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DEVELOPMENT OF LARGE DIAMETER X70 HIGH TOUGHNESS HSAW LINEPIPE FOR GAS TRANSMMISION

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ABSTRACT

X70 large diameter linepipe with helical seam SAW were developed, with1016mm OD and 14.6mm WT. Acicular ferrite type linepipe steel is adopted for the base material, which was found having high toughness and low yield strength loss after pipe forming. The very stringent requirements for toughness, i.e. 190J/140J for average/minimum for pipe body and 120J/90J for average/minimum for weld and HAZ were meet successfully. The yield strength loss due to Bauschinger effect was found lower than 20 MPa, which benefited.

INTRODUCTION

The development of east China lead a condition of energy shortage. As an clean energy, natural gas was planned to be transmitted form west China to east China. Driven by cost considerations, gas transmission companies have a trend to adopt higher strength steels to permit gas transportation at higher pressures. The operation pressure of the pipeline was designed as 10MPa, with diameter of 1016mm OD, 14.6mm for the wall thickness. The grade of the pipe is X70. Pipe with high quality is the fundamental factor of maintaining the safety of the pipeline. For high-pressure gas pipelines, longitudinal submerged arc welded (SAW) linepipe has been widely used. In China, we have considerable experience applying helical SAW linepipe for gas pipeline. This project represents the first high-pressure, large diameter helical SAW X70 gas pipeline in China. All the factors affecting the safety of the pipeline shall be considered. The main factor to be considered is the toughness, including the base material, weld metal and the HAZ. For the base material, the ductile to brittle transition temperature and toughness must be controlled to avoid fracture propagation over long distances [7-10]. In the specification of the pipe, the toughness requirements was stipulated as, Charpy absorbed energy (full size) 190J/140J for average/minimum for pipe body and 120J/90J for average/minimum for weld and HAZ at -20℃, 75% and 80% DWTT shear area at -5 ℃.

As the advantage of it's weldability, high strength and high toughness, low carbon micro-alloyed steel was widely used for the linepipe production. Since the steel is deformed during the pipe manufacturing, tensile properties may change. The yield strength loss caused by Bauschinger effect must be determined. To assure the strength of the pipe, this factor shall be considered for the hot coil, i.e. the strength of the coil shall have enough margin to compensate the loss of the strength. The actual strength of the coil must be high than the minimum yield strength requirements of the pipe. Conversely, high strength coils require high forming capacity . In order to reduce the yield strength loss form the Bauschinger effect, acicular ferrite steel is developed .

As cold expanding is not used for most helical SAW pipe, residual stress control must be considered. The forming parameter may be optimized to minimize the residual stress .

The development of X70 high-toughness linepipe steel and helical seam SAW linepipe was a co-operative effort between domestic steel/pipe mills, West-East Pipeline company of Petrochina, Tubular Goods research center and Government.

Material

Chemical

The alloying considerations in the developing of the X70 linepipe steel was based on the typical chemical composition for high strength micro alloyed steels[12, 13]. Table1 shows the product chemical requirements of specification of the linepipe. The Low carbon(<0.10%), low Ceq(≤ 0.42) and Pcm(≤0.21) and limitation of hardening elements were stipulated for consideration of the weldability of the material. Due to the high toughness and low brittle to ductile transition temperature requirements, low sulphur (≤0.005) and phosphorus (≤0.020) were required in the specification.

Table1 Chemical requirements max,wt%

C	Si	Mn	P	S	Cr	Mo
0.10	0.35	1.65	0.020	0.005	0.25	0.30
Ni	Cu	Nb	V	Ti	Ceq	Pcm
0.30	0.30	0.08	0.06	0.025	0.42	0.21

In order to obtain high toughness, high strength and proper weldability, chemical composition was strictly controlled in steel making. Ca treatment was used to modify the shape of sulphide inclusion. Nb,V, and Ti was added. Ti is added to inhibit austenite grain growth during reheating and grain coarsing of the the HAZ. The precipitation effect of Nb(C,N) was adopted to get the material strengthened. Table2 shows the typical chemical composition of the coil. The Cqe and Pcm was controlled below 0.20 and 0.40 respectively. Mo was added to delay the formation of polygonal ferrite and pearlite.

Table 2 Typical chemical of the steel

C	Si	Mn	P	S	Cr	Mo
0.05	0.20	1.55	0.014	0.003	0.03	0.22
Ni	Cu	Nb	V	Ti	Ceq	Pcm
0.18	0.24	0.05	0.04	0.018	0.39	0.19

Microstructure

Ferrite-Pearlite steels were widely used in the production of line pipe for grade below X70. For linepipe steels over grade X80, acicular or bainite microstructure was adopted[14-17]. Acicular ferrite steel has several advantage over traditional Ferrite-Pearlite steel in toughness, strength etc. This microstructure develops a continuously yielding tensile stress-strain behavior, which imparts less strength loss during pipe forming and specimen flattening due to Bauschinger effect. Figure1 shows the typical microstructure of the developed X70 linepipe steel. Figure2 shows the TEM observation of the microstructure. In figure1, it can be seen that the structure is consist mainly of acicular ferrite(80%) and some polygonal ferrite(less than 20%) . Martensitic islands are contained in the acicular ferrite matrix. Pearlite at the ferrite boundary would be detrimental to toughness.

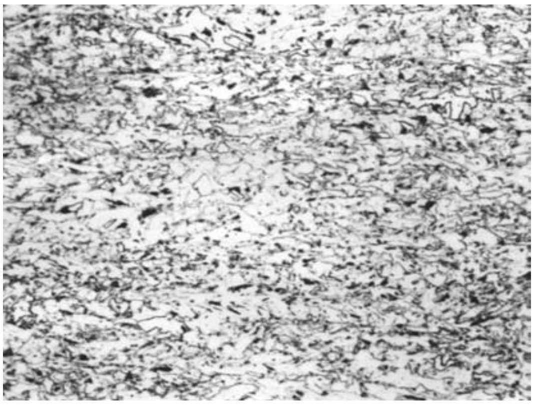

Fig1 Typical microstruture (optical)   500×

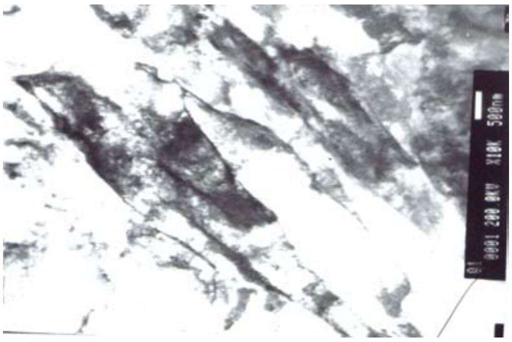

Fig2 Acicular ferrite lath   (TEM)

Mechanical property

Yield strength and toughness of the coil are two main mechanical properties be considered in the developing of the steel. Thermomechanical controlled rolling process and accelerated cooling was used to the manufacture of the coil to obtain fine acicular ferrite microstructure. In Table3, the tensile properties in three directions are given. The yield strength is lowest in the longitudinal direction, highest in the transversal. The yield ratio is controlled below 0.90, which is generally 0.85. much less than the specified 0.90. Table 4 gives the typical toughness value of the coil. As the limitation of the capacity of Charpy machine (max 409J), some specimen was unbroken. Transverse Charpy and DWTT transition curve are shown in fig3, 4.

Table3 Typical tensile strength value

Specimen orentation	$\sigma_{t0.5}$	σ_b	$\sigma_{t0.5}/\sigma_b$	δ
Longitudinal	525	695	0.75	36
transversal	580	730	0.80	37
30°	550	715	0.73	37

Table 4 Typical toughenss value

Specimen orentation	Charpy (full size) -20℃		DWTT -15℃	
	Energy J	Shear area %	Energy J	Shear area %
Longitudinal	380	100	/	/
transversal	310	100	6900	100
30°	350	100	7200	100

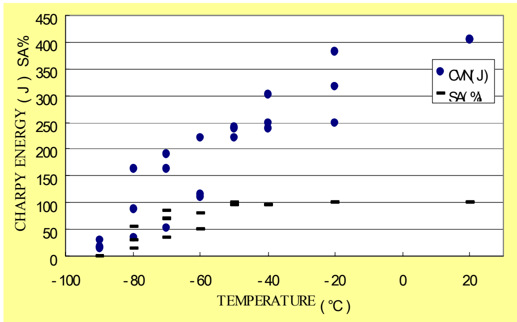

Fig 3 Charpy transition curve

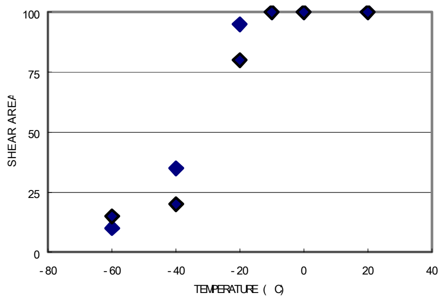

Fig 4   DWTT transition curve

The Charpy transition temperature is below -60℃, and 85% DWTT transition temperature is below -20℃. X70 linepipe steel coil with high toughness and low transition temperature were developed.

MANUFACTURE OF PIPE

The key process of the manufacture of the linepipe is forming and welding. OD control forming machine was used in the forming process. The forming parameter is adjusted to get low residual stress in the pipe. Welding is carried out online before cutting into length. MnMoTiB alloy multi welding wire and agglomerated flux was used to get more acicular ferrite in the weld metal to obtain high weld toughness. Heat input is optimized to control the property of the weld and the HAZ. After small trials, production trails was carried out, and then normal production started. Over 10 thousands tons of pipe have been produced.

Mechanical properties

a) Strength

The strength of the pipe produced is given in Table 5

Table 5 Tensile strength test results

	Average	Max	Min
Yield strength, MPa	546	620	490
Tensile strength, MPa	702	720	650
Yield-to-tensile ratio	0.80	0.85	0.76
Percent elongation	38	42	36

For helical seam linepipe, cold expending is not generally used. Yield loss during pipe forming and specimen flattening due to Bauschinger effect can not be compensated by expending. Yield margin shall be considered for the strength control of the coil. The metallurgical design of the microstructure is acicular ferrite, which shows less yield loss compared with traditional ferrite-paerlite structure. The transverse yield strength distributions of yield strength of the pipe and coil are given in Fig 5. The average yield loss is below 15Mpa. It is found that, coil with higher yield strength behaves more yield loss than the coils with lower yield. The strength of pipe can meet the specified min 485Mpa as long as the yield of the coil not less than 505Mpa.

b) Toughness

The toughness of the pipe produced is given in Table 6. The average value of Charpy energy of pipebody is much higher than the specified 190J and often exceeded the capacity of the Charpy machine (>409J) and requiring frequent machine recalibration.

The Charpy energy of the weld is high due to the acicular microstructure of the weld metal as shown in fig 6.

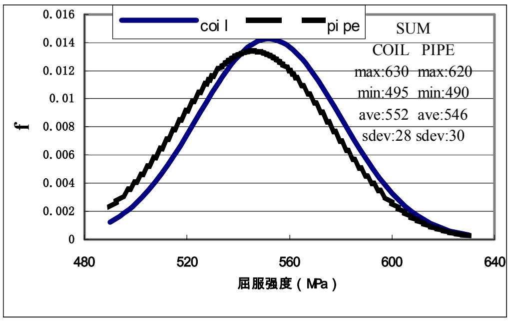

Fig 5 Comparison between pipe and coil yield

Table 6 The Charpy energy at -20℃ of the pipe

Location	Average	Max	Min
Pipebody	310	409	158
Weld centerline	180	240	120
HAZ	220	275	128

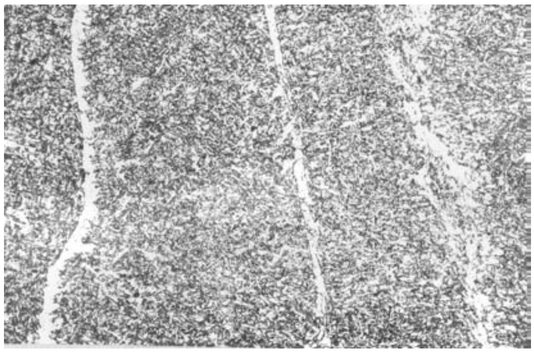

Fig 6 Microstructure of the weld 200×

CONCLUSIONS

In summary, high toughness X70 helical seam linepipe (1016mm OD and 14.6mm WT.) has been developed in China. Acicular ferrite microstructure was considered for the linepipe steel coil, which has high toughness and less yield loss during pipe forming. Over 10 thousands tons of pipe has been produced and meet the requirements of the specification.

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