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To cite this article: Rusnaldy *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **547** 012059

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## ***Effect of heat treatment on the stress corrosion cracking (scc) susceptibility of the 13Cr martensitic stainless steel for steam turbine blade***

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**Abstract.** Two different constant loads have been used to evaluate the effect of heat treatment on susceptibility to stress corrosion cracking (SCC) of 13 Cr martensitic stainless steel in 3.5% NaCl. The steel specimens were austenitized at 1050°C for 1 hour followed by oil quench to obtain martensite structure. Then, specimens were tempered at 400, 500, 600, 650 and 700°C for 1 hour. To investigate the SCC susceptibility, SCC tests were carried out at two different constant loads of 40% and 80% of ultimate tensile strength (UTS) in accordance with the method developed by Nishimura et.al. After the SCC tests, scanning electron microscope (SEM) observations of the fracture surface on the fractured specimens were conducted to investigate fracture mode. The experimental results showed that the 13Cr martensitic stainless steel was highly susceptible to SCC in a solution 3.5% NaCl at high constant load (80% of UTS) in almost tempered conditions. The least susceptible steel was the tempered one at 700°C. At lower constant load (40% of UTS), the highly susceptible steels were the tempered ones at 400 and 500°C. Steels which were tempered at high tempering temperature were not failed for 240 hours of SCC testing. The mechanism responsible for this susceptibility is thought to be secondary phenomenon where carbide precipitation of  $M_7C$  or  $M_{23}C_6$  occurs. The fracture surfaces exhibited intergranular cracks and dimple rupture fracture for steels tempered at 400, 600 and 650°C and transgranular cracks and cleavage fracture for steels tempered at 500°C.

**Keywords:** heat treatment, martensitic stainless steel, stress corrosion cracking, turbine blades

### **1. Introduction**

Steam turbine blades are the critical component in power plant which convert the linear motion of high temperature and high pressure steam flowing down a pressure gradient into a rotary motion of the turbine shaft [1]. The blades are susceptible to failure due to stresses arising primarily from centrifugal loads and bending forces related to the steam mass flow [2]. And also during operation, the blades operate in a wet steam environment and their failure modes are typically either stress corrosion cracking or corrosion fatigue [3].

In blade design, attention is being focused on using the higher strength alloys and improving resistance to corrosion and environment induced cracking [4]. Among the various blade materials, the most popular is 12%Cr martensitic stainless steel (MSS) which has an excellent combination of strength, toughness and corrosion resistance as well as high inherent damping



characteristics [5]. The other martensitic stainless steel that has been used for turbine blades due to its mechanical properties and moderate corrosion resistance is MSS with 13 wt% Cr [6,7].

The corrosion resistance and mechanical properties of martensitic stainless steel can be optimized by chemical composition modification and heat treatment process. Heat treatments have a significant effect on microstructures and properties of steels. Mabururi et.al tried to modify 13Cr MSS by adding Mo and Ni [8]. They investigated the influence of Mo and Ni in tempered condition on their tensile properties. They found that the addition of 1% and 3% Mo will increase both the tensile strength and the elongation of the steels, but the addition of 3% Ni will decrease both the tensile strength and the elongation of the steels. The effect of heat treatment on hardness and microstructure of the modified 13Cr steam turbine blade steel was also investigated by Prifiharni et.al [9]. The steels were austenitized at 1050°C and tempered at 300°C until 700°C. They showed that increasing tempering temperature until 500°C can improve hardness due to formation of precipitation carbide  $M_{23}C_6$  into microstructure. Increasing tempering temperature from 500 to 650°C can decrease Cr content on carbide and increase Mo content on carbide.

In this work, the effect of tempering temperature of 13Cr martensitic stainless steels was investigated to evaluate the susceptibility of 13Cr martensitic stainless steel to SCC in a solution of 3.5% NaCl and the fracture modes caused by SCC.

## 2. Materials and Methods

The material used in this study was 13Cr martensitic stainless steel (AISI 410). The chemical compositions are listed in Table 1. For SCC test, tensile specimen configuration was used in this study and it shown in Fig. 1. The specimens were austenitized at 1050°C for 1 hour followed by oil quench to obtain martensite structure. Then, specimens were tempered at 400, 500, 600, 650 and 700°C for 1 hour.

Tensile tests were also carried out in this study. Heat-treated plate specimens were machined to make the tensile specimens with dimension complied with ASTM E8 [10]. The tensile testings were carried out by using universal testing machine until the specimens broke.

To investigate the SCC susceptibility, SCC tests were carried out at two different constant loads of 40% and 80% of ultimate tensile strength (UTS) for each heat-treated specimen in a solution of 3.5% NaCl, in accordance with the method developed by Nishimura et.al [11]. After the SCC tests, scanning electron microscope (SEM) observations of the fracture surface on the fractured specimens were conducted to investigate fracture mode.

Table 1. Chemical composition (wt %) of the 13Cr martensitic stainless steel (AISI 410)

C	S	P	Mn	Si	Cr	Mo	Ni	Fe
0,034	0	0,0079	0,310	0,861	13,535	0,00474	0,0842	Bal.

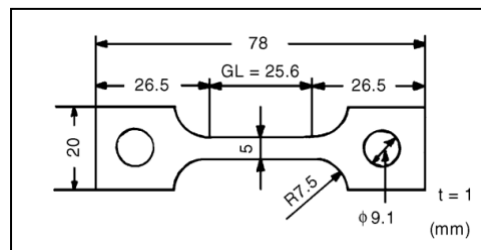


Fig. 1. Specimen's configuration for SCC test

### 3. Results and Discussion

Table 2 shows the effect of tempering temperature of the 13Cr martensitic stainless steel on the mechanical properties. It can be seen that the yield strength and ultimate tensile strength decrease as tempering temperature increases. At tempering temperature of 500°C, embrittlement occurs. According to Bezuidenhout and van Rooyen [12], sensitization happens when martensitic stainless steel is held at a temperature of 450-550°C causing the steel to be susceptible to intergranular stress corrosion cracking. But when the tempering temperature increases from 500 to 600°C, the yield strength and ultimate tensile strength increase. The increasing of strength from 500 to 600°C is maybe related to secondary hardening phenomenon due to formation of  $M_7C_3$  carbides within the martensite lath [9]. On the other side, decreasing strength when tempering temperature increases from 600 to 700°C occurs due to the  $M_7C_3$  carbide started to coarsen and partially transform to  $M_{23}C_6$  carbides [13]. The highest strength was achieved when specimen was tempered at temperature of 400°C.

Figs. 2 and 3 show the results of the SCC test. The effect of tempering temperatures on time to failure at constant load of 40% and 80% of ultimate tensile strength (UTS) of each heat-treated 13Cr martensitic stainless steel was investigated. The tests were carried out for 240 hours. At constant load of 40% of UTS (see Fig. 2), it can be seen that specimens which were tempered at 400 and 500°C were failed and were tempered at 600, 650 and 700°C were not failed. At tempering temperature of 400 and 500°C, steels were failed after 28.32 and 17.36 hours of SCC testing respectively. Meanwhile, at tempering temperature of 650 and 700°C, steels have the lowest increase of length during testing, i.e 0.12 and 0.10 mm respectively. When the constant load increases to 80% of UTS (see Fig. 3), among the heat-treated steels in this work, only steel which was tempered at 700°C was not failed for 240 hours of testing. It can also be seen that the lower tempering temperature more susceptible the steel to SCC. Carbide transformation from  $M_7C_3$  to  $M_{23}C_6$  at high tempering temperature has significant role to increase corrosion resistance and decrease pitting potential [14]. It could be related to the high susceptibility of steel which was tempered at 700°C.

The fracture surfaces for tempered specimens at constant load of 80% of UTS were shown in Fig. 4. The fracture surface for tempered specimens at 400, 600 and 650°C were similar (see Figs 4a, 4c and 4d). The fracture surfaces exhibited intergranular cracks and dimple rupture fracture and these fracture surfaces correspond to ductile failure. At tempering temperature of 500°C, steel has transgranular cracks and cleavage fracture on its fracture surface (see Fig. 4b). This kind of fracture could be caused by embrittlement and secondary hardening where carbide precipitation of  $M_7C_3$  or  $M_{23}C_6$  occurs [9]

Table 2. Mechanical properties of heat-treated 13Cr martensitic stainless steel (AISI 410)

Tempering Temperature (°C)	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Elongation (%)
400	673.70	778.95	8.30
500	648.32	686.57	9.10
600	658.34	865.73	6.50
650	405.86	598.33	9.90
700	358.10	518.57	11.10

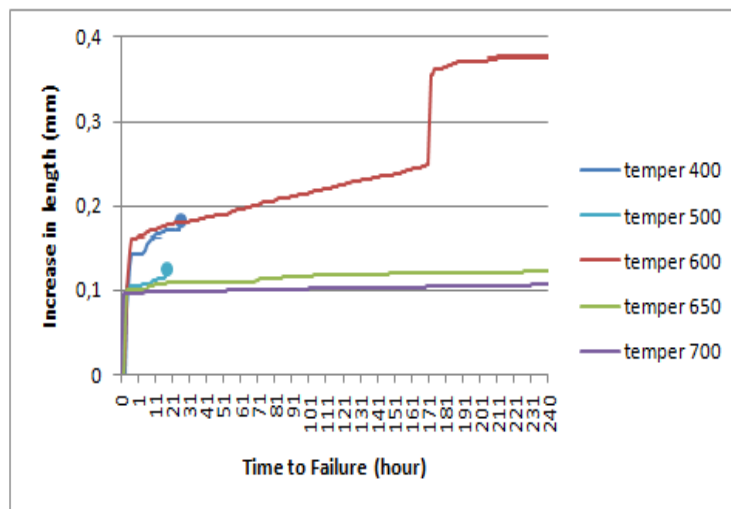


Fig. 2. The effect of tempering temperature on time to failure of 13Cr martensitic stainless steel at constant load of 40% of ultimate tensile strength

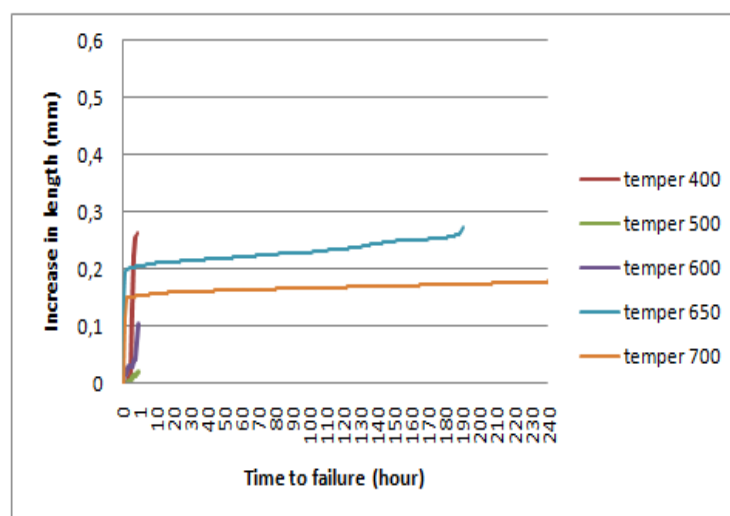


Fig. 3. The effect of tempering temperature on time to failure of 13Cr martensitic stainless steel at constant load of 80% of ultimate tensile strength

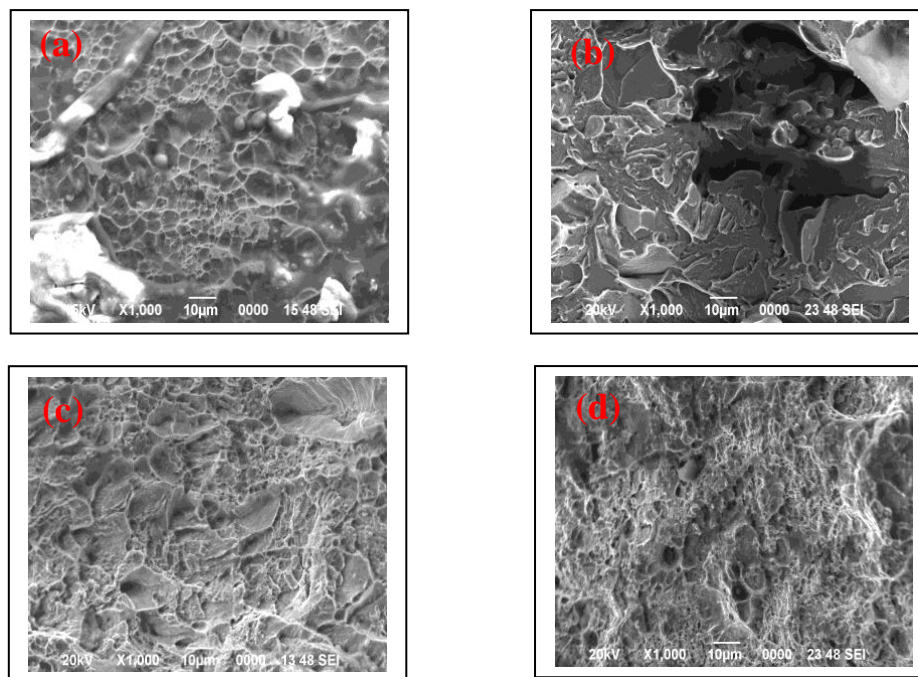


Fig. 4. Fracture surfaces for tempered specimens at constant load of 80% of UTS at tempering temperature of (a) 400°C, (b) 500°C, (c) 600°C and (d) 650°C

#### 4. Conclusions

The susceptibility of 13Cr martensitic stainless steel (AISI 410) at various tempered conditions was investigated. The 13Cr martensitic stainless steel was highly susceptible to SCC in a solution 3.5% NaCl at high constant load (80% of UTS) in almost tempered conditions. The least susceptible steel was the tempered one at 700°C. At lower constant load (40% of UTS), the highly susceptible steels were the tempered ones at 400 and 500°C. Steels which were tempered at high tempering temperature were not failed for 240 hours of SCC testing. The mechanism responsible for this susceptibility is thought to be secondary phenomenon where carbide precipitation of  $M_7C_3$  or  $M_{23}C_6$  occurs. The fracture surfaces exhibited intergranular cracks and dimple rupture fracture for steels tempered at 400, 600 and 650°C and transgranular cracks and cleavage fracture for steels tempered at 500°C.

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