Quantitative research on the heat affected zone of weave bead welding for Invar alloy

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Abstract *Quantitative research on the heat affected zone (HAZ) of weave bead welding (WBW) joint for Invar alloy is carried out in this paper. Based on the morphology and related data analysis of the weld seam, the width difference of each layer and the forming mechanism are analyzed. Results show that the bottom layer (Layer 1) has the widest HAZ and the smallest fluctuation, which reaches* 1 200 μm. *HAZ width of layer 2 to 5 is relatively narrower which is basically below* 600 μm, *while the amplitude fluctuation is greater. The main reason lies in the welding path. The long straight welding without weave causes the base metal near the groove fully melts which causes by the long straight welding without weave, while welding with weave leads to the uneven and inadequate melting of metal near groove.*

Key words heat affected zone, weave bead welding, Invar alloy

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0 Introduction

Invar alloy has received great attention since its discovery. It is a functional material with special performance relying on its iron-based high-nickel composition. It has a lower coefficient of linear expansion in a certain temperature range than any other metal materials. It also has good ductility and weldability, excellent machinability and corrosion resistance, hence it is widely used in the electronics industry, aerospace and other fields[1-2].

Nowadays, thick plate welded structures are more and more widely used in pipeline construction, shipbuilding, heavy machinery and marine engineering[3-7]. However, when welding the thick plate, the amount of deposited metal is large and the welding time is long. Besides, the huge heat input results in the high welding residual stress and poor welding quality, meanwhile, hot cracks and cold cracks may occur during or after the welding process[8-9]. As an advanced improved welding method, WBW can help to obtain the welded joint with wider weld seam and less weld passes, which can effectively improve the production efficiency and avoid defects[10].

In the current study, quantitative research on the HAZ of WBW welded joint for invar alloy is carried out. The HAZ microstructure of each weld layer is observed and the reason for the phenomenon of uneven HAZ width is discussed.

1 Experimental details

The schematic diagram of WBW is shown in Fig. 1. The swing angle is set to be 1.26°.

The dimensions of Invar alloy used in WBW experiments are 100 mm × 100 mm × 19.05 mm, as shown in Fig. 2a. The chemical compositions are given in Table 1. The solid filler wire of Invar M93 with diameter of 1.2 mm is selected, whose chemical composition is similar with the base metal. The diagram of groove is shown in Fig. 2b, where the V groove is 60°, the root face is 1 mm thick and the space between two half plates is 1 mm.

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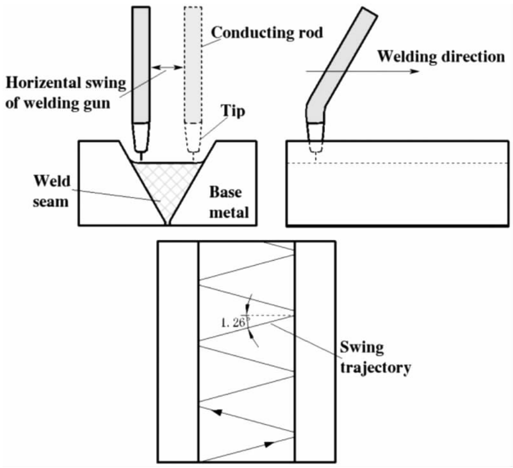
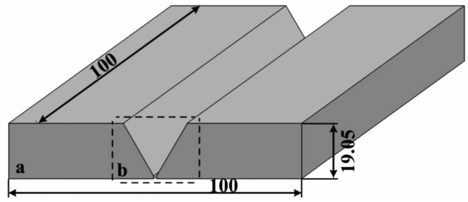
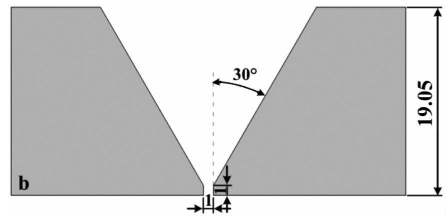


Fig. 1 Schematic diagram of WBW process



(a) Dimensions of the work piece



(b) Size of groove

Fig. 2 Dimensions of Invar alloy plate (mm)

The welding devices used in this experiment include a YD－ABD35 full digital MIG/MAG welding power source, a Panasonic robot of YA－1TAR61 with control box, workbench, frontiers wire feed system and shielding gas system, as shown in Fig. 3.

Table 1 Chemical composition of the Invar alloy (mass fraction, %)

Ni	C	Si	Mn	P	S	Cr	Co	Fe
35.5－36.5	≤0.01	≤0.2	0.2－0.4	≤0.007	≤0.002	≤0.15	≤0.4	Balance

The welding parameters are shown in Table 2. Besides, the pure argon with 99.99% concentration is used as the shielding gas whose flow rate is 20 L/min.

Table 2 Basic parameters of WBW

Layer	Welding current / A	Welding voltage / V	Welding speed / ($m \cdot min^{-1}$)	Weave amplitude / mm	Weave frequency / Hz	Sidewall residence time / s
1	232－238	26.8－27.3	0.38－0.32	0	0	0
2	238－243	27.3－27.6	0.32－0.27	2.0－3.0	1.6	0.1
3	238－243	27.3－27.6	0.26－0.21	4.0－5.0	1.0	0.1
4	243－248	27.6－28.0	0.20－0.16	5.5－6.5	0.9	0.1
5	243－248	27.6－28.0	0.16－0.12	7.0－8.0	0.8	0.1

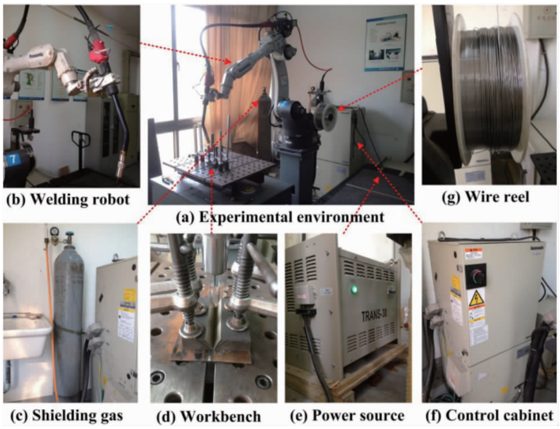
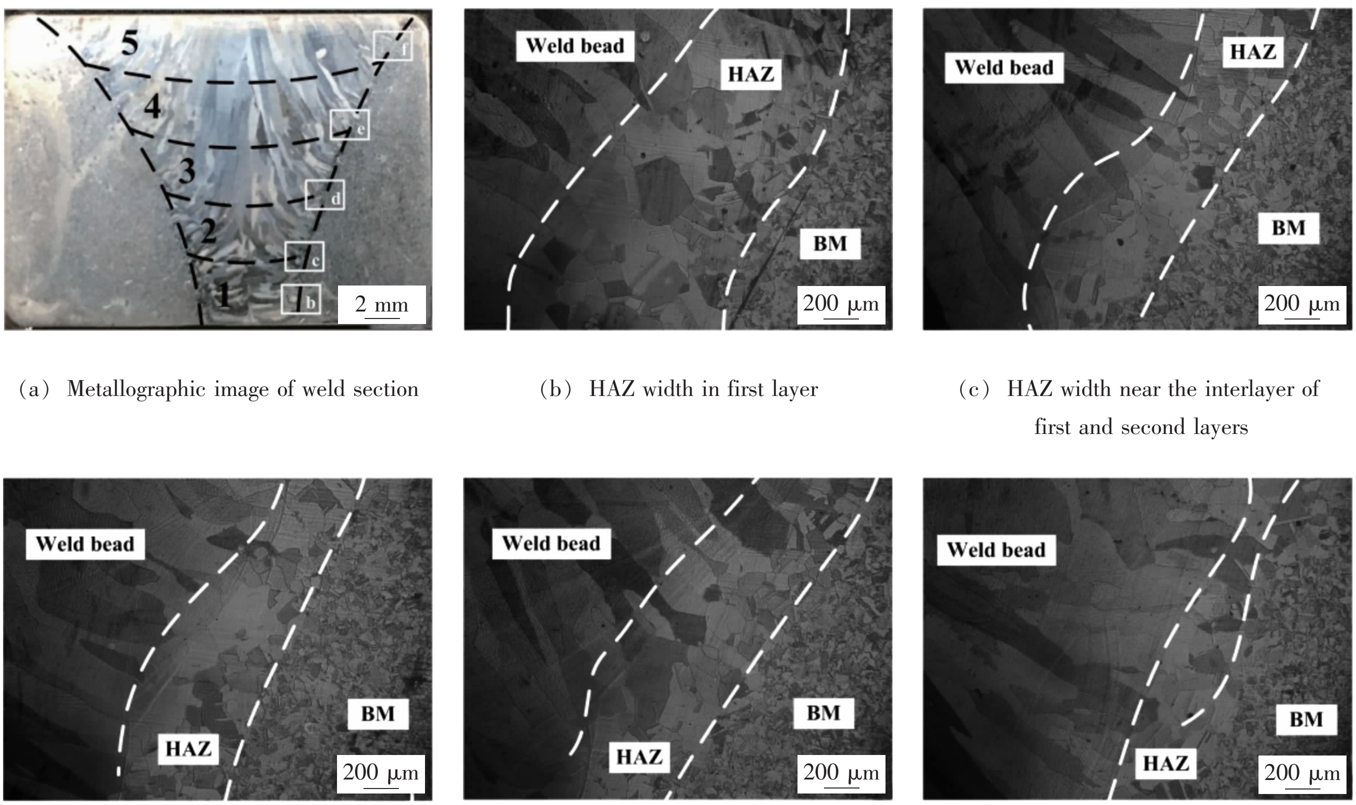


Fig. 3 Welding systems employed for Invar alloy plate

2 Results

The HAZ width of WBW welded joint is shown in Fig. 4, where the sectional diagram of weld seam is shown in Fig. 4a, and the metallographic diagrams of each layer are shown in Fig. 4b – Fig. 4f. It can be seen that the HAZ width changes significantly along the longitudinal direction of the weld seam. The bottom layer (Layer 1) has the widest influence area and the smallest fluctuation, while the HAZ width of layer 2 to 5 are relatively narrow which have strong fluctuation. In general, when the material and the welding environment are fixed, the width of the HAZ depends on the heat input and heat dissipation. However, the welding path is considered to be a more important factor in the current experiment. As shown in Fig. 5a, the bottom layer is the long straight weld seam which does not use the swing trajectory. During the welding process of first layer, the frequency of the current pulse is high, and the heat input can be assumed to be continuous, which result the base metal near the groove is fully melted. Due to above reason, the molten pool is always in a continuous cooling and solidification process, besides, the temperature difference is small along the ver-



(a) Metallographic image of weld section

(b) HAZ width in first layer

(c) HAZ width near the interlayer of first and second layers

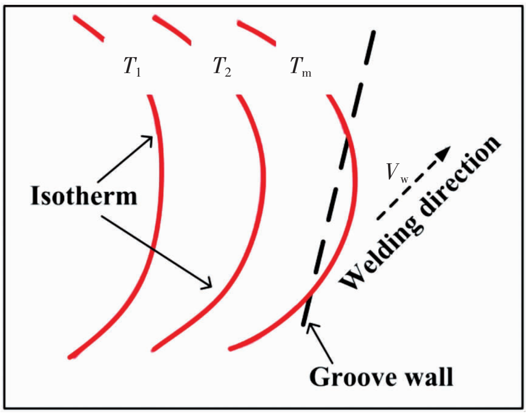
(d) HAZ width near the interlayer of second and third layers

(e) HAZ width near the interlayer of third and fourth layers

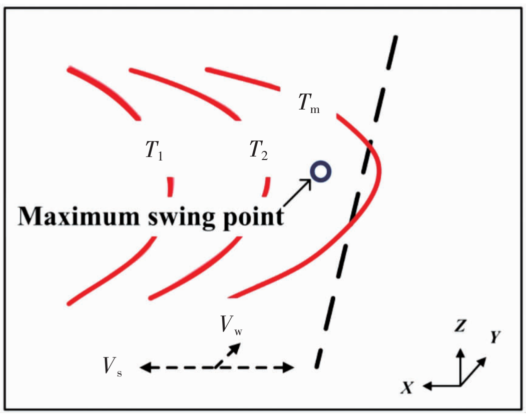
(f) HAZ width in fifth layer

Fig. 4 The HAZ width of WBW

tical temperature gradient. Therefore, the width of HAZ is relatively stable. As for the welding of second to fifth layers, the base material near the groove starts to melt only when the torch moves close to the maximum amplitude. When the welding gun leaves the maximum amplitude point, the molten pool begins to cool and solidify, as shown in Fig. 5b. Therefore, the narrow distribution of the weld pool isotherm near the groove and the velocity component in the X direction of the moving torch are the reasons that lead to the instability of HAZ width.



(a) Welding without weave



(b) Welding with weave

Fig. 5 Two kinds of welding path

As shown in Fig. 6, the width of the HAZ is quantitatively analyzed, where horizontal axis represents the distance from the measuring point to the bottom of the weldment and vertical axis represents the HAZ width. It is observed that the HAZ width of the first layer is much larger than that of other layers, and the maximum width reaches 1 200 μm. The HAZ width of the second to fifth layer is basically below 600 μm, while the amplitude fluctuates greatly.

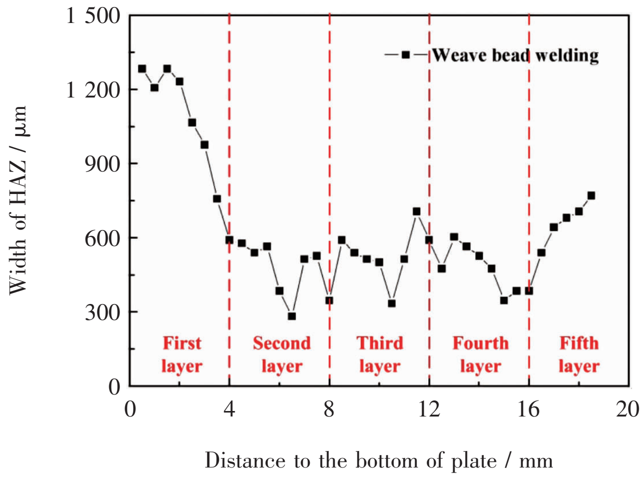


Fig. 6 The width of the HAZ

3 Conclusions

(1) WBW is carried out to weld thick plate Invar alloy in this paper. It can be derived from the sectional diagram of the weld and the weld metallographic diagrams of each layer that the welding path is the main factor influencing the width of HAZ.

(2) The HAZ width of bottom layer is relatively stable, while the HAZ width of the second to fifth layer fluctuates greatly. It can be concluded that the HAZ width of the first layer is much larger than that of other layers, and the maximum width reaches 1 200 μm. The HAZ width of the second to fifth layer is basically below 600 μm, while the amplitude fluctuates greatly.

Acknowledgements

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