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Effect of grain size on solidification cracking susceptibility of type 347 stainless steel during laser welding[†]

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KEY WORDS: (Grain size) (Solidification cracking) (Stainless steel) (Laser welding) (Fine grain) (In-situ observation) (Critical strain)

1. Introduction

It has been reported that coarse grains can induce a high solidification cracking susceptibility compared with fine grains. Matsuda et al. evaluated the effect of grain size of weld metal on solidification cracking susceptibility of aluminum alloys by using various self-restraint hot cracking tests [1,2]. In this report, microstructure of weld metal indicated the equiaxial grain. On the other hand, the effect of grain size of the base metal on solidification cracking susceptibility has not been reported yet. Meanwhile, although some reports have been found on the effect of grain size on liquation cracking during laser welding of Ni-base alloys [3], there are few reports found on the effect of grain size of weld metal in columnar structures on solidification cracking susceptibility for materials, except aluminum alloys.

In this paper, the effect of grain size on solidification cracking was investigated by using a U-type hot cracking test with in-situ observation method. Firstly, Type 347 stainless steel specimens with different grain sizes were made by heat treatment. Then, high temperature ductility curves of the specimens with different grain sizes were obtained, and cracking susceptibilities were evaluated by the CST.

2. Materials used and Experimental Procedure

Type 347 stainless steel (100'x30"x5mm^t) was used as the test piece. The chemical composition is shown in **Table 1**. The thickness of welding part was machined from 5 to 3mm. The specimen was heated in an electric furnace for different holding times to obtain different grain sizes of the base metal before welding. The holding temperature was 1200°C. The holding times were set as 0.5h, 1h, and 4h.

Table 1 Chemical composition of material used (mass%)

Material	C	Mn	Si	P	S
Type 347	0.17	0.16	0.27	0.02	0.002
	Cr	Ni	Fe	Nb	
	19.18	10.34	Bal.	0.575	

Figure 1 shows the experimental setup of U-type hot cracking test [4,5] with the developed vertical in-situ observation. The inclination angle of laser welding head was set as 30 degree to avoid the interference between camera and laser head. The fiber laser was used at the power of 1.6kW and the travelling speed of 0.4m/min. Solidification behavior near the molten pool during laser welding was obtained with a high speed camera with 7 times magnification in U-type hot cracking test. By using movie, critical strain of solidification crack was measured. [6] In this study, gauge length was changed into 0.2, 0.5 and 1mm.

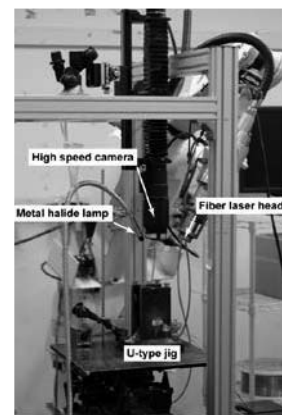


Fig. 1 Experimental setup of the vertical in-situ observation method

3. Results and Discussion

Figure 2 shows grain size for the specimens used. Regarding grain size of weld metal, the average width of the columnar grain was measured as the average grain size. The measurement area was set in the bead centre. Compared with grain size of base metal as 13μm(0h), 79μm(0.5h), 126μm(1h), 237μm(4h), the grain size of weld metal shows as 69μm(0h), 168μm(0.5h), 179μm(1h), 210μm(4h). It can be seen that the grain size of weld metal is related to the grain size of the base metal.

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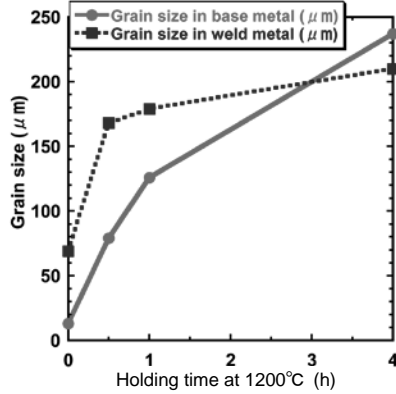


Fig. 2 Grain sizes compared between base metal and weld metal

About 6-7 strain-time curves were obtained in each grain size sample by the in-situ observation measurement method. The crack initiation strain could be measured in each strain-time curve. The strain-time curve was change to the strain-temperature curve using the cooling curve in the weld metal. Each plot indicates the crack initiation strain in Fig. 3. By connecting these plots, the high temperature ductility curves of various grain sizes in weld metal were drawn as shown in Fig. 3. For the weld metals with different grain size, the measured critical strains decrease from 2.2 to 0.6% with an increase in grain size from 69 to 210μm.

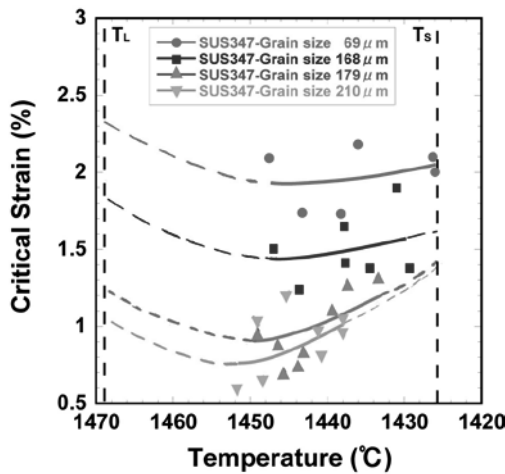


Fig. 3 High temperature ductility curves of used specimens with different grain size

Figure 4 shows the critical strain rate of temperature drop (CST) based on the high temperature ductility curves in Fig. 3. The CST of specimen-0h is about $4.7 (\times 10^{-4} \text{C}^{-1})$. With increasing the grain size, the CST declines considerably to about $3.8 (\times 10^{-4} \text{C}^{-1})$ for the specimen-0.5h. Then, the CST drops slowly with increasing the grain size. The CST shows about $3.4 (\times 10^{-4} \text{C}^{-1})$ for specimen-4h the largest grain size used. Therefore, it can be seen that a coarse grain size of base metal induces a high solidification cracking susceptibility. That is to say, regarding the solidifying weld metal, the larger grain size, the lower

ductility, thus, the more easily solidification cracks occur. For the specimens of different grain sizes obtained in this study, the cracking susceptibility was highest for the specimen-4h in the weld metal.

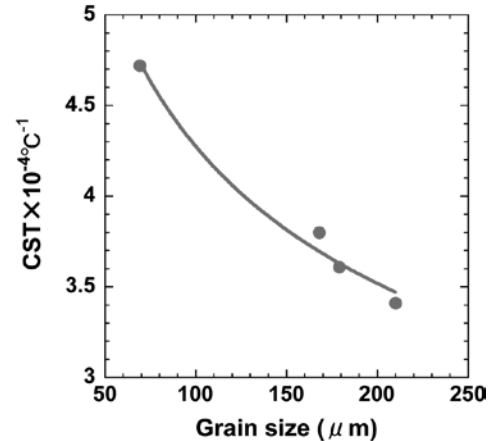


Fig. 4 Evaluation of solidification cracking susceptibility by high temperature ductility curves

The Trans-Varestraint test has been famous for evaluation of solidification cracking susceptibility, quantitatively. This test can measure BTR, but the lowest ductility is not so accurate. It is clear that solidification cracking susceptibility can be evaluated more accurately and quantitatively by means of combining both the critical strain obtained by U-type hot cracking test with in-situ observation method and BTR obtained by Trans-Varestraint test.

4. Conclusions

The effect of columnar grain size on solidification cracking susceptibility of Type 347 stainless steel was investigated by using U-type hot cracking test with developed in-situ observation method. The obtained conclusions are as follows.

- (1) Specimens whose grain sizes of columnar structure in weld metal varied from 69 to 210μm were prepared by changing the grain size of the base metal using heat treatment.
- (2) Local critical strains of solidification cracking were measured by four specimens with different grain sizes of weld metal from 69 to 210μm. High temperature ductility curves were obtained based on various critical strains.
- (3) The effect of grain size on solidification cracking susceptibility was evaluated quantitatively by using the CST of high temperature ductility curves. It was found that a specimen of coarse columnar grain size of the weld metal shows a high solidification cracking susceptibility comparing with that of fine grain size.

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