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Study on Creep Rupture Strength of Friction Welded Super304H Steel Weld Joints

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Abstract. In this paper, the creep rupture strength for Super304H weld joints was evaluated by isothermal method. Service life prediction curves indicate that Super304H weld joints could guarantee safety service for 10^5 hours at 625°C, which is in accordance with the Ultra-supercritical units steam conditions. When the stress is higher, the rupture mode of creep specimens was transcrystalline fracture, and results in forming dimples. When the stress is lower, the rupture mode of creep specimens was creep rupture, and results in cleavage rupture. So under the effect of long term low stress, creep cavities joined each other along the grain boundary.

1. Introduction

The less fuel consumption was brought about by the increase in steam pressure and temperature of the conventional boiler/steam power plant. The research and development of the steel with superior creep resistance, oxidation resistance and corrosion resistance is the most important. The austenitic stainless steels with outstanding creep strength and oxidation resistance are the best choice for the power plant [1]. The new developed Super304H austenitic steel showed a good future for exceptional creep rupture strength. The Super304H welding joints showed excellent creep rupture strength, the precipitation strengthening of the precipitated phases such as Nb(C,N) is the main reason [2]. Friction welding is a solid state welding process, and the welding temperature was under the melting temperature. Combined with the autogenous nature of this welding process nullifies adverse effects of low temperature eutectics segregation and the uncertainties in the filler metal selection. The process of friction welding was automatic, the weld joints performed excellent performance. So, the friction welding can be successfully applied for welding of austenitic stainless steel joints for higher temperature application [3-5].

2. Experimental Procedures

The pipes of Super304H austenitic stainless steel that in the sizes of $\Phi 44.5\text{mm} \times 9\text{mm}$ were used as base metals. The pipes of Super304H 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, the upset pressure was 200 MPa and the friction time was 5s respectively. The creep experimental temperature was 625°C and loading stress of 200, 220, 240, 260 and 280 MPa. The creep specimens were ruptured under the loading stress of 220, 240, 280 MPa respectively, the fractographs and the metallograph of the creep specimens were observed and analyzed by the scanning electron microscopy with an energy dispersive spectroscopy (EDS) system.



3. Results and Discussion

Under the loading stress of 200MPa, 220MPa and 240MPa, the creep rupture locations of the Super304H weld joints is the base material. Under the loading stress of 260MPa and 280MPa, the creep rupture locations of the Super304H weld joints is the heat affected zone. Table 1 shows creep strength experiment results of Super304H weld joints under the loading stress ranging from 200 MPa to 280MPa. With the loading stress increased, the rupture time reduced. The creep strength vs rupture time curves for Super304H weld joints were shown by lg-lg coordinates in Fig. 1. The creep strength experiment under constant loading stress was described by the creep rupture time and loading stress seen in Eq.(1)[6]:

$$t=A\sigma^{-B} \quad (1)$$

σ is referred to as loading stress, t is referred to creep rupture time, A, B are referred to as the test temperature constant and materials constant respectively. Take the logarithm of the Eq.(1):

$$\lg t = \lg A - B \lg \sigma \quad (2)$$

The $\lg \sigma$ is linear with $\lg t$, and take linear regression of loading stress and the creep rupture time using least squares method. The corresponding parameters of A and B is as follows

$$\sigma = 757.234t^{-0.153} \quad (3)$$

Under the loading stress of 30 MPa and 40 MPa, the rupture times were more than a 10^5 h by the polynomial fitted curve. Furthermore, the long-term creep rupture strengths for Super304H weld joints can be expressed by polynomial fitted curves, which give a theoretical support for the long-term service life for Super304H weld joints. So, the Super304H weld joints could guarantee safety service for 10^5 hours under the loading stress of 30 MPa and 40 MPa., that is in according with the Ultra-supercritical units steam conditions.

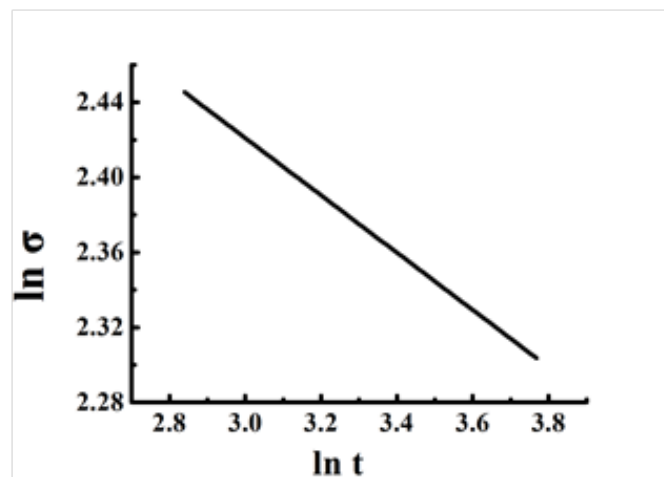


Figure 1. The service life prediction curves of Super304H weld joints

Table 1. The creep rupture strength of Super304H weld joints

Sample No.	Test temperature /°C	Loading stress /MPa	Creep rupture time /h	Rupture location
1	625	200	5873.8	base material
2		220	2960.1	
3		240	2375.3	
4		260	978.1	heat affected zone
5		280	691.5	

The fracture surface of creep specimens for loading stress ranging from 200 to 280 MPa are observed in Fig. 2. The fracture surface for the specimen under the loading stress of 200 MPa is observed in Fig. 2(a), the specimen exhibited an excellent ductility because of a lot of dimples in the fracture surface. Many dimples gather with each other that lead to the fracture in the specimen. The fracture surface for the creep specimens under the loading stress of 280 MPa is observed in Fig. 2(c), the rupture mode of creep specimens was intergranular brittle fracture. The fracture surface of the specimens change with the loading stress in Fig. 2. With the loading stress increased, the number of the fracture surface dimples decreased. The brittle fracture became serious on the fracture surface. Therefore, the plastic deformation degree decreases. The rupture mode of creep samples changed from ductile fracture to brittle fracture. Fig. 3 shows metallograph of creep specimens ranging from 200 to 280 MPa respectively. From Fig. 3(c) (f), there is significant contraction on the fracture surface at 280 MPa, the grains are obviously elongated. In fig. 3(a) (d), the contraction on the fracture surface is ignored, and the grains are not elongated.

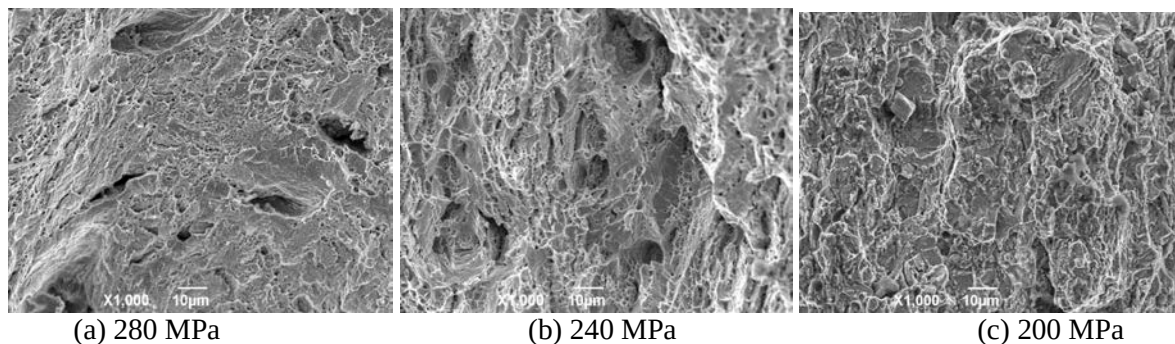


Figure 2. The creep rupture appearance of welded joints

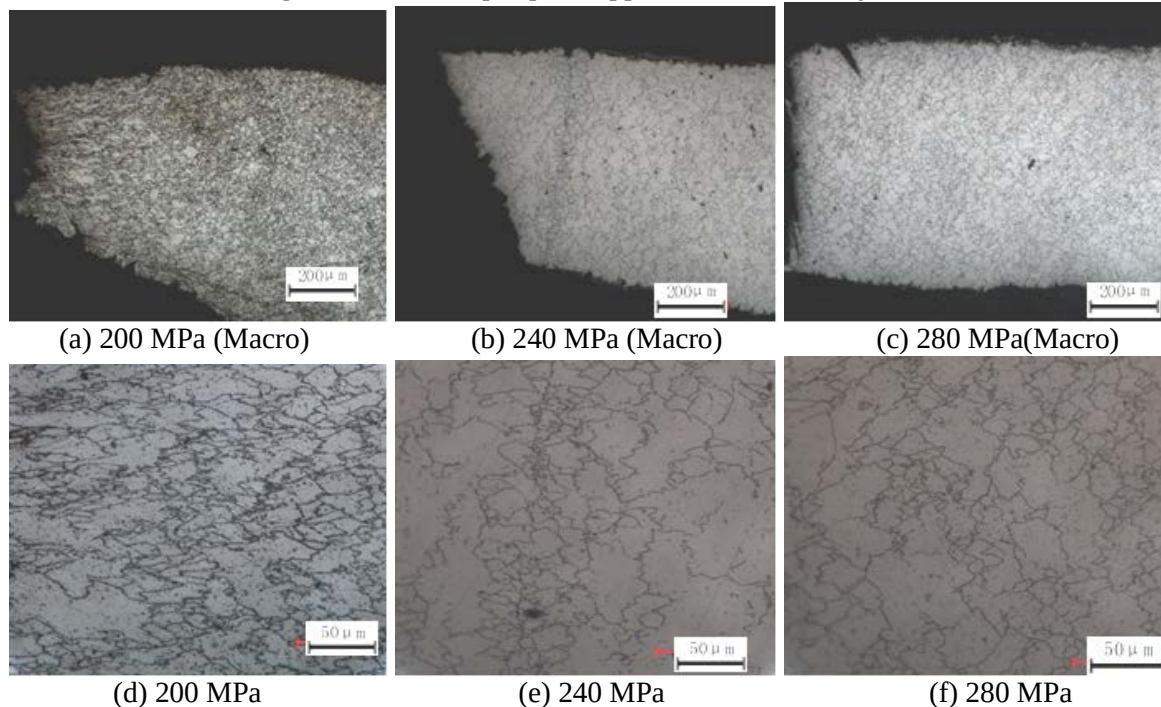


Figure 3. The metallograph of welded joint

Fig 4 exhibited the precipitated phase in the specimen for loading stress at 200MPa and 280 MPa with EDS to show the elements of the precipitated phases. Table 2 exhibited the EDS analysis results of the precipitated phases as shown in Fig 4. Fig 4 (a) shows the shape of precipitated phases of welded joints for loading stress at 280 MPa, the precipitated phase A is Nb(C, N) and the precipitated

phase B is Cr_{23}C_6 . It can be observed some fine Cr_{23}C_6 and Nb(C, N) distributed along the grains boundaries and in the interior of grains. Fig 4 (b) shows the shape of precipitated phases of welded joints for loading stress at 200 MPa, the precipitated phase A is Nb(C, N) and the precipitated phase B is Cr_{23}C_6 . The Cr_{23}C_6 distributed along the grains boundaries continuously, and the Nb(C, N) distributed in the interior of grains in chains. The aggregation and growth of Cr_{23}C_6 were obviously. Some Cr_{23}C_6 that distributed isolated were coarse and lath-like.

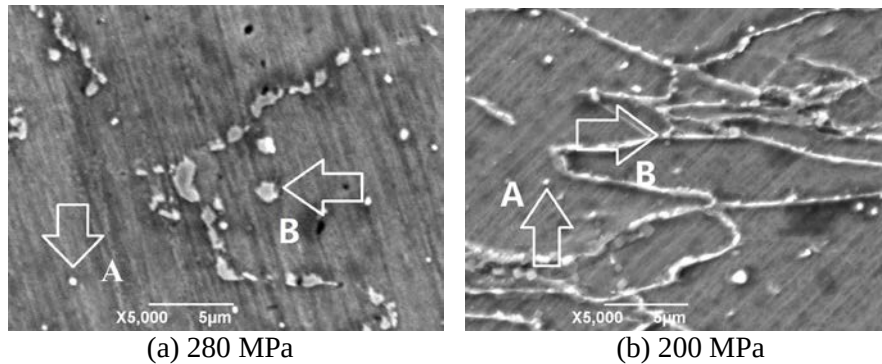


Figure 4. The shape of precipitated phases of welded joints: (a) 280 MPa; (b) 200 MPa

Table 2. The energy spectrum analysis of the precipitated phase (at%)

	C	N	Cr	Fe	Ni	Cu	Nb
The precipitated phase A(280 MPa)	15.83/48.17	4.45/11.61	8.4/5.9	22.12/14.48	1.87/1.17	0.18/0.12	47.15/18.55
The precipitated phase B(280 MPa)	26.33/60.17	3.01/5.89	16.3/8.6	41.97/20.63	5.32/2.49	0.9/0.39	6.18/1.83
The precipitated phase A(200 MPa)	29.34/66.72	1.9/3.7	13.08/6.87	29.41/14.38	2.38/1.11	1.08/0.52	22.8/6.7
The precipitated phase B(200 MPa)	24.87/58.76	2.3/4.66	15.64/8.53	47.27/24.02	5.09/2.64	0.68/0.3	4.14/1.27

Fig 5 shows the cracks of the welding joints for loading stress at 200MPa and 280 MPa. When the loading stress are 260 MPa and 280 MPa, the austenite grains under the effect of higher stress is in the process of deformation, produced a lot of dislocations. Dislocation produced displacement under the combined action of stress concentrates and thermal activation. In the creep deformation, the proportion of grains boundary sliding is lower, the grains boundary is elongated, and the transcrystalline fracture is exhibited. Because the slidable interface between the matrix and the Cr_{23}C_6 and Nb(C,N) precipitated phase cannot transmitted shear stress and transmitted normal stress only. So the plasticity of the precipitated phase is poor, resulting in the formation of cracks. Therefore, the Cr_{23}C_6 and Nb(C,N) precipitate phase generated cracks firstly. As the cracks go through the different grains, this fracture mode belongs to transcrystalline fracture. When the loading stress are 220 MPa and 200 MPa, the austenite grains fracture is mainly creep rupture under the effect of lower stress, the process of fracture is the nucleation and growth of microcracks and voids. Since the creep fracture is mainly generated at the austenite grains boundaries, the structure and precipitation of the austenite grains boundaries have a greater influence on the creep rupture. As a result of higher grain boundary energy,

Small cavities formed on the austenite grains boundaries and then grow up, the adjacent creep cavities connect with each other to form a creep crack. With the stress reduced continuously, the proportion of sliding deformation of the austenite grains boundaries increases during creep deformation, resulting in the formation of creep cavities on the austenite grains boundaries and the formation of cracks, which are characterized by intergranular fracture. The creep cracks can be divided into the cavities cracks and the wedge cracks. The wedge cracks were formed from the higher stresses, and the cavities cracks were formed from the lower stresses[7]. The Super304H welded joints showed excellent creep rupture strength, the precipitation strengthening of the precipitated phases such as Cr_{23}C_6 and $\text{Nb}(\text{C},\text{N})$ is the main reason. The effect of precipitation strengthening is related to the type, size, shape and stability of the Cr_{23}C_6 and $\text{Nb}(\text{C},\text{N})$ precipitated phases. When the Cr_{23}C_6 and $\text{Nb}(\text{C},\text{N})$ precipitated phases is uniformly distributed by the dispersed fine particles, the precipitation strengthening effect is improved. When the precipitated phases are aggregated and grow up, the precipitation strengthening effect is weakened. The precipitated phases is more stable, and the less likely to aggregate, which is favorable for precipitation strengthening. The $\text{Nb}(\text{C},\text{N})$ phases precipitated during higher temperature creep process is fine and stable, which showed excellent strengthening effect.

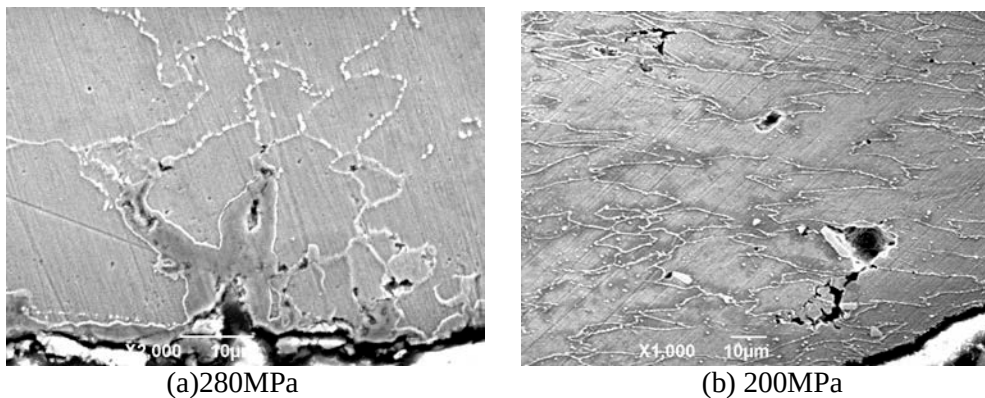


Figure 5. The cracks of Super304H welded joints

4. Conclusions

In this paper, creep rupture strength is evaluated using isothermal method. Service life prediction curves indicate that Super304H weld joints could guarantee safety service for 10^5 hours at 625°C , which is in accordance with the Ultra-supercritical units steam conditions. When the stress is higher, results in the transcrystalline fracture that forming dimples. When the stress is lower, the rupture mode belongs to creep rupture that forming cleavage rupture.

5. References

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