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Friction stir welding automatic effect on building the microstructure and properties of high nickel steel

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The high nickel steel friction stir welding process of microstructure construction was studied, analyzing the influence of the stability of austenite on the tensile properties of materials. The results show that the austenite grains in the stir zone are more refined and the dislocation accumulation is due more to the rotation speed of the stirring head. During the welding process, the austenite structure of the mixing area is more stable, which improves the strength and elongation of the joint. Therefore, the stability of the retained austenite can be improved and the friction stir welding is an effective method to improve the strength of building materials.

Keywords*:* friction stir welding, high nickel steel, building materials, austenite

INTRODUCTİON

Friction stir welding is a solid state welding technology（FSW), the research and development of the mixing head and the technical conditions promote the application of friction stir welding. During the process of friction stir welding, the material is experiences plastic flow and friction heat is produced, thus friction stir welding can be regarded as a thermo mechanical process, similar to the hot rolling of steel [1]. The thermal mechanical process is accompanied by phase transformation. Therefore, the phase transformation can be controlled by controlling the conditions of friction stir welding, which can improve the mechanical properties of the welding parts. Studies were done of the rotating head speed, welding process and microstructure of the phase change process parameters, welding speed and so on. But the stability mechanism and its influence on the tensile properties of the retained austenite during friction stir welding have not been fully elucidated [2].

Because of its high mechanical strength, good corrosion resistance, low thermal expansion coefficient and high - strength it is widely used in construction, industry, metallurgy and other industries. In addition, due to the martensitic transformation temperature, the high nickel steel (Ms) is low and the phase change process is commonly used to study martensite. Therefore, the high nickel steel material after welding, the microstructure due to phase transformation and its performance will change. The building material of the high nickel steel microstructure changes automatically mixing the friction welding process studied allowing for an analysis of the influence of the stability of austenite on the tensile properties of materials.

EXPERIMENTAL METHODS

Experimental material was synthesized for vacuum induction furnace smelting and pouring into ingots from high nickel steel, the chemical composition is 24 wt%Ni-0.1%C-bal.Fe. At a temperature of 1073 K the hot rolling process yields plate material with a thickness of 1.6 mm, then the surface oxide is removed and we have automatic friction stir welding as a result. The rotational speed of the rotary head is 400 mm/min, and the rotation speed is 200300 and 400 r/min, respectively. The welding load range is kept within 2000-3000 kg to ensure a constant insertion depth. The material of the stirring head is a hard alloy steel, the diameter of the stirring shoulder is 12 mm, the stirring needle diameter is 4 mm, the length is 1.4 mm and the stirring head dip angle is 3 degrees. The observed direction of the microstructure is the welding direction (WD), which is perpendicular to the horizontal (TD) and normal (ND), as shown in Figure 1. In order to prevent parts welding and rotating hair oxidation, Ar is used as a protective gas, the flow rate is 20L/min.

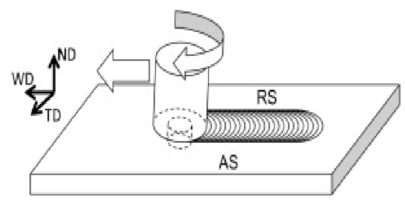

Fig. 1. Schematic diagram of friction stir welding.

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The welded samples were observed by an optical microscope after cutting, mechanical polishing and solution corrosion in turn. The samples are electronic polishing at 290 K and 20 V in a 900 ml CH3COOH + 100 ml HClO4 mixed solution, then with electron backscatter diffraction (EBSD), field emission scanning electron microscopy (FE-SEM) the microstructure and fracture surfaces of the specimens are observed [3]. The geometry and sampling position of the three drawing samples in the mixing area are shown in Figure 2 and the distance between the samples is 2 mm. The sample size of the base material is the same as that of the mixing zone and the sampling method is the same. The tensile test at room temperature is 0.5 mm/min. Before the test, the sample is polished to a thickness of 1 mm, to avoid the influence of the thickness of the test results.

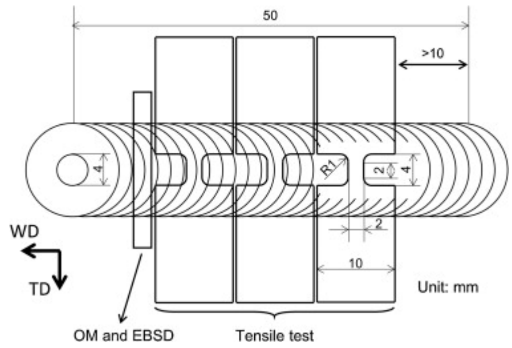

Fig. 2. Geometry and sampling locations of the tensile specimen.

EXPERIMENTAL RESULTS AND ANALYSIS

Microstructure of the base metal

The EBSD analysis in Figure 3 shows the crystal orientation of the high nickel steel base metal as a color map. By comparison with the aid of the standard triangle marked as the color key, the crystal orientation in the lateral (TD) parallel direction are determined. In Figure 3 the BCC and FCC phases are separated by the same position, each color represents the BCC crystalline phase and the FCC phase orientation, the color of the volume fraction of the image area proportion of both the BCC and FCC phases, the proportion of the Analysis and automatic analysis software OIM are given by EBSD. The microstructure of the base metal is composed of martensite and retained austenite. The original austenite grain size is about 30-60 µm, with the length and width of the martensite crystal about 10µm and 2-3µm.

Figure 4 shows the orientation map in the same area of the base metal. The orientation diagram of the BCC and FCC phases in the same position is given and the maximum intensity is indicated at the bottom of the orientation map. It can be seen that the FCC phase with a high strength are in the [011] orientation and [111] orientation. In addition, it can be observed that the relationship between the crystal degree is [011]//[111], that is, the K-S (Kurdjumov-Sachs) relationship [4].

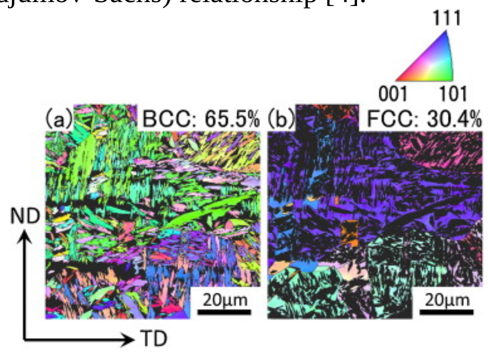

Fig. 3. Diagram orientation of high nickel steel (a) BCC (b) FCC

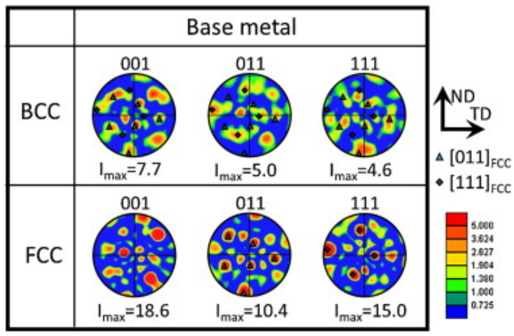

Fig. 4. The diffraction pattern of grain orientation in the same area of the base material.

The joint microstructure

The welding speed is 400 mm/min and the rotation speed is 200, 300 and 400r/min respectively. The friction welding is carried out on high nickel steel and the welding direction is respectively sampled. The optical microscope image is shown in Figure 5. The right side of the figure is the welding direction (AS) and the white dotted line shows the shape of the rotating head. Generally the friction stir welding joints are divided into the base material (BM), stir zone (SZ), heat affected zone (HAZ) and heat affected zone (TMAZ). The mixing zone is deformed under the action of the stirring shoulder or the stirring needle, and the recrystallization phenomenon is obvious. The heat affected zone is affected by the frictional heat and the grain size will obviously grow. The heat affected zone is located in the transition zone between the mixing zone and the heat affected zone. But in this paper, it is difficult to determine the heat affected zone and the heat affected zone, which may be due to the microstructure of the welded specimens. A large number of black stripes were found in the corrosion images of all the joints, and their morphology was similar to that of the trees. The bright corrosion area of the welded joint obtained by rotating at a speed of 200r/min is the biggest. With the increase of the rotating speed, the corrosion area becomes smaller and smaller. The EBSD diagram (Fig. 6) shows the area corresponding to the austenite phase in the bright corrosion area. In addition, at the speed of 300 and 400r/min in the joint, the small defects can be observed along the cross section of the needle (shown in Figure 5B and C in the white arrow). In order to simplify the comparison of the welded joints, this paper makes a further study of the most obvious characteristics of the micro structure.

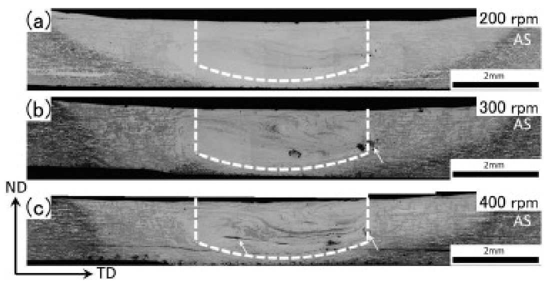

Fig. 5. Optical microscopy: (a) 200r/min (b) 300r/min (c) 400r/min of the joints at different rotation speeds.

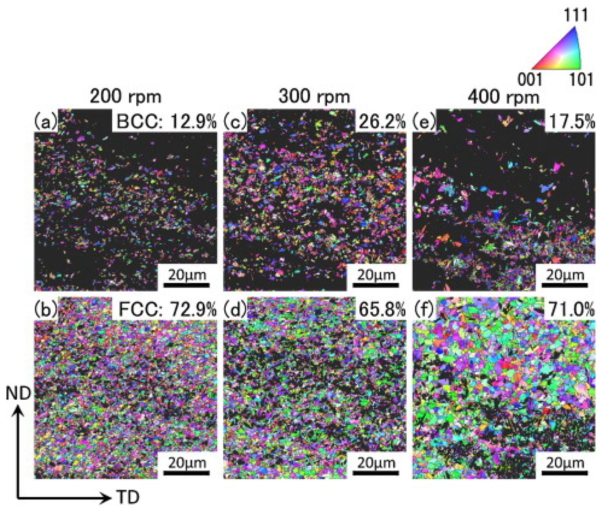

Fig. 6. The crystallization orientation of the joint in the mixing zone. (a,b)200r/min (c,d)300r/min (e,f)400 r/min.

Figure 6 shows the crystal orientation of 0.7 mm at the center of the mixing zone at different rotating speeds. According to the color the crystal orientation can be determined in parallel to the TD. It can be established that the fibrous tissue in the mixing region is composed of BCC grains (martensite) and FCC grains (retained austenite), which is the same as that of the parent material. However, after friction stir welding, the area of the retained austenite was significantly increased and the austenite grain size was obviously refined. The austenite grain size decreases with the decrease in the rotational speed. In addition, with the decrease of the grain size of the austenite, the martensite grains become smaller. The distribution of the martensite is not uniform, which may be related to the inhomogeneous material flow during friction stir welding.

The orientation map of the mixing zone of the mixing zone at different rotational speed is shown in figure 7-9.

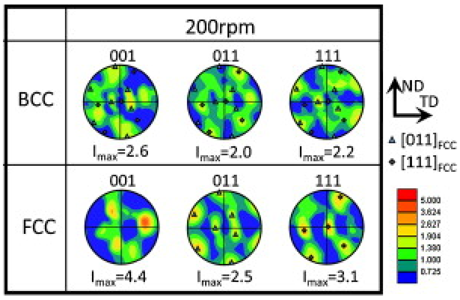

Fig. 7. The orientation of the mixing zone of the 200r/min joint with a rotation speed.

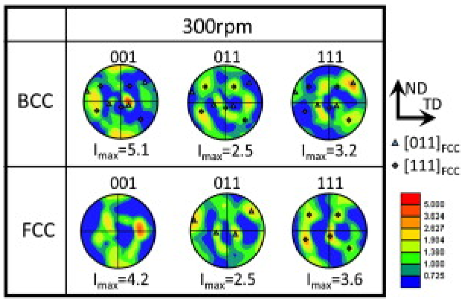

Fig. 8. The orientation of the mixing zone of the 300r/min joint with a rotation speed.

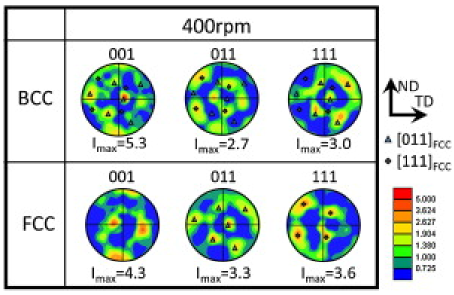

Fig. 9. The orientation of the mixing zone of the 400r/min joint with a rotation speed.

The Figure with a triangle and diamond indicate a strong accumulation phase in the [011] and [111] FCC orientation and the maximum intensity value is given at the bottom of each drawing. According to the density of [011] and [111] in the BCC phase and FCC phase, the relationship between the crystal phase and crystal degree can be observed, which is [011]BCC//[111]FCC and [111]BCC//[011]FCC, that is K-S (Kurdjumov-Sachs). It is indicated that the martensite is formed by the transformation of austenite during the cooling of the friction stir welding process.

Figure 10 shows the distribution of the grain orientation difference in the parent material and the mixing region of the FCC phase. The small angle grain boundary (LABs) and large angle grain boundary (HABs) of more than 15 degrees are respectively indicated by the red and green lines in the graph. From figure 10A we can estgablish that the base material contains less LABs and HABs. In contrast, due to the refinement of the austenite, the number of HABs in the stir zone was significantly increased and the LABs were also densely distributed in the austenite grains (Fig. 10b-d). For a quantitative analysis, the average length of the unit area LABs is established and the correlation data of the FCC and BCC phases are given in Figures 11 and 12, respectively. In the figure, VFCC and sigma (1-5) respectively, are the total length of the FCC phase area fraction and 1-5 degrees of dislocation. It can be seen that with the decrease in the orientation difference, the proportion of LABs gradually increased. By comparison of the base metal and the mixing area, we can see that the density of LABs in the BCC phase and FCC phase was significantly increased after welding. The density of LABs in the BCC phase did not show a specific correlation with the rotational speed, but in FCC, the density of LABs decreased gradually (FIG. 11 and 12) with the increase of the rotational speed. The density of LABs was higher in the FCC phase, which indicated that the plastic deformation dislocation accumulated in the process of friction stir welding.

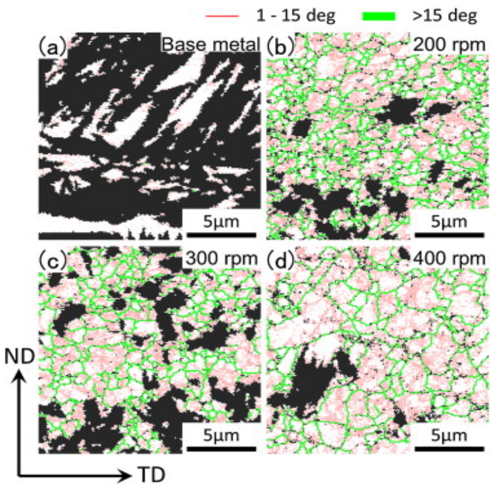

Fig. 10. Grain orientation difference distribution of the base material (a) and stir zone (B, C, d) in the FCC phase.

In the process of friction stir welding, the microstructure of austenite has two changes: grain refinement and LABs increase (FIG. 10). The grain refinement can be realized by recrystallization in the welding process and can be accelerated by the plastic deformation under the high strain rate condition. These two changes should make the austenite tend to be stable, which significantly affects the martensite transformation.

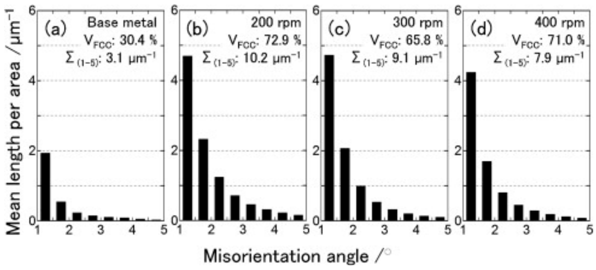

Fig. 11. FCC phase of parent material (a) and stir zone (B, C, d) the proportion of specific bits of the angle histogram.

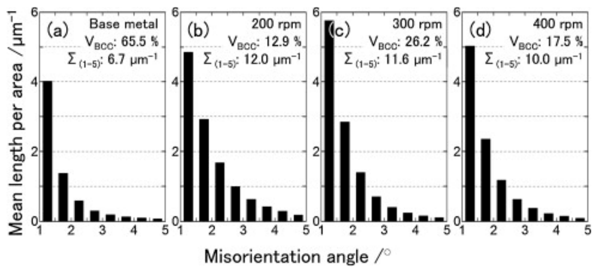

Fig. 12. BCC phase of parent material (a) and stir zone (B, C, d) the proportion of specific bits of the angle histogram.

Tensile properties

Stress - strain curves obtained from 200, 300 and 400 r/min samples obtained by a tensile test at room temperature, respectively. Figure 14 and table 1 provide the ultimate tensile strength of each specimen measured (UTS o max), yield strength (YS: y) and elongation (Ef). It can be seen that the parent material has experienced high work hardening and fracture at a low elongation rate. In general, with the increase of the tensile strength, the elongation of grain refinement in the process of welding is gradually reduced. However, this paper studies the limit of tensile strength and elongation at the same time, as shown in Figure 13.

The stress-strain curve in the concave stir zone shows that the work hardening rate (D /d sigma epsilon) gradually increased. The stress-strain curve of the metastable austenitic stainless steel which has the phenomenon of phase transformation induced plasticity (TRIP) is very similar to that of [5]. Therefore, the tensile property of the stir zone is enhanced and the phase transformation induced plasticity is shown in the residual austenite of the friction stir welding.

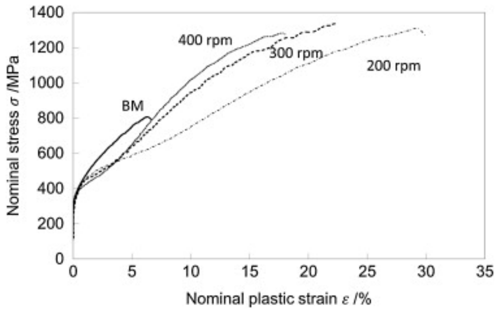

Fig. 13. Stress - strain curves of the samples of the parent material and the mixing zone.

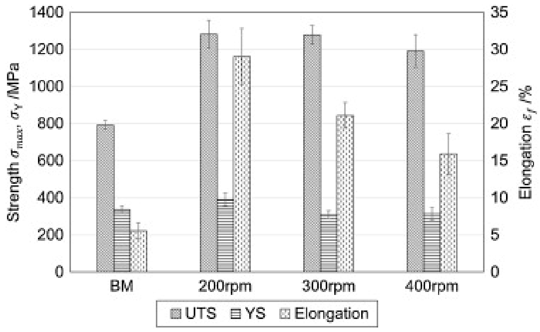

Fig. 14. The tensile properties of the base metal and the mixing zone.

Table 1. Tensile properties of the base metal and the mixing zone.

	Ultimate tensile strength /MPa	Yield strength /MPa	elongation at break /%
BM	793±24	336±20	5.6±1.1
SZ(200r/min)	1283±74	390±35	29.0±3.8
SZ(300r/min)	1279±50	308±22	21.1±1.7
SZ(400r/min)	1192±88	315±35	15.9±2.8

Figure 15 shows the SEM images of the center of the fracture surface of the base metal and the room temperature tensile specimen of the mixing zone. It can be seen that the fracture surface of the base material is flat and smooth (Fig. 15a), which shows that it is shear fractured. The fracture surface of the mixing zone is a ductile surface with a small pit (Fig. 15b-d), so it is a ductile fracture. This change is caused by the phase change of the fracture site. It is showed that the friction stir welding not only increases the strength and elongation, but also changes the fracture mode.

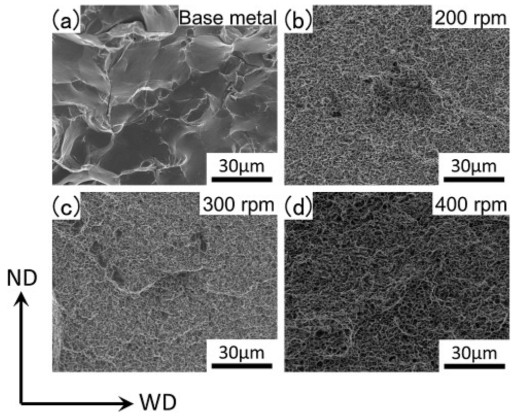

Fig. 15. Fracture surface of a and D (c) in room temperature tensile test specimens.

CONCLUSIONS

In this paper, the microstructure and tensile properties of high nickel steel were studied by automatic friction stir welding. Due to the plastic deformation of the material during the welding process the austenite in the mixing area is more stable. With the reduction of the rotational speed of the mixing head, the austenite grains in the stir zone are more refined and the dislocation accumulation is more significant. During the welding process, the stability of the austenite structure in the stir zone increases the strength and elongation of the joint due to the phase transformation induced plasticity. These results show that the stability of the retained austenite can be improved and the friction stir welding is an effective method to improve the strength of the material.

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ЕФЕКТ НА ТВЪРДО-ФАЗНОТО ЗАВАРЯВАНЕ ВЪРХУ ОБРАЗУВАНЕТО НА МИКРОСТРУКТУРАТА И СВОЙСТВАТА НА ВИСКО-КАЧЕСТВЕНА НИКЕЛОВА СТОМАНА

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(Резюме)

Изследван е процесът на твърдо-фазно заваряване върху микроструктурата на никелова стомана и е анализирано влиянието на аустенита върху усукващите свойства на материала. Резултатите показват, зърната аустенит в зоната на заварката са по-фини,а натрупването на дислокации се дължи на повече на скоростта на въртене на заваряващата глава. Структурата на аустенита е по-стабилна по време на заваръчния процес, което подобрява здравината и удължаването на образеца. Затова стабилността на запазения аустенит може да се подобри, а твърдо-фазното завряване да бъде ефективен метод за подобряване на якостта на строителните материали.