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Investigation of the Effects of Temperature on Physical, Mechanical and Electrical Properties in AISI 310S Austenitic Stainless Steel

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In our study, annealing was done to AISI 310S stainless steel at 800 °C. The effects of these annealing on structural, morphological, mechanical and electrical conductivities were investigated. From XRD results, it has been observed that the material is austenite and cubic in nature. SEM analysis has shown that the surface of AISI 310S steel changes with temperature. The tensile test of the material was made and it was observed that the tensile strength of the material decreased with the effect of temperature. In addition, the conductivity behavior of AISI 310S steel was measured with four probe technique depending on heat treatment. As a result of the measurements, it was observed that the resistance value increased and the conductivity value decreased in the heat treated material.

Keywords: AISI 310S austenitic stainless steel, mechanical properties, electrical conductivity.

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Introduction

Austenitic stainless steels are widely used in many fields such as automotive, shipbuilding and chemical industries, food and beverage equipment, components within the energy-producing industry due to their good formability and high corrosion resistance [1-3]. Recently, studies on the use of solid oxide fuel cell (SOFC) applications are being conducted. Solid oxide fuel cells generally operate at 600 - 800 ºC and superior perform at high temperatures. Austenitic stainless steels to be used in SOFC applications have several disadvantages. The first is the oxide layer formed on their surface as a result of their contact with air. This oxide layer thickens over time to form an insulator passive film. This situation affects electrical conductivity negatively. The second is the high thermal expansion coefficients [4]. The third is M23C6 carbide and σ phase precipitation, which will occur in high chrome stainless steels that will operate at high temperatures [5, 6]. Davies et al. [7], studied the performance of 9 different types of stainless steel, Ti alloy and graphite plates at the end of 1400 hours. They stated that the resistivity of all stainless steel samples was higher due to the passive film layer formed on their surface compared to the graphite plate. They say that the relative interface resistors are listed as 321 > 304 > 347 > 316 > Ti > 310 > 904 > Incoloy 800 > Inconel 601 > Graphite. The operating temperature, which was initially 1000ºC in SOFC applications, has been reduced to 800ºC or even lower due to the development of a number of new materials and manufacturing technologies [8, 9]. These developments have led to the need to develop new interconnector materials, use existing materials and evaluate their performance. Also, considering commercial applications, austenitic stainless steels are advantageous in terms of cost compared to other steels, for example Crofer 22 APU. It was anticipated that limitations of austenitic steels could be overcome by lowering the SOFC operation temperatures [9]. The fact that stainless steels such as 304 and 316 containing 18 % Cr 'exhibit high oxidation rate at 600 -700 ºC turned the attention into stainless steels containing higher Cr, the chromium content up to 25 %Cr such as 310. Zeng and Natesan [10], stated that the increase in Cr amount positively affects the oxidation resistance in SOFC applications. In this study, the preferred AISI 310S

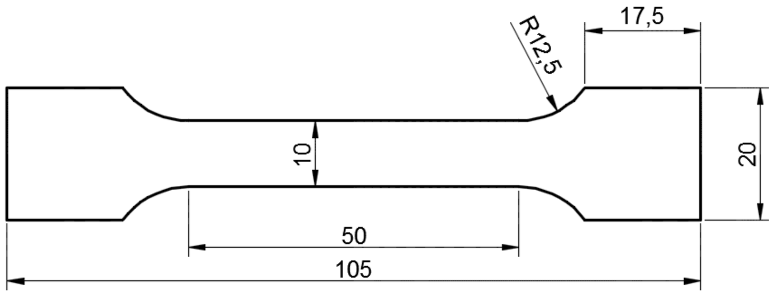

Fig. 1. Dimensions of tensile test specimen (mm).

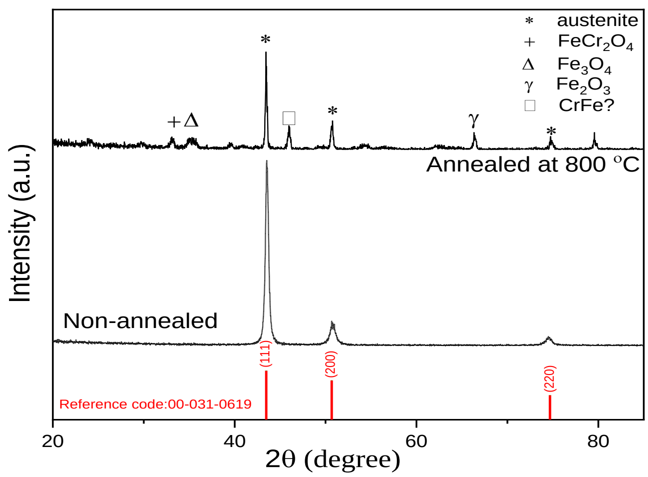

Fig. 2. XRD results of AISI 310S steel before annealing and after 20 hours annealing at 800 ºC.

stainless steel is similar to AISI 310 in terms of many features, but it contains lower C, which reduces its strength slightly. Nevertheless, it still provides good ductility, excellent strength, resistance to hydrogen embrittlement and corrosion/oxidation at high temperatures but can be susceptible to oxide spallation.

However, the corrosion resistance of the alloy has been developed up to 600 ºC with the addition of Zr [11-14]. AISI 310S performs well under humid and harsh design conditions at high temperatures [6]. When working at high temperatures, Ti and Nb are added to reduce or delay $M_{23}Cr_6$ and Sigma phase precipitation [15, 16]. Bsat and Huang [11], conducted a study to determine the corrosion behavior of AISI 310S material. In their studies, they exposed the samples to superheated steam at 800 ºC for 1000, 2000 and 3000 hours. As a result of their work, they observed that Cr_2O_3 and (Fe, Mn) Cr_2O_4 oxide layers were formed on the surface. Tavares et al. [17], conducted a study on the corrosion behavior and microstructure changes of AISI 310S material in the 600 – 800 ºC temperature range. They stated that chromium carbide and Sigma phase deposits occurring at the grain boundaries at all temperatures caused sensitivity.

In this study, it is tried to determine how behaves AISI 310S austenitic stainless steel, which is preferred in high temperature applications, at 800 ºC.

I. Experimental

In the study, AISI 310S austenitic stainless steel with a thickness of 5 mm was used. AISI 310S sample used in the experiments contains 0.053 % C, 24.665 % Cr, 1.459 % Mn, 0.016 % N, 19.165 % Ni, 0.026 % P, 0.001 % S, 0.530 % Si. Nowadays, Crofer 22 APU is generally used as interconnector material in solid oxide fuel cell applications. However, this material is very costly and difficult to obtain. Many researchers are in search of alternative materials. In this respect, we want to use AISI 310S austenitic stainless steel material as an alternative material in interconnector manufacturing in solid oxide fuel cell applications. Medium temperature solid oxide fuel cells generally operate in the temperature range of 600 - 800 °C. In this regard, the annealing temperature of the material was determined to be 800 °C. The material was annealed at 800 °C for 20 hours in the air. Structural features of the samples were performed with Philips X'Pert PRO (CuKα, λ = 0,154056 nm) XRD device, SEM photos with Zeiss EVO LS-10 device and elementary analysis with Bruker Quantax EDS device. The schematic representation of tensile specimen with dimensions is shown in Fig. 1. Tensile tests were carried out using Zwick/Roell Z600 universal testing machine (UTM) under the constant speed mode with a nominal strain rate of 1×10^{-3} s^{-1}. The tensile tests were carried out at test temperatures of room temperature (RT), 400 ºC, 800 ºC. The conductivity behavior of AISI 310S steel has been measured from room temperature to 600 ºC with four probe technique. In this measurement, Keithley 2400 Source meter device was used.

II. Results and discussion

As seen in Figure 2, XRD results of 310S steel are

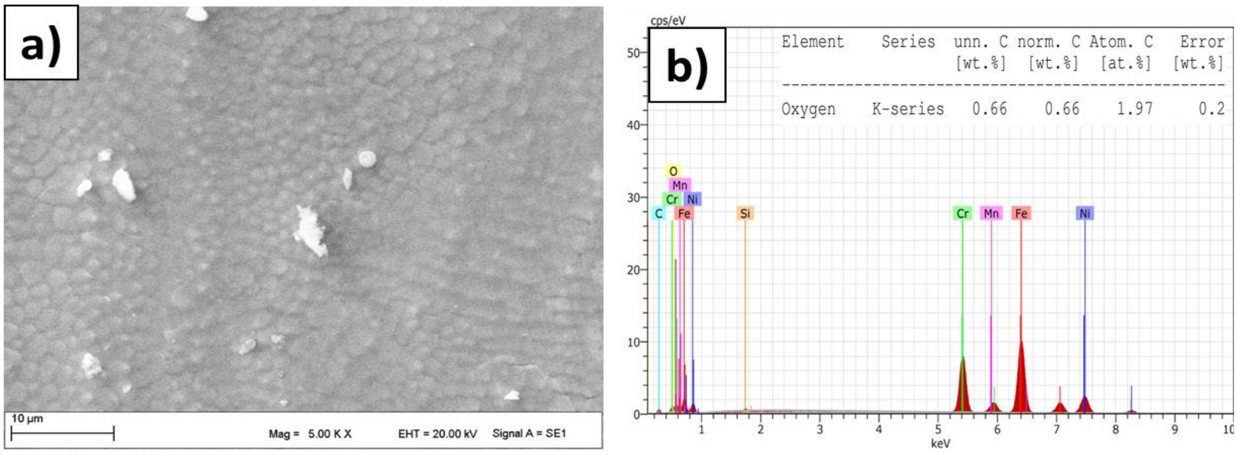

Fig. 3. a) SEM images and b) EDX results of the Non-annealed sample.

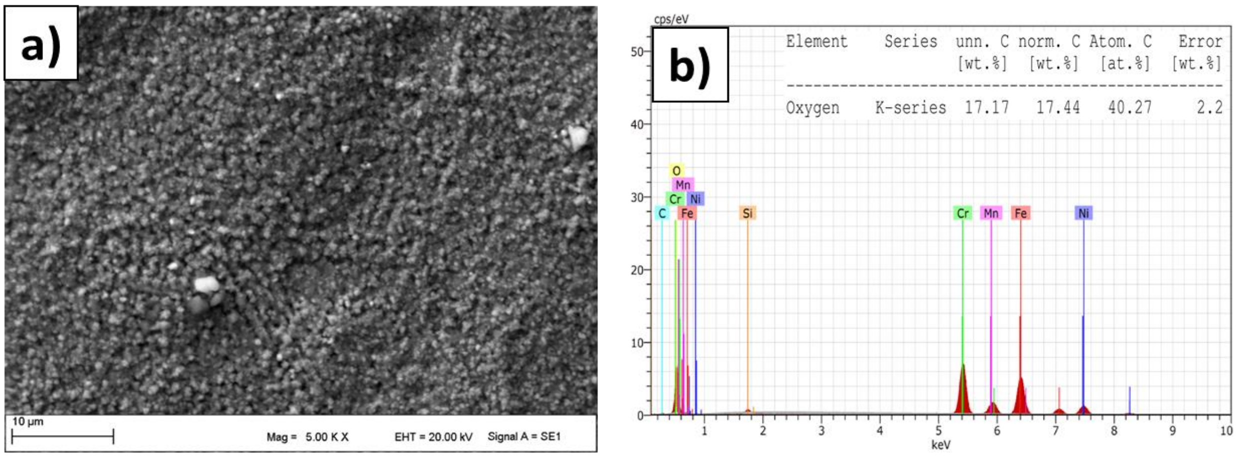

Fig. 4. a) SEM images and b) EDX results of the annealed sample.

shown. From the XRD results, (111), (200) and (220) oriented peaks were observed before annealing. Here the XRD results are compatible with the reference code 00-031-0619. This shows that the material is austenite and has a cubic structure. When the XRD results of the samples annealed at 800 ºC for 20 hours were examined, they were observed at different peaks alongside the reference peaks. It is understood from here that the material is oxidized by the effect of temperature and structures with oxide components are formed. The peaks of the new phases that are formed are shown on the figure. SEM and EDX measurements support these results.

From SEM images (Fig. 3a) it is seen that the surface of the material is regular and smoother before annealing. It is observed that the roughness on the surface increases and the appearance becomes darker after annealing (Fig. 4a).

Here we can conclude that oxidation increases with annealing. EDX results can generally determine the proportions of elements in a certain area in the material. According to the graphics given in Figure 3 b and Figure 4 b the peaks corresponding to the elements are seen. Here, the increase in oxygen ratio after annealing is clearly visible compared to non-annealing. In this case, it appears to be consistent with XRD and SEM results.

Engineering stress–strain curves of AISI 310S tested at various temperatures are shown in Fig. 5a. The effect of test temperature on yield strength, tensile strength and elongation are shown in Fig. 5b. The tensile strength and yield strength decreases, with increase in test temperature. Elongation decreased when the temperature increased to 400ºC and then increased again. The decrease in elongation from RT to 400ºC was 13 %, but at 800ºC was 5 %. AISI 310S showed decreasing ductility with increasing temperature compared with RT.

In Figure 6, the conductivity result of AISI 310S sample, which is non-annealed and annealed at 800˚C for 20 hours is given. As can be seen from the figure, the conductivity of the annealed sample in general is lower. From here, when heat treatment is applied, the resistance is increased and the conductivity value is decreased. The reason is that the oxide layer formed on the surface increases the resistance value according to the SEM and EDX results. It was observed that conductivity decreased as the temperature increased in both samples. This is suitable for metal characteristics and is compatible with the literature [18-20].

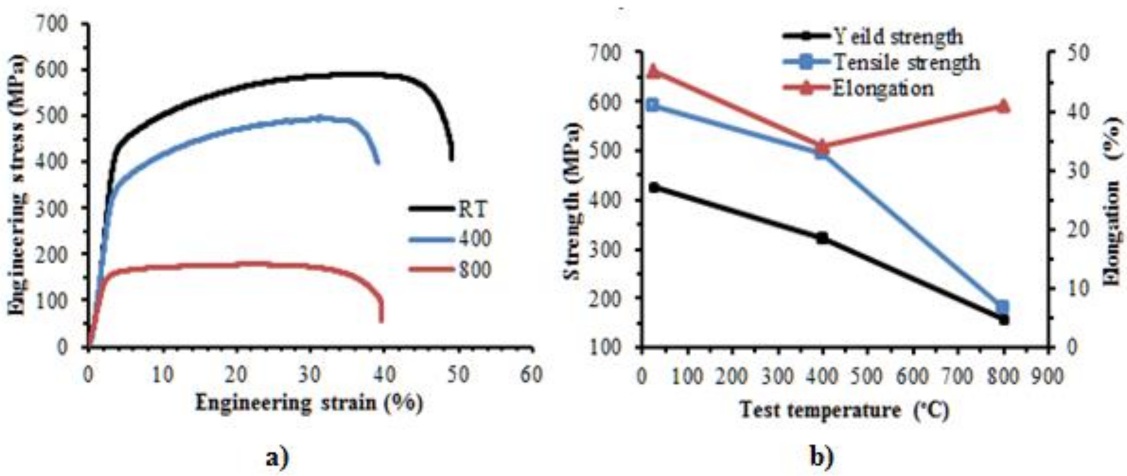

Fig. 5. a) Engineering stress–strain curves at various test temperatures, b) Effect of test temperature on strength and elongation.

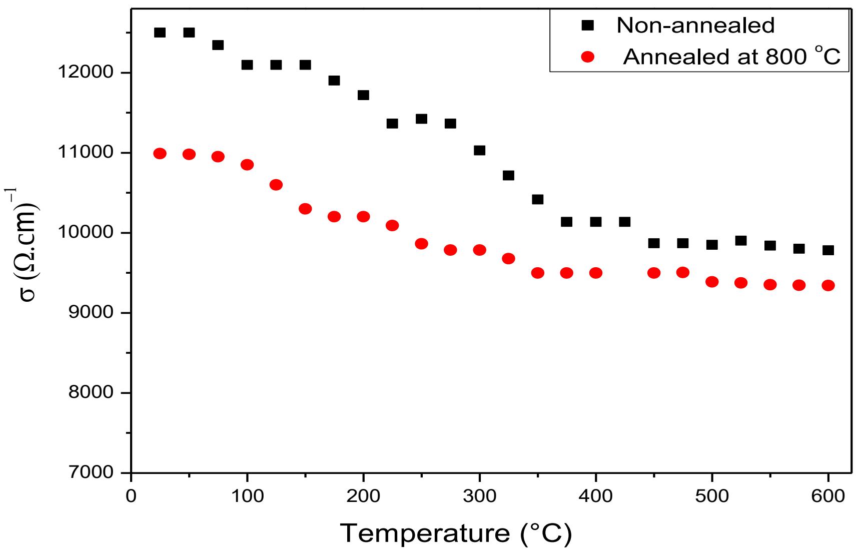

Fig. 6. Conductivity results of non-annealed and annealed samples.

Conclusion

Structural feature of AISI 310S stainless steel was examined, it was observed that oxide layer was formed on steel by annealing at 800 °C and XRD peaks were formed accordingly. It also supports this situation with SEM and EDX measurements. From SEM images, it was clearly observed that the amount of annealing oxide increased on the sample, and the amount of oxygen increased elementally in EDX results. In the mechanical tests, it was revealed that the yield strength and tensile strength decreased significantly with the increase in temperature. In electrical conductivity tests, it has been observed that the annealing in samples decreases the conductivity value. Also, it was determined that conductivity values decreased in the samples depending on the temperature.

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Дослідження впливу температури на фізичні, механічні та електропровідні властивості аустенітної нержавіючої сталі AISI 310S

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У дослідженні виконано відпал нержавіючої сталі AISI 310S при 800°C. Досліджено вплив цього відпалу на структурні, морфологічні, механічні властивості та електричну провідність. За результатами XRD помічено, що матеріал є аустенітним і має кубічну природу. SEM-аналіз показав, що структура поверхні сталі AISI 310S змінюється з температурою. Було проведено випробування матеріалу на розтяг і виявлено, що межа міцності матеріалу на розтяг знижується під впливом температури. Крім того, провідність сталі AISI 310S вимірювалася чотиризондовим методом в залежності від термообробки. В результаті вимірювань отримано, що величина опору зростала, а величина провідності у термообробленому матеріалі зменшувалась.

Ключові слова: аустенітна нержавіюча сталь AISI 310S, механічні властивості, електропровідність.