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Effects of TIG Welding Parameters on Morphology and Mechanical Properties of Welded Joint of Ni-base Superalloy

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Abstract

The influences of parameters of tungsten inert gas arc welding on the morphology, microstructure, tensile property and fracture of welded joints of Ni-base superalloy have been studied. Results show that the increase of welding current and the decrease of welding speed bring about the large amount of heat input in the welding pool and the enlargement of width and deepness of the welding pool. The increase of impulse frequency has the same effect on the microstructure compared with the increase of welding current. The effect of welding parameters on the tensile strength and fracture was analyzed. It is found that the root of welding joint is unwelded when the welding current is lower, so that the strength and elongation of welded joint are inferior. And the more welding defects in the welding zone and the more hard and brittle phase precipitates in the overheated zone when the welding current is too high. Consequently, the strength and plasticity go up first and then go down, i.e. they have a peak value with welding current increasing. In addition, the decrease of impulse frequency is beneficial to the strength of the welded joint.

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Keywords： *Ni-base superalloy*；*TIG*；*microstructure*；*tensile property*；*fracture*

1. Introduction

Superalloys are widely used in many industry fields because of its superior properties, such as high strength at high temperature, good oxidation and hot corrosion resistance[1-3]. At present there exist some processing problems, which affect the quality and property of welded joint, in the welding of superalloy structural components[4-6]. In the case of tungsten inert gas (TIG) arc welding, the root of welding joint is often unwelded when single bevel groove with backing locked is employed, and there also exists unwelded part in the back of butt girth welding seam. So the welding of superalloy structural components is one of the key problem to solve their processing technology.

The influences of parameters of tungsten inert gas (TIG) arc welding, such as welding current, welding speed, impulse frequency, weld remelting number and grooves, on the morphology, microstructure, tensile property and fracture of welded joints of Ni-base superalloy have been studied in this paper, optimized processing parameters are proposed, which provide experimental guidance for the application of Ni-base superalloy.

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2. Materials and Experimental

Materials for experiments are plates of Ni-base superalloy, grade GH99, with a thickness of 1.2 mm and 1.5 mm respectively. Composition of GH99 alloy is(wt%): C≤0.08, Fe≤2, Mn≤0.4, Si≤0.5, Cr17~20, W5~7, Mo3.5~4.5, Nb5~8, Al1.7~2.4, Ti1.0~1.5, Ni Balance. Tungsten inert gas (TIG) arc welding is employed to process butt weld of the plates with equal thickness.

The welding parameters are as follows: welding current 55~165A, welding speed 19~29cm/mm, impulse frequency 2~5Hz. 23 kinds of process were adopted and they are shown in Table 1.

Table 1 Tensile properties of the welded joints of GH99 superalloy under different welding parameters

Process No.	Welding current I，A	Welding speed v，cm/min	Impulse frequency f，Hz	Plate width h，mm	assembly clearance l，mm	Remelting time n,times	Groove	Tensile Strength σ，MPa	Yield strength $\sigma_{0.2}$，MPa	Enlonga-tion δ，%
1	55	25	3	1.5	0	0	no	333	322	2.7
2	60	25	3	1.5	0	0	no	396	378	3.0
3	80	25	3	1.5	0	0	no	837	522	32.1
4	95	25	3	1.5	0	0	no	759	489	4.0
5	90	25	3	1.5	0	0	no	811	511	30.5
6	90	25	4	1.5	0	0	no	771	498	23.4
7	90	25	5	1.5	0	0	no	759	467	26.5
8	90	21	3	1.5	0	0	no	751	476	24.7
9	90	23	3	1.5	0	0	no	787	505	24.9
10	90	27	3	1.5	0	0	no	802	515	28.6
11	90	29	3	1.5	0	0	no	790	509	25.0
12	90	25	3	1.2	0	0	no	743	429	27.2
13	90	25	3	1.2	0	0	yes	760	436	31.4
14	90	25	3	1.5	0	0	yes	812	440	32.1
15	90	25	3	1.2	0.2	0	no	700	532	13.9
16	90	25	3	1.2	0.5	0	no	748	596	21.6
17	90	25	3	1.2	0.8	0	no	742	470	31.4
18	90	25	3	1.5	0.2	0	no	712	539	36.7
19	90	25	3	1.5	0.5	0	no	738	522	31.2
20	90	25	3	1.5	0.8	0	no	728	410	24.3
21	90	25	3	1.2	0	2	no	802	472	25.0
22	90	25	3	1.2	0	3	no	861	529	19.4
23	90	25	3	1.2	0	4	no	896	510	29.8

Samples for metallographic observation, hardness examination and tensile property measurement were cut from the welded plates at three positions, which were located at the arc striking end, middle part of the seam, and the arc retreating end respectively. Instron Series Ⅸ material tester was applied to measure the tensile property at room temperature, with a tensile speed of 2.0 mm/min. The morphology of fracture surface was observed by CamScan MX2600FE scanning electron microscope. The microstructure of welded joint obtained under different parameters was observed through Carl Zeiss Axiovert 40 Mat metalloscope.

3. Results and Discussion

3.1. Effects of TIG welding parameters on the morphology and microstructure of welded joints of GH99 alloy

Fig. 1 shows the macro morphology of butt welding joints under the current of 55, 80 and 95A respectively. The amount of heat input is small under low current, as a result the width and depth of the weld pool are small, and the root of welding joint is probably unwelded (see Fig.1a). The increase of welding current brings about the enlargement of the width and depth of the weld pool. When the current is too large, the amount of heat input is overlarge and even much more melt metal penetrates the back face of the seam, which leads to the collapse of the front face of seam and to the uplift of its back face. This situation causes the stress concentration and so degrades the strength of welded joint.

Fig.2 displays the microstructure in different part of the welded joint. There are some coarse dendrites in the seam center. Coarse column crystals form along the heat dissipation direction which is perpendicular to the interface of fusion, in the near fusion zone of the seam. From the melting boundary to the seam center, the temperature gradient decreases gradually, while the speed of crystallization increases, so the crystal morphology changes from cellular crystal to columnar crystal, and then to free dendritic crystal.

The microstructure and morphology of different part in the heat affected zone are determined by many factors, such as the peak temperature of thermal cycling, heating rate, staying time at high temperature and the subsequent cooling speed. According to the difference of microstructure, from seam center to base meal, it can be divided into four parts: fusion zone, overheated zone, fine-grained zone and incomplete recrysatllized zone. The temperature of the fusion zone is between the solidus and liquidus. Overheated zone is located at the position near the base metal. In this zone the temperature is above the austenite formation temperature for long time that the grains grow dramatically, at last overheated coarse structure forms. The fine-grained zone are formed due to the high cooling speed of the base metal. In the incomplete recrysatllization zone, since only some of the metal recrystallizes, the grain size are various.

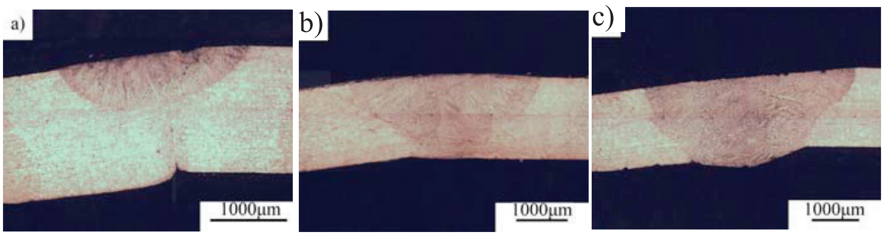

Fig.1: Effects of welding current on the macro morphology and microstructure of the butt welding joint Welding current (a) 55A; (b) 80A; (c) 95A. (impulse frequency 3Hz, welding speed 25cm/min)

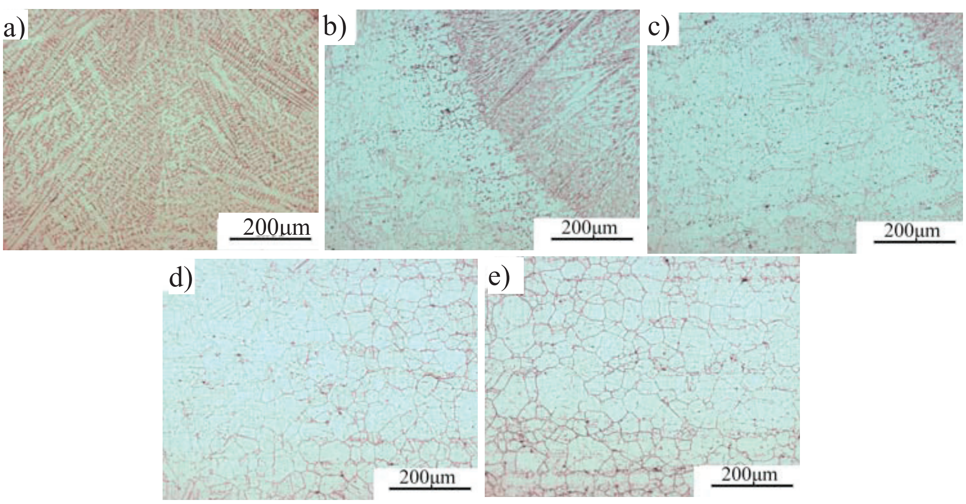

Fig.2 Microstructure of the seam zone and the heat affected zone center
(a) seam; (b) fusion zone; (c) overheating zone; (d) fine-grained zone; (e) incomplete recrysatllization zone

From the results of the metallographic structure, it can be found that at a constant welding speed, the overheating degree of metal in the welding pool increases with the increment of the welding current (or heat input), which result in the decrease of the temperature gradient, but the enlargement of the constitutional supercooling zone and the degree of supercooling, at this situation, columnar dendrits and even equiaxed dendrites come to appear. The heat affected zone widen with the enlargement of the welding current.

The reduction of welding speed displays the same effect on the microstructure of different part in the welding joint with that of the increment of welding current. The heat input is proportional to the welding current but inversely proportional to the welding speed. When the welding speed increases, it shortens the residence time of arc,

which idecreases the heat input, the width and depth of the welding pool diminish and the crystal morphology of the seam changes from dendrites to columnar dendritic crystal and then to dendritic crystal.
With the increase of the impulse frequency, the welding pool widens and the amount of columnar crystal with shorter length in the seam reduces.

Large assembly clearance can aggregate the deformation of the welded joint and reduce the width of the welding pool. Welding with groove has little effect on the microstructure of the seam and heat affected zone. With more remelting times, the width and depth of the welding pool increase, and the deformation enlarges; the column crystals in the seam widen, while the free dendrites in the seam center decrease; the heat affected zone changes little. After each remelting, the column crystals grow longer.

3.2. Effects of TIG welding parameters on mechanical properties of the welded joint of GH99 alloy

Table.1 indicates the welding parameters and the corresponding tensile property of the welded joint of GH99 alloy. From Process 1~4 it is known that when the welding current (55~60A) is too small, the root of the welded joint can be unwelded, this lead to the low tensile strength and elongation of the welded joint; when the welding current (over 90A) is too high, defects like undercutting and collapse appear in the seam. With the increment of welding current, the tensile strength, yield strength and elongation of the welded joint all go up first and then fall down. Finally, the optimized value of welding current is determined to be 80A.
It can be known that from Process 8~11 the heat input is inversely proportional to the welding speed. With the acceleration of welding speed, the tensile properties go up first then fall down. Finally, the optimized welding speed is determined to be 25 cm/min.

It can be seen that according to Process 5~7 the tensile strength decreases with the increase of impulse frequency. Because at high impulse frequency, the time interval between two adjacent peaks of impulse current shortens, which enlarges the average value of current and increases the heat accumulation. Finally, the optimized value of impulse frequency is determined to be 3Hz.

Fig.3 shows the typical morphology of the fracture surfaces. It can be seen that ductile fracture is the main fracture style, dimples are scattered on the fracture surfaces. Comparing Fig.3a) (welding current 55A, elongation 2.7%) with Fig.3b) (welding current 80A, elongation 32.1%), it is known that under low welding current, the elongation is poor due to the small fusion zone; while the fracture still shows the features of dimples, the amount and depth of the dimples are lower than that under high welding current.

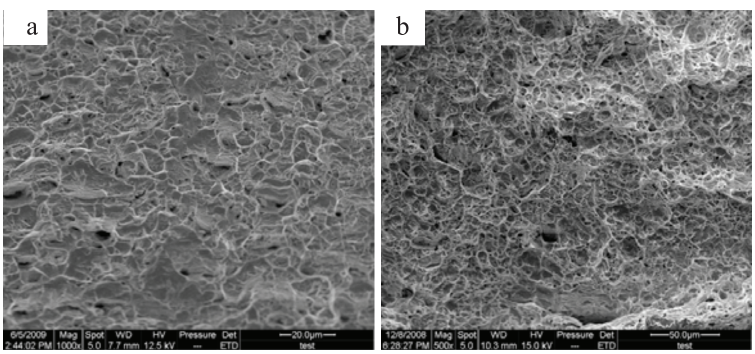

Fig.3 Typical morphology on the fracture surface Welding current a) 55A； b) 80A

4. Summary

The heat input increases with the decrease of welding speed and the increase of welding current. It can induce the widening and deepening of the welding pool, the decreasing of columnar crystals and the increasing of free dendritic crystals in the seam; moreover, it can cause that the strength and the elongation of welded joints go up first and then fall down. The increment of the impulse frequency may lower the strength and the elongation. The tensile fracture is ductile and the dimples scatter on the fracture surface.

Combining the microstructure with the tensile properties, the optimized process parameters can be achieved. The optimized processes are number 5, 14 and 23, i.e. the welding current is 80~90A, the welding speed is 25 cm/min, the impulse frequency is 3Hz.

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