EFFECT OF HOT-BENDING PROCESS ON MICROSTRUCTURE AND MECHANICAL PROPERTY OF K65 SUBMERGED ARC WELDED PIPE

Liming Dong, Yu Zhang, Xin Pan, Yinbai Wang

Institute of Research of Iron and Steel, Sha-steel, Zhangjiagang, Jiangsu, China, 215625

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Abstract

Hot-bended pipes are essential parts in the construction of long distance pipeline. They are usually made from longitudinally submerged arc welding (LSAW) pipes subjected to hot bending process including quenching and tempering process, which often deteriorates the impact property of the welded pipe. A hot-bended LSAW pipe with a wall thickness of 30.8 mm was fabricated by double-sided four wires submerged arc welding with solid wire and fused flux. Microstructural and property of both as-weld and as-bended pipe were examined. The pipes in two states show a similar tensile strength of 665-670 MPa, and fail in the heat affected zone during the tensile test. The weld metal of as-welded pipe consists of acicular ferrite and small fraction bainite and M-A constituents, while mixture of polygonal ferrite, degenerate perlite and precipitated carbides of metal elements was found in the weld metal of the as-bended pipe. The hot bending process decreases the fraction of acicular ferrite from 66.4 to 47.5%, and the fraction of high angle grain boundary from 76.8 to 67.1%. Therefore, both the type of microstructure and the fraction of ductile microstructures were the influencing factors of weld metal impact toughness, which lead to a reduction from 162 J to 84 J at -40ºC.

1. Introduction

The growing demand for energy needs the exploration of remote natural oil and gas fields [1]. Long distance gas transmission pipeline goes through many complex region in laying process, corners and connections for changing the route and slope of the pipeline are needed depending on geological changes [2]. At present there are three methods to make the direction change of pipeline, i.e., elastic curve laying, cold elbow and hot bending pipe [3], of which the last one is generally applied in project of high grade steel. Pipeline of Bovanenkove-Ukhta project at Russia adopts K65 steel grade, which has a similar strength requirement to API X80 [4]. It requires a toughness value ≥ 60 J at -40ºC, as compared to the toughness requirement of at -20ºC of API X80. The currently used hot bending process usually deteriorates the toughness property of weld metal of the pipes [5,6]. However, there are few studies dealing with this subject, and thus the toughness degradation mechanism remains unknown [7,8]. In this paper, a K65 pipe was fabricated by submerged arc welding with solid wire and fused flux, and the microstructure and property changes of LSAW and hot bend pipe were examined.

2. Experimental

30.8 mm thick K65 steel plate having a composition of (mass, %) 0.05 C, 1.61 Mn, 0.21 Si, 0.007 P, 0.002 S plus 0.85 Ni+Cr+Cu+Mo were used to fabricate pipe. The plate has a microstructure of acicular ferrite (AF) and bainite (B), which shows yield strength (YS) of 585 MPa and tensile strength (TS) of 695 MPa.

Double-sided four wire submerged arc welding were used to fabricate the longitudinally submerged arc welded (LSAW) pipe. The composition of self-developed welding wire was listed in Table 1, and the fused flux contains 22.4 % SiO_2, 20.6 % Al_2O_3, 24.8 % MgO and 14 % CaF with a basicity of 2.1 [9]. The welding parameters were listed in Table 2. The hot bending process includes online heating accompanied by bending and water spraying, and then offline tempering at furnace, and the details were listed in table 3.

Table 1. Chemical composition of the designed welding wire

C	Si	Mn	Ni+Mo	Ti+B	P	S
0.10	0.10	1.50	1.25	appropriate	≤0.009	≤0.005

Table 2. Submerged arc welding parameters

	Current (A)				Voltage (V)				Velocity (mm/min)	Heat input (kJ/cm)
	I_1	I_2	I_3	I_4	U_1	U_2	U_3	U_4	V	E
inside	980	820	700	650	32	37	39	39	110	62.4
outside	1120	920	680	640	32	37	39	40	120	66.5

Table 3. Process parameters of bending and heat treatment of the 30.8mm thick K65 pipe

Heating Temperature (℃)	Pressure of cooling water (MPa)	Bending velocity(mm/min)	Tempering temperature (℃)	Time of temper preservation (min)
1020~1080	0.22	30	550	90

Microstructure and mechanical property of weld metal of LSAW pipe were examined on both as-welded and hot-bended state. Charpy v-notch (CVN) impact tests using samples of standard size (10×10×55 mm) were performed on a machine with a 450 J capacity. Round tensile specimens were tested at room temperature on an Instron machine with a 250 kN capacity. Vickers hardness was measured with a load of 5 kg. Samples for microstructural observation were etched in a 4 % nital solution and observed on an optical microscopy and a field emission scanning electron microscope (JSM-7001F) equipped with an electron back-scattered diffraction (EBSD) camera. The EBSD study was conducted with a step size of 0.2 μm, and the data were then analyzed by HKL Channel 5.0 software.

3. Results

3.1 Microstructure of the pipe

(a) Cross section of the welded pipe Fig.1 shows typical cross-section of the welded joint of the LASW pipe, and no evident defects such as cracks and undercut can be found. Reinforcement and width-depth ratio of the weld were well controlled due to careful selection of welding parameters. Area A in Fig.1 is the position where microstructure observation and hardness test were conducted. Sample for CVN tests is located at the lower center of the joint, as shown in Fig.1.

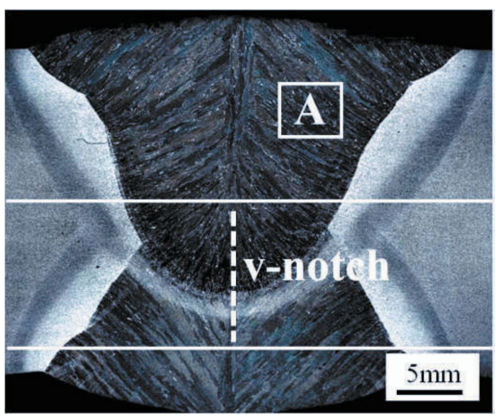

Fig.1 Typical cross-section of the welded joint

(b) Microstructure of the weld metal Fig.2 shows microstructure of the weld metal of the LSAW pipe in both as-welded and as-bended state. The weld metal of as-welded pipe mostly contains interlaced AF with a size of 1-5 μm, and few M-A particles and Bainite are also observed (Fig.2a). No evident large grain boundary ferrite (GBF) and ferrite side-plate (FSP) were observed. The weld metal of hot-bended pipe includes polygonal ferrite (PF), precipitated carbides of metals (MC) and degenerate pearlite (DP), as shown in Fig.2b. The PF has a scattered size range from several to a dozen of micron. The DP has a shape of strip or blocky, and have a size smaller than 5 μm, as shown in Fig.3. Few cementite particles are dispersed around DP and grain boundary, which is believed to be caused by Mo through restraining the segregation of carbon and other impurity on grain boundary during bending process [10错误!未定义书签。].

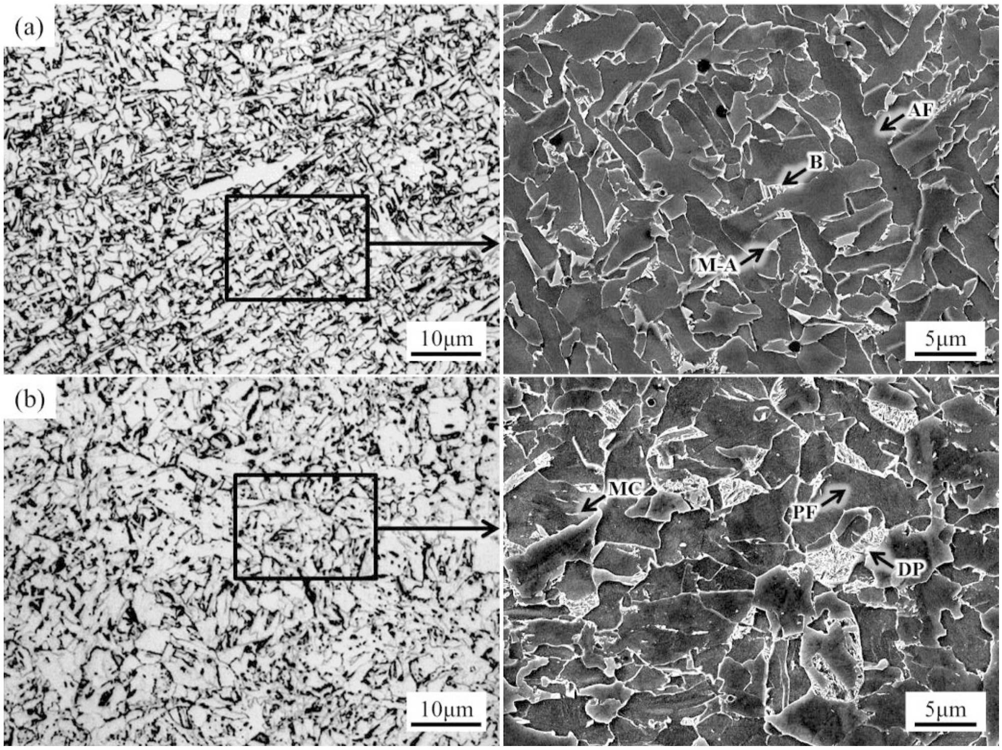

Fig.2 Micrograph of the weld metals of the LSAW pipes：(a) as-welded; (b) as-bended

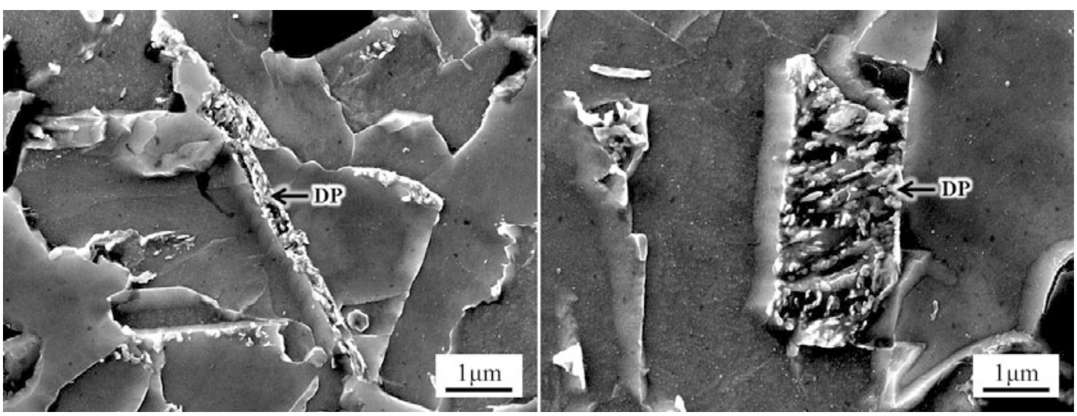

Fig.3 SEM micrograph of DP in Fig.1b

3.2 Mechanical property of weld metal of the pipe

Table 4 shows mechanical properties of the LSAW pipes. The pipes in both as-welded and as-bended states failed in heat affected zone (HAZ) during tensile tests, and they exhibited a similar tensile strength values between 665 and 670 MPa, which satisfies the minimum requirements of 640 MPa of the weld joint. The weld metal of as-welded pipe shows an absorbed energy ≥152 J, as compared to the value of ≥73 J of the as-bended pipe. The hot bending process reduced the mean value of the weld metal from 162 J to 84 J. The toughness deterioration in weld metal perhaps relates to the formation of blocky PF with coarse grains in weld metal of the as-bended pipe. In addition, the hot bending process decreased weld metal hardness from Hv 239 to Hv 230, both of which also satisfy the requirements of prescribed standard [11].

Table 4 Properties of the LASW pipe

	Tensile property of the weld joint		Properties of the weld metal	
	Tensile strength/MPa	Failure position	Akv -40 ℃/J	Hardness/HV5
Requirements	≥640	-	≥50/60	≤248
As-welded (a#)	670	HAZ	175,159,152/162(Mean)	238,240,240/239(Mean)
As-bended (b#)	665	HAZ	73,98,80/84 (Mean)	227,231,231/230(Mean)

4. Discussion

Section 3 reports the microstructure and property of the pipes in both as-welded and as-bended state. The hot bending process leads to microstructure change of weld metal from mostly AF to a mixture of AF, PF and few DP and MC. The process also decreased the impact toughness of weld metal from 162 J to 84 J at -40 ℃, and decreased the hardness of weld metal from Hv 239 to Hv 230.

DP and MC are brittle because of high carbon content and high hardness, and are more prone to crack nucleation [12]. Otherwise AF and PF are tough due to low carbon content and low hardness, which is affected by its size and shape [13]. The microstructural variations suggest that the as-welded metal is tougher than the as-bended weld metal.

It has been reported that high-angle grain boundaries (HAGB) with more than 15° misorientation are more effective for prohibiting the propagation of brittle fracture [14,15]. EBSD analysis was conducted to determine average grain size and HAGB fraction in weld metal of the LSAW pipes. Figs 4a and 4b show grain boundary maps of the weld metals in as-welded and as-bended pipes, respectively, and the black lines represent HAGB.

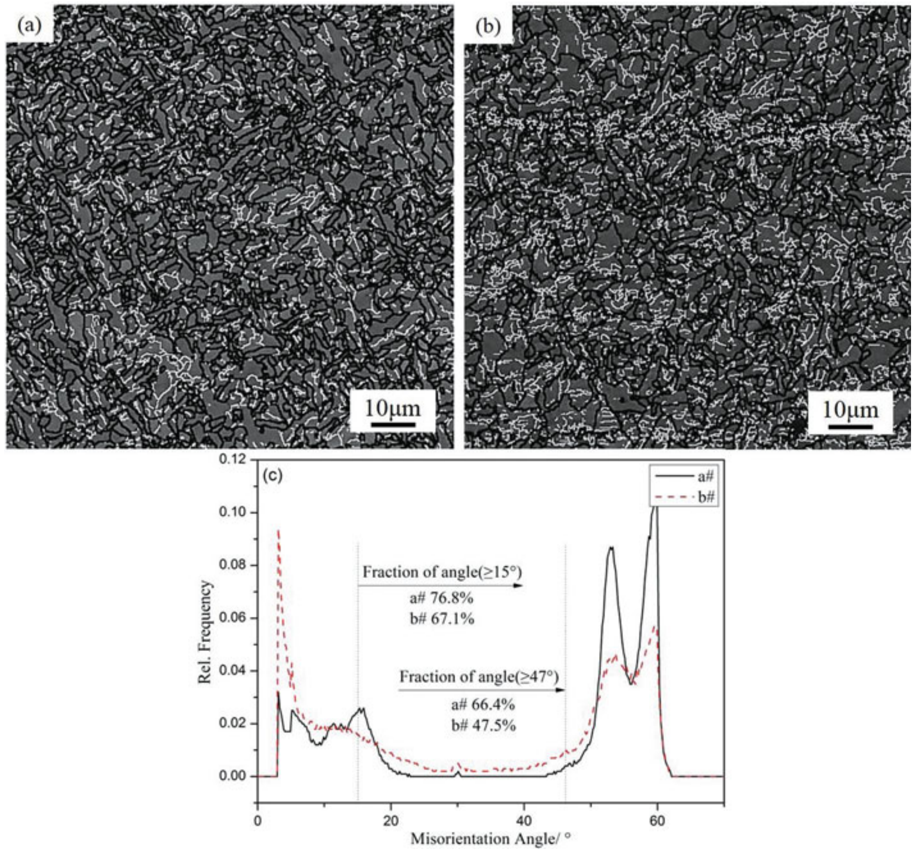

Fig.4 EBSD analysis of the weld metals: (a) and (b) are grain boundary maps in a# and b#, respectively, the black and white lines represent the grain boundaries of large angle and small ones ; (c) Fraction of high-angle grain boundary (≥15°)

It is clear that the as-welded weld metal contains 76.8 % HAGB as compared to 67.1 % in the as-bended weld metal, as shown in Fig. 4c. A very interesting crystallographic characteristic is the absence of misorientation across the plate-boundaries within the range of 20-47°. This is the consequence of realized austenite transformation mechanism into AF which is displacive and corresponds to K/S or N/W relationship. Under this condition, the relationship can not be related by misorientation in the range of 20-47° [16,17]. AF plates exhibit misorientation angles lying between 47-60°, and its fraction was calculated to be 66.4 and 47.5% in the as-welded and as-bended weld metals, respectively. This agrees well with the microstructure result as discussed in the above section.

Fig.5 shows fracture morphologies of the weld metal of pipes in both states. The weld metal of as-welded pipe shows a ductile feature consisting of 5-15 μm dimples. In addition, large size tearing ridges are also observed, which implies the existence of plastic deformation prior to the final failure during impact test. In contrast, small and hollow dimples along with cleavage cracks were observed in the weld metal of the as-bended pipe, which suggests a quasi-cleavage fracture mode, as shown in Fig.5b. The formation of dimples is believed to be caused by the plastic deformation of PF, while the origination of cleavage facets is assumed to be induced by DP and MC located on the prior austenite grain boundary.

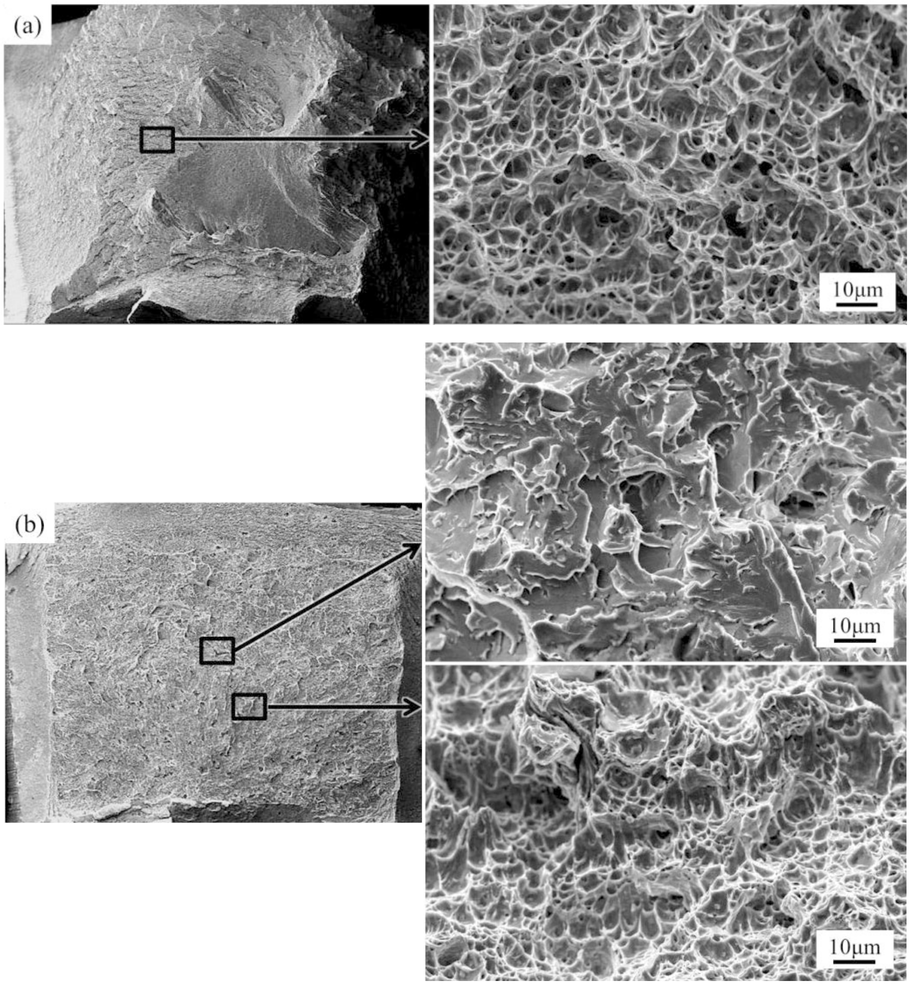

Fig.5 SEM micrographs showing fracture morphology of impact samples of weld metal：(a) a#; (b) b#

5. Conclusion

A hot bended longitudinally submerged arc welded K65 pipe with a wall thickness of 30.8 mm was fabricated by double-sided four wires submerged arc welding process with a proprietary wire and fused flux, and microstructure and property changes of the weld metal in pipe at both as-welded and as-bended state were examined. The pipes show a similar tensile strength of 665-670 MPa, and fail in the heat affected zone during tensile test. The weld metal of as-welded pipe contains mostly 5-10 μm acicular ferrite, while a mix of acicular ferrite, polygonal ferrite and plus a few M-A constituents and degenerate pearlite are observed in the weld metal of as-bended pipe. The hot bending process decreases the fraction of acicular ferrite from 66.4 to 47.5%, and the fraction of high angle grain boundary from 76.8 to 67.1%.The microstructural changes lead to a reduction in impact toughness of weld metal from 162 J to 84 J at -40 ℃, and a change from ductile to quasi-cleavage mode.

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