Effects of Friction Time on microstructures and mechanical properties of friction welded T92/Super304H dissimilar steel weld joints

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Abstract. In this paper, the T92 martensitic steel and the Super304H austenitic steel were welded by continuous drive friction welding technique. The friction welding joints exhibited good mechanical and metallurgical properties. The influence of friction time on the microstructure and mechanical properties of T92/Super304H dissimilar steel joints was investigated. With an increase in the friction time, the grains in the welding zone and the heat affected zone didn’t grow up and the number of second-phase particles precipitates increased. The tensile fracture location was in the Super304H base metal and didn’t change. With an increase in the friction time, the tensile strength didn’t change, and the impact toughness decreased.

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. 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critical power generation, traditional heat-resistant steels used in the subcritical and supercritical units have been replaced by those new heat-resistant steels. The recently developed Super304H (0.1C-18Cr-9Ni-3Cu-Nb-N) austenitic steel has shown considerable promise due to its high oxidation resistance, corrosion resistance and creep resistance. The Super304H has higher strength at elevated temperatures are required for super heater tubes in the boilers. This excellent creep rupture strength is based on finely precipitated particles such as Nb(C, N) and NbC, Thus, it is widely used for super heaters and reheaters, which have the abominable service environment in Ultra-super critical boilers. The T92 (9Cr-0.5Mo-2-W-V-Nb) martensitic steel approximately similar to T91 but with a little modification in chemical compositions for preferable high temperature properties. The T92 martensitic steel will certainly have a broad application prospect in forth coming ultra-super boilers [1,2]. In this case, the welding between T92 and Super304H steels will be necessary.

At present, the T92 martensitic steel and Super304H austenitic steel are welded through a gas tungsten arc welding (GTAW) technique usually in engineering applications. The GTAW technique is mature and suitable for field welding. Nevertheless, the T92/Super304H joints welding through the conventional fusion welding still exhibit inferior mechanical properties, due to: (i) The base metal near the fusion line during the fusion welding process is prone to form the wide heat affected zone with coarse grains; (ii) A transition layer (fusion zone) will appear in the welding zone near the weld line;
The friction welding is a solid state welding process, and the welding temperature was under the melting temperature. This welding process nullifies adverse effects of the uncertainties in the filler metal selection by GTAW technique. The friction welding has a number of advantages over the conventional fusion welding process. The major advantage relies on the direct conversion of mechanical energy into thermal energy at the joint interface in contrast to fusion welding. The very high temperature gradient available in the joint area accounts for a very small heat affected zone. Owing to the narrow the heat affected zone, the welding distortion is kept minimum. Additionally, because it is a solid state process, the defects associated with melting solidification phenomenon, such as porosity and slag are not present [3-5]. The aim of this paper is to fabricate a combination with better mechanical properties between the Super304H austenitic steel and the T92 martensitic steel using continuous drive friction welding. The effect of friction time on the microstructure and mechanical properties of the welded joints were thus investigated.

2. Experimental procedures

The pipes of Super304H austenitic steel and T92 martensitic steel that in the sizes of Φ44.5mm x 9mm were used as base metals. The pipes of Super304H and T92 were friction welded by a continuous drive friction welding machine. In the process of friction welding, the friction speed was 1500 rpm, the friction pressure was 150 MPa and the upset pressure was 200 MPa. In the process of friction welding, the friction time was 6 S of Process 1, 10 S of Process 2 and 14 S of Process 3 respectively. The metallographs and fractographs of the welding joints were performed by an optical microscope and a scanning electron microscope respectively. The tensile samples were tested using a testing instrument. The impact samples were tested using an impacting instrument.

3. Results and Discussion

Figure 1, 2 and 3 shows the metallography of the welding joints with different friction time respectively. During the friction welding process, the welded zone produced agglutinate and shear tear behaviour, which led to the deformation of the grains in the welding zone, the dynamic recrystallization driving force and lattice distortion energy increased. The thermoplastic deformation temperature and unit volume free energy of recrystallized grains decreased, which produce a large number of recrystallized nucleations. The welding zone included a welding interface that was straight and clear, the areas (about 50μm from the welding interface) on both sides of the welding interface. The Super304H side of the welding zone was mainly composed of fine equiaxed austenite grains because of grain refinement. The martensite grains which in the T92 side of the welding zone were austenitized due to the higher temperature generated in the friction process. Than it produced a large number of fine equiaxed austenitic grains by dynamic recrystallization. In the cooling process, the recrystallization of the equiaxed austenitic grains takes place, resulting in the formation of the fine plate martensite grains. The welding zone of T92/Super304H dissimilar steel welded by friction welding process had the typical coarse δ-phase grains. The coarse δ-phase grains were not formed in the welding zone by the friction welding. Because that the welding interface is well combined, and the austenite grains and plate martensite grains on both sides of the welding interface was fine, so the welding zone of the welding joints exhibit excellent mechanical properties. The heat input during the friction welding process was much less than the heat input during the fusion welding process. The width of the heat affected zone caused by friction welding process were much smaller than the width of the heat affected zone caused by the fusion welding process. The tendency of grains growth during the friction welding process was less obvious than the tendency of grains growth during the fusion welding process. So the heat affected zone of the welding joints with the fine grains showed excellent microstructure. [6, 7]. So the friction welded Super304H/T92 joints with the fine grains in the welding zone and heat affected zone showed excellent microstructure and mechanical properties.
The surface temperature of the welding joints was equal to the temperature of the welding heat source in friction welding process. So the surface temperature of the welding joints had a great influence on the microstructure and mechanical properties of the welding joints. The surface temperature of the welding joints was calculated according to the Eq (1)

**Figure 1** The metallography of welded joints for Process 1 (a) the T92 heat affected zone, (b) the welding zone, (c) the Super304H heat affected zone

**Figure 2** The metallography of welded joints for Process 2 (a) the T92 heat affected zone, (b) the welding zone, (c) the Super304H heat affected zone

**Figure 3** The metallography of welded joints for Process 3 (a) the T92 heat affected zone, (b) the welding zone, (c) the Super304H heat affected zone
\[ T(t) = qt/(\pi \lambda C) \]  

(1)

\( T \) was referred to the surface temperature of the welding joints, \( t \) was referred to friction time and \( q \) was referred to friction heating power. When friction heating power was constant, as the friction time increased, the surface temperature of the welding joints increased correspondingly. Because that melting process did not occur in the welding zone, although the surface temperature of the welding joints increased, the size change of the grains in the welding zone was not detectable. As the friction time increased, the heat input during the friction welding process increased in the heat affected zone, and the temperature of the heat affected zone increased accordingly. The size change of the grains which in the Super304H heat affected zone and in the T92 heat affected zone was not detectable, but the amount of the precipitated phases in the both heat affected zone increased obviously [8,9].

Table 2 depicted the variation of the yield strength and tensile strength as a function of the friction time. It was detected that the fracture position of the welding joints was in the Super304H base metal for the different friction time. The fractographs of the tensile strength samples were shown in figure 4. The fracture morphology was characterized by typical ductile fracture, and a lot of fine and shallow dimples distributed on the fracture surface. As the friction time increased, the tensile strength change of the welding joints was not obviously. The tensile strength change is certainly corresponding to the microstructure evolution. Table 2 depicted the variation of the impact toughness as a function of the friction time. The grains size had a great influence on the impact toughness of each zone of the welded joints. When the grains size was smaller, the impact toughness was higher. The grain size of the heat affected zone was the larger, so the impact toughness of the heat affected zone was the lower. As the friction time increased, the dislocation density and lattice distortion energy in the welding zone increased, and the impact toughness of the welding zone decreased. The precipitation of the \( \text{Cr}_23\text{C}_6 \) carbides were main reason that the impact toughness of the heat affected zone decreased with the friction time increased. The fractographs of the impact toughness samples were shown in figure 5, 6 and 7. The fracture mode of the impact toughness samples was ductile fracture with the aggregation dimples on the fracture surface. In the welding zone, the dimples were distributed densely and deeply, and the shapes of dimples were round. In the heat affected zone, the dimples were distributed sparsely and shallow, and the shapes of dimples were flat.

**Table 1** The mechanical properties of Super304H/T92 welded joints

| Fracture position | Tensile strength /MPa | Impact toughness /J |
|-------------------|-------------------|------------------|
| Welding zone      | R_p0.2 | R_m | Super304H base metal | 83.8 | 78.7/65.2   |
| Heat affected zone|       |     | (Super304H/T92)      |      |             |
| Process 1         | 454.77 | 670.79 | Super304H base metal | 83.8 | 78.7/65.2   |
| Process 2         | 432.62 | 689.05 | Super304H base metal | 74.3 | 61.6/49.9   |
| Process 3         | 475.82 | 712.43 | Super304H base metal | 71.8 | 52.8/43.4   |
Figure 4 The fracture appearance of the tensile strength samples (a) Process 1, (b) Process 2, (c) Process 3

Figure 5 The fracture appearance of the impact toughness samples for Process 1 (a) the T92 heat affected zone, (b) the welding zone, (c) the Super304H heat affected zone

Figure 6 The fracture appearance of the impact toughness samples for Process 2 (a) the T92 heat affected zone, (b) the welding zone, (c) the Super304H heat affected zone

Figure 7 The fracture appearance of the impact toughness samples for Process 3 (a) the T92 heat affected zone, (b) the welding zone, (c) the Super304H heat affected zone
Conclusions
The T92/Super304H dissimilar steel welded joints with excellent properties were welded by continuous drive friction welding technique. The welding interface was well combined, and the austenite grains and plate martensite grains in the welding zone was fine. The fracture position of the welding joints was in the Super304H base metal. The influence of friction time on the microstructure and properties of T92/Super304H dissimilar steel joints was investigated. With the friction time increased, the grains of weld zone didn’t grow up and the number of second-phase particles precipitates increased. The impact toughness decreased, the tensile fracture didn’t change.

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