Research on the Softening Phenomena of HAZ in Welded Joint of Coiled Tubing

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1. Introduction

The failure of coiled tubing is often occur from the heat affected zone (HAZ) of welded joint. The softening HAZ is prevalent problem for welding of coiled tubing with fine-grained microstructure. From the consideration of the strength, softening zone is the weakest link in joint [1]. When the welding technology of coiled tubing was formulated without controlling the layer temperature, it was found that the fracture of coiled tubing located at the HAZ of welded joint. Welded joint is composed of two main parts, named weld metal and heat affected zone. The strength and toughness of weld metal are generally controlled by welding metallurgy through electrode or coating, but the properties of HAZ are difficult to control. So the study of softening zone in HAZ while TIG welding of coiled tubing is important for improving the properties of welded joint.

2. Experimental procedure

2.1 Experimental material

In this experiment, the base metal is CT80 coiled tubing which is belonging to controlled rolling steel. The chemical compositions of CT80 used in this study are shown in Table 1[2-3].

Table 1 the chemical compositions of CT80 (wt. %)

C	Mn	Si	S	P
0.139	0.780	0.326	0.004	0.009
Cr	Ni	Mo	Cu	Nb
0.426	0.006	0.147	0.197	0.026

2.2 Experimental method

An automatic TIG machine was adopted for welding coiled tubing. The first run was welded with no filler metal and the other layers were welded with filler metal. The welding parameters which use in each layer of welding are the same. In this experiment a circle in coiled tubing is divided into five different sections. The welding heat cycle curves of the five sections were measured by thermocouple in different distances to the fusion line. The thermal cycle of HAZ is characterized by the peak temperature(T_{max}) and the cooling time from 800℃ to 500℃($T_{8/5}$).

The microstructure of the first, the fourth, and the fifth section with one layer of welding and two layers of welding were observed by optical microscope. The experiment of micro-hardness is done on the HXD-100ZMC micro hardness tester with 300gf, holding 15s [4].

3. Experimental results

3.1 The experiment of welding thermal cycle

Table 2 is the welding thermal cycle parameters of each section near the fusion line for one layer of welding and two layers of welding, which is not control the layer temperature. The highest T_{max} of one layer of welding is in the fifth section, followed by the fourth section. The higher T_{max} and the lower $T_{8/5}$ of two layers of welding is in the first section and in the fifth section. The peak temperature is high and the cooling rate is low in the section which is nearby the fusion line. The grain grows and the toughness declines seriously with the increasing of T_{max}. According to the analysis of welding thermal cycle, the microstructure and the hardness experiment in the first, the fourth and the fifth section in the sample of welding thermal cycle will be studied.

3.2 The analysis of the hardness in HAZ

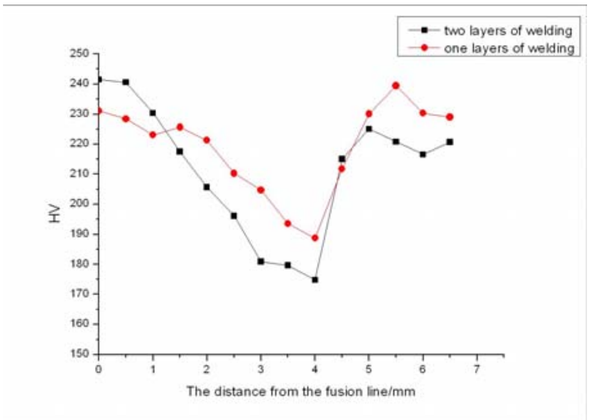
Table 2 Welding thermal cycle parameters of each section near the fusion line

Sections		The first section	The second section	The third section	The fourth section	The fifth section
T_{max}(°C)	one layer of welding	1016.5	1008.0	1009.0	1077.5	1087.0
	two layers of welding	1113.0	1021.0	1036.0	1086.0	1101.0
$T_{8/5}$(s)	one layer of welding	6.5	21.5	24.5	23.5	20
	two layers of welding	27.5	46.5	51.5	39.5	30

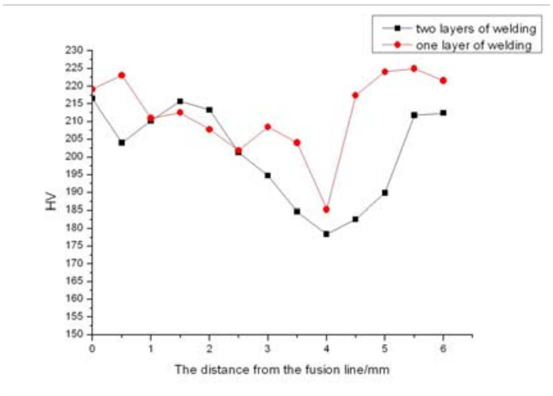
Table 2 T_{max} of the welding thermal cycle in the point which is different located from the fusion line

The distance from the fusion line (mm)		0	2	4	6	8	10	12
T_{max}(°C)	one layer of welding	1016.5	813	647	459	416.5	363	333
	two layers of welding	1113	856	687	581	499	493	399

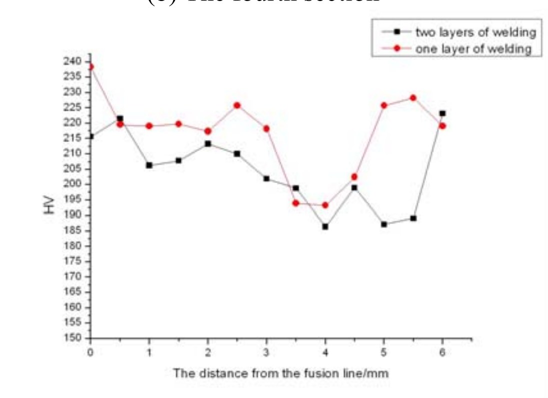
Figure 1 is the changes of hardness during each thermal cycling in HAZ. It can be seen that it has a significant softening tendency where the point is about 4mm from the fusion line, which is not control the layer temperature. As seen in **Figure** 1, the point which is 4mm from the fusion line is the tempering zone because the peak temperature is about 700℃. The hardness rapidly decreased in this zone as the result of the tempering action for the microstructure. The area with low hardness named softening zone. Moreover, the figure 1 also shows that the hardness of softening zone continues to drop with the increasing of layers of welding. As the process of the two layers of welding which is not controlled the layer temperature, the T_{max} increased and tempering action for the microstructure enhanced. By comparison, the width of HAZ softening zone in two layers of welding is much thicker.



(a) The first section



(b) The fourth section



(c) The fifth section

Fig. 1 the contrast of hardness in each section

3.3 The influence of welding thermal cycle on the microstructure

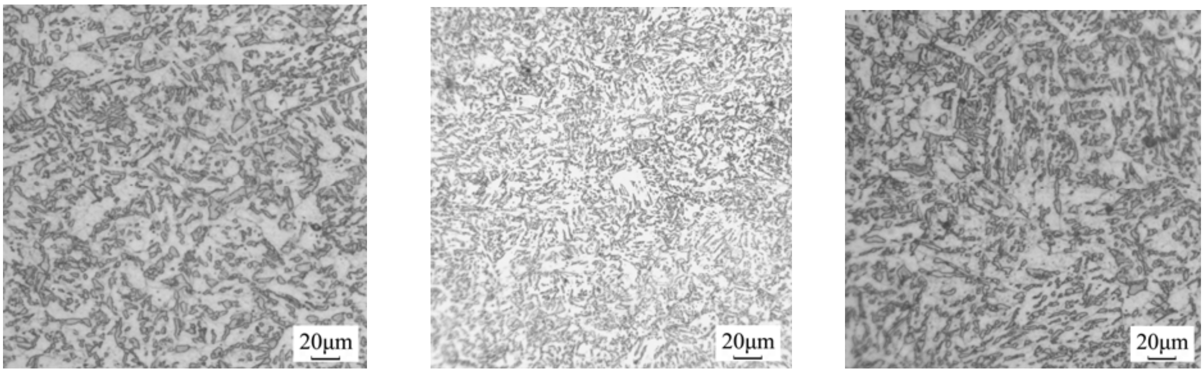
Figure 2 to Figure 3 is the microstructure of HAZ softening zone under the condition of uncontrolled the layer temperature in one layer and two layers of welding. The original microstructure in HAZ is ferrite, the strip-shaped pearlite and bainite. When HAZ was reheated in the follow welding, the original massive ferrite has a tendency to grow. The bainite which has the role of strengthen in the original base metal is tempered and the dislocations disappeared. So the hardness of this zone has declined, its width is about 1-2mm.

In theory, the welding thermal cycle will be superimposed on HAZ in multi-layer welding, the second layer welding will do heat treatment on the microstructure of HAZ, and the grain should be small relatively. In this experiment, the grains size of HAZ softening zone are larger in two layers. From Table 2, it can find that the peak temperature in each section of one layer and two layers of welding are similar, but $T_{8/5}$ in each section of two layers of welding is longer than that of one layer of welding. It shows that the rate of cooling in two layers of welding is slow. Due to the coiled tubing is a kind of controlled rolling steel, the fine grain is more sensitive to heat. The grain size and hardness in HAZ should be controlled by the inter-layer temperature and proper welding parameters for improving the welded joint strength of coiled tubing.

4. Conclusion

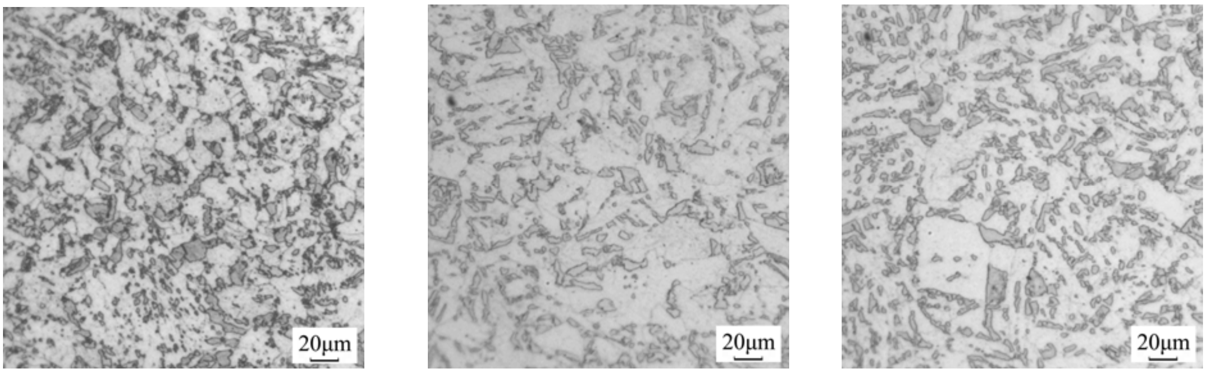
According to the measurement of welding heat cycle curve, the analysis of the microstructure in HAZ and the experiment of hardness, the conclusions of this study are summarized as follows:

(1) In order to obtain good appearance of weld, the girth



(a) the first section (b) the fourth section (c) the fifth section

Fig. 2 The microstructure of the softening zone in one layer of welding



(a) the first section (b) the fourth section (c) the fifth section

Fig. 3 The microstructure of softening zone in two layers of welding

weld was divided into five sections using different welding technology. T_{max} in the first, the fourth and the fifth section are large as the coiled tubing is linked using multi welding technique.

(2) The rate of cooling is slow in two layers of welding when it doesn't control the layer temperature, and the grain is easy to grow.

(3) The softening zone in HAZ is appeared about 4mm from the fusion line when it doesn't control the layer temperature.

References

[1] Zhu Liang, Chen Jianhong. Translation Of The China Welding Instraction, 2004, 25(2):61-65.

[2] Bi Zhongyue, Jing Xiaotian, Zhang Wanpeng, Xue Leihong. Materials for Mechanical Engineering, 2010, 34(11):58-64.

[3] W.D. Van Arnam, D. Smith. Houston: SPE/ICoTA Coiled Tubing Roundtable, 2000.

[4] Lei Zhen, Wang Xuyou, Teng Bin, Zhen Hongyang. Translation Of The China Welding Instraction, 2010, 31(11):33-37.