Effect of the Aging Treatment on the Tensile Strength and Impact Toughness of Friction Welded Super304H Joints

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Effect of the Aging Treatment on the Tensile Strength and Impact Toughness of Friction Welded Super304H Joints

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Abstract: In this paper, the tensile strength and impact toughness of the friction welded Super304H joints were studied after aging at 625 ℃ for different time. As the aging time increased, the welding zone, heat affected zone and base metal were still austenite, and the number of precipitates gradually increased. The impact toughness of the joints decreased, the tensile strength of the joints increased firstly, than decreased after aged for 500 h, this is attributed to the aggregation and growth of the $Cr_{23}C_6$ carbides. The rupture mode of tensile strength and impact toughness samples changed from ductile fracture to brittle fracture.

1. Introduction

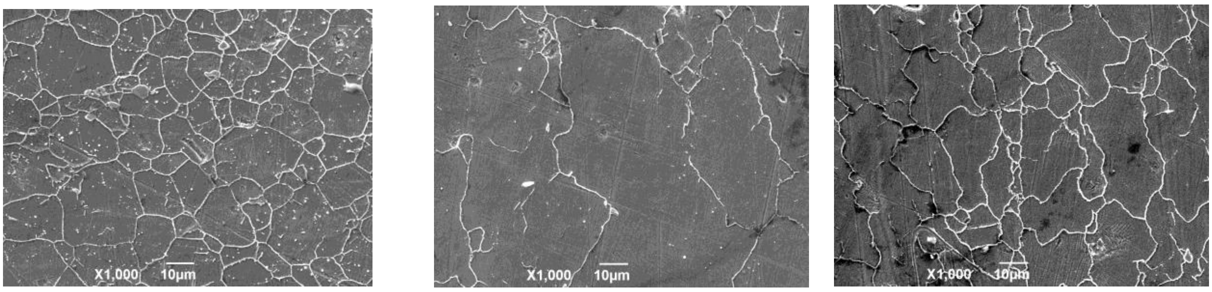
Energy shortage and environmental pollution around the world urges people to develop new techniques of clear and high efficiency thermal power generation. Nowadays, the ultra super critical power generation technique with much higher parameters including vapor temperature and pressure, has been generally accepted as the most feasible and reliable thermal power generation technology [1-3]. In order to fulfill the tough parameters of the ultra super critical power generation, traditional heat-resistant steels used in the subcritical and supercritical units have been replaced by those new heat-resistant steels, such as Super304H. To meet the critical demands for the ultra super critical power generation, a new austenitic stainless steel Super304H (0.1C-18Cr-9Ni-3Cu-Nb-N) has been developed. The Super304H has higher strength at elevated temperatures are required for super heater tubes in fossil fired boilers. However, in this situation, a questions is how to join these new austenitic stainless together. The conventional fusion welding joints of austenitic stainless steel exhibit inferior mechanical properties due to the formation of intermetallic compounds at the joint interface, and the excessive residual stresses. The friction welding can be more suitable than fusion ones since many problems associated with melting are eliminated or reduced [4-6]. In order to use friction welded Super304H joints widely in higher temperature environment, the effect of aging time on the properties of the joints is investigated. This study aims to investigate the tensile strength and impact toughness of the friction welded Super304H joints after aged at 625 ℃. The analysis of mechanical properties at different aging time provides the more fundamentals for wide application of the friction welded Super304H joints at higher temperatures.

2. Experimental procedures

The pipes of Super304H austenitic stainless steel that in the sizes of Φ44.5mm x 9mm were used as base metals. Friction welding was carried out using a continuous drive friction welding machine. During the friction welding operations, the friction welding parameters were set to the following combinations: a friction speed of 1500 rpm, a friction pressure of 150 MPa, an upset pressure of 200 MPa and a friction time of 5s. These specimens were heated respectively in a tube furnace at 625 ℃ for 0h, 500h, 1000h, 1500h, 2000h, 2500h, and 3000 h, respectively. The microstructures of the aged samples were observed and analyzed by using scanning electron microscopy. The tensile samples were tested using a testing instrument. The impact samples were tested using a impacting instrument.

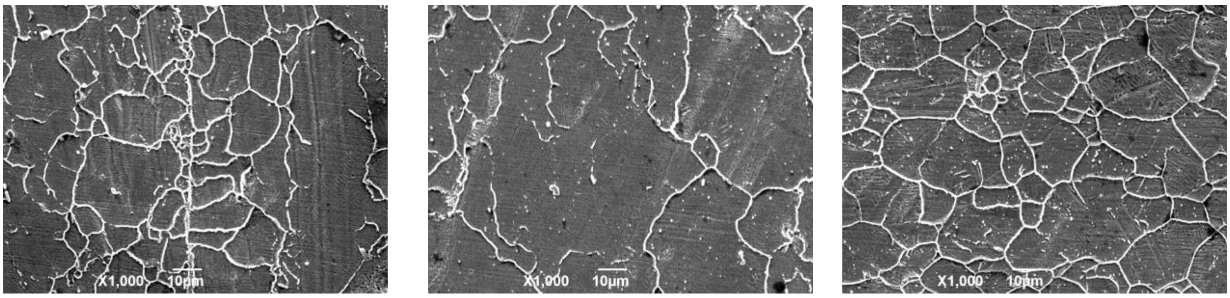
3. Results and Discussion

Fig 1-3 shows morphology aged for 1000h, 2000h and 3000 h, respectively. During the friction welding process, the welded zone produced agglutinate and shear tear behavior, which led to the deformation of austenite grains, the dynamic recrystallization driving force increased. The thermoplastic deformation temperature and free energy of recrystallized grains decreased, which produce a large number of recrystallized nucleations that leading to the fine grained dynamic recrystallization structure of the weld zone, the effect of dynamic recrystallization was obvious. The welded zone of austenitic stainless steel welded by fusion welding was typical dendritic morphology with large grains. Compared with the conventional fusion welding joints, the friction welded austenitic stainless steel joints were mainly composed of fine equiaxed austenite crystals. The friction welding was solid state welding techniques, the melting process did not occur in the welded zone and heat affected zone. So the heat input during the friction welding process was much less than the heat input during the fusion welding process. So the friction welded joints with the small grains showed excellent microstructure. After aged at 625 ℃, the grain size change of the joints was not detectable. However, the precipitation and growth of the $Cr_{23}C_6$ carbide particles along the austenitic grain boundaries is evident. Meanwhile, the precipitation of the $Cr_{23}C_6$ carbides inside the austenitic grains occured with a rather smaller size[7]. As the aging time increased, the amount of $Cr_{23}C_6$ carbides increased obviously.



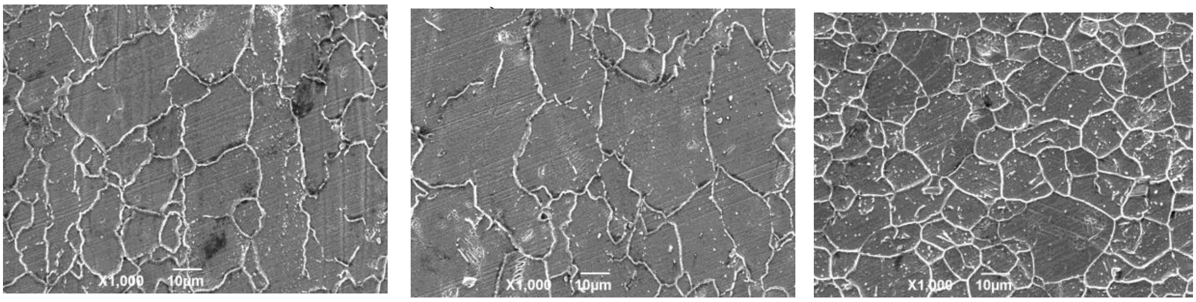
(a) (b) (c)

Figure.1 The metallograph aged for 1000h: (a) the welding zone, (b) the heat affected zone, (c) the base metal



(a) (b) (c)

Figure.2 The metallograph aged for 2000h: (a) the welding zone, (b) the heat affected zone , (c) the base metal



(a) (b) (c)

Figure.3 The metallograph for 3000h: (a) the welding zone, (b) the heat affected zone , (c) the base metal

Fig. 4 depicts the variation of yield strength and tensile strength as a function of the aging time. It was detected that the fracture position of the joints was in the heat affected zone after aged for different time. As the aging time increased, the tensile strength of the joints increases sharply (<500 h), and then decreases (500-3000 h). In the aging process, the mechanical property change of the joints is certainly corresponding to the microstructure evolution. Precipitation, aggregation and growth of the $Cr_{23}C_6$ carbides phases are main reasons of the microstructure evolution of the joints [8]. In the early aging stage, the dispersion strengthening effect of the $Cr_{23}C_6$ carbides may be overwhelming, the yield strength and tensile strength of the joints increased. As the aging time increased continuously, aggregation and growth of the $Cr_{23}C_6$ carbides takes place, the dispersion strengthening effect of the $Cr_{23}C_6$ carbides decreases simultaneously, resulting in the apparent drop of the yield strength and tensile strength. As shown in Fig. 5, the fractographs of the joints change with the ageing time. After aged for 1000h, fine and shallow dimples distribute on the facture surface. As the aging time increased, the density of the dimples on the facture surface reduces. The shear deformation on the facture surface turns to be severe. Therefore, the plastic deformation degree decreases. The rupture mode of tensile strength samples changed from ductile fracture to brittle fracture.

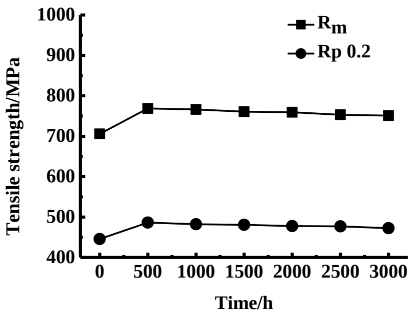
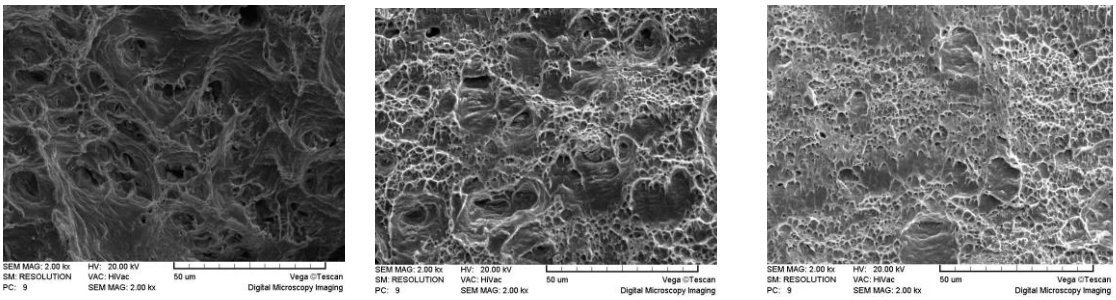


Figure.4 The tensile strength of the welding joints after aged for different time



(a) (b) (c)

Figure.5 The rupture appearance of the the welding joints: (a) 1000h, (b) 2000h, (c) 3000h

Fig. 6 depicts the impact toughness of the joints drop monotonously with increasing the aging time, indicating the impact property of the welding joints is much sensitive to the higher temperature aging process. The precipitation, aggregation and growth of the $Cr_{23}C_6$ carbides are the main reason that the impact toughness of the joints decreased with the aging time increased. The grain size of austenite grains has a great influence on the impact toughness of each part of the welded joints. When the grains size was smaller, the impact toughness was higher. The grains size of the heat affected zone was the largest, the grains size of the base metal was the smallest. So the impact toughness of the base metal was the highest, and the impact toughness of the heat affected zone was the lowest. The heat affected zone with coarse austenite grains was the weakest part of the welding joints. As shown in Fig 7- Fig 9, the fractographs of the welding joints change with the aging time. The joints aged for 1000h, a dimple aggregation fracture mechanism was observed. The dimples on the fracture surface were shallower with more $Cr_{23}C_6$ carbides on the bottom of them. As the aging time increased, more and larger $Cr_{23}C_6$ carbides precipitated. Correspondingly, the rupture mode of impact toughness samples changed from ductile fracture to brittle fracture.

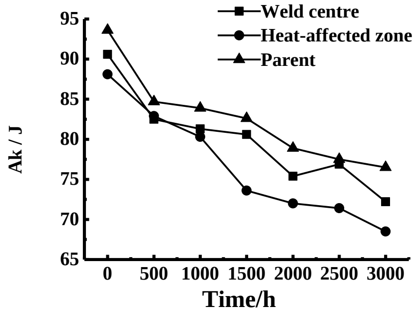
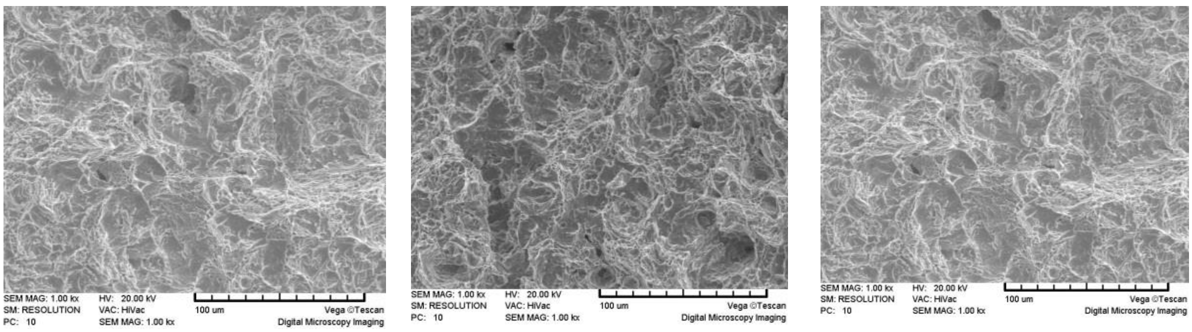
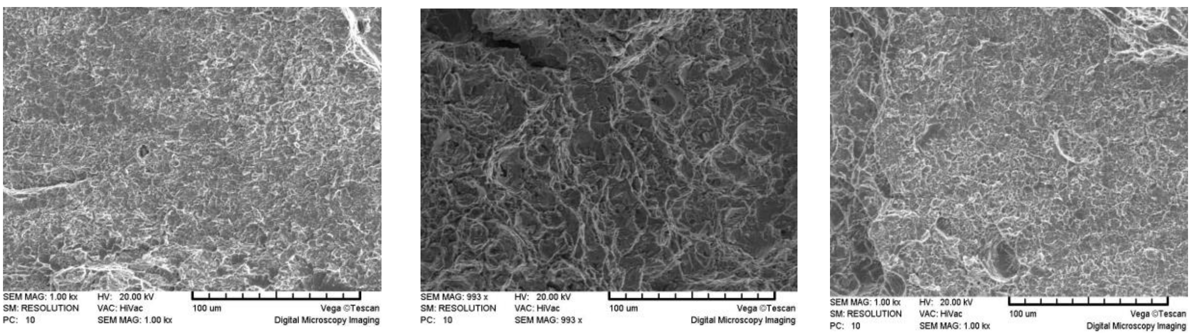


Figure.6 The impact toughness of the welding joint after aging for different time



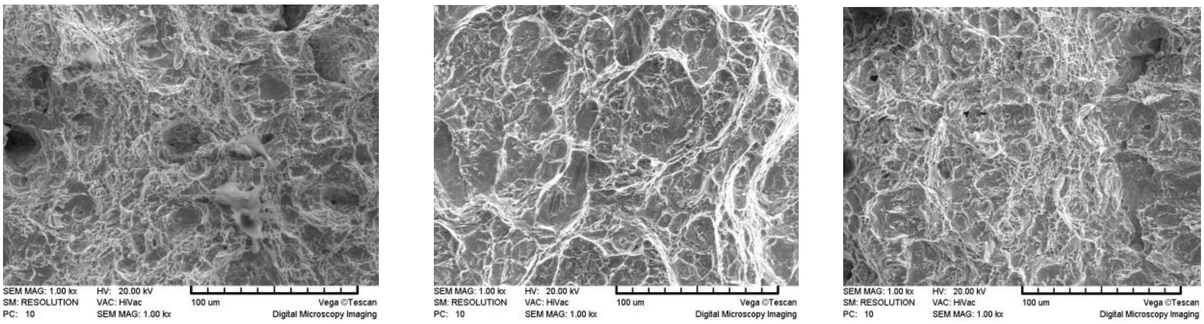
(a) (b) (c)

Figure.7 The rupture appearance of aged for 1000h: (a) the welding zone, (b) the heat affected zone , (c) the base metal



(a) (b) (c)

Figure.8 The rupture appearance of aged for2000h: (a) the welding zone, (b) the heat affected zone, (c) the base metal



(a) (b) (c)

Figure.9 The rupture appearance of aged for3000h: (a) the welding zone, (b) the heat affected zone , (c) the base metal

4. Conclusions

In the aging process, microstructure of the friction welded Super304H joints was exhibited. Precipitation, growth and aggregation of the $Cr_{23}C_6$ carbides were the main microstructure mechanism, resulting in the mechanical property change of the joints with the aging time. As the aging time increased, the tensile strength of the joints increased in the initial stage, than decreased after aged for 500 h. The impact toughness of the joints monotonously decreased with the aging time. The rupture mode of tensile strength and impact toughness samples changed from ductile fracture to brittle fracture.

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