The Influence of Homogenization and Solution Annealing Process on the Microstructure and Mechanical Properties of 1.4470 Ferritic-austenitic Stainless Steel

Z. Mahmoodzadeh*[1] , M. Tajally [2], H. Abdollah-Pour [3], H. Rastegari [4]

[1,2,3] Department of Materials and Metallurgical engineering, Semnan University, Semnan, 35131-19111, Iran
[4] Department of Mechanical and Materials Engineering, Birjand University of Technology

Abstract

In the present research, the effect of homogenization process and annealing temperature were investigated for the 1.4470 ferritic-austenitic stainless steel in as-cast condition. In this regard, microstructural evolutions, hardness and impact energy of the steel was evaluated with different heat treatment conditions. The results showed that the minimum volume fraction of austenite phase (about 42%) was formed in as-cast condition; while the maximum content of austenite phase could be achieving by annealing at 1010 °C for 45 min without homogenizing process (about 56%). Moreover, a good combination of impact energy and hardness were obtained by homogenizing at 1120 °C for 45 min and subsequent annealing at 1010 °C for15 min followed by oil quenching. In this condition, the same volume fraction of ferrite and austenite phase formed in the microstructure.

Keywords: Ferritic-austenitic stainless steel; Heat treatment; Microstructure; Mechanical properties.

1. Introduction

Ferritic-austenitic stainless steels are generally used for industries of oil, gas, petrochemical, nuclear, marine and transportation [1]. About this kind of dual phase stainless steel, the best combination of mechanical properties (strength, toughness, impact energy and hardness) as well as corrosion behavior can be achieved with approximately equal volume fraction of ferrite (α) and austenite (γ) phases in the microstructure [2]. In this regard, the volume fraction, morphology and distribution of ferrite and austenite phase in the microstructure are significantly dependent on the heat treatment process which, in turn, designed based on the chemical composition of stainless steel [3]. Therefore, it is essential to control the microstructural features during the heat treatment process with regard to the heating and cooling cycles [4, 5]. It should be noted that duplex stainless steels are susceptible to form secondary detrimental phases (carbides and nitrides) during inappropriate heat treatment process (soaking the temperature range of 560-900 °C) which resulted in the reduction of toughness and corrosion resistance [6-8]. Tan et al. was investigated the effect of annealing temperature on the pitting corrosion resistance of super duplex stainless steel. The results have shown that increasing annealing temperature led to the formation of pit initiation sites within the ferrite phase instead of austenite islands for the specimen annealed at 1080 °C/2 h which exhibits the

** Corresponding author*
Email: mahmoodzadezahra@yahoo.com
Address: Department of Materials and Metallurgical engineering, Semnan University, Semnan, 35131-19111, Iran
1. M.Sc.
2. Associate Professor
3. Assistant Professor
4. Assistant Professor

best pitting corrosion resistance [2)]. In Addition, Zhang et al. was shown that increasing in annealing temperature resulted in the higher volume fraction of austenite phase and lower values of pitting potential (Epit) and critical pitting temperature (CPT) [9)]. In another research, Park et al. evaluated the effects of nitrogen content and solution temperature on the microstructure and tensile properties of 25Cr–7Ni– 1.5Mo–3W–xN duplex stainless steel. It is suggested that increasing in nitrogen leading to decreasing the ferrite volume fraction as well as changing the solidification mode. On the other hand, increasing in solution temperature leading to increasing the ferrite volume fraction, followed by higher yield strength and lower elongation [10)]. Ghosh et al. have demonstrated that decreasing γ/α ratio (in vol. %) as well as coarse and uniform distribution of austenite phase reduces the tensile strength of a duplex stainless steel [11)].

Although, some earlier researchers have studied the effect of heat treatment parameter on microstructure and mechanical properties of duplex stainless steels [2,4,7,9-13)], a few works have been performed to evaluate the effect of homogenizing and solution annealing on microstructure and mechanical properties of 1.4470 stainless steel. Therefore, the main purpose of present research is to identify the appropriate heat treatment condition which no harmful phases formed and also to obtain the best combination of mechanical properties.

2. Materials and Experimental Procedures

The material used was a duplex stainless steel Plate of 1.4470 with 15mm thickness in as-cast condition. The chemical composition of the steel is listed in Table 1. In order to investigate the effect of homogenizing process and solution annealing, samples were heat- treated as shown in Table 2 (based on the ASTMA890 standard). For metallographic preparation, the polished specimens were electro-etched in 30% KOH solutions under a voltage of 2.5 V for 3 s. This etching process made ferrite appear dark and austenite bright [14)]. Microstructures were characterized using optical microscopy (Olympus BH2-UMA). The imageJ software was employed for phase fraction measurement. Charpy V notch impact test was performed according to ASTM E23 standard, using GT-7052-D30 Gotech machine. In addition, the fracture surface of impact specimens was examined using electron microscopy (Philips XL30). Brinell hardness test was carried out after removing surface oxide layer with a static hardness machine) TWIN model, Ernest company).

Table 1. Chemical composition of 1.4470 steel (wt. %).

C	Si	Mn	Cr	Ni	Mo	Cu	N	p	S
0.034	0.59	0.62	22.6	6.0	3.2	0.15	0.14	0.02	0.009

Table 2. Heat treatment conditions applied to the 1.4470 steel.

Specimen	Heat treatment condition
A	As-cast
B	Homogenizing at 1120 °C/45min followed by air cooling
C	Homogenizing at 1120°C/45 min and subsequent annealing at 1010°C/15 min followed by oil quenching
D	Homogenizing at 1120°C/45 min and subsequent annealing at 1050°C/15 min followed by water quenching
E	Annealing at 1010°C/45 min followed by oil quenching

3. Results and Discussion

3.1. Microstructural observations

The purpose of annealing process is to avoid the formation of harmful precipitates (intermetallic and second phases) and to eliminate the macro-segregation inherited from casting and also to achieve an equal amount of ferrite and austenite that will resulted in the improvement of mechanical properties 15). Fig. 1 shows an optical micrograph of microstructures after different heat treatment conditions. As seen, all of the microstructure consisted of the austenite (light region) distributed in the ferrite matrix (dark region). The microstructure of 1.4470 stainless steel in the as-cast condition is shown in Fig. 1a. The microstructure consists of dispersed Widmanstätten austenite with needle Morphology (about 42 %vol) in the ferrite matrix (about 58 %vol), which is in accordance with the (Cr/Ni) equivalent and ASTM A800 standard[16). However, Widmanstätten austenite was converted to equiaxed austenite by performing the homogenization process at 1120 °C for 45 minute followed by air cooling (Fig. 1b). The occurrence of such a morphology conversion has already been reported by Jebaraj et.al [17)]. Fig. 2 exhibits the variation in volume fraction of ferrite and austenite phase as a function of heat treatment condition. It can be concluded from Fig. 1b-e and Fig. 2 that the heat treatment cycles could lead to the different α/γ ratio, morphology and grain size. In this regard, homogenizing at the temperature of 1120 °C for 45 minute and subsequent annealing at the temperature of 1050 °C for 15 minute followed by water quenching (specimen D) resulted in the formation of nearly equal amounts of ferrite and austenite as well as finer austenite grain size. In addition, the highest amount of austenite could be obtained by removing the homogenization process and extending the annealing time from 15 to 45 minute (specimen E). By comparing the specimen C, D and E, it can be seen that with increase of the annealing temperature or time, the ferrite content reduces as well as the austenite phases become finer. In addition, more equiaxed grain structure was established by increasing the annealing temperature.

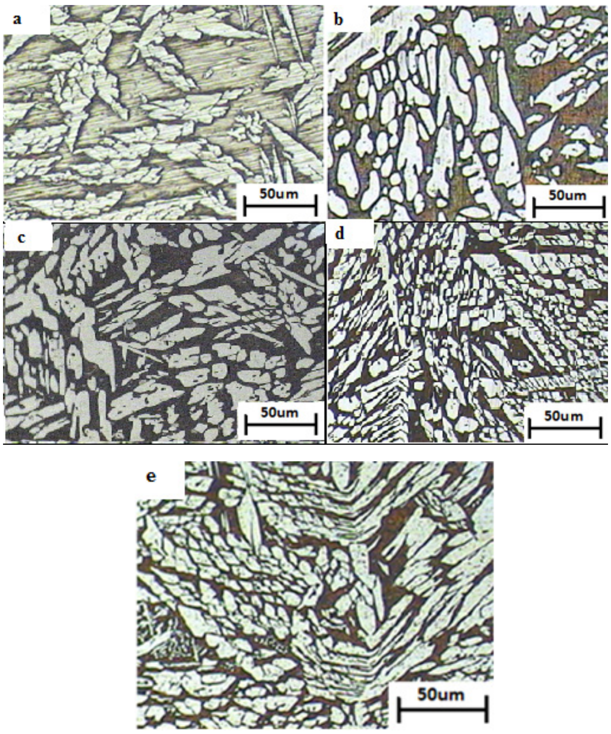

Fig. 1. Optical micrograph of 1.4470 stainless steel after different heat treatment conditions, (a) specimen A, (b) specimen B, (c) specimen C, (d) specimen D and (e) specimen E.

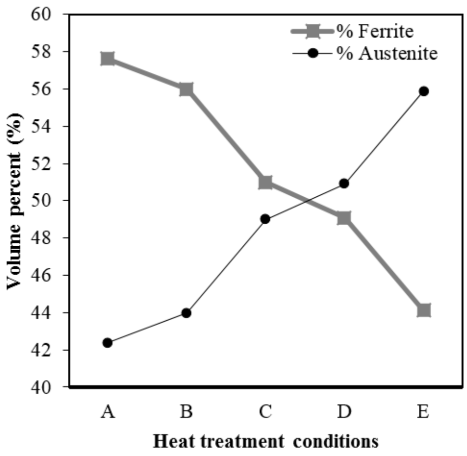

Fig. 2. Variation in volume fraction of ferrite and austenite phase as a function of heat treatment condition.

3. 2. Evaluation of mechanical properties

The average values of impact energy from the different samples are shown in Fig 3. As expected, the least amount of impact energy was achieved for as-cast condition. However, homogenization processing at the temperature of 1120 °C for 45 minutes (specimen B) resulted in the considerable increase in the impact energy. It can be concluded that homogenization should be considered as an essential step during heat treatment of 1.4470 stainless steel. Indeed, homogenization process removes the chemical segregation by high temperature heat treatment to improve the mechanical properties and to obtain a more uniform structure.

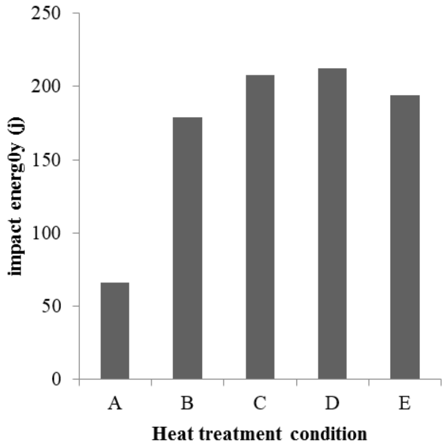

Fig. 3. Impact energy of 1.4470 stainless steel in various heat- treated conditions.

In addition, it can be found that the absorbed energy increased slightly with decreasing the amount of ferrite phase. Indeed, higher amount of austenite phase with finer grain size and equiaxed morphology were the main reason for increased impact energy, which reported previously 18, 19). Solution annealing process was performed after the homogenization (Specimen C) leads to an increase in the impact energy from 180 to 210 joules. By comparing the two samples C and D, it can be found that increasing the solution annealing temperature had little effect on the impact energy in contrast to homogenization process. Due to high alloying element content of 1.4470 ferritic-austenitic stainless steel followed by high level of segregation during casting and solidification, performing the homogenization heat treatment at a proper temperature is significant.

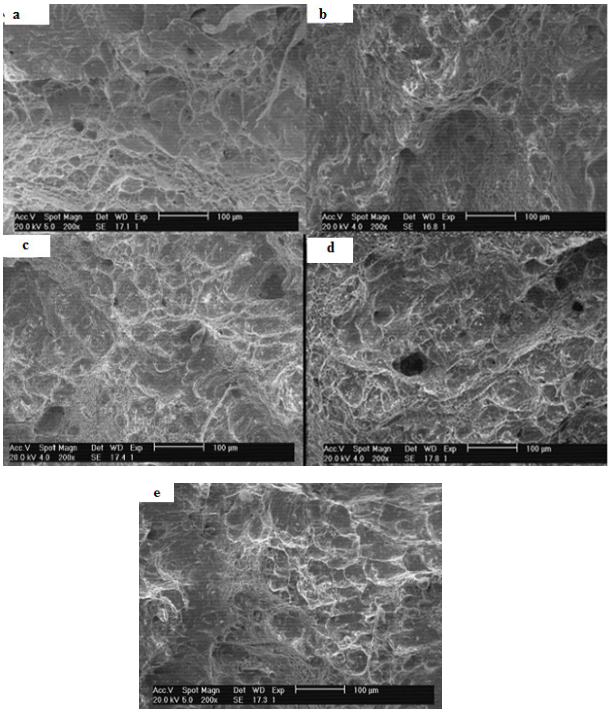

Fig. 4. SEM micrograph of fracture surface of impact test specimens after different heat treatment conditions, (a) specimen A, (b) specimen B, (c) specimen C, (d) specimen D and (e) specimen E.

As can be seen, by removing homogenization process and performing solution annealing process directly after casting (specimen E), the amount of impact energy was reduced from about 212 to 194 joules. In fact, due to increasing solution annealing time from 15 minutes to 45 minutes, and relatively high annealing temperature, the homogenization process has occurred during annealing solution.

To study the mechanism of fracture, the fracture surface of impact test specimens was examined by scanning electron microscopy. (Fig. 4). As seen, fracture surface of as-cast specimen containing the main feature of brittle fracture (i.e. cleavage morphology) which resulted in the lowest impact properties. However, specimen C and D show the most ductile fracture (i.e. dimple morphology) containing the larger dimple size. The larger dimples were associated with the higher impact properties.

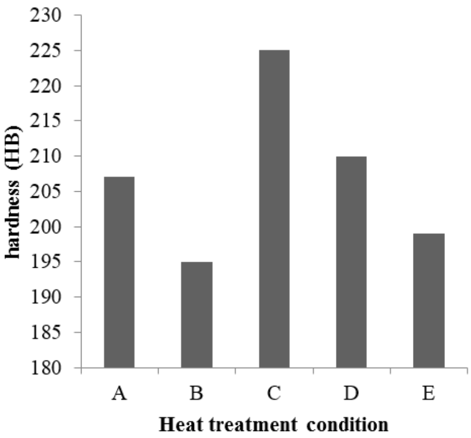

Fig. 5. Hardness value of 1.4470 stainless steel in various heat- treated conditions.

Brinell hardness values of the as-cast and heat- treated specimens were summarized in Fig. 5. The hardness is strongly related to the percentage of sigma phase formed during heat treatment process as well as microstructural features. It is reported that annealing treatments has direct influence on the internal stresses, dislocations substructures and crystallographic textures of DSS1.4462 7).

It is obvious that by removing the homogenization process before solution annealing (specimen E), the hardness was reduced. It can be related to the maximum percentage of austenite phase which obtained for this heat treatment condition. However, the increased percentage of austenite results in lower hardness of the heat- treated specimens that have also reported in previous studies 4). The highest value of hardness was obtained for specimen C. Comparing the specimen C and D, it is obvious that with an increase in the solution annealing temperature, the hardness reduced due to reduction of harder phase (ferrite). Moreover, the best combination of hardness and impact properties were achieved for the specimen C that underwent homogenizing at 1120 °C/45 min and subsequent annealing at 1010 °C/15 min followed by oil quenching.

4. Conclusion

In this research, the effect of homogenization process and annealing temperature on the mechanical properties of 1.4470 stainless steel were investigated. The following conclusions can be drawn from this study:

Increasing the annealing temperature or time tends to achieve lower ferrite content as well as finer and more equiaxed grain austenite phase.

The least amount of impact energy was achieved for as-cast condition Homogenization process should be considered as an essential step during heat treatment process of 1.4470 stainless steel.

The best combination of mechanical properties was achieved by homogenizing at 1120 °C/45 min. and subsequent annealing at 1010°C/15 min. followed by oil quenching.

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