International Symposium on Microalloyed Steels for the Oil and Gas Industry
Edited by W.J. Fazackerley, P. Bordignon, K. Hulka, and F. Siciliano
TMS (The Minerals, Metals & Materials Society), 2007

THE DEVELOPMENT AND APPLICATION

OF X80 LINE PIPE STEEL AND PIPES IN CHINA

Jun-hua Kong[1], Lei Zheng[2], Guo-jian Huang[3], Lin Zheng[1], Xiao-jun Ding[4], Xiao-xiang Wang[5], Yao-rong Feng[6],

[1] Wuhan Iron and Steel (Group) Company, Wuhan, Hubei, 430080, China
[2] Baoshan Iron and Steel Group Co. Ltd., Shanghai, 201900, China
[3] Anshan Iron and Steel Group Company, Anshan, Liaoning, 114021,China
[4] Baoji Pipe Company, Baoji, Shanxi, 721008, China
[5] Huabei Pipe Company, Qingxian, Hebei, 062650, China
[6] Tubular Goods Research Center of CNPC, Xian, Shanxi,China

Key Words:Pipeline Steel, X80, linepipe, SSAW, LSAW, application.

Abstract

Recently, the demand for and transportation of natural gas have been developing rapidly in China, and cost reduction of long distance transportation becomes more and more important. For these challenges, X80 high strength linepipes have been researched and developed in China. Wuhan Iron & Steel (Group) Company (WISCO) and Baoshan Iron & Steel Co. Ltd. (BAOSTEEL) have researched and developed X80 pipeline steel coil, and Anshan Iron & Steel Group Company (ANSTEEL) has researched and developed X80 pipeline steel plate. In cooperation with CNPC, the X80 coils 15.3mm thick were made into SSAW pipes with outside diameter of 1016mm by Baoji Pipe Company and Huayou Pipe Company, and the X80 plates 18.4mm thick were made to LSAW pipes with outside diameter of 1016mm by Julong Pipe Company. The steel and the pipes have been evaluated by the Tubular Goods Research Center of CNPC. The results show that X80 pipeline steel developed in China has high strength, high toughness, good weldability, and excellent HIC-resistance and SSC resistance, fully meeting the requirements of API SPEC 5L Grade X-80 and the specification for the X80 Linepipe Application Project of China. The X80 linepipes have been laid in the first Chinese X80 Gas Pipeline Application Project which is 8 km long in 2005..It has been demonstrated that X80 grade linepipe skelp and pipe can be commercially produced and the market is going to mature in China.

Introduction

In view of the production and consumption structure of the Chinese oil and gas industry, and stratagy for developing the Western China, long distance, large diameter, high pressure and corrosion resistant products are necessary attributes of pipelines for oil and gas. From 1995 when X60 was first used in the Shan-Jing Project until the construction of the X70 trial part of the Se-Ning-Lan Project in 2000, pipeline steel strength had increased rapidly from X60 to X70 in our country. Higher requirements have been specified for strength and other properties of the pipeline steel. First of all, the steel grade has been enhanced in order to reduce the construction cost. In recent years, X70 has been the dominant grade for pipeline projects in the world, while X80 began to be volume-applied in projects[1] and X100 is being developed and on trial. Second, the toughness needs to be increased simultaneously with the strength. Furthermore, HIC (hydrogen induced cracking) resistance needs to be improved because the partial pressure of H_2S will increase as the steel grade and the transporting pressure are enhanced[2].

X80 strip with thickness of 17.5mm and 15.3mm as well as plates with thickness of 18.4mm have been developed successfully in China. The pipes have been installed without event in the 8 km “Ji-Ning Pipeline Project ” which belongs to “West to East Pipeline Project ” in March, 2005.

Development and Production Of X80 Strip and Plate for Pipeline Steel in China

Mechanical Property Requirements for X80 Steel Strip and Plate

Table 2.1. Requirements of tensile and hardness tests for X80 steel

Type	Sampling direction	Tensile Test				Hardness Test
		$R_{t0.5}$/MPa	R_m/MPa	A/%	$R_{t0.5}/R_m$	
Strip	30^0	580-690	≥625	API 5L	≤0.92	≤275HV_{10}
Plate	Transverse	560-670	≥625	API 5L	≤0.92	

Note: The requirement for yield strength has considered Bauschinger Effect after manufacturing pipes. The steel suppliers must also assure the yield strength of the pipes no less than 555 MPa.

Table 2.2 Toughness requirements for X80 steel

Type	Sampling direction	Charpy Impact Test at –20°C				Drop Weight Tear Test at –15°C	
		Impact Energy/J		Shear Area/%		Shear Area/%	
		Single	Average	Single	Average	Single	Average
Strip	30^0	≥170	≥220	≥80	≥90	≥70	≥85
Plate	Transverse	≥170	≥220	≥80	≥90	≥70	≥85

Chemical Composition of X80 Pipeline Steels

In order to get high strength, high toughness, and good weldability, the chemical composition of X80 linepipe is based on low carbon, high manganese, high niobium and appropriate alloys such as copper, nickel and molybdenum. Higher contents of niobium are needed for strip versus plate because of the high speed of the continuous hot strip-rolling process. Molybdenum in the range 0.20 – 0.40 percent is also added to the steel to retard the formation of primary ferrite and pearlite in skelp with large thicknesses or to compensate for an insufficient cooling rate. The research results[3] indicate that the bainite transformation temperatures(Bs, Bf) are reduced by adding 0.40wt. percent molybdenum to X80 steel, and the microstructure of bainite becomes finer. Deformed austenite transforms to a finer bainite microstructure even if the continuous cooling rate is not high. The continuous transformation curve of X80 steel is shown in Figure 2.1.

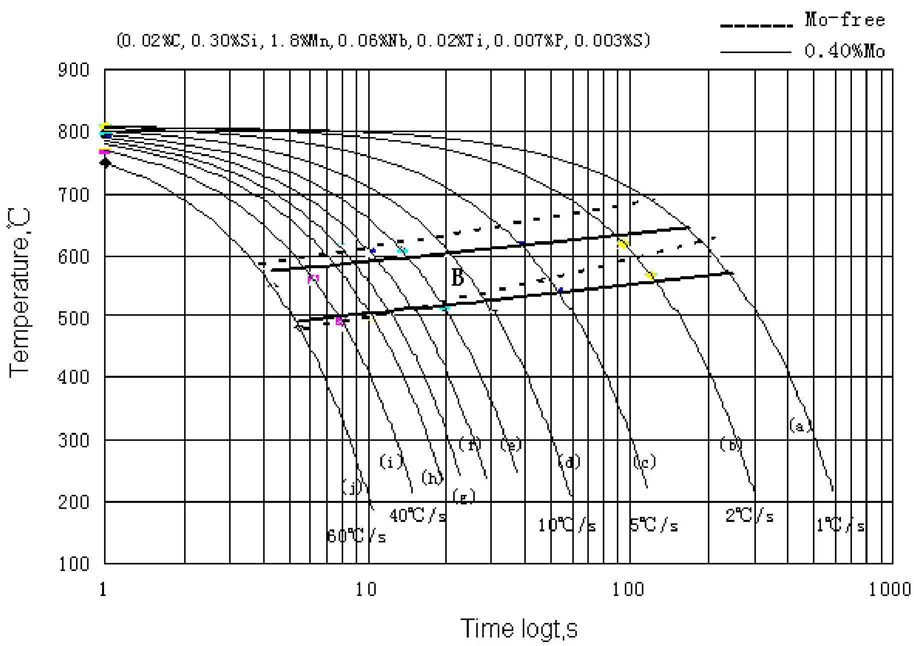

Fig.2.1 Continuous cooling curves for steels with 0.40%Mo and Mo-free

Chemical compositions of X80 strip and plate are listed in Table 2.3. The low Pcm (Parameter for Crack, Modified) values are good for weldability of X80 steel.

Table 2.3 Chemical compositions of X80 strip and plate in China wt percent

Type	wt.%(C)	wt.%(Si)	wt.%(Mn)	wt.%(P)	wt.%(S)	wt.%(Nb)	wt.%(V)	wt.%(Ti)	wt.%(Fe)	Pcm*
Strip	0.05	0.28	1.85	0.012	0.001	0.07	/	0.012	Balence	0.19
Plate	0.04	0.27	1.70	0.010	0.001	0.05	0.04	0.02	Balence	0.17

Note: (1)Alloys such as Mo, Cu, Ni are added to the steels.

(2)*Pcm=C+Si/30+(Mn+Cu+Cr)/20+Ni/60+Mo/15+V/10+5B

Production Processing of X80 Hot-rolled Strip

Steel-making Process: (1) By applying clean steel production technology, harmful elements such as sulfur and arsenic etc. have been well controlled and restricted in the molten iron. Through degassing and refining of the molten steel, sulfur can be controlled below 0.002wt percent and phosphorus below 0.015wt percent, nitrogen below 0.006wt percent. Inclusion shape also has been well controlled through calcium treatment; (2) Soft reduction has been used before solidification so as to improve the homogeneity of the composition and microstructure.

Hot-rolling Process: Through proper TMCP high strength and toughness can be obtained. First, the reheating temperature was controlled sufficiently low to avoid austenite grain coarsening, but not too low to reduce solute micro-alloy element solubility. Second, in the first rolling stage, it was important to ensure all rolling steps were finished above the austenite re-crystallization temperature. For the high content of niobium in X80 steel, the austenite re-crystallization temperature is above 950°C. Third, during finish rolling, control of total reduction and finishing temperature is essential to produce the required mechanical properties. For lower finishing temperatures higher yield strength and toughness could be achieved because of the higher density of dislocations remaining, this led to more nucleating positions for acicular ferrite. Last, accelerated cooling after finish rolling was applied to the strip to restrict the formation of primary ferrite. Through the control of coiling temperature, acicular ferrite was formed while coiling.

Mechanical Properties of 15.3mm X80 Strip

Tensile Test Results: As listed in Table 2.4, the difference of yield strength on uncoiled strip was about 70MPa between longitudinal and transverse samples. The transverse yield strength and yield ratio were highest amongst the three directions investigated.

Table 2.4 Tensile test results of X80 strip in three directions

Sampling direction	$R_{t0.5}$/MPa	R_m/MPa	A_{50}/%	$R_{t0.5}$/ R_m
Longitudinal	585	695	38.0	0.84
	570	700	38.0	0.81
30^0	600	705	42.0	0.85
	610	710	41.0	0.86
Transverse	650	740	37.0	0.88
	650	740	37.5	0.88

Note: The mechanical properties were obtained on uncoiled plate in the middle part of the strip.

Charpy Test Results at Various Temperatures: As it is shown in Figure 2.2, impact energy decreased rapidly when the test temperature was reduced to –100°C. ETT_{50}(Energy Transition Temperature) of three directions were around –100°C.

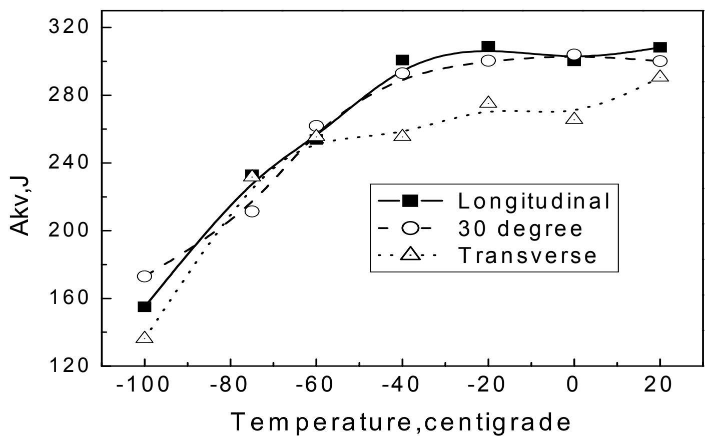

Fig. 2.2 Impact energy of X80 strip tested at various temperatures

Drop Weight Tear Test (DWTT) Results at Various Temperatures: The longitudinal fracture appearance transition temperature based on 85 percent shear area of DWTT was lowest in three directions as shown in Table 2.5. The results show that X80 strip has excellent fracture toughness at low temperature and in suitable for manufacture of large diameter gas transmission pipeline.

Table 2.5 DWTT results of X80 strip at various temperatures

Temp/□	Longitudinal,SA%			30^0, SA%			Transverse, SA%		
	Single		Average	Single		Average	Single		Average
20	100	100	100	100	100	100	100	100	100
0	100	100	100	95	97	96	99	97	98
-15	100	100	100	92	95	93.5	98	89	93.5
-30	98	98	98	98	95	96.5	59	64	61.5
-40	97	96	96.5	83	73	78	50	37	43.5
FATT85	<-40°C			-36°C			-19°C		

Mechanical Properties of 18.4mm X80 Plate

Tensile Test Result. The results shown in Table 2.6 indicated that X80 plate had a suitable margin of strength compared with the requirement.

Table 2.6 Tensile test results of X80 plate

Sampling direction	$R_{t0.5}$/MPa	R_m/MPa	A_{50}/%	$R_{t0.5}$/ Rm
Transverse	624	686	39.8	0.91
	617	685	38.8	0.90
Longitudinal	602	700	39.0	0.86
	604	672	39.0	0.90

Charpy Test Results at Various Temperatures: As is shown in Table 2.7, impact energy did not decrease when test temperature was reduced to –60°C. ETT_{50} of transverse and longitudinal directions were below –60°C.

Table 2.7 Absorbed energy of X80 plate tested at various temperatures

Test Temp/°C	Absorbed energy,J	
	Transverse	Longitudinal
20	313	303
0	333	320
-20	348	315
-40	322	313
-60	302	317
ETT_{50}	<-60°C	<-60°C

Drop Weight Tear Test (DWTT) Results at Various Temperatures. The FATT 85 percent shear in the longitudinal direction was lower than that of transverse direction as shown in Table 2.8.

Table 2.8 DWTT results of X80 plate at various temperatures

Temp/°C	Transverse, SA%			Longitudinal, SA%		
	Single		Average	Single		Average
20	100	100	100	100	100	100
0	100	91	96	100	100	100
-5	95	95	95	100	100	100
-15	90	90	90	100	100	100
-40	60	60	60	90	85	88
-50	64	19	42	54	73	64
-60	10	10	10	5	5	5
FATT85	-19°C			-40°C		

Microstructures of X80 Pipeline Steel

Optical and TEM Observations of X80 Strip: From Figure 2.3(a) it can be seen, that the microstructure of X80 steel was mainly acicular ferrite with some fine M-A islands dispersed on the matrix. These islands were helpful to improve the strength without deteriorating the toughness because they were of fine size and distributed uniformly. Fig 2.3(b) and (c) show the sub-structure and dislocation arrays in acicular ferrite, so the effective grain size was very small.

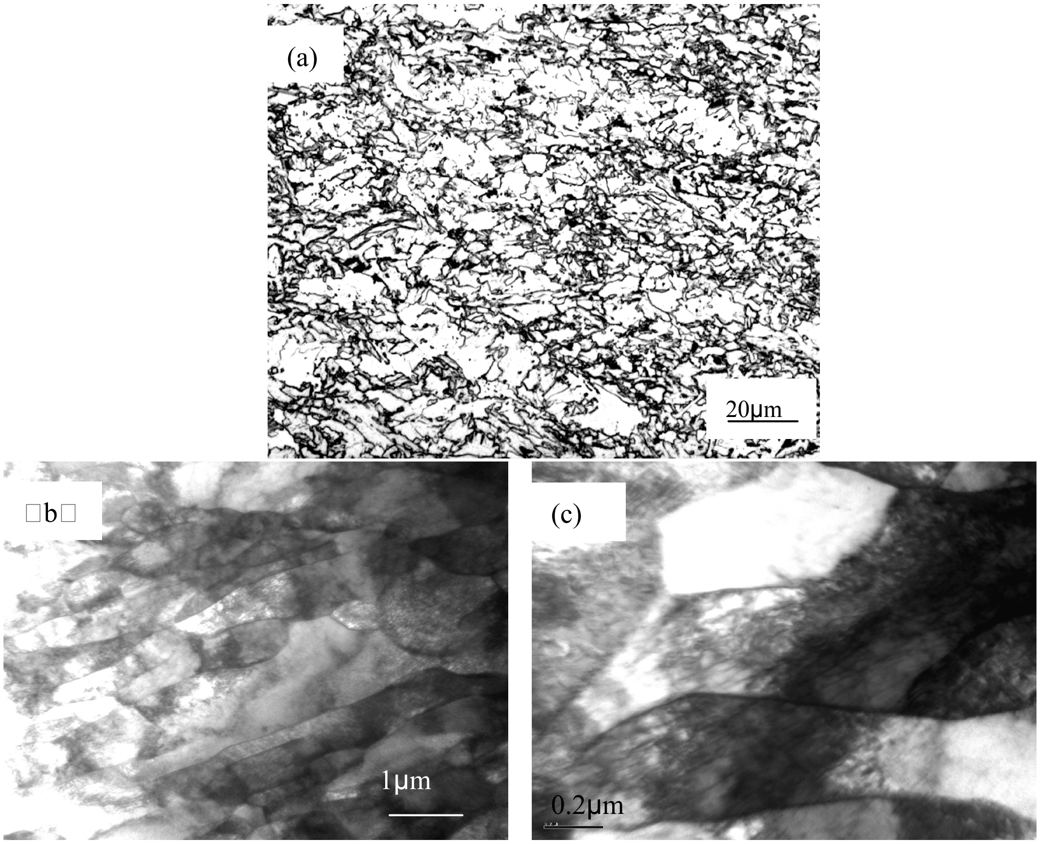

Figure 2.3 Microstructures of X80 strip (a)Optical micrograph of X80 strip; (b)TEM photomicrograph of acicular ferrite; (c) The TEM photomicrograph shows dislocations of high density

Effect of Exit Temperature of Roughing (RT_2) on Microstructure of X80 Strip: In Figure 2.4 the microstructures of two steels experiencing different exit temperatures of roughing are compared. There is an obvious difference in the two microstructures. In Fig 2.4(a) polygonal ferrite and quasi-polygonal ferrite can be seen which has irregular grain boundaries with uneven grain size. This was caused by mixed austenite grain sizes. Homogeneous acicular ferrite microstructure can be seen in Fig 2.4(b). Higher strength and toughness was reached through the microstructure of Figure 2.4(b).

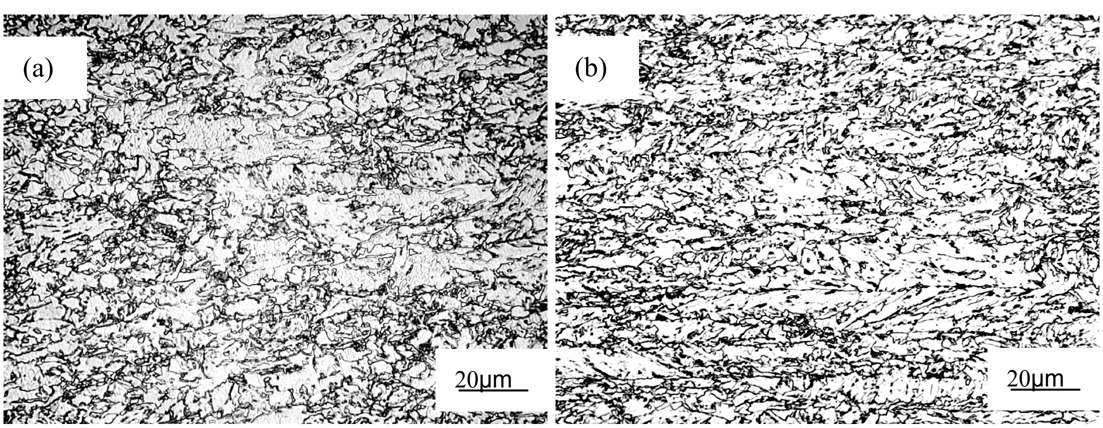

Fig 2.4 Microstructures of X80 steels: (a) RT_2=950°C; (b) RT_2=980°C

Effect of Finish Rolling and Coiling Temperatures on Microstructure of X80 Strip: Figure 2.5 compares the difference of microstructures of the steels fabricated by the two processing regimes[4].

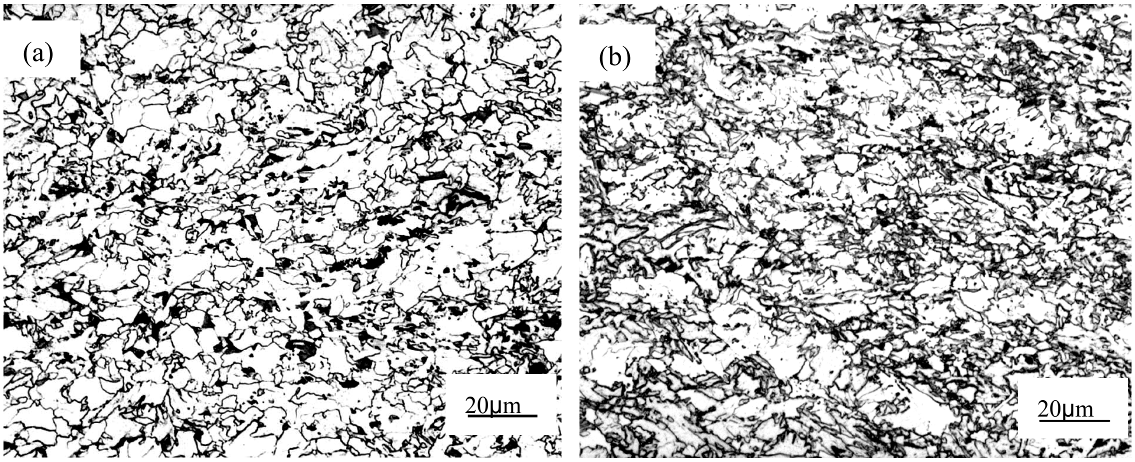

Figure 2.5 Optical and SEM images of two kinds of processes:
(a): Finish rolling temp. 850°C, coiling temp. 590°C;
(b): Finish rolling temp. 800°C, coiling temp. 540°C

When rolling was finished at higher temperature, the final microstructure was much coarser, with large M-A island forming while cooling. This coarse island structure is found to reduce fracture toughness remarkably. If the strip is subsequently coiled at relative high temperature a smaller portion of acicular ferrite forms. In Figure 2.5a the microstructure consisted of acicular ferrite, polygonal ferrite, coarse island phases and scattered pearlite. The microstructure in Figure 2.5b was mainly acicular ferrite with fine dispersed island phases.

Development And Application Of X80 Line Pipes In China

Electric Resistance Welded (ERW) pipe was first developed in 2000 in China [5], later SSAW pipe having a diameter of 1016mm and thickness of 17.5mm was adopted using WISCO strip. Additionally for the "Ji-Ning Pipeline Project", Φ1016mm X80 SSAW with a thickness of 15.3mm and LSAW pipes with thickness of 18.4mm were produced in Baoji, Huabei and Julong Pipe Companies.

3.1 Requirements for SSAW and LSAW X80 Pipes

Requirements for SSAW and LSAW X80 pipes are shown in Tables 3.1 and 3.2.

Table 3.1 Requirements for tensile tests, and DWTT for SSAW and LSAW X80 pipes

Sampling direction	Tensile Test				DWTT at –5°C		Hardness Test
	$R_{t0.5}$/ MPa	R_m/ MPa	A/ %	$R_{t0.5}$/ R_m	Shear Area/%		HV_{10}
					Single	Average	
Transverse	555-690	≥625	≥21	≤0.92	≥80	≥90	≤275

Table 3.2 Impact Test Requirements for SSAW and LSAW X80 pipes

Charpy Impact Test at –20°C							
Transverse body				Weld center and HAZ			
Impact Energy/J		Shear Area/%		Impact Energy/J		Shear Area/%	
Single	Average	Single	Average	Single	Average	Single	Average
≥150	≥200	≥80	≥90	≥60	≥90	≥30	≥40

<u>3.2 Development for 1016 mm diameter SSAW X80 Line Pipes with Wall Thickness of 15.3mm</u>

Coil inspection and tests including surface quality, chemical composition and mechanical properties were carried out before pipe production. Coils were proven to be qualified to fabricate SSAW pipes.

<u>Mechanical Properties of SSAW X80 Line Pipes.</u> Statistic data for mechanical test results for the pipes made by Baoji Pipe Company using strips from WISCO are shown in Table 3.3 and Figure 3.1, 3.2, 3.3.

Table 3.3 Statistical data for tensile tests of X80 SSAW pipes

Frequency	Item	Sampling position	$R_{t0.5}$/MPa	R_m/MPa	A_{50}/%	$R_{t0.5}$/ R_m
N=32	Minimum	Transverse of the pipe body	565	698	31.5	0.82
		Weld metal	-	736	-	-
	Maximum	Transverse of the pipe body	655	764	37.8	0.91
		Weld metal	-	790	-	-
	Average	Transverse of the pipe body	619	732	35.1	0.85
		Weld metal	-	766	-	-

Figures 3.1, 3.2, 3.3 show statistical results for Charpy impact energy (Test Temperature: –20^{0}C).

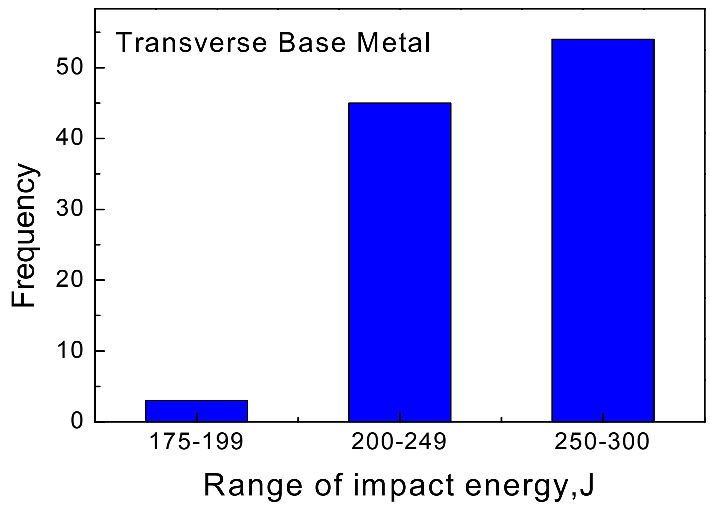

Figure 3.1 Histogram of impact energies for base metal (transverse)

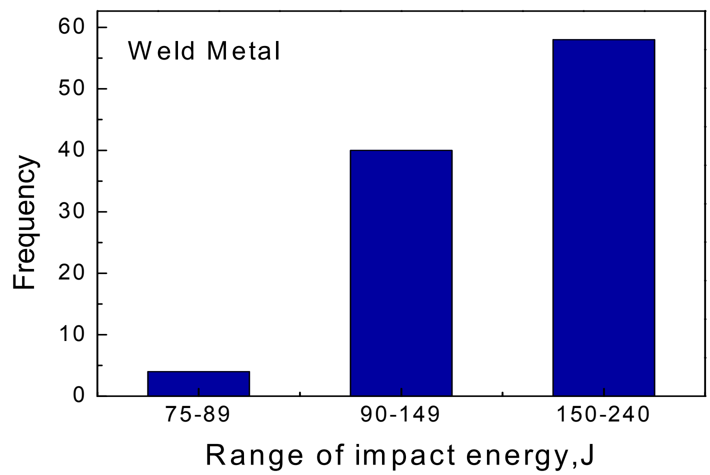

Figure 3.2 Histogram of impact energies of weld metal

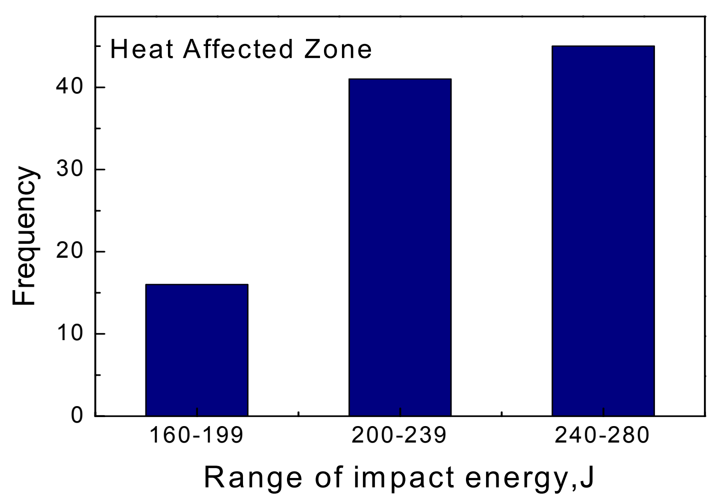

Figure 3.3 Histogram of impact energies of HAZ

Charpy impact results at various temperatures are shown as Figures 3.4, 3.5 and DWTT in Figure 3.6. The FATT85 $_{(DWTT)}$ of transverse pipe body is –28°C. The results show that X80 SSAW pipe has excellent fracture toughness at the required design temperature.

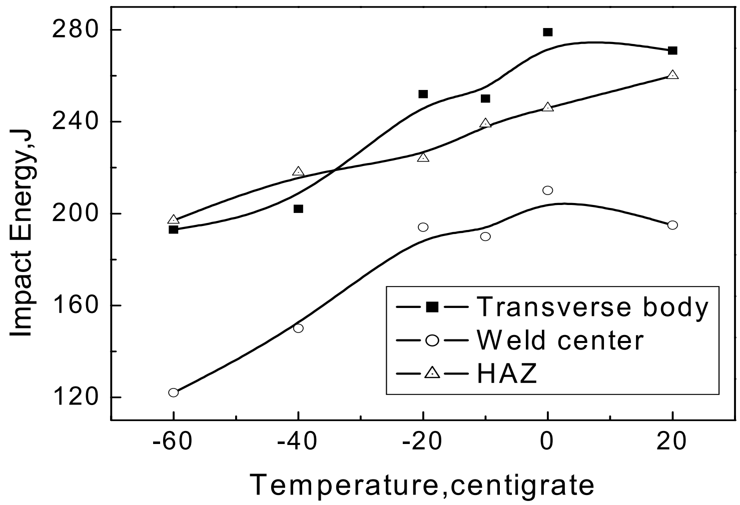

Figure 3.4 Curve of Charpy Impact Energy vs. Temperature

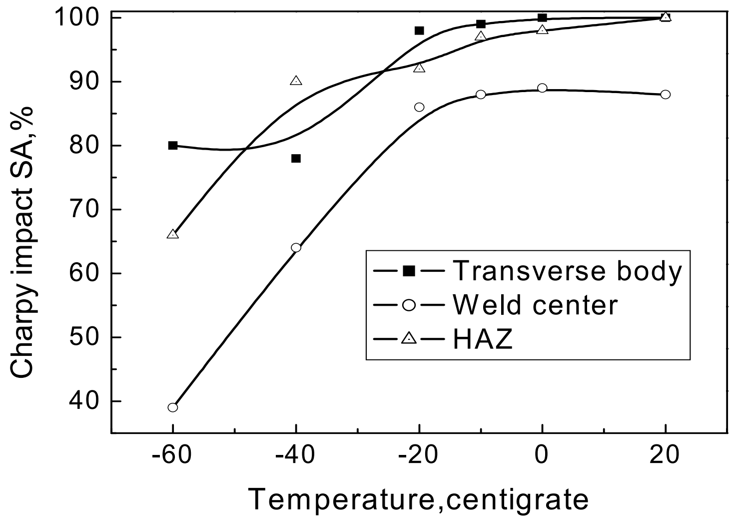

Figure 3.5 Curve of Charpy Shear Area vs. Temperature

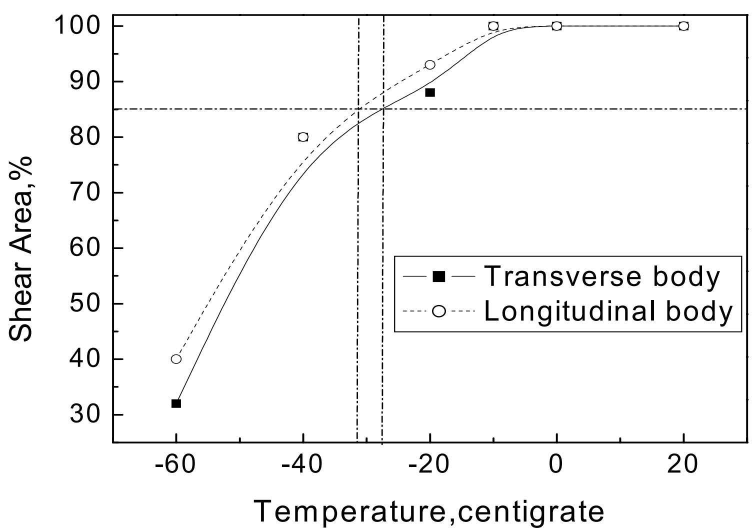

Figure 3.6 Shear Area vs. Temperature of DWTT

Bauschinger Effects. X80 SSAW pipes were tested in different positions of the strip. By sampling the 30 degree angle of the strip and the transverse direction in the corresponding pipe, yield strength could be compared. The following table shows that Bauschinger effects were not large.

Table 3.4 Difference of yield strength of X80 SSAW pipes compared with strip

	Sampling position and direction	Tail of the coil	Middle of the coil	Head of the coil
$R_{t0.5}$, MPa	30^0 of the strip	584 585 599	585 595 591	605 597 609
	Transverse of the pipe body	589 587 593	585 601 597	594 598 590
$\Delta R_{t0.5}$, MPa		-12~+9	-10~+16	-19~+1

Cold Bend Test and Hardness Test: Results of the cold bend test are shown in Table 3.5.

Table 3.5 Cold Bend Test

Bend direction	Mandrel/mm	Bend Angle/°	Result
Face	Φ90	180	No Crack
Root	Φ90	180	No Crack

The test position for a section of welded joint is shown in Figure 3.7. The maximum hardness did not exceed the 275Hv$_{10}$ requirement as shown in Table 3.6.

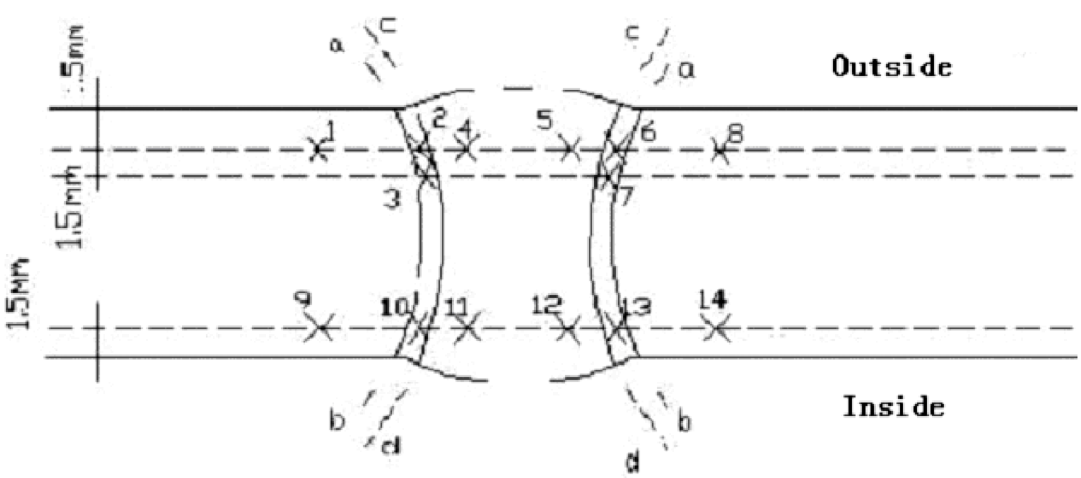

Figure 3.7 Locations of hardness tests

Note1□ab——Margin of HAZ and unheated base

Note2□cd——Margin of HAZ and welded metal

Table 3.6 Hardness Test Results

Pipe No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
300552	243	222	235	216	233	221	219	238	251	232	253	253	232	245
300557	260	218	219	237	233	219	218	251	249	232	262	254	227	260

Hydraulic Test. A hydrostatic test was performed on each pipe using a test pressure 95 percent SMYS (15.8MPa) and time 20 seconds. Following is an example of the recorded pressure curve.

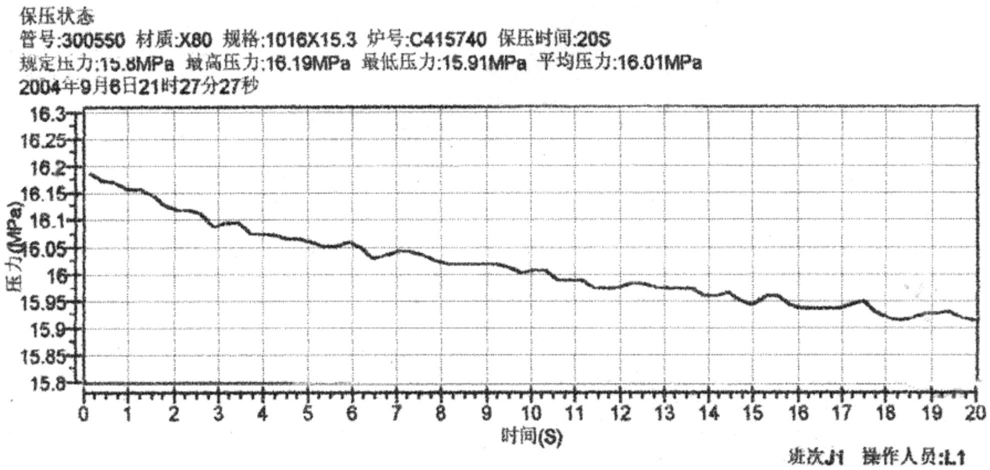

Figure 3.8 Pressure Curve for Hydrostatic Test

Hydraulic Burst Test. Test pressure: Ps=20.23MPa, P_b=22.56MPa, P_k=20.95MPa(actual burst pressure). Corresponding strength of pipe: σs=672MPa, σ_b=749MPa, σ_k=696MPa.

The circumferential elongation is shown as Table 3.7. The appearance of a burst X80 pipe is shown in Figure 3.9. The burst started from the body of the pipe and the appearance of fracture was 100 percent ductile.

Table 3.7 Circumferential length of burst pipe (mm)

Locations	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000	11000
Original	3195	3195	3195	3196	3196	3196	3196	3196	3196	3196	3196
Burst	3373	3607	3704	3425	3411	3390	3362	3350	3338	3331	3278
Elongation	5.57	12.90	15.93	7.17	6.73	6.07	5.19	4.82	4.44	4.22	2.57

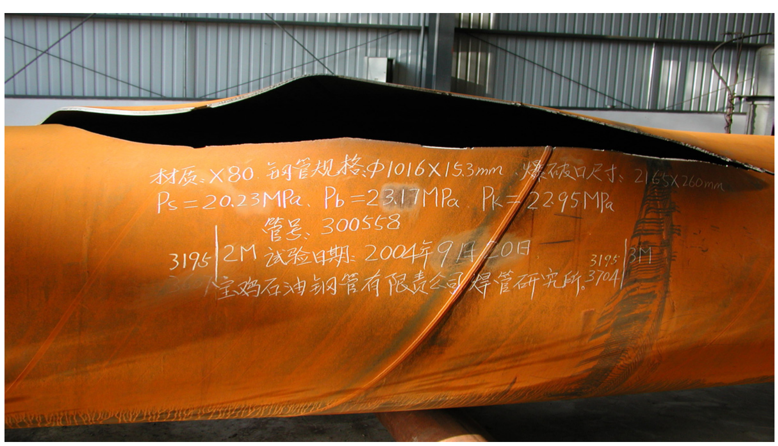

Figure 3.9 Burst Pipe

<u>Hydrogen Induced Cracking (HIC) and Sulfide Stress Cracking (SSC) Resistance of SSAW X80 Pipe:</u> 1016mm diameter SSAW pipe with a wall thickness of 17.5mm was tested for HIC resistance according to the specification of NACE TM 0177-90 and SSC resistance according to NACE TM 0177-96, Solution B (aqueous solution composed of 5%NaCl, 0.23% glacial acetic, and 0.4% sodium acetate (PH =3.4~3.6) with saturated hydrogen sulfide gas).

Table 3.8 HIC test results for SSAW X80 pipe

Sampling position	Specimen No.	CLR/%	CTR/%	CSR/%
Base metal	11	0	0	0
	21	0	0	0
	31	0	0	0
	Average	0	0	0
Weld metal	12	0	0	0
	22	0	0	0
	32	0	0	0
	Average	0	0	0

The HIC test results show that the base and weld metal of X80 pipe have excellent resistance. The sulfide stress cracking tests(SSC) results for the transverse pipe body and welded joint in the NACE TM 0177-96 Solution B show that the threshold stress of the base metal and weld metal both exceed 90 percent of yield strength.

Table 3.9 Constant load tension test results for a welded joint of SSAW X80 pipe

Specimen No.	Diameter/mm	Stress Level	Test time/h	Crack or not
1	4.88	$0.60R_{t0.5}$	720	No crack
2	4.98	$0.72R_{t0.5}$	720	No crack
3	4.98	$0.80R_{t0.5}$	720	No crack
4	4.98	$0.80R_{t0.5}$	720	No crack
5	4.95	$0.90R_{t0.5}$	720	No crack
6	5.00	$0.90R_{t0.5}$	720	No crack

Table 3.10 Constant load tension test results for the body of SSAW X80 pipe

Specimen No.	Diameter/mm	Stress Level	Test time/h	Crack or not
6	4.93	$0.50R_{t0.5}$	720	No crack
7	4.95	$0.60R_{t0.5}$	720	No crack
8	4.94	$0.72R_{t0.5}$	720	No crack
9	4.98	$0.72R_{t0,5}$	720	No crack
10	4.85	$0.80R_{t0,5}$	720	No crack
11	4.95	$0.80R_{t0.5}$	720	No crack
12	4.97	$0.90R_{t0.5}$	720	No crack
13	4.87	$0.90R_{t0.5}$	720	No crack

3.3 Development of 1016mm diameter 18.4mm LSAW X80 line pipes

Mechanical Properties of LSAW X80 Line Pipes [6]. The results are shown in Tables 3.11, 3.12 and Figure 3.10.

Table 3.11 Statistical data for X80 LSAW pipes

Items	Tensile Test					Hardness
	Pipe Body				Weld Metal	HV_{10}
	$R_{t0.5}$/Mpa	R_m/Mpa	$R_{t0.5}$/ R_m	A/%	R_m /Mpa	
Max.	625	700	0.89	42	725	251
Min.	575	675	0.83	34	690	201
Average	598	691	0.86	39	707	222
Requirement	555~690	≥625	≤0.92	≥21	≥625	≤275

Table 3.12 Statistical data for X80 LSAW pipes (continuous)

Items	Charpy Impact Test						DWTT
	Impact Energy/J			SA / %			SA/%
	Body	Weld Center	HAZ	Body	Weld Center	HAZ	
Max.	310	200	300	100	80	95	100
Min.	280	145	240	85	60	80	88
Average	298	181	274	98	73	86	96
Requirement	Single≥150 Ave.≥200	Single≥60 Ave.≥90		Single≥80 Ave.≥90	Single≥30 Ave.≥40		Single≥70 Ave.≥85

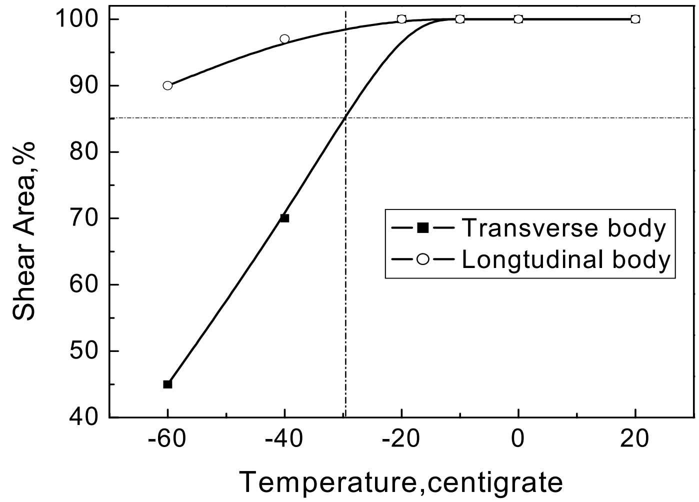

Figure 3.10 Shear area of DWTT vs. temperature

Cold Bend and Hardness Tests. The results conformed completely with the requirements of the specification.

A Hydrostatic Burst Test was carried out. It was determined that the measured values were greater than the calculated values. The fracture initiation and arrest locations were 200mm from the weld seam.

3.4 Application of 1016mm diameter SSAW and LSAW line pipes

Pipe of 1016mm diameter (SSAW and LSAW X80) were first installed as a trial part of the "Ji-Ning Pipeline Project " in March, 2005 in Hebei province of China. Wuhan, Baoshan, Anshan Iron and Steel Group Companies supplied X80 steel coils and plates for the project, and Baoji, Huabei, Julong Pipe Companies made the pipes. The entire trial length totalled 8 km comprising nearly 6 km of SSAW X80 pipes and 2 km of LSAW X80 pipes. Figure 3.11 illustrates the X80 line pipes being laid in the project.

Figure 3.11 1016mm diameter X80 line pipes being laid in the Ji-Ning pipeline project

Conclusions

(1) High strength, high toughness, good weldability, good HIC and SSC resistance for grade X80 linepipe were obtained through appropriate alloying and proper TMCP processing.

(2) The FATT $85_{(DWTT)}$ for 30 degree angle of the X80 strip and the transverse SSAW pipe body were –36°C and –28°C respectively. The results showed that X80 strip and pipe had excellent fracture toughness at low temperature suitable for use in large diameter, high pressure gas transmission pipelines.

(3) The properties of 1016mm diameter SSAW and LSAW X80 grade line pipes fully complied with the specifications for X80 gas transmission line pipe of CNPC. Bauschinger effects of the X80 SSAW pipes to strip were negligible.

(4) Construction of the first X80 pipeline trial project demonstrated that Grade X80 steel and pipes can be mass produced and are to mature in China.

Acknowledgements

The present work was financially supported by the China National “ten-fifth” project. The authors are grateful to Dr. Zhou Guifeng, Mr. Guo Bin, Mr. Liu Changming, Mr. Liu Xiaoguo’s cooperation with the experiments. The authors also appreciate the support of China National Petroleum Corporation.

References

1 Yutaka Nagahama, Sadahiro Yamamoto. High Performance Steel Pipes and Tubes Securing and Exploiting the Future Demands. NKK Technical Review. 2003(88): 81-87

2 Yin Chengxian, Lan Xinzhe, Huo Chunyong, etc, Discussion on affecting factors of pipeline HIC resistance for oil and gas transmission. Welded Pipe and Tube, 25(5)(2002): 20-24

3 Junhua Kong, Changsheng Xie. Effect of Molybdenum on Continuous Cooling Bainite Transformation of Low-carbon Microalloyed Steel. Materials and Design, available online

4 J.H. Kong, L. Zhen, C.S. Xie. Development and Production of X80 Hot-rolled Thick Steel Strips in WISCO. In: W. Chen, Pipelines for 21st Century. Calgary, Canada, 2005:57-67

5 Ding Xiaojun: “Development of Grade X80 Welded Pipes for Oil and Gas Transmission in China”, WELED PIPE AND TUBE, 28(2) (2005):29-35

6 Li Yanfeng: “Manufacture of Φ1016mm×18.4mm Grade X80 LSAW Pipes”, Welded Pipe and Tube, 28(4)(2005).