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Welding technique and quality of large diameter X70 line pipe for gas transmission of China

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Abstract: X70 grade large diameter line pipe with helical and longitudinal seam SAW was developed and used in West-East Pipeline Project of Petrochina. The operation pressure of the pipeline was designed as 10 MPa, with diameter of 1016 mm OD. This project represents the first high-pressure, large diameter and high strength grade gas pipeline in China. All the factors affecting the safety of the pipeline shall be considered. The welds quality of line pipe is very important for safety of the pipeline. Acicular ferrite type X70 grade pipeline steel was adopted for the base material. The welds performances of X70 line pipes with 1016mm OD and 14.6-21.0 mm WT has reached a very high level, especially of low temperature Charpy V impact toughness of welds metal. Welding technique and quality status of X70 line pipe of China are investigated in this paper.

Key words: X70 line pipe; welding; technique; quality

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1 Introduction

West-East Gas Transmission Pipeline Project was a great and key project of China in 2001 to 2003. The total length of the pipeline is about 4000 km. The initial gas transmission is 12×10^9 m^3/a and final transmission will be 20×10^9 m^3/a. The design pressure is 14 MPa and operating pressure 10 MPa. About 1.6×10^6 t of line pipe were used for the project. It will transmit the natural gas from western of China where have rich energy to eastern where energy is very shortage, and so greatly promote economy growth and line pipe technology development.

X70 is micro-alloy high strength pipeline steel developed in 1970s in the world. It has excellent strength, toughness and weldability, and so is widely used in the world.

Welding is one of key technique for oil & gas transmission pipe mill. The welding quality of pipe is concern to the safety of pipeline, and can be used to review line pipe welding technical level of one country. After many years hard working and many problems have been solved by many corporations, spiral submerged arc welded pipes with outside diameter 1016 mm of X70 grade had been developed in 2001 and longi-

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tudinal submerged arc welded pipes in 2002. About one million tons of X70 grade domestic line pipe have been used in West-East Pipeline Project. By analysis for statistical data of pipe used in the project, welding technique and quality status of X70 line pipe of China have been investigated in this paper.

2 Welding procedure

The outside diameter of pipe for West-East Gas Transmission Project is 1016mm, but the wall thickness is different from 14.6mm to 26.2mm according to the class of area. Two sorts of pipe have been used in the project, they are spiral submerged arc welded (SSAW) pipes and longitudinal submerged arc welded (LSAW) pipes. Most of pipe mills of China have only SSAW pipes product line because of history reason. There were six pipe mills that produced SSAW pipe for the project, and all were online welding. One of six pipe mills built one product line for producing LSAW pipe for the project in 2002.

Welding process of all pipe mills were double submerged arc welding (SAW). Welding equipments were made by Lincon Company of US or Messer Company of Germany. The primary welding procedure parameter of *D*1016mm X70 SAW pipe can be seen in Table 1. The property of welding joint is assured by controlling welding heat input.

Table 1 Primary welding process parameter of *D*1016 mm X70 SAW pipe

Thickness /mm	Pipe Type	Welding process	Groove Type	Wire quantity		Welding speed /(mm · min^{-1})	Heat input /(kJ · cm^{-1})
				Inner	outside		
14.6	SSAW	SAW	Y	1 or 2	2	~1200	Approx 20
17.5	LSAW	SAW	X	4	4	~1800	Approx 22
21.0	LSAW	SAW	X	4	4	~1600	Approx 22

3 Welding material

Welding materials of weld line pipe include wire and flux for submerged arc welding. Most of pipe mills used H08C trademark wire to weld X70 grade pipe for the project. The chemical content of the wire belongs to Mo-B-Ti micro-alloyed type, and the content of C, S, P and impurity is very low. Because of micro-alloyed strengthen and fine grain strengthen, the welds of the wire have the most of acicular Ferrite microstructure, and possess high strength and high toughness at the same time. The typical chemical analysis and mechanical property (match with flux SJ101G) of the wire welds is given in Table 2. The typical microstructure of welds is shown in Fig. 1. Some pipe mill used JW-9 trademark wire to weld X70 grade pipe. The wire has the approximate chemical content and mechanical property[1].

Table 2 ypically chemical analysis and mechanical property of H08C wire

Element content/%									σ_b /MPa	σ_s /MPa	CVN (−20℃) /J
C	Si	Mn	P	S	Mo	Ti	B	Cr+ Ni+Cu			
0.086	0.18	1.54	0.020	0.0015	0.32	0.030	0.0048	0.080	638	523	175

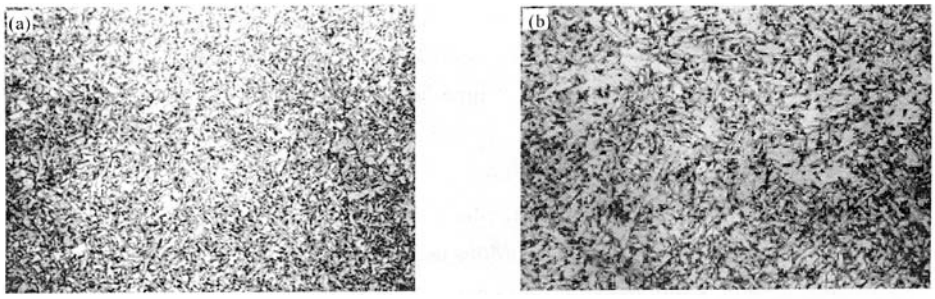

Fig. 1 Typical microsturcture of SSAW welds(a) and LSAW welds(b), 400×

The flux for welding the X70 grade pipe for the project has 2 trademarks. They are SJ101 and SJ101G. The SJ101 trademark flux is fluorine-alkali type, the basicity of which is about 1.8, the chemical composition is Ti-Al_2O_3-MgO. The SJ101 trademark flux has good performances to prevent absorbing humidity from air, arc stab and deslagging easiness. SJ101G trademark flux is fluorine-alkali type too, the basicity of which is from 1.6 to 2.0. The chemical composition of the weld slag of this flux is CaO+MgO+MnO+CaF_2≥50%, SiO_2≤20%, CaF_2≥15%[2].

4 Welding quality

3.1 Appearance of welds

The quality of welds appearance include reinforcement, offset, transition between welds and base metal, welds shape, uniform of width, etc. Because SSAW line pipe for the project was online welding and welding condition was effected by shaping equipment, welding parameter couldn't be adjusted to the best condition, and the quality of welds appearance was generally not very good. The bad appearance welds were not smooth transition between welds and base metal, saddle welds and excceding reinforcement, etc. The welds appearance quality of LSAW line pipe was generally better than SSAW linepipe. Fig. 2 is a typical welds appearance of SSAW and LSAW line pipes.

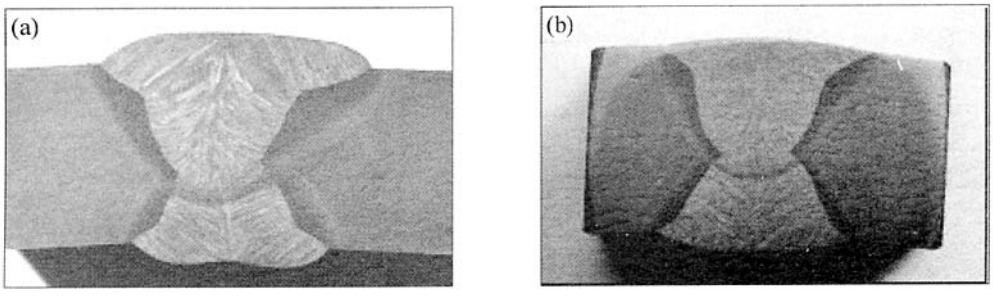

Fig. 2 Typical welds appearance of SSAW(a) and LSAW(b) line pipes

3.2 Inner quality of welds

Welds inner quality is soundness of welds, that is no defect character. The ratio of accepted pipe to total pipe exceeds 97% in the project. The main welding defects are lack of complete fusion, lack of penetrated, slag inclusion and blowhole. The ratio of one times accepted pipe is not high. Considerable pipes need to be repaired to meet the requirement of pipe specification. Repair by welding is one of main work of pipe mill.

By investigation for the domestic pipe for the project, the results show that the ratio of unacceptable pipe by welds NDT to total is about 55% for SSAW pipe and about 45% for LSAW pipe. We can see it is main reason of unacceptable pipe that welding inner quality is not good.

3.3 Mechanical property of welds

The welds mechanical property of X70 grade line pipe can be evaluated by tensile strength, Charpy impact toughness and hardness of welding joint. Main welds mechanical property data of domestic pipes for the project is given in Table 3, and the same property value of imported pipes which produced in some period is listed in Table 3 at same time. Welding joint tensile strength of domestic pipes meet the requirement of the specification($\geqslant$570 MPa), and is higher than that of imported pipes. Welds and HAZ hardness of domestic pipes meet the requirement of the specification(Hv10$\leqslant$270), and hardness average value is moderate, but maximum value is higher than the general requirement for transmission acidity nature gas line pipe (Hv10$\leqslant$248) (remark: the transmission gas of West-East project is not acidity nature gas).

Table 3 Main welds mechanical property data of pipes for the project

Pipe mill	Pipe size /mm	Pipe type	Tensile strength of welding joint /MPa			Charpy impact energy(−20℃)/J						Hardness (Hv10)			
						Welds			HAZ			Welds		HAZ	
			Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Max	Ave	Max	Ave
B Pipe mill of China	*D*1016×14.6	SSAW	655	785	726	50	278	161	52	340	235	264	228	255	213
H Pipe mill of China	*D*1016×14.6	SSAW	635	755	727	60	289	185	32	443	247	268	232	268	222
L Pipe mill of China	*D*1016×14.6	SSAW	620	750	700	43	276	152	31	396	272	266	241	264	230
J Pipe mill of China	*D*1016×17.5	LSAW	595	755	680	33	252	143	63	345	251	268	228	262	211
J Pipe mill of China	*D*1016×21.0	LSAW	615	775	688	80	250	173	122	343	246	258	220	245	204
Z Pipe mill of Japan	*D*1016×14.6	LSAW	610	634	623	145	230	195	250	312	280	228	214	218	196
Z Pipe Mill of Japan	*D*1016×21.0	LSAW	612	650	629	66	248	196	188	452	276	221	210	240	229

The specification of the project line pipe requirement that the average value of crack initiation toughness (Charpy impact energy) of three specimens at weld centerline and heat affected zone (HAZ) in West-East Gas Transmission Pipeline is not less than 90 J and the lowest value of single specimen is not less than 60 J. That is a very high requirement for welding joint. We can see from Table 3 that Charpy impact energy of welds and HAZ of domestic pipes are in the same level with import pipes, the average value of domestic pipes is very high. Certainly there are some value below the requirements of the Specification, but the quantity of those pipes is very little. Fig. 3 is welds Charpy impact energy (at −20℃) probability distribution chart of domestic accepted pipes.

3.4 Welding residual stress

It is well-known that conventional stress test methods is complex and unfeasible. In order to control residual stresses, cut-ring test is adopted as the method of test residual stress by the project specification. This test method cuts a section about exceeding 100 mm long, and than cut the section apart from welds 100 mm along the longitudinal direction, the circumferential opening was measured. The residual stress of line pipe can be estimated through establishing an equation between the residual stress and the circumferential opening in cut-ring test. By this method, we can test indirectly welding and shape stress of pipe. This method is simple, easy, quick and intuitional. The cut-ring test circumferential opening of domestic pipes for the project is generally under 50 mm for LSAW pipes (most is about 20 mm) and meet the requirement

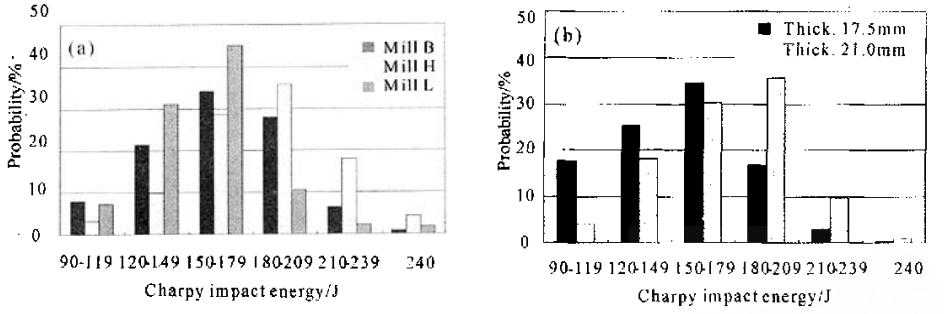

Fig. 3 Charpy impact energy(at −20℃) probability distribution pipe welds of 14.6 mm SSAW pipe(a) and 17.5 mm and 21.0 mm LSAW pipe(b)

of Specification (not more than 80 mm) for SSAW pipes. In general, the stress level of SSAW pipes is higher than that of LSAW pipes.

5 Conclusion

Promoted by the West-East Gas Transmission Project, large diameter X70 grade SSAW and LSAW line pipe has been developed in China. Domestic pipe mills have essentially mastered welding technique of X70 pipeline through pipes volume-production for the project. Welding technique and quality level reached a rather high degree. But in some aspect, such as welds appearance quality, inner quality, welding residual stress, etc, need to be improved.

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