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Effects of TIG Process on Corrosion Resistance of 321 Stainless Steel Welding Joint

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Abstract. In this paper, the effects of different TIG welding parameters on corrosion resistance of 321austenitic stainless steel welding joint were studied. Intergranular corrosion, stress-strain curves of SSRT and the fracture surface of the welding joint were investigated by means of intergranular corrosion test, SCC test and SEM. The results showed that the intergranular corrosion cracks did not occur for all joints welded in the range of TIG welding current of 130A~190A. In pure water at room temperature, strain rate at the range of 1×10^{-5} s^{-1}~1×10^{-6} s^{-1} had little effect on the maximum tensile strength of the material under the same welding conditions and the time of joint fracture increased as the strain rate decreased. At strain rate of 1×10^{-6} s^{-1}, the maximum tensile strength of the joint welded in the current of 130A and 150A decreased significantly in the dyeing assistant and presented stress corrosion sensitivity. Joints welded in the current of 170A and 190A, showed excellent resistance to stress corrosion. Through the analysis of the fracture surface of joints, the joint welded in current of 130A presented a tendency to brittle fracture, while the joints in the current of 170 A and190 A were characterized with ductile fracture.

Introduction

Austenitic stainless steel with good corrosion resistance, heat resistance and plasticity has been widely used in the support structure, sealed container, architecture,kitchen equipment and medical device products[1-5]. The intergranular corrosion resistant ability of the conventional 18-8 type austenitic stainless steel is weak[6], thus the stablization of austenitic stainless steel by adding Ti and Nb has been developed gradually, for example 321 stainless steel, which is as the material of high temperature and pressure dyeing machine extensively used in textile enterprises. The content of titanium and niobium in stainless steel up to 1.0% (mass fraction) can effectively reduce the carbon content in the matrix, which will make the precipitation of chromium-rich carbide difficult, so the possibility of sensitization is decreased[7].

In the process of periodic inspection, multiple cracks have occurred in the welding zone of the dyeing machine cylinder. So in this paper, the influence of different Tungsten Inert Gas (TIG) Welding parameter on the the intergranular corrosion and the stress corrosion resistance of the joint has been studied through the intergranular corrosion test (IGC) and slow strain rate tension (SSRT).

Experiment Process

TIG Process. 321 hot rolled stainless steel plates were used as the base metal. In order to satisfy the special operational performance of austenitic stainless steel, it is requested that the filler should have the similar chemical composition as the base metal. Thus ER321 with a diameter of 2.5mm was adopted as the filler metal. The chemical compositions of base metal and filler are listed in Table 1.

Table 1. Chemical composition of 321 stainless steel and ER321

Material	Composition /*wt*. (%)							
	C	Si	Mn	P	S	Cr	Ni	Ti
321	0. 0167	0. 5385	1. 1398	0. 0258	0. 0015	17. 265	9. 1077	0. 0982
ER321	0. 0260	0. 4000	1. 8100	0. 0220	0. 0010	19. 010	9. 2800	0. 3000

The welding process was conducted with two passes welding by a Panasonic WXⅡ300TIG machine. The geometric dimension of welding joint is shown in Fig. 1, the thickness of the test plate is 4mm. Before welding, the groove and the area around it within 20mm should be cleaned with acetone and ethyl alcohol. The different welding parameters are listed in Table 2. The interpass temperature should be controlled around 60℃.

Table 2. Welding parameters

Sample	Welding current /A	Welding voltage /V	Welding rate /(mm/min)	Electrode diameter /mm	Argon gas flow /(L/min)
No. 1	130	15	126	3	8~10
No. 2	150	16	184	3	8~10
No. 3	170	17	207	3	8~10
No. 4	190	18	226	3	8~10

Intergranular Corrosion Test. According to GB/T4334-2008, copper sulphate-sulphuric acid test with flocks copper was conducted to inspect the austenite intergranular corrosion tendency. Copper scraps or copper particles (purity is no less than 99.5%) according to the GB/T466 were put in the bottom of flask. The test solution should be higher than the top-level specimen at least 20mm. Heat the solution about 16h continuously, and remain the state of the micro-boiling. Then take samples out, clean, dry and bend. The face bending and root bending angle should attain to 180° along the fusion line. The geometric dimension of the sample for bending test is shown in Fig. 2.

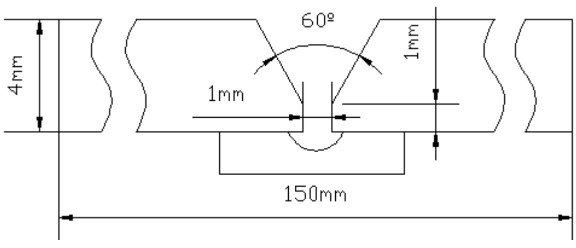


Fig. 1 Geometric dimension of welding joint

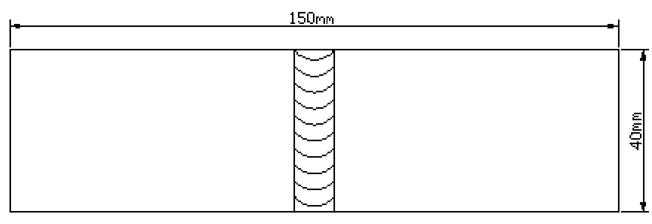


Fig. 2 Geometric dimension of welding joint for bending test

SSRT. The SCC-1 stress corrosion test system was adopted to SSRT. The gauge length of the specimen is 40mm×6mm×4mm. The test solution is dyeing assistant applied in acid dyes provided by the manufacturer, and the dyeing assistant formula is NaCl 2.5g/L, sodium sulphate Na_2SO_4 10g/L. The deionized water is adopted as the contrast sample, three strain rates $1\times10^{-5}s^{-1}$, $5\times10^{-6}s^{-1}$and$1\times10^{-6}s^{-1}$ were applied to the test.

Results and Discussion

Results of Intergranular Corrosion Test. Intergranular corrosion of austenitic stainless steel is mostly due to the metallurgical change with the range of 427℃~816℃, and corrosion degree also depends on the time of exposuring in the corrosive medium. In HAZ of most austenitic stainless steel welding joint, the chromium-rich $M_{23}C_6$ carbide precipitates along grain boundary first, which will produced the chromium depleted zone along grain boundary, then intergranular corrosion emerges in corrosive environment.

No cracking was observed at the front and back of all the specimens, for example, the results of No. 3 shown in Fig. 3. According to the analysis: the combination of chromium and titanium, which exists in the stainless steel and wire supplement is stronger than the combination of carbon and chromium, so chromium depletion will not appear. There is also no knife line attack owing to the short time of being in the sensitized temperature during the welding. In summary, four joint specimens at different welding parameters after TIG welding did not appear intergranular corrosion, namely all of them had excellent intergranular corrosion resistance.

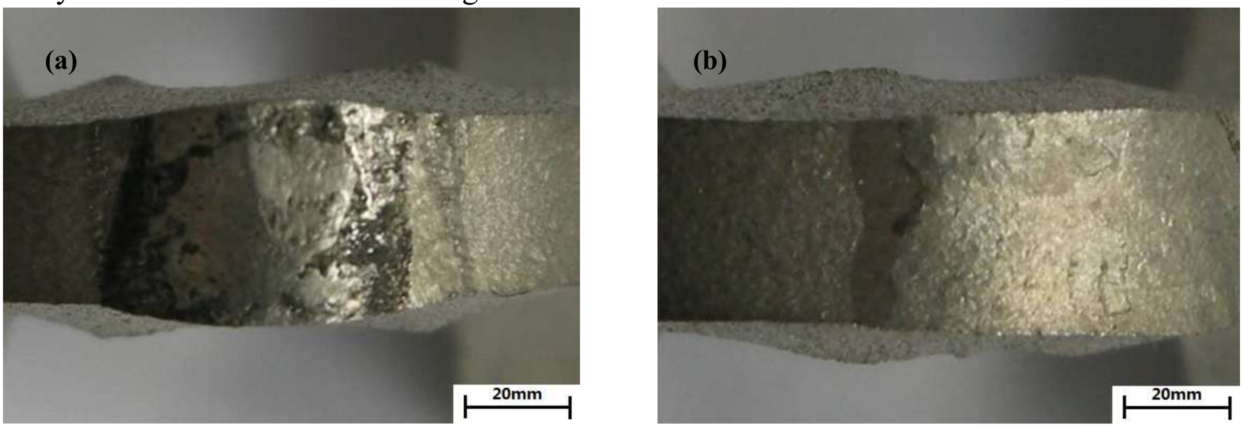
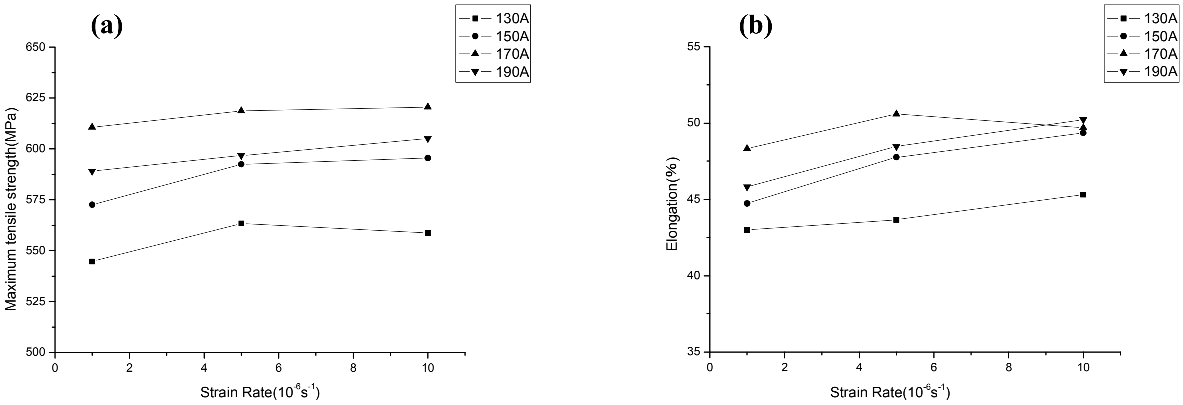


Fig. 3 Macro-appearance of intergranular corrosion specimen in the current of 170A after bending (a) face bending (b) root bending

The Results of SSRT. Fig. 4 shows the maximum tensile strength, elongation and fracture time of the welding joint specimens in deionized water at room temperature under different welding currents and different strain rates. As the Fig. 5shown, under the same welding current conditions, the tensile strength increases with the strain rate increasing, but the rise is small; the elongation presents a increasing tendency, the maximum difference between the elongation is about of 5% in the current of 190A. The fracture time is abbreviated as the strain rate increases, and it is more obvious at the rate of $1\times10^{-6}s^{-1}$. At the same strain rate, the maximum tensile strength increases first and then has a decreasing trend with the welding current increasing.



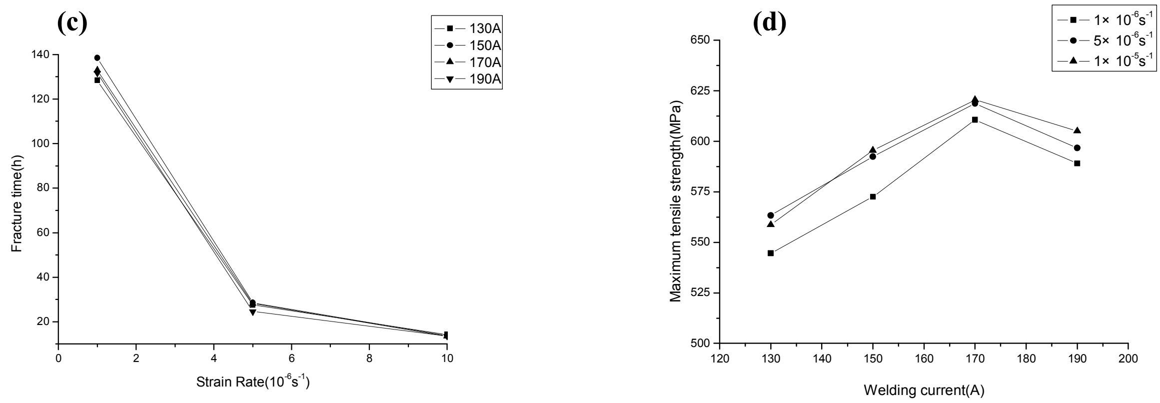


Fig. 4 Results of SSRT for 321 stainless steel in deionized water at room temperature

Different welding current:(a) Maximum tensile strength (b) Elongation (c) Fracture time
Different strain rate: (d) Maximum tensile strength

Fig. 5 shows the maximum tensile strength, elongation and fracture time of the welding joint specimens in dyeing assistant at room temperature under different welding currents and different strain rates compared with the condition of deionized water at room temperature, under the same welding current and strain rate most of the maximum tensile strength and elongation reduce, and all of the fracture time decrease. Especially at the strain rate of $1{\times}10^{-6}s^{-1}$ in the welding current of 130A and 150A, it is more obvious; when the welding current is 170A, tensile strength and elongation do not appear to decline substantially relative to deionized water at room temperature, it means that in this condition the stress corrosion resistance of welding joint is better; in the welding current of 190A, it also declines. Thus, in dyeing assistant, the strain rate is an important factor of resistance against stress corrosion, and the strain rate of $1{\times}10^{-6}s^{-1}$ has the greatest impact on the stress corrosion resistance.

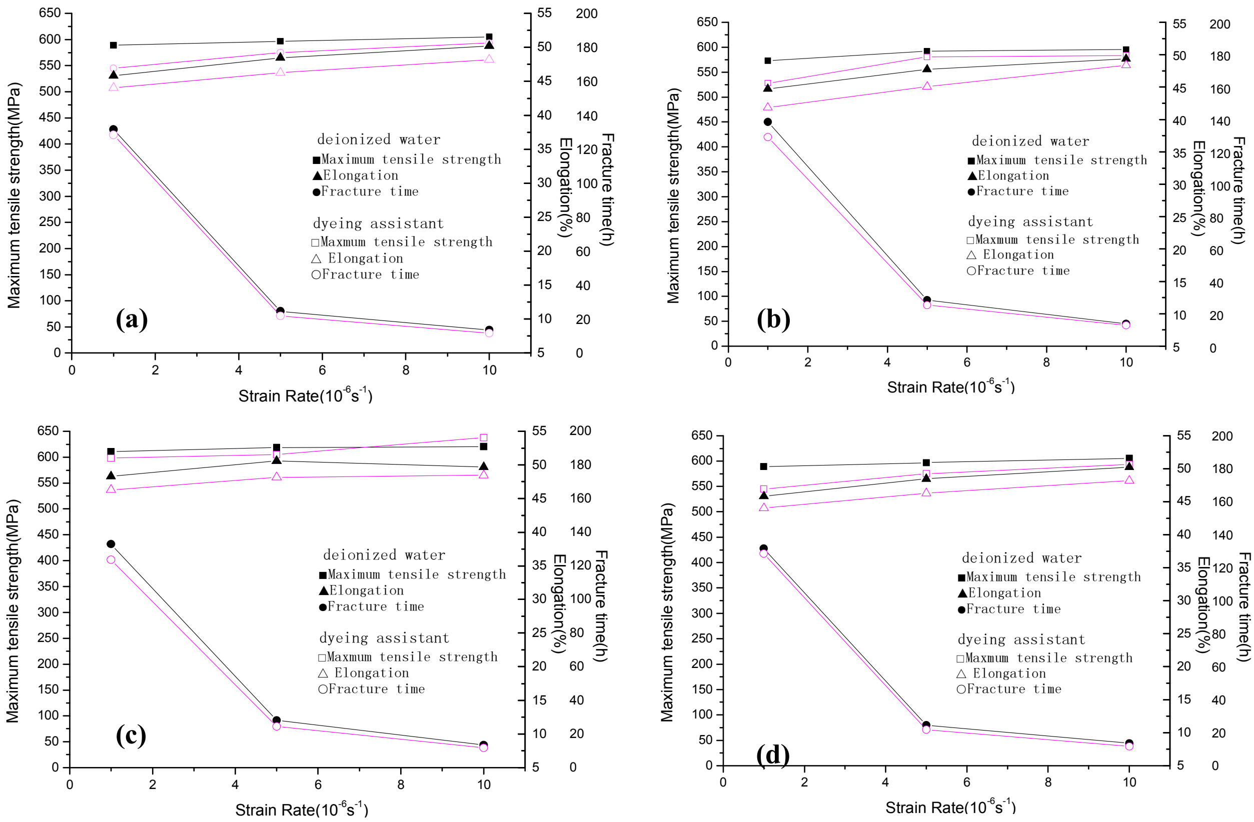


Fig. 5 Results of SSRT for 321 stainless steel in dyeing assistant and deionized water at room Temperature (a) 130A (b) 150A (c) 170A (d) 190A

The elongation F(δ) in Table 3 is the stress corrosion sensitivity factor by calculating, the smaller the F(δ) is, the greater the stress corrosion sensitivity is. As shown in Table 3, at the rate of $1\times10^{-6}s^{-1}$, the minimum F(δ) is -6.46 in the welding current of 130A, which demonstrates strong stress corrosion sensitivity. Under the welding current of 170A and 190A, the F(δ) values change little with the strain rate varying, which means the stress corrosion sensitivity is not obvious.

Table 3. Results of sensitivity factor F(δ) for 321 stainless steel in dyeing assistant at room temperature

Welding current(A)	Strain Rate(s^{-1})	F(δ)
130	1×10^{-5}	-1. 02
130	5×10^{-6}	-3. 57
130	1×10^{-6}	-6. 76
150	1×10^{-5}	-2. 00
150	5×10^{-6}	-5. 57
150	1×10^{-6}	-6. 46
170	1×10^{-5}	-2. 47
170	5×10^{-6}	-4. 64
170	1×10^{-6}	-4. 18
190	1×10^{-5}	-4. 08
190	5×10^{-6}	-4. 52
190	1×10^{-6}	-3. 90

Fig. 6 shows fracture morphology of 1~4 specimens at the strain rate of $1\times10^{-6}s^{-1}$ in dyeing assistant at room temperature. No. 1 and No. 2 compared to No. 3 and No. 4, the dimple density increase significantly, dimple diameter reduce and the depth shallow. Especially in the current of 130A, it has displayed the tendency of brittle fracture, and in the edge of the fracture it has quasi-cleavage fracture, but it is still mainly ductile fracture. No. 3 and No. 4 showed typical necking. The entire fracture interface is covered with dimples microporous, middle of larger dimples have small dimple, and holes also exist at the bottom of the dimple. It means that during the continuous strength intense plastic deformation occurred,and the crack initiated at the inclusion of the sample.

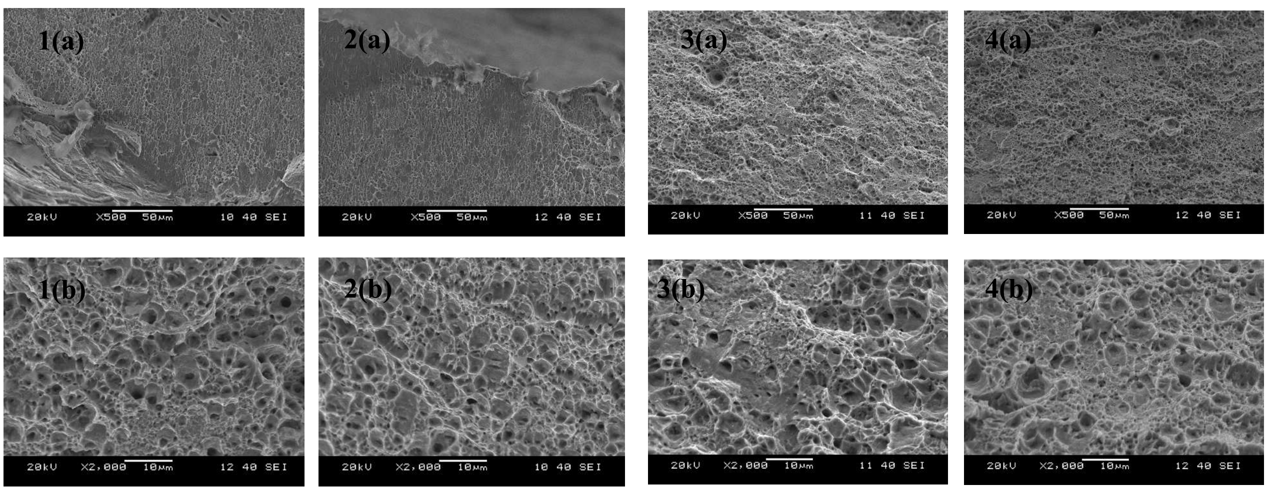


Fig. 6 The fracture morphology of 1~4 at the strain rate of $1\times10^{-6}s^{-1}$in dyeing assistant
(a) low magnification (b) high magnification

The microstructures of the welding zone and HAZ of No.1 and No.3 are shown in from Fig. 8.γ base phases(white) and δ phase(black) are the two main phases in the austenite stainless steel welding joint. According to the phase diagrams of Fe-Ni-Cr and Scheafler[8], when the cooling temperature is in the region of δ-ferrite + austenite phase, δ-ferrite will transform to austenite by solid-state phase transformation of δ→γ. With lower welding speed, the alloy elements of Cr, Ni have more time to diffuse, then δ→γ transforms fully, as shown in Fig. 7-1(a). While welding in higher speed, the corresponding cooling speed becomes fast and diffusion become difficult in phase transition of ferrite to austenite, which lead to more side-plate ferrite retained[9], shown in Fig. 7-2(a).With the higher heat input ,the bigger grains will appear in HAZ of No.1 shown in Fig. 7-1(b).

Because the amount of S, P, Si, and Nb elements can dissolve in ferrite, the alloy elements of welding materials transits to welding seam become more and more. The solid solution strengthening and phase transforming strengthening can prevent these elements from segregating and avoid low melting point eutectic forming[10]. Therefore the maximum tensile strength of No.3 and No.4 in dyeing assistant and deionized water are better. Larger heat input results in larger size of grains, so the strength of No.4 are lower than those of No.3. In short, the δ phase ratio, distribution and the grain size of the welding joint are important factors of stress corrosion resistance of 321 austenitic stainless steel welding joint.

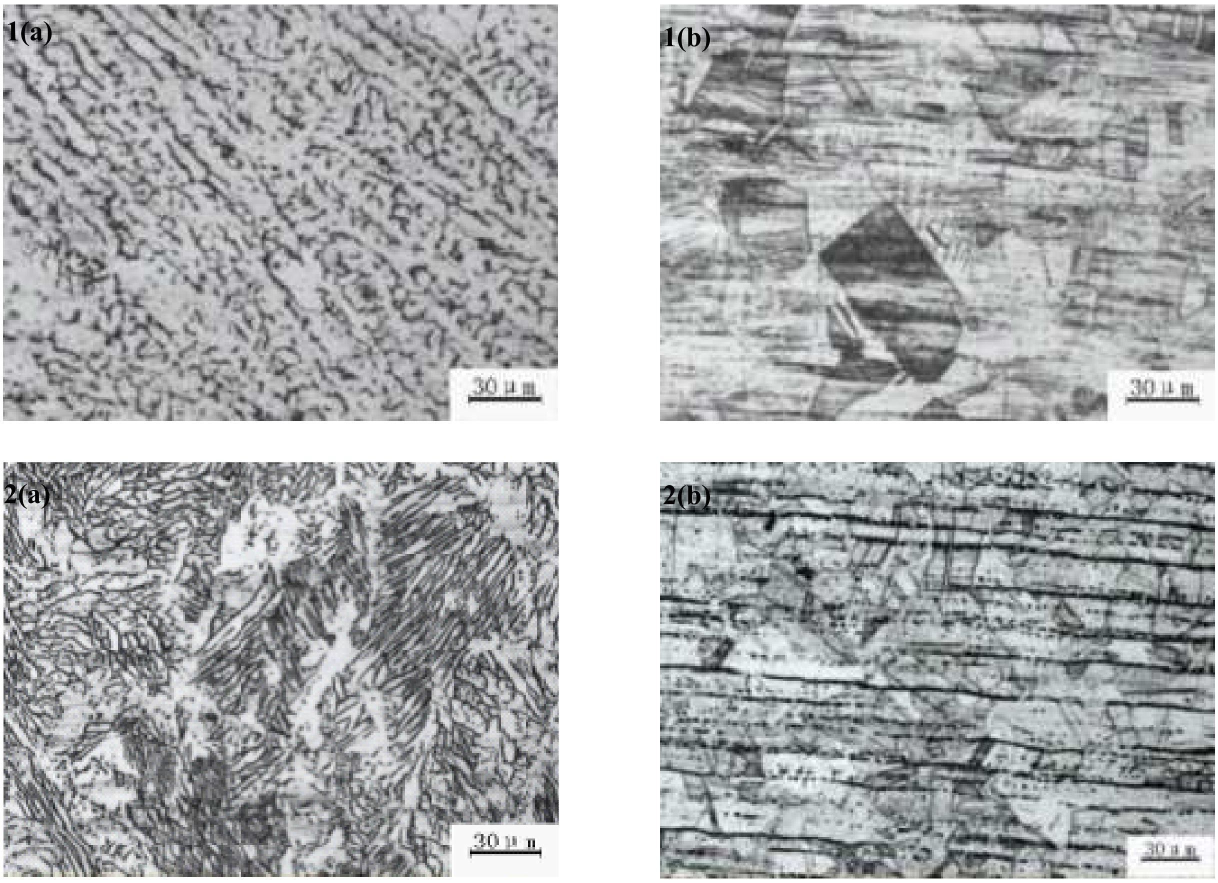


Fig.7 Microstructure of No.1(1) and No.3(2)
(a)welding zone (b) HAZ

Conclusion

1.Within the range of 130A~190A in TIG welding, there is no intergranular corrosion cracking in the welding joint, which means that all of the welding joint have excellent intergranular corrosion resistance.

2.In deionized water at room temperature, under the same welding parameters, strain rate from $1\times10^{-5}s^{-1}$ to $1\times10^{-6}s^{-1}$ have little influence on the maximum tensile strength of the material. And the fracture time extends as the strain rate decreases.

3. The strain rate is an important factor of resistance against stress corrosion, and the strain rate of $1\times10^{-6}s^{-1}$ has the greatest impact on the stress corrosion resistance. In the welding current of 130A and 150A at the strain rate of $1\times10^{-6}s^{-1}$, the maximum tensile strength significantly decreases relative to deionized water at room temperature, showing a greater sensitivity of stress corrosion; in the current of 170A and 190A, the obvious sensitivity to stress corrosion does not appear, and the welding joint in the current of 170A has better stress corrosion resistance.

4. Under the welding current of 130A, the fracture morphology specimens of SSRT has the tendency of brittle fracture, while in the current of 170A and 190A only ductile fracture exist in samples.

Acknowledgments

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