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EFFECT OF CONTINUOUS WELDING ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF ANGLE AND T-BAR

Section steels produced by welding are essential parts for shipbuilding and offshore plant production. T-type and H-type section steels are produced by handwork for secondary processing, which is a generally difficult and tedious activity. Therefore, automatic welding, with sound welding properties and a high-speed process, is necessary to meet the production demands. Welding conditions can be optimized by controlling various parameters to obtain suitable and highly reliable microstructural properties. In this study, the heat affected zone and weld defects of fillet-welded Angle and T-bar parts were investigated in terms of their microstructural, macrostructural, and mechanical properties to ensure the soundness of AH36 section steel parts joined by continuous welds.

Keywords: T-bar and angle steel, Fillet welding, Bainitic transformation

1. Introduction

Secondary machining (welding, marking and cutting, plastic working, etc.) is ordinarily carried out for section steels. The production ratio by the manual process is high due to various characteristics of materials and simple processing, which relies on the skill and knowledge of the workers obtained after years of experience [1]. However, secondary machining exposes workers to various industrial safety accidents and occupational diseases, resulting in a high turnover rate, which means that the supply rarely meets the demands of the industry [2,3]. Therefore, there is a necessity for automatic welding technology and a high-speed production process.

Welding heat on steel results in a special heat treatment condition, which causes a different microstructure compared to the base metal. Heat input decreases by high speed welding, which leads to the deterioration of soundness, and bainitic and martensitic transformation due to rapid cooling rate and undercooling of transformation [4]. It is necessary to optimize welding conditions by controlling various parameters to obtain the desired welding bead shapes and a high reliability for the microstructural properties of the welded zone. Microstructural evaluation and control of the internal defects are also necessary to satisfy suitable mechanical properties.

In this study, the heat affected zone (HAZ) and weld defects of the fillet-welded Angle and T-bar parts were investigated by microstructural and macrostructural analysis. Calculation of the bead angle, throat and leg length, observation of the phase transformation were performed to ensure the soundness of AH36 section steel parts, which were joined by continuous welding process. The microstructural evolutions and mechanical properties of each HAZ were analyzed and evaluated according to the different welding sequence and shape of welding parts.

2. Experimental

In this study, AH36 steels were used; their chemical composition is shown in Table 1. The chemical composition of the filler metals is shown in Table 2. Two thick plates were set vertically, and the tangents were welded automatically. The Angle was welded only on one side, and the T-bar was welded on both sides. T-bar welding was carried out with time lags between the both sides, and the right bead was welded first. The welding conditions were 360 A, 36.4 V and 750 mm/min. The calculated heat input capacity was 10.5 kJ. In order to observe the microstructures and macrostructures of the HAZ and to measure the throat (a), leg length (h), and bead angles (θ) (Fig. 1), the specimens were prepared by grinding and polishing, and then etching with a reagent (100 ml ethanol, 3 ml HNO_3 / 90 ml ethanol, 10 ml HNO_3). The weld zones were classified as the fusion zone (FZ), coarse grain HAZ (CGHAZ), fine grain HAZ (FGHAZ), and

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inter critical HAZ (ICHAZ), depending on the microstructure. To evaluate the mechanical properties, the hardness of the FZ, HAZ and BM (base metal) were measured each at 7 points by micro Vickers hardness test (1 kgf), and the average values were calculated.

TABLE 1

Chemical composition of AH36 steel

Elements	C	Mn	Si	S	P	N
Composition (max. wt.%)	0.21	1.7	0.55	0.035	0.035	0.02

TABLE 2

Chemical composition of filler metal

Elements	C	Mn	Si	S	P
Composition (max. wt.%)	0.05	1.34	0.63	0.011	0.014

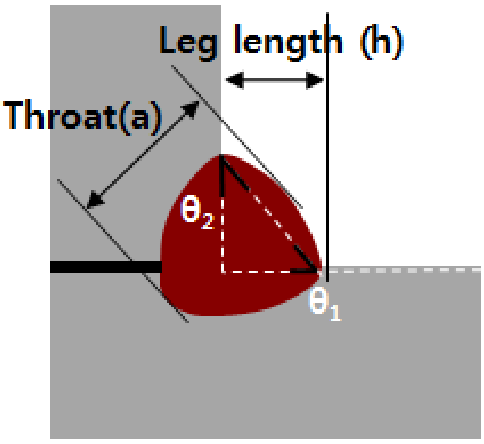


Fig. 1. Schematic diagram of bid angle, throat, and leg length

3. Results and discussion

The macrostructures of each weld type are shown in Fig. 2. For the Angle, the HAZ in the vertical direction (VD) and horizontal direction (HD) were uniform. For T-bar, the HAZ of the last weld (L, left) was more twice wider than the HAZ of the first weld (R, right) in the VD and approximately 1.5 times wider in the HD. By observing the macrostructure, the throat (a) and leg length (h) were measured to calculate the deviation between each side of the bead and its angles (θ) (Table 3). In the case of fillet welding, the beads flowed down because the two thick plates were welded vertically. The large deviation in the bead angles by flowed-down beads weakens the joint strength [5]. For the Angle, the deviation ratio between the bead angles (θ_1, θ_2) was 1.5%. However, the deviation ratio of T-bar was approximately 17% in the first weld (R) and 30% in the last weld (L). The reasons for the differences in the HAZ and bead angle in the VD according to the welding sequence are as follows. Because of the time lag, the last weld (L) was subjected to more thermal effects in the VD due to the preheating effect during the first welding. The thermal effect therefore widens the area of the HAZ in the last welds, and further melting of the filler metal in the VD increases h_2 value

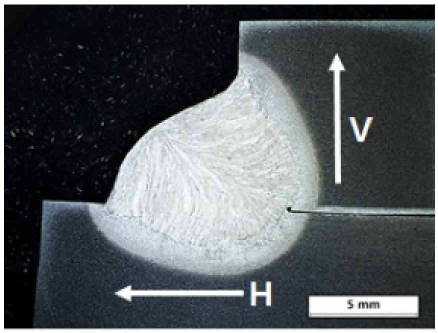
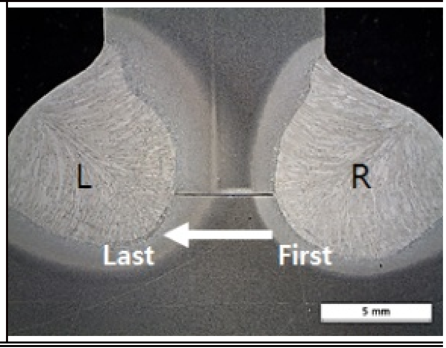
Specimens	Macrostructure
Angle	
T-bar	

Fig. 2. Macrostructures of welded specimens at various weld types

TABLE 3

Variation of bid angle, throat, leg length according to weld types

Specimens		h_1 (mm)	h_2 (mm)	a (mm)	θ_1 (°)	θ_2 (°)	Dev. ratio
Angle		6.61	6.53	7.59	44.7	45.3	1.5%
T-bar	L (last)	5.26	7.01	8.38	53.1	36.9	30.6%
	R (first)	7.04	6.05	8.43	40.7	49.3	17.5%

Fig. 3 showed the HAZ microstructure of the Angle and the T-bar in the VD according to the welding sequence. There was no significant difference in the microstructures of the FZ according to all shapes and sequences. Most of the microstructures consisted of acicular ferrite (AF). Other microstructures were also observed; such as grain boundary ferrite (GBF), Widmänstatten ferrite (WF), polygonal ferrite (PF), and upper bainite (UB). It is reported that GBF contributes to low-temperature crack propagation, and WF and UB are microstructures with high low-temperature crack sensitivity due to their low-angle grain boundary which doesn't assist refracting during crack generation and propagation [6]. However, AF has high-angle grain boundary and inter-locking structure. Low temperature crack resistance is better because it prevents and refracts the crack propagation [7,8]. CGHAZ is coarse because it experiences the higher heat effects. It is easy to harden by fast cooling which can make it

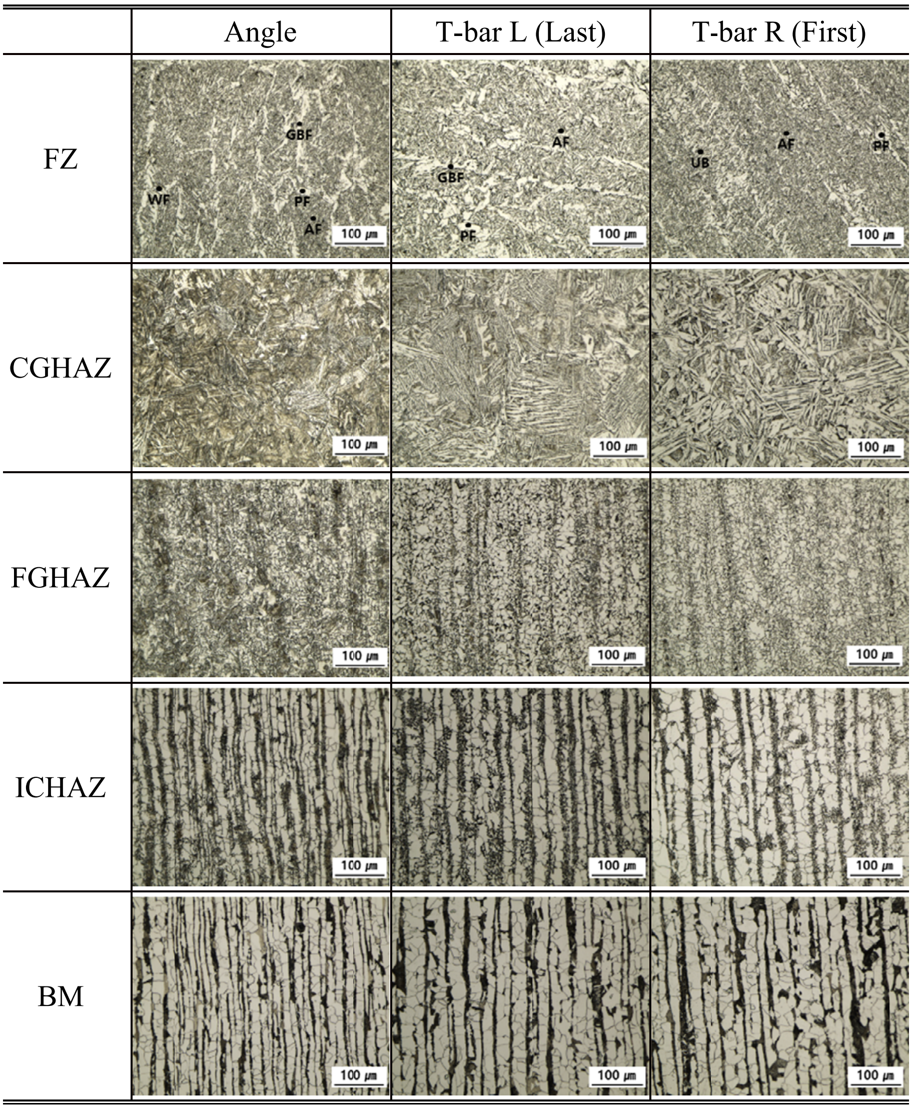


Fig. 3. Optical micrographs of each welded regions of the Angle and the VD of the T-bar

prone to cracking [9,10]. In the CGHAZ, bainite was formed in the coarse prior austenite. Bainite in the Angle was much fine and compact compared to the T-bar. In the case of T-bar, indirect heat before and after receiving the weld heat was found to affect the opposite weld zone. In Fig. 4, heat effect by (A) reduced the cooling rate of T-bar L (last) by preheating effect of the initial welding, and heat effect by (B) caused bainite in the CGHAZ of the T-bar to soften by tempering effect. For the FGHAZ, crystallization by welding heat resulted in fine grains. For the ICHAZ, pearlite could only be observed as transformed and spheroidized. In the case of the T-bar, it was identified that the FGHAZ and ICHAZ were coarsened slightly compared to those of the Angle due to indirect heat effects.

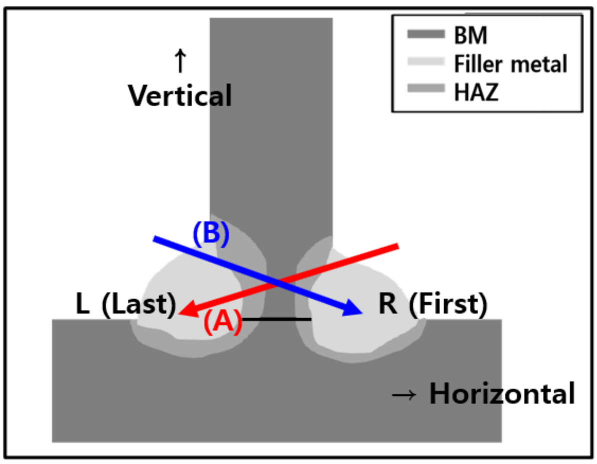


Fig. 4. Schematic diagram of the T-bar welding process

Measurements of the micro Vickers hardness of the HAZ according to shape and welding sequence are shown in Figure 5. The CGHAZ had the highest value regardless of the shape and welding sequence. Similar values were measured for FZ whose microstructure were composed mainly of AF. Hardness was slightly lower for the T-bar in the FGHAZ and ICHAZ than in the Angle due to coarser grains. Significant differences in the hardness according to shape and welding sequence were shown in the CGHAZ. This is because of the indirect heat effects before and after receiving the weld heat, resulting in the formation of fine, compact bainite in the order of T-bar R (first), T-bar L

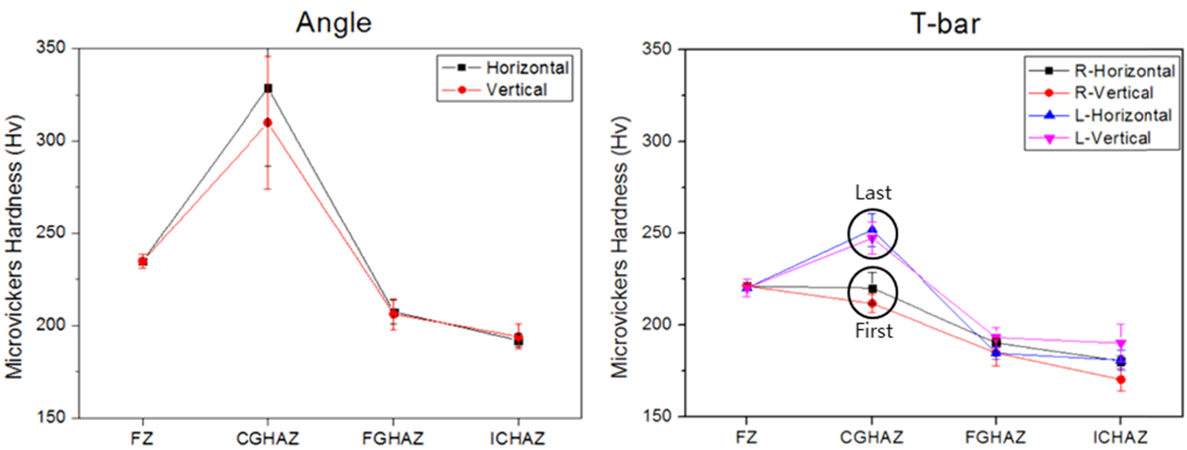


Fig. 5. Variation of micro-Vickers hardness according to weld types in each welded regions

(last), and Angle. It was found that the CGHAZ hardness of the T-bar R (first) was the lowest, and that the tempering effect of the welded part was greater than the preheating effect.

4. Conclusions

In this study, the relationship between the microstructure and the mechanical properties according to weld shape and sequence was analyzed and evaluated. GBF, WF, PF, and UB were observed in the FZ of both the Angle and the T-bar, and most of the microstructures consisted of AF. The crystallization caused by the welding heat in the FGHAZ resulted in fine grains, and the only pearlite observed in the ICHAZ was transformed and spheroidized. However, in the CGHAZ of the T-bar, the heat effects on the weld zone increased, resulting in coarsening and a softer bainite, compared to the CGHAZ of the Angle, which decreased its hardness. This is because in the case of the T-bar, the indirect heat before and after receiving the weld heat was found to affect the opposite weld zone. Indirect heat generates a preheating effect that prevents rapid cooling by slowing the cooling rate of the last welds, and causes a tempering effect that softens the rapidly cooled bainite of the first welds. Therefore, the predictions of direct and indirect heat effects on both beads could improve crack resistance and soundness of the material by softening the CGHAZ and reducing hardness during fillet welding.

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