Investigation on ductility dip cracking susceptibility of filler metal 82 in welding†

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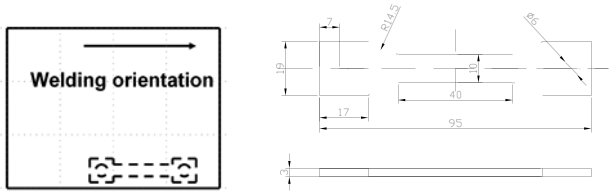
1. Introduction

The Ni-base alloys have widely been used in nuclear power plant, particularly to variety pipe welding. Ductility Dip Crack mainly happens in a Ductility Dip Temperature Range (DTR) below the solidus temperature when a stroke is exerted[1]. Currently, among all the Ni-base alloys that have been used, Inconel600 is a kind of Ni-Cr-Fe alloy with excellent high temperature strength and corrosion resistance. A significant amount of research has been performed to identify the mechanisms of DDC. Rines and Wray's [2] work shows that DDC is formed by void accumulation during shear loading, which has great similarity to creep cracking. Another hypothesis is studied by Zhang, et al. [3], who believe that intergranular precipitate, intergranular sliding and boundary tortuosity have complex effects on DDC susceptibility. And K. C. WU and R. E. [4] Herfert think that appearance of DDC is due to grain boundary weakening, as intergranular strength be comes lower then intragranular strength when heated up to a certain temperature. This work mainly studies DDC susceptibility of Filler Metal 82 under different stress states.

2. DDC susceptibility test in uniaxial stress state

Filler Metal 82 strip is used for study and overlay welding is performed on steel for 3 layers (12mm), shown as **Fig. 1**a. To avoid components fluctuation by steel, only the upper layers are chosen to make samples by wire cutting. The shape of samples is shown as Fig. 1b. Spot welding (diameter about 7mm) in both sides of samples is required.

First, Zwick and Gleeble machine are used for tensile test to find the ductility dip range, and Stress-Strain curves under different temperature are achieved. Later, Strain to Fracture(STF)tests take the temperature history loading, as shown in **Fig. 2**, at DTR of DDC.



(a) Welding orientation (b) Shape of samples

Fig. 1 Schematic diagram of sample

Samples are heated to 1000℃ and held for 10s. And then cooled to a certain temperature (750℃, 850℃, 900℃, 950℃, 1000℃, 1050℃), a stroke is loaded after holding the temperature for 10s. The stroke is also held for 10s, later, cooling till room temperature. Along with the surfaces holding at 1100℃, 1150℃, 1200 ℃, the critical strain of DDC is found.

Finally, corroding on the sample surfaces, optical microscope and SEM are used to observe the surface cracks and microstructure.

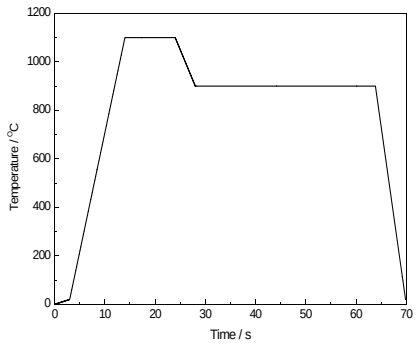


Fig. 2 Temperature history loading

Yield strength and elongation of FM82 decrease with increasing temperature, from the figure, the stress-strain curves have obvious hardening periods from room temperature till 850℃. On the other hands, yield platform appears in the stress-strain curves above 950℃.

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It indicates that intergranular strength is inferior to intragranular strength at lower temperature. For most of the deformation happens intergranularly, dislocation slipping and climbing lead to a hardening period. With temperature increasing, materials strength decreases, till a certain temperature, intragranular strength be comes inferior to intergranular strength, which results in grain boundary （GB）, sliding the main form of deformation. As DDC is due to intergranular cracks at high temperature and caused by uncoordinated intergranular deformation and voids accumulation, FM82 is much more susceptible to DDC above 900℃. At high temperature above 1100℃, the strengthened re-crystallization can prevent the crack propagation, which reduces the DDC sensitivity effectively. [5]

According to STF results, from 900℃to 1200℃with a stroke rate of 0.5mm/s, the minimum critical strain of FM82 is less than 3% and the most sensible temperature is about 1100℃, as **Fig. 3** shows.

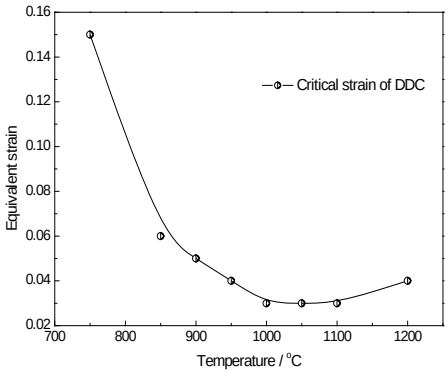


Fig. 3 Critical strain at different temperature

3. DDC susceptibility under complex stress state

FEM model of TIG welding is built up by ABAQUS common software with size of 100×100×2mm plate. The welding parameter used are as follows, current I=100A, voltage U=10V, welding speed ν=2mm/s, and a double ellipsoid heat source is used. **Figure 4** shows the distribution of welding temperature.

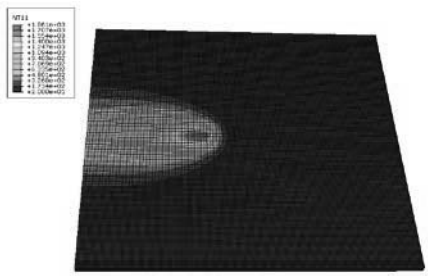
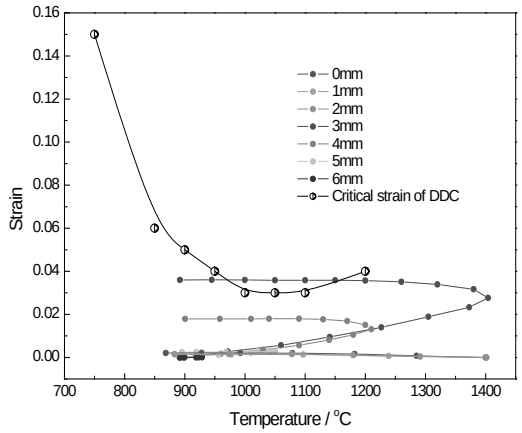
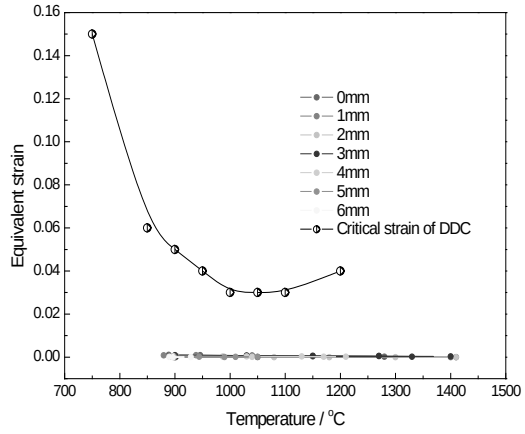


Fig. 4 Temperature distribution of single pass welding

In order to evaluate the DDC susceptibility, the equivalent strain increment to temperature curve is achieved at DTR (900-1350℃). As **Fig. 5**a shows, when the welding speed is 2mm/s, the curve of 3mm to weld



(a) Welding speed of 2mm/s



(b) Welding speed of 5mm/s

Fig. 5 Equivalent strain changing with temperature

gets across the sensitive range. It means that the strain at this location is higher than critical strain and prone to DDC propagation.

When raising the welding speed in the case of the same weld width, in light of conductive time, strain changes more behind the temperature peak compared to speed of 2mm/s. Thus deformation is slight in DTR. From the curve of equivalent strain increment to temperature (Fig. 5b), the position around the weld has less DDC susceptibility.

According to the simulation results of single-pass welding, welding strain decreases against distance to the fusion line. Moreover, optimizing welding parameters, such as increasing welding speed, can effectively decrease DDC susceptibility. With the increase of welding speed, strain changes respectively behind the temperature peak, which enables deformation to avoid the sensitive temperature range.

4. Conclusions

According to the experiment and simulation results, the following conclusions can be obtained:

（1）STF test samples show that the minimum critical strain of FM82 is less than 3% at 1100℃. GB weakening and sliding is the main reason for DDC formation by the

tensile test. When deformation is over the critical strain GB can endure, void accumulation results in crack propagation perpendicular to loading.

（2）By the FEM model of single pass welding, 3mm from weld center has the most susceptibility at this welding condition. Upon the same weld width, simulation shows that increasing welding speed can effectively improve DDC resistance.

Acknowledgement

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