Effect of the aging treatment on the tensile strength and impact toughness of friction welded T92 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 600°C for different time. As the aging time increased, the welding zone, heat affected zone and base metal were still plate martensite, and there was no change in the size of martensite strip. The impact toughness of the joints decreased. The tensile strengths of the joints drop firstly, then rise and finally tend to be stable, this is attributed to the aggregation and growth of the second-phases. The rupture mode of tensile strength and impact toughness samples changed from ductile fracture to brittle fracture.

Introduction

Increased heat efficiency is always the innovative driving forces in the development of ultra-supercritical boilers for fossil power plants, whose steam temperature is up to 600°C and pressure exceeds 27 MPa. Under this ultra-supercritical condition, the heat efficiency can rise to around 45%. However, with the increase of steam parameters, requirements for the materials applied in the ultra-supercritical boilers components are becoming higher. Thus, many new generation steels have been developed in recent years, including T92 martensitic steel. In comparison with T91 steel, the resistance to creep of T92 is about 30% higher. However, a question is how to join these new martensitic steel together. The conventional fusion welding joints of martensitic 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 [1-3]. In order to use friction welded T92 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 T92 joints after aged at 600°C. The analysis of mechanical properties provides the more fundamentals for wide application of the friction welded T92 joints at higher temperatures.

Experimental procedures

The pipes of T92 martensitic steel 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 1200 rpm, a friction pressure of 120 MPa, an upset pressure of 150 MPa and a friction time of 5s. These specimens were heated respectively in the furnace at 600 °C for 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.
Results and Discussion

Fig. 1-3 shows morphology aged for 1000h, 2000h and 3000h, respectively. During the friction welding process, completely austenification of martensitic grains and growth of the austenite grains occurred in the welding zone. Because the welded zone produced agglutinate and shear tear behavior, which led to the deformation of 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[4-6]. The welded zone of martensitic steel welded by fusion welding was typical coarse δ-phase grains with no martensite laths. the second-phase particles randomly distributed inside the prior austenite grains. The friction welding was solid state welding techniques, the melting process did not occur in the welded zone. So the heat input during the friction welding process was much less than the heat input during the fusion welding process. The coarse δ-phase grains were not formed in the welding zone. So the T92 friction welded joints with fine plate martensite grains with excellent microstructure. In the heat affected zone, the heat temperature was lower than the complete austenifying temperature of martensitic. So, the austenification of the martensite grains is not complete in the heat affected zone. In the cooling process after welding, the cooling rate in the heat affected zone was also higher than that in the welding zone, the recrystallization of the undercooled austenite takes place, resulting in the formation of the fine plate martensite in the heat-affected zone. After aged at 600°C, the grain size change of the plate martensite grains was not detectable. Precipitation, aggregation and growth of the second-phases are main styles of the microstructure evolution of the joints. It was known that Cr$_2$C$_6$ carbides and MX carbonitrides were two main second-phases in the high-temperature aged welding joints. Most of the Cr$_2$C$_6$ carbides distribute along the prior austenite grain boundaries and the martensite lath boundaries. As the ageing time increased, more and more alloying elements, such as Cr and C, separate out from the prior austenite grains, segregate along the prior austenite grain boundaries to accelerate the formation and growth of the Cr$_2$C$_6$ carbide [7]. As the aging time increased, the MX carbonitrides gradually precipitate and dispersively distribute in the prior austenite grains obviously.
The metallograph aged for 3000h: (a) the welding zone, (b) the heat affected zone, (c) the base metal

Fig. 4 (a) 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 base metal after aged for different time. As the aging time increased, the tensile strength of the joints increases (<500 h), and then decreases (500-2000 h), finally is nearly constant (2000–3000 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 second-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, 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 drop of the yield strength and tensile strength. In the final ageing stage, the MX carbonitrides gradually precipitate and dispersively distribute in the prior austenite grains to bring about the dispersion strengthening effect. Therefore, the weakening and strengthening effects by precipitating the second-phase particles exist at the same time and even to establish equilibrium of these effects in the final ageing stage. So when the joints aged for more than 2000h, the yield strength and tensile strength were nearly constant. As shown in Fig. 5, the fractographs of the tensile strength samples change with the ageing time. After aged for 1000h, 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.

Fig. 4(b) 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 and the MX carbonitrides are the main reason that the impact toughness of the joints decreased with the aging time increased. As shown in Fig 6- Fig 8, 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, the rupture mode of impact toughness samples changed from ductile fracture to brittle fracture.
Fig. 4 The mechanical properties of the welding joints: (a) tensile strength, (b) impact toughness

Fig. 5 The rupture appearance of the tensile strength samples: (a) 1000h, (b) 2000h, (c) 3000h

Fig. 6 The rupture appearance of the impact toughness samples aged for 1000h: (a) the welding zone, (b) the heat affected zone, (c) the base metal

Fig. 7 The rupture appearance of the impact toughness samples aged for 2000h: (a) the welding zone, (b) the heat affected zone, (c) the base metal
Fig. 8 The rupture appearance of the impact toughness samples aged for 3000h: (a) the welding zone, (b) the heat affected zone, (c) the base metal

Conclusions

In the aging process, microstructure of the friction welded joints was exhibited. Precipitation, growth and aggregation of the Cr$_{23}$C$_6$ carbides and the MX carbonitrides 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, then decreased after aged for 500 h, and finally tend to be stable. 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.

References