Dissolved oxygen in the solution will increase as the temperature in the solution is rising. The rate of oxygen diffusion increases with increasing temperature [24]. When corrosion is controlled by diffusion of oxygen, the corrosion rate at a given oxygen concentration approximately doubles for every 30°C rise in temperature [25]. In an open vessel, allowing dissolved oxygen to escape, the corrosion rate increases with temperature about 80°C and then falls to a very low value at the boiling point. The lower corrosion rate above 80°C is related to a marked decrease of oxygen solubility in water as the temperature is increase, and this effect eventually overshadows the accelerating effect of temperature alone [26].

Increasing chloride concentration also increases the corrosion rate (Figure 3). The addition of chloride ions has a strongly effect on the corrosion behavior of stainless steel in acidic solutions, since in the presence of this ion, a passivity breakdown process takes place above a certain potential that decreases with the chloride concentration. Chloride ions slowly penetrate into the surface, at which the
protective film is destroyed and the steel begins to corrode. Chloride corrosion tends to evenly pit the entire surface area of the specimens with shallow, flat-bottomed, irregular shaped pits. Chloride penetration in metal is due to the presence of different mechanisms, mainly diffusion and capillary absorption [27].

4. Conclusion
Tempering temperature and holding time affect on corrosion resistance of the modified 410 martensitic stainless steel. Corrosion rate of the modified 410 martensitic stainless steel after tempering at 700°C for 6 hours was increase as increasing NaCl concentration and temperature operation. The minimum value of corrosion rate is 0.198 mmpy that was obtained in 3.5% NaCl concentration at room temperature. Rise in temperature lead to higher corrosion rate due to the rate of oxygen diffusion increases with increasing temperature. And also, the chloride ion has a strongly effect on the corrosion behavior of the modified 410 martensitic stainless steel. Hence, the highest corrosion rate was obtained in 20% NaCl concentration at 80°C.

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Acknowledgment

This paper is part of development of high temperature material for power plant research. The authors would like to be obliged to Research Center for Metallurgy and Material of Indonesian Institute of Sciences for providing laboratory facility and funding this research.