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Research and Production of Heavy Pipeline Plate for Submarine Gas Transmission Lines at Shougang Steel

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Abstract

Strong gas demand pushes the development of submarine gas transmission projects. The production of submarine pipelines demands heavy thickness, high strength, lower temperature toughness, and sour service crack resistance. This paper reports on the experience with the production of linepipe up to 31.8mm in wall thickness grade X70 intended for offshore applications in China. The alloy/processing design along with production parameters are introduced. The achieved mechanical properties in both plate and pipe are reported. Even with this X70 strength level and heavy wall thickness the low temperature fracture toughness achieved was excellent. Drop weight tear testing (DWTT) achieved an average of 94% shear at –15 °C. Evaluation of the heavy gauge X70 sour service performance was performed according to specifications of NACE TM 0284 and DNV-OS-F101 in low pH (~3) solution A. The results demonstrated that the production had extremely high resistance to HIC and SSCC failure in the testing.

Introduction

With the development of economy and society, the demand for oil and natural gas are increasing progressively throughout the world[1].However there serves of oil and gas on the land have been reduced and the cost of oil and gas extraction has been gradually increasing, so the development of offshore oil and gas is a means to replace the reduction of reserves on land. There have been several significant offshore pipeline projects put into service of the past years in the world. In order to resolve the energy requirement and optimize the structure of energy, several offshore pipeline projects were constructed also in China, as shown in Table 1.

TABLE 1: MAJOR OFFSHORE PIPELINE PROJECTS IN CHINA

Project	Grade	Thickness/mm	Completed Time/Year
The South Sea	X70/X65	22～31.8	2012
Ledong Gas	X65	13～15	2007
Panyu-Huizhou	X65	23～44	2005

Chunxiao Gas	X60	15.9	2003
Shengli Oil	X52	12.7	2000

Compared with pipeline projects on land, it was urgent to develop the submarine pipeline system to keep up with the offshore development effort. Because of the severe environment of submarine pipeline systems, the steel pipes used for the pipeline should be provided with better comprehensive properties, such as, low temperature toughness, anti-corrosion (HIC), resistance to high pressure, and so on.
The submarine pipeline in the South China Sea is China's first deep sea gas field, which has proven reserves about 150 billion cubic meters. The uniqueness of this pipeline to the Chinese pipeline producers is the water depth which is up to 1500 m. To prevent collapse of the pipeline at this depth from an ambient external pressure of about 150 bars, the linepipe to be used has to meet severe requirements. The most important requirements for the pipe are shown in Table 2. The extreme pipe size consists of a wall thickness of 31.8 mm at an inside diameter of 765.2 mm.

TABLE 2: THE SOUTH CHINA SEA PIPELINE PROJECT REQUIREMENTS

Items	Direction	Standard
Grade	X70-sour	
Yield strength	transverse	505-605 MPa
	longitudinal	500-600 MPa
Tensile strength	transverse	570-750 MPa
	longitudinal	570-750 MPa
Ratio of YS/TS	transverse	≤0.88
	longitudinal	≤0.90
CVN base @ -20 °C	transverse	≥160 J
DWTT @ -15 °C	transverse	≥85%

Mechanical strength and sour service crack resistance of the pipe are the two important factors for offshore pipelines. In addition the pipe is often required to meet the requirements for yield strength also in the longitudinal direction. The toughness requirements are quite high at ≥160 J average @ - 20 °C for the base material. DWTT testing also requires an average of 85% shear at – 15 °C. At the same time, the sour service test of the products must be performed according to specifications of NACE TM 0284 and DNV-OS-F101 utilizing HIC and SSCC testing in low pH (~3) solution A. The acceptance criterion is CLR≤15%, CTR≤5%, CSR≤2%, sample surface without any surface crack.

Alloy/processing design

The offshore pipeline steel of heavy gauge X70 grade was developed at Shougang Steel's 4.3 m heavy wide plate mill in Qinhuangdao China (Shouqin).For high grade and thick-walled pipeline plates, how to control the balance between the strength, the toughness and the weld ability is very important. The chemical composition of materials used in this offshore project was a low carbon micro-alloyed design. Details of the chemistry of the heavy gauge X70 pipeline steels can be found in Table 3.

TABLE 3: CHEMICAL COMPOSITION USED FOR HEAVY GAUGE X70 OFFSHORE PLATE (WT%)

C	Si	Mn	S	Nb + Ni +Mo	others
≤0.07	≤0.35	≤1.85	≤0.0015	≤0.80	Ti, Cr..

Ultra low carbon micro-alloyed steel was used to obtain excellent toughness (Charpy and DWTT) along with enhancement to the weldability. Due to the heavy thickness of the plates for this application, molybdenum can be used to create acicular ferrite (low carbon bainite) uniformly from surface to center of the thickness even though the surface to center cooling rates are not equal[2].

Shouqin Company has the recently installed and commissioned a state of the art Siemens VAI heavy slab caster with a maximum slab thickness of 400 mm. This is the largest available continuously cast slab in China. This equipment has the dynamic soft reduction function assisting in achieving a slab with excellent centerline segregation across the width, as shown in the examples in Figure 1. Both pictures are from the same slab, photograph 1 is from near the edge of the slab and photograph 2 is from the center width of the slab.

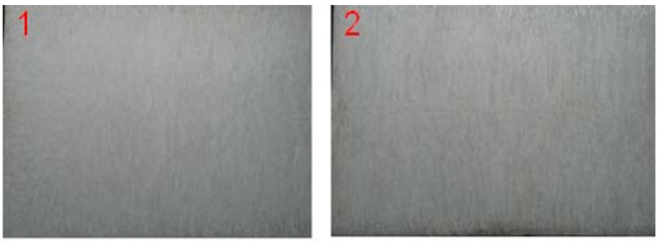


FIGURE 1: SHOUQIN 400MM CONTINUOUSLY CAST SLAB MACROSTRUCTURE FOR OFFSHORE PIPELINES

It can be seen in the Figure 1 slab macroetch the centerline chemical segregation is not visible which would rate this slab on the Chinese YB "Standard Diagrams for Macroetch and Defects in Continuously Cast Slabs" as a Grade C class 0.5 (Grade C class 0.5 is the highest standard in the Chinese YB standard). Excellent casting slab quality is benefit for the properties of heavy gauge X70 offshore plate.

The thermo-mechanical control process of thick-walled X70 plate was carefully controlled, as shown in Figure 2, including slab reheating, TMCP rolling and post rolling cooling. Slab reheating temperature was controlled to assure the dissolution of the micro-alloying element niobium and to minimize austenite grain coarsening[3,4]. Rolling design strategies were such to assure that proper deformations were taken to optimization of the austenite grain size conditioning from surface to center of austenite recrystallization and accumulate dislocation of non-recrystallization, to refine austenite grain size, improve low temperature toughness of plate[5,6,7].Post rolling cooling was controlled to achieve the appropriate cooling stop temperature and cooling rate to obtain the ideal microstructure consisting of a small volume fraction of polygonal ferrite and larger volume fraction of acicular ferrite with a small volume fraction of M/A phase for good mechanical properties including improved DWTT performance[8].

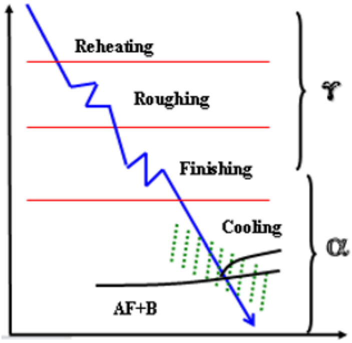


FIGURE 2: PROCESSING SCHEME OF HEAVY X70 PLATE

It should also be noted that the first few deformation passes in the rough rolling stage are mainly focused on creating proper final plate dimensions and hence only work the surface of plate. During the early roughing stage rolling the center region of the slab does not receive full mill force penetration to properly condition the cross sectional austenite grains, so the latter passes of the rough rolling stage must be of sufficient deformation achieve good conditioning of the austenite grain through the entire cross section of the plate. An ideal rolling deformation distribution strategy can be seen in Figure 3.

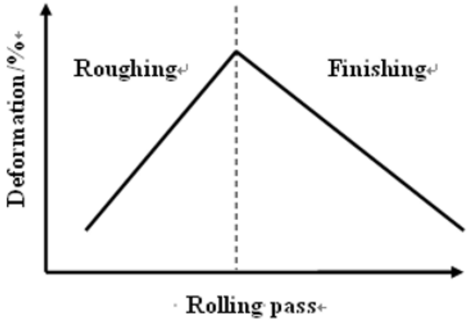


FIGURE 3: IDEAL ROLLING DEFORMATION STRATEGY

Shouqin Level 2 model rolling strategy is designed to apply proper reductions (heavy and at the optimum passes) in the austenite recrystallization and non-recrystallization region to properly refine the austenite grain size, most importantly in the center of the thickness of the heavy gauge plate.

Results – microstructure, mechanical properties and NACE Testing

On the basis of the above alloy/processing design, an expected microstructure was obtained in the 31.8 mm X70 pipeline plate. Figure 4 shows the typical optical micrograph of the thick walled X70 pipeline plate. Matrix microstructure was composed of uniform acicular ferrite from the surface to center thickness of the plate. The average measured ASTM grain size was 13. Scanning electron microscopy(SEM) and transmission electron microscopy (TEM) techniques were used to identify major microstructure phases, as shown in Figures 5 and 6, respectively.

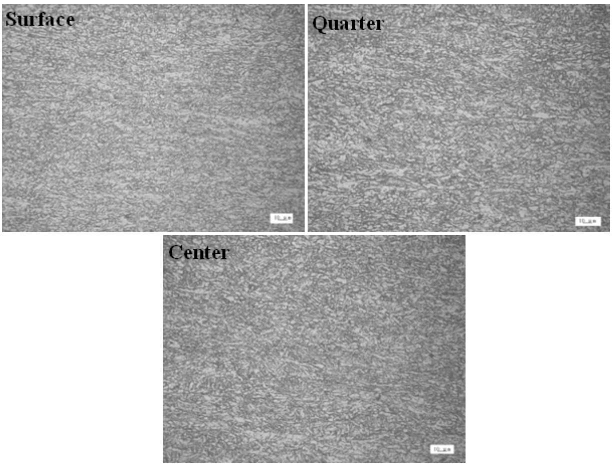
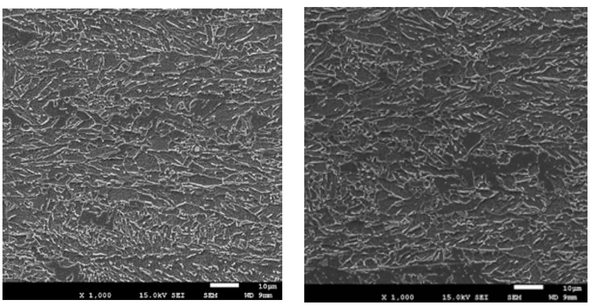
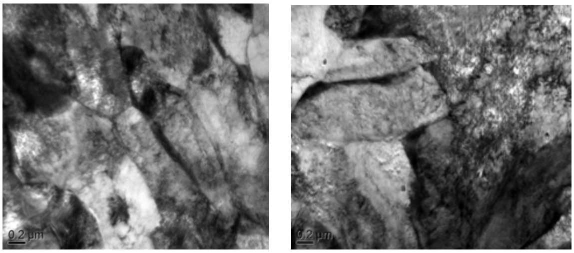


FIGURE4: OPTICAL MICROSCOPY OF 31.8 MM X70 PLATE



Quarter Thickness **Center Thickness**

FIGURE 5: SEMANALYSIS OF 31.8 MM X70 PLATE



Quarter Thickness **Center Thickness**

FIGURE6: TEMANALYSIS OF 31.8 MM X70 PLATE

Microstructure plays a role in steel's ability to perform in the harsh, deep water environments. The tensile properties of the developed microstructure in the transverse and longitudinal direction were taken from the center of the width with the results shown in Table 4.The transverse and longitudinal Charpy impact and DWTT samples were taken from the quarter of width position with the results shown in Table 5.

TABLE 4: TENSILE PROPERTIES OF31.8MM PLATE

Sample type	Rt0.5	AVE	Rm	AVE	YS/TS	AVE
Flat strap-Transverse	524	519	685	679	0.76	0.76
	518		677		0.77	
	514		675		0.76	
Round bar-Transverse	505	508	653	655	0.77	0.77
	509		651		0.78	
	509		661		0.77	
Flat strap-Longitudinal	505	505	652	656	0.77	0.77
	502		657		0.76	
	509		660		0.77	
Round bar -Longitudinal	512	518	644	642	0.80	0.81
	528		639		0.83	
	515		642		0.80	

TABLE 5: TOUGHNESS PROPERTIES OF31.8MM X70

Sample type	Charpy Impact Toughness @ -20 °C				DWTT @ -15 °C (Full Thickness Samples)	
	CVN/ J		Shear Area/ %		Shear Area/ %	
	Ind	Ave	Ind	Ave	Ind	Ave
Transverse	472	484	100	100	95	95
	490		100			
	489		100		95	
Longitudinal	483	455	100	100	90	93
	403		100			

	478		100		95	

As mentioned above, the thick walled X70 pipeline plate developed for deep water offshore application shad uniform strength and good low temperature toughness. For these excellent mechanical properties, lower carbon content and carbon equivalent as measured Pcm play an important role.

To research and develop steel plates intended for deep water pipeline applications，the plates were formed into longitudinal seam submerged arc welded pipes produced by the JCOE pipe processes. The corresponding required mechanical properties were tested and evaluated, by which it could be concluded whether these pipes were qualified for being used on the offshore pipeline. The tensile samples were taken from the 180° position of the pipe body with the results shown in Table 6.

TABLE6: TENSILE PROPERTIES OF31.8MM PIPE

Position	Sample type	Rt0.5	Rm	A/%	YS/TS
Pipe body 180^{O}	**Flat strap-Transverse**	599	682	57.9	0.88
	Round bar-Transverse	589	682	26.0	0.86
	Flat strap-Longitudinal	565	665	53.5	0.85
	Round bar -Longitudinal	551	641	25.2	0.86

It should be noted that there is an expected upward shift in YS during pipe making，which is due to the creation of a fine uniform acicular ferrite microstructure from the alloy/processing design.

The transverse Charpy impact samples were taken from the body, weld seams and heat affected zone (fusion line+2 mm) with the results shown in Table 7.

TABLE 7: IMPACT TOUGHNESS OF31.8MM PIPE

Position	**Charpy Impact Toughness @ -20℃**			
	CVN/ J		**Shear Area/ %**	
	Individual	**Ave**	**Individual**	**Ave**
Body	462	473	100	100
	485		100	
	471		100	
Weld Metal	241	240	60	58
	213		55	
	267		60	
HAZ (FL+2mm)	350	340	90	85
	330		80	
	340		85	

The transverse and longitudinal DWTT samples were taken from the 90° position of the pipe body with the results shown in Table 8.

TABLE 8: DWTT TOUGHNESS OF31.8MM PIPE

Sample type	DWTT @ -20 °C		DWTT @ 0 °C(Full)	
	Shear Area/ %		Shear Area/ %	
	Individual	Ave	Individual	Ave
Transverse	85	88	99	99
	91		99	
Longitudinal	87	87	98	98
	87		98	

The fracture appearance of the DWTT pipe samples at 0 °C is shown in Figure 7.The fracture has a good ductile appearance with no significant separations. This resulted in the excellent DWTT performance.

FIGURE7: DWTT FRACTURE OF X70 PIPE

To gain a base understanding of the performance of the 31.8 mm x 765mm OD X70 LSAW pipe in the harsh, deep water environments, the pipe samples were tested according to specifications of NACE TM 0284/0177 and DNV-OS-F101 utilizing HIC and SSCC testing in low pH (~3) solution A. The results of the NACE testing can be found in Table 9 and 10. The macrograph of the NACE sample exposed surface is shown as Figure 8 and 9.

TABLE 9: RESULTS OF NACE TM0284 LOW pH (SOLUTION A) TESTING OF X70 PIPE

Position	Micro Inspection	Crack (X100)	CSR (%)	CLR (%)	CTR (%)
Pipe Body	No Hydrogen Blisters	No Crack	1 Individual		
			0	0	0
			3 Average		
			0	0	0
Weld Metal	No Hydrogen Blisters	No Crack	1 Individual		
			0	0	0

			3 Average		
			0	0	0

TABLE 10: RESULTS OF NACE TM0177 LOW pH (SOLUTION A) TESTING OF X70 PIPE

Position	Stress Condition	Crack Inspection
Pipe Body	$0.72\sigma_s$	No Crack
	$0.85\sigma_s$	No Crack
Weld Metal	$0.72\sigma_s$	No Crack
	$0.85\sigma_s$	No Crack

FIGURE8: MACROGRAPH OF PIPE BODY SAMPLE

FIGURE9: MACROGRAPH OF WELD MATAL SAMPLE

As mentioned above, the results for31.8 mm x 765 mm ODX70 LSAW pipe in this corrosive environment testing performed as expected. The low carbon, low sulfur, clean steel and good internal slab quality coupled with the homogeneous fine acicular ferrite microstructure had extremely high resistance to HIC and SSCC failure in the NACE and DNV testing.

Conclusions

Heavy thickness, high strength and excellent toughness represent the development trend in the present and in the future for gas transmission pipelines, especially for the deep-water pipeline. The thick-walled 31.8 mm X70 plates for the South China Sea

Deepwater Pipeline Project have been successfully developed in China.

The 31.8 mm X70 heavy plates produced at Shougang Steel have uniform strength performance and good low temperature toughness, fluctuations of the yield strength were controlled to less than 25MPa. Even with this X70 strength level and heavy wall thickness, the drop weight tear testing (DWTT) performance of the plate achieved an average of 94% shear at – 15 °C.

After pipe making by JCOE processing, the mechanical properties of the 31.8 mm x 765 mm OD X70 LSAW pipe can meet the technical specifications of "The South China Sea Deepwater Gas Development" completely. Meanwhile the produced X70 pipes had extremely high resistance to HIC and SSCC failure in low pH (~3) solution A. Overall, all of these results demonstrated that the heavy wall X70 production at Shougang Steel's 4.3 m wide heavy plate mill (Shouqin) can meet the technical specifications of submarine gas transmission pipelines.

This work represents the initial stages of developing heavy gauge X70 plates used in harsh, deep water applications in China. Although there is still much work to do, further study is necessary to evaluate the relationship in production parameters, microstructures and their mechanical properties, and to identify the best options for batch productions.

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