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Microstructure Analysis of Linear Friction Welded AISI 321 Stainless Steel Joint

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Abstract

In this study, the microstructure evolution of AISI 321 stainless steel during linear friction welding (LFW) was investigated. The results show that LFWed AISI 321 joint has a distinct weld zone (WZ) and thermo-mechanically affected zone (TMAZ). The WZ presents a narrow band of about 400μm thick, which is characterized by a fine-grained recrystallized structure with the average grain size of 2.3μm. Besides, a strong {001}<110> type texture has been formed in the WZ. The TMAZ presents typical streamlines, the thickness of which increases gradually from the weld center to the margins.

Keywords: Linear friction welding, Austenitic stainless steel, Microstructure

1.Introduction

Linear Friction Welding (LFW) is a solid state joining process, suitable for joining non-axisymmetric workpieces[1]. During LFW, two parts are brought into contact under a pressure and linear oscillation of one component commences. Friction heat and deformation are generated, and result in continuous yielding at the interface between two parts. Once sufficient plasticity has occurred, friction movement is rapidly stopped and the forging force is applied, and finally the welding is completed[2]. The temperature during the process does not reach the fusion point of the parent material (PM), thus, solidification problems (e.g. hot cracking, porosity, segregation, etc.) are avoided[3]. Because of high-quality welds by solid state, no spatter, no need for filler material and gas protection [4-5] are necessary, LFW is becoming a key technology to manufacture and repair blisks in aeroengines[6-8].

AISI 321 is a Ni-Cr-Ti type austenitic stainless steel. As an important industry material, stainless steel has many excellent properties, such as high strength, corrosion resistance, and easy processing. However, there are certain difficult problems when welding stainless steels with traditional fusion welding, such as formation of strong directional columnar grains easily leading to solidification cracking[9], and harmful hexavalent chromium fumes[10]. Solid state welding processes, such as friction welding, become the preferable methods. Some attempts has been made to study the friction welding characteristics of stainless steel employing continuous drive friction welding machine[11-13]. A. Hascalik et al.[13] found that mechanical properties and microstructural features are affected significantly by rotation speed and the fatigue strength of friction-welded samples decrease with increasing rotation speed. I. Bhamji et al.[3] reported that mechanically sound linear friction welds could be produced in 316L stainless steel. But the flash of 316L welds was bifurcated (the flash coming from the two weld halves splits and forms two separate collars), which has not been observed when LFW Ti and its alloys, where a single wing like structure is formed[14]. Besides, they found that there has a strong {111}<112> type texture at the centre of the weld, which is a typical shear texture in face center cubic materials[3]. However, no further work is focused on LFW stainless steels. Therefore, the aim of this work is to examine the microstructure of LFWed AISI 321 stainless steel joint, to provide basis and reference for the practical application of stainless steel.

2. Experimental

AISI 321 stainless steel (cold rolling steel) blocks of 10mm width × 17mm length × 45mm height were used as the PM, which has the nominal compositions as given in Table 1.

Table 1. Nominal compositions of AISI 321/wt.%.

C	Si	Mn	P	S	Ni	Cr	Ti	Fe
0.08	1.0	2.0	0.045	0.03	9.0-12.0	17.0-19.0	5c-0.70	Bal

The custom made LFW machine of NPU was used and the welding parameters employed are shown in Table 2.

Table 2. Welding parameters used in this study.

Friction time /s	Frequency /Hz	Amplitude /mm	Pressure /MPa
10	35	3	50

After welding, welded samples were sectioned transversely to the oscillation direction, grinded and polished. Polished specimens were etched in aqua regia (the volume ratio of hydrochloric acid and nitric acid is 3:1) for

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microstructural analysis with the optical microscope (OM) and the scanning electron microscope (SEM), and then electrolytically polished in oxalic acid solution (10g oxalic acid and 100ml water) for electron backscatter diffraction (EBSD) analysis.

3. Results and discussion

3.1. Microstructure of the parent material

The parent AISI 321 presents the typical austenitic structure with some ferrite strips as shown in Figs. 1(a) and 1(b). The ferrite appears as pits due to etching (Fig. 1(b)). The phase map and pole figure of PM are shown in Fig. 1(c) and 1(d), respectively. In Fig. 1(c), yellow represents austenite while red is ferrite. The result shows that the austenite is 70.7vol.%, while the ferrite is 13.8vol.%. From Fig. 1(d), it can be seen that the texture of austenitic phase in PM is complicated. The texture of austenitic phase may be S texture {123}<634> and copper texture {112}<111>, whicoften appears in fcc materials after cold rolling.

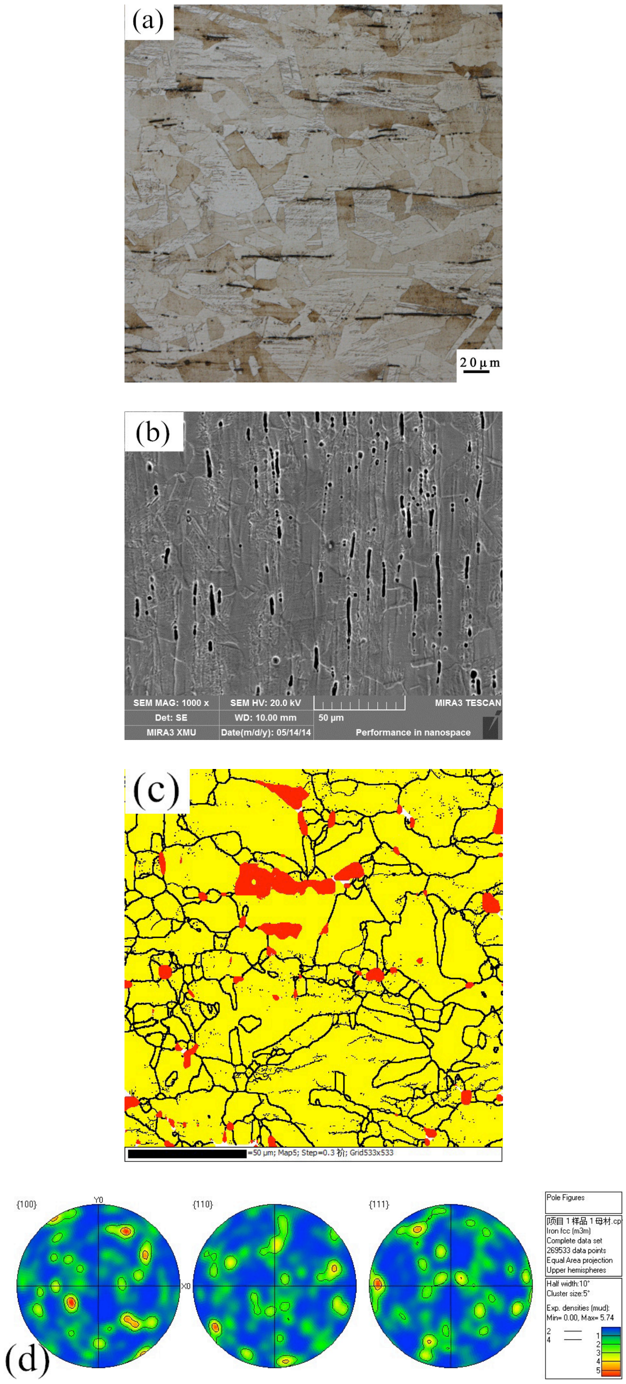

Fig. 1. OM (a) and SEM (b) micrographs of PM, phase fraction map (c), and pole figures of austenitic phase (d).

3.2. Microstructure of the joint

Fig. 2 is an OM macrograph of the welded joint along the oscillation direction. The joint can be divided into three microstructural zones[15], which are the weld zone (WZ), thermomechanically affected zone (TMAZ) and the PM. The WZ is located in the area near the friction interface, which presents a bright band with a thickness of about 400μm. The TMAZ is located in both sides of the WZ, whose thickness changes from the narrowest center of joint gradually. It is expected that the high temperature plastic metal is continuously extruded from the center to the sides, thus leaving a wider TMAZ due to thermal conduction. Furthermore, it was found that a sound 316L joint could be produced in LFW, with the weld region having a higher ultimate tensile strength than the parent material.

In addition, the clear streamlined structure can be observed in the TMAZ (marked by red curves in Fig. 2), which is characterized by the ferrite strips. The direction of the streamlined structure shows the flow and deformation direction of plastic material during welding.

After welding, the yielded metal, which has not been extruded from the weld center, cools rapidly and forms the weld line. The OM micrograph of the WZ is shown in Fig. 3(a). Compared to that of PM (Fig. 1(a)), it can be found that the black strips in the WZ are much less, with most of them dispersing in the matrix. The phase fraction map (Fig. 3(b)) confirms that there is almost no ferrite phase in the WZ (about 0.2%), compared with those of 13.8% and 3.6% in the PM and TMAZ, respectively. This is, on the one hand, because the ferrite in the WZ is broken after extrusion and deformation, thus forms dispersed microstructure; on the other hand, part of ferrite decomposes into γ (austenite) and σ phase during the process. It should be noted that stainless steel has a low stacking fault energy (SFC) and is prone to dynamic recrystallization, thus, grain refinement has occurred in the WZ during welding (Fig. 3(b)). By image analysis, the average grain sizes of the PM, TMAZ and WZ are 9.1μm, 2.9μm and 2.3μm, respectively. Besides, the WZ shows a strong {001}<110> type texture (rotation-cube texture) (Fig. 3(c)). It is considered that the textures which form in the fcc metals after cold rolling (S texture, copper texture), readily transform into cubic texture via recrystallization.

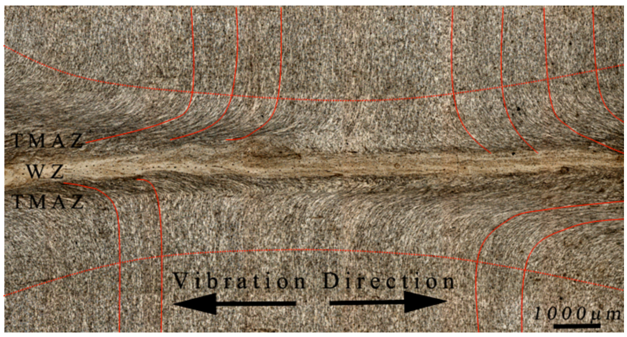

Fig. 2. OM macrograph of the LFWed 321stainess steel joint.

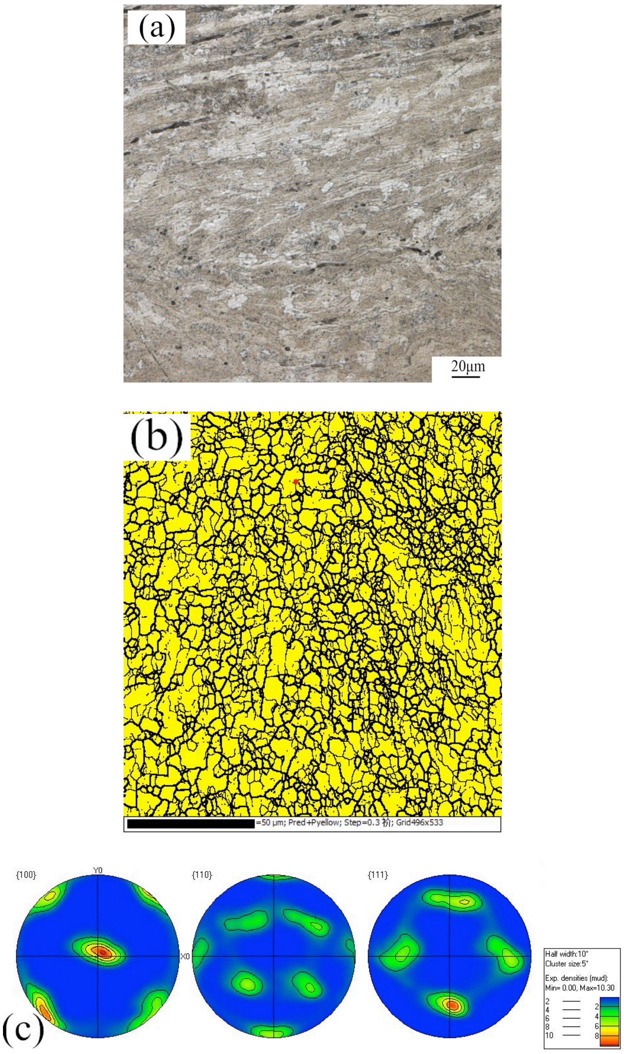

Fig. 3. OM micrograph (a), phase fraction map (b) and pole figures of austenitic phase (c) in the WZ.

The phase fraction map of the TMAZ is shown in Fig. 4. Compared to the PM, grain refinement of the TMAZ is obvious. The result shows that the austenite is 72.5vol.%, while the ferrite is 3.6vol.%.

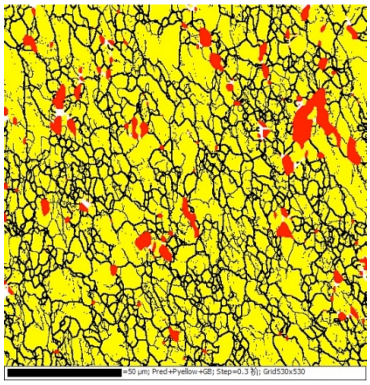

Fig. 4. phase fraction map of the TMAZ.

3 Conclusions

Based on the observations of this study, the following conclusions can be drawn:

Microstructural analyses shows substantially defect-free AISI 321 stainless steel joint. Welded joint can be divided into the WZ, the TMAZ and the PM. The WZ presents a narrow band of about 400μm thick, which is characterized by a fine-grained recrystallized structure with the average grain size of 2.3μm. In addition, the WZ shows a strong {001}<110> type texture, namely rotation-cube texture. The TMAZ changes in thickness and shows a typical streamline distribution. The direction of the streamlined structure shows the flow and deformation direction of yielded material during welding.

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