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PIPE BENDING TEST WITH GIRTH WELDING ON X80 GRADE SAW PIPES

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ABSTRACT
This study was planned as a part of a test program to confirm the effect of girth welds on the strain capacity of pipes. In this study, full-scale pipe bending tests are performed by using X80 SAW pipe.

This paper covers pipe manufacturing procedure, developed welding procedure to obtain even match weld metal and properties of welded joints. And this work demonstrated that the X80 pipes welded under the developed procedure fractured in base metal remote from girth welded portion by full scale pipe bending test conducted under the internal pressure of 72 % SMYS of X80.

INTRODUCTION
Oil and gas exploration from extreme region such as remote areas, arctic areas and so on will increase due to extensive needs for oil and gas resources. High strength steel pipe (X80 and over) for gas transmission pipelines has been developed to reduce the gas transportation by high-pressure operation. To maximize economic advantages, the use of high strength steels in pipeline systems has been investigated. X80, X100 and X120 grade steels have been developed and utilized for gas pipelines [1-4]. Welding of these high strength pipes posed challenges because of their sensitivity to variations of welding conditions. Thus several kinds of investigations have been conducted to characterize the properties of X80 and X100 welds under specific conditions [5-7].

On the other hand necessity of strain based design in pipeline systems is discussed more seriously with spreading applications of a higher strength pipes. Many factors such as D/t, type of yielding behavior (shapes of stress-strain curve), Y/T ratio, geometrical imperfections (ovality and misalignment), HAZ softening, weld strength matching and material anisotropy are concerned and studied as the potential factors on strain capacity in terms of tensile and compression (bending) strain along the longitudinal direction of pipes [8-15].

This study was planed as a part of a test program to confirm the effect of girth welds on the strain capacity. In this study, full-scale pipe bending tests are performed by using X80 SAW pipe. And the first welding procedure to simulate the field girth welding was developed. The developed welding procedure was aimed to produce even-matched welding joint. This paper covers pipe and joint properties, developed welding procedure and results of full scale pipe bending test with girth welded portion. And the analysis of full scale test based on FEA modeling was described in the paper of IPC2010-31408.

PRODUCTION OF X80 UOE PIPE

X80 UOE pipe with outside diameter of 610 mm (24”) and wall thickness of 15.6 mm was produced at UOE pipe mill in Kashima steel works of Sumitomo Metals. The pipe size was determined under a limitation of pipe bending test facility. The steel was melted and refined in a 250 tonne converter ladle furnace, vacuum degassed, and then continuously cast to 250 mm thick slabs. Table 1 provided general compositional information. The steel is low carbon and is alloyed with Mn-Cu-Ni-Cr-Mo-Nb-V-Ti. The resulting Pcm is 0.18 mass%. During TMCP, the steels were strictly controlled rolled and accelerated cooled. In this production low cooling finishing temperature less than 200 deg. C was selected to obtain low yield/ tensile ratio. The manufacturing conditions applied to this production were listed in table 2. The pipes were formed by the UOE process and welded using one-pass submerged-arc welding on each side

Table 1 Chemical composition of the steel (mass %)

C	Si	Mn	P	S
0.06	0.14	1.72	0.006	0.0012
Others			Ceq(IIW)	Pcm
Cu, Ni, Cr, Mo, Nb, V, Ti			0.43	0.18

Table 2 Plate rolling conditions (Aimed conditions)

Slab reheating temp.	1120 deg.C
Rolling finish temp.	720 deg. C
ACC start temp.	660 deg.C
ACC finish temp.	< 200 deg.C

TENSILE AND CHARPY PROPERTIES OF THE PIPE

Tensile properties in circumferential (C) direction of the pipe were measured by using round bar specimen. Specimens were sampled 30 degree pitch in C-direction. The zero degree position means seam welded portion. The specimen size was diameter of 6.0 mm and gage length of 25 mm. Measured yield and tensile strength were shown in Fig. 1. The minimum yield strength was 641 MPa and the maximum value was 665 MPa. The minimum tensile strength was 743 MPa and the maximum value was 761 MPa. The yield/ tensile ratio(Y/T ratio) were distributed from 0.86 to 0.90. Yield and tensile strength were also measured by using API strip specimen sampled from 90 degree position. Yield and tensile strength by strip specimen were 639 and 787 MPa. The Y/T ratio of 0.81 measured by strip specimen was lower than that by round bar specimen because of Bauschinger effect during specimen flattening.

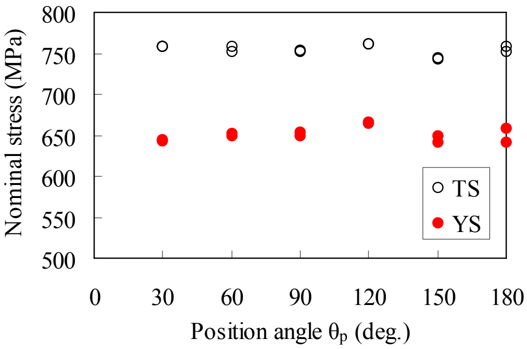

Fig. 1 Yield and tensile strength in C-direction

Tensile properties in longitudinal (L) direction of the pipe were measured by using round bar specimen. Specimens were sampled 15 degree pitch in C-direction for L-direction tensile test. The specimen size was diameter of 8.9 mm and gage length of 50 mm. Measured yield and tensile strength were shown in Fig. 2. The minimum yield strength was 541 MPa and the maximum value was 576 MPa. The minimum tensile strength was 717 MPa and the maximum value was 741 MPa. The Y/T ratio was distributed from 0.74 to 0.79.

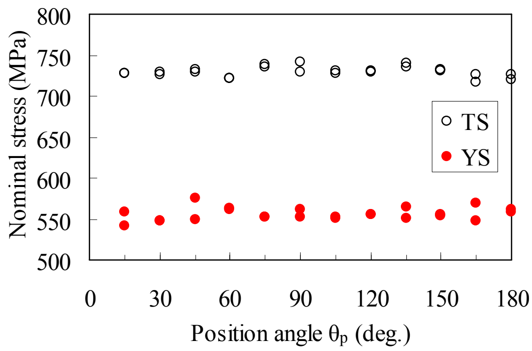

Fig. 2 Yield and tensile strength in L-direction

Typical stress-strain charts were shown in Fig. 3. Stress-strain curves have round house type shape in both in C and L direction.

Charpy impact tests were conducted in both C and L directions. The specimens were sampled at mid wall thickness. The results were shown in Fig. 4. In the results for L-direction, the Charpy energy more than 200 J was obtained at -90 deg. C or higher. The Charpy energy for C-direction was lower than that for L-direction. For the C-direction, Charpy energy more than 200 J could obtain at -30 deg. C or higher.

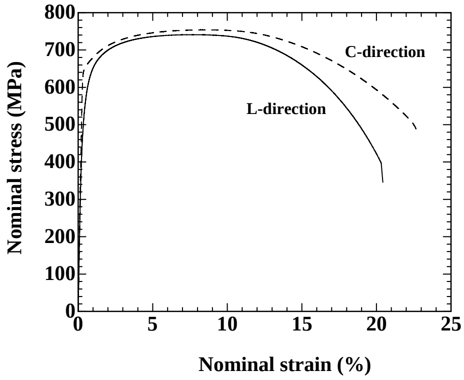

Fig. 3 Examples of stress-strain curve

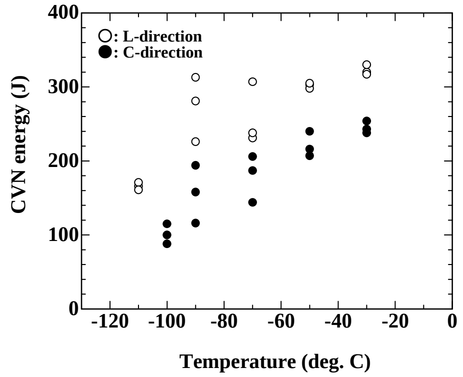

Fig. 4 Charpy impact test results in base metal.

GIRTH WELDING PROCEDURE

Narrow gap and mechanized GMAW process was selected to simulate field girth welding in this study. The pipe ends were prepared by machining with a bevel angle of 5 deg., a hot pass bevel angle of 45 deg. and an offset distance of 2.8mm. A root pass bevel angle was 37.5 deg.. The root pass bevel depth was 1.0 mm and a root face was 1.3 mm. A schematic diagram of the bevel preparation and pass sequence are shown in Fig. 5.

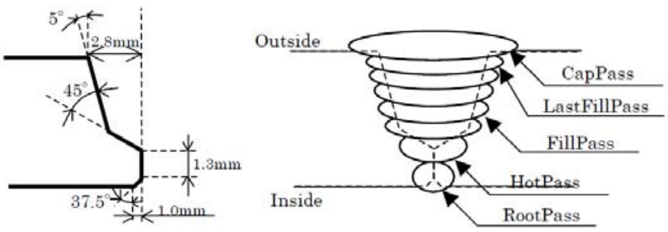

Fig. 5 Bevel preparation and pass sequence

Girth welding procedure in this study was listed in Table 3. The root pass welding was conducted from inside by using semi-auto GMAW process. Pipes were fixed by outer cramp during the root pass welding. Welding position of root pass welding was pipe rotating (1G) position. Hot, fill and cap pass welding was conducted by using mechanized P-GMAW machine of RMS Welding System in fixed pipe (5G) position. For the hot pass welding, 100% CO2 gas was applied as shielding gas to obtain enough penetration. Preheating was not applied and inter-pass temperature was controlled less than 100 deg. C. Welding consumable equivalent for AWS 5.18 ER70S-G was selected to make even-match weld metal. Chemical composition of girth weld metal was shown in Table 4. The Pcm value of girth weld metal was 0.19 as same as base metal. The girth weld metal had leaner Ceq value than base metal.

Table 3 Welding procedures

Pass	Root (Inside)	Hot	Fill～Cap
Process	Semi-auto	GMAW	PGMAW
Position	1G	5G	5G
Equipment	DAIHEN DM-350	RMS	RMS
Welding wire	Nippon-Sumitomo YM-SCV (1.0 mm) (Eq. AWS 5.18 ER70S-G)		
Shielding gas	75%Ar-25%CO2	100%CO2	70%Ar-30%CO2
Heat input (kJ/mm)	-	0.3	0.4~0.7
Note	Preheating was not applied Inter pass temp < 100 deg.C		

Table 4 Chemical composition of girth weld metal (mass %)

C	Si	Mn	P	S
0.069	0.71	1.48	0.009	0.005
Cu	Ni	Cr	Mo	V
0.31	0.04	0.04	0.02	0.01
Ti	Nb	B	Sol-Al	Insol-Al
0.002	0.008	0.0006	0.008	<0.001
O	N	Pcm		Ceq (IIW)
0.03	0.0033	0.19		0.35

HARDNESS DISTRIBUTION IN WELDED PORTION

Measurement lines of hardness distribution were shown in Fig. 6. Figure 7 shows the hardness distribution measured through thickness along the weld center line (a-a' line in Fig. 6). Cyclic variations in hardness were observed in this result. The maximum hardness was Hv 274, the minimum value was Hv 219, and the average value was 244 Hv. The cyclic variation in hardness must be provided by pass sequence. Cross weld hardness distributions were measured at 1 mm distance from the outside surface, middle wall thickness and 1 from inside surface. The test results were shown in Fig. 8. Girth weld hardness was almost same as base metal hardness in all positions. That indicated the even match joint was obtained. The maximum hardness in HAZ was 269Hv, it is not so higher than the average hardness of base metal (251 Hv). This result meant no significant hardening occurred in this joint. On the other hand HAZ softening was observed. The minimum hardness measured in HAZ was 219 Hv. this value is 87 % of average hardness of base metal.

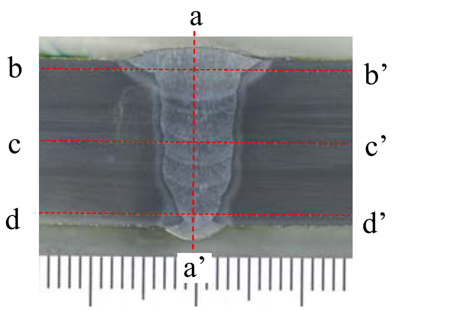

Fig. 6 Measurement lines of hardness distribution

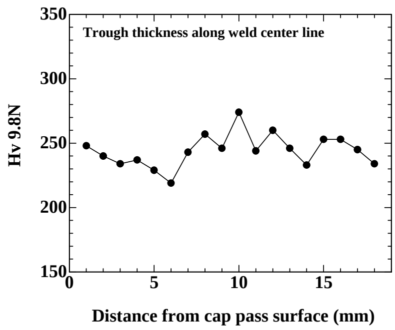

Fig. 7 Hardness distributions through thickness along weld center line

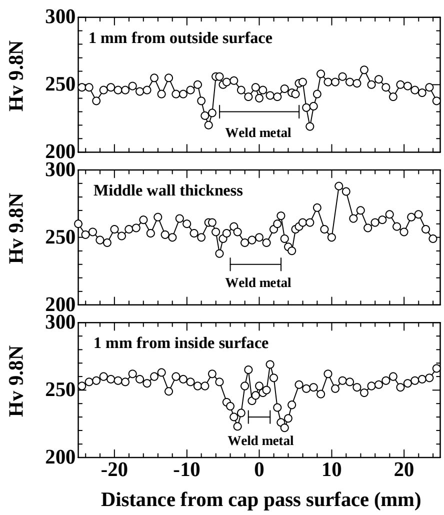

Fig. 8 Cross weld hardness distributions

TENSILE PROPERTIES IN GIRTH WELDED PORTION

As shown in Fig. 7, the girth weld metal has cyclic variation in hardness provided by multi-pass welding. The multi-pass welding must be influence tensile properties in local. Thus two types of tensile test specimens were taken from the girth weld metal. The first type of tensile test specimen was round bar specimens. The round bar specimens with diameter of 3.0 mm were taken at three depths within the girth weld metal. The second type was "full strip" type specimen with width of 15 mm and 1.0 mm thickness. Specimens' sampling positions were shown in Fig. 9.

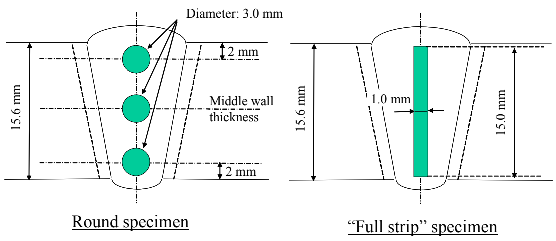

Fig. 9 Schematic illustration showing location of tensile specimen

Stress-strain curves obtained by the round bar and "full strip" bar specimens are shown in Fig. 10. Yield and tensile strength were listed in table 5. From comparison among the round bar specimens' results, stress-strain curves provided the specimens taken from middle wall thickness and 2 mm from inside surface were almost the same. These curves have typical Luder's elongation type shapes and high yield strength of 708 and 693 MPa. On the other hand, specimen taken from 2 mm from outside surface gave typical round house type S-S curve and lower yielding strength of 574 MPa. The difference of S-S curves must be provided by thermal aging and/or tempering effect during reheating cycles in multi pass welding. In the case of strip type specimen, the S-S curve had typical Luder's elongation type shape and the values of yield and tensile strength were similar to S-S curves of round bars from mid wall and near inside surface.

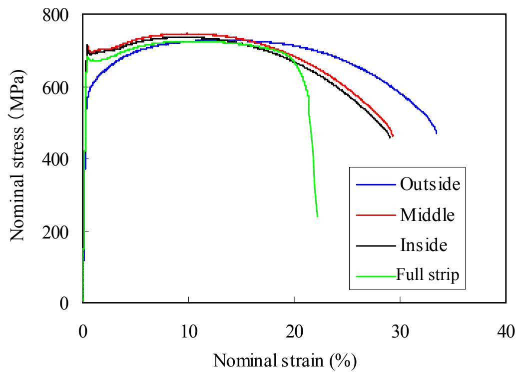

Fig. 10 Stress-strain curves of girth weld metal

Table 5 Results of tensile test on girth weld metal

Specimen type	location	Yield strength (MPa)	Tensile strength (MPa)
Round bar	Outside	574	728
	Middle	708	745
	Inside	693	734
Strip	Full thickness	674	725
Base metal data		541~576	717~741

Cross weld tensile test using strip bar specimen were conducted and the joint fractured in base metal remote from the welded portion. Fracture appearance was shown in Fig. 11.

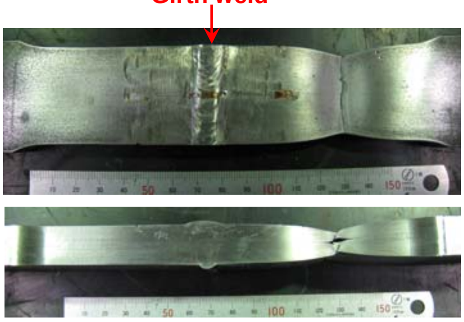

Fig.11 Fracture appearance after the cross weld tensile tests

CHARPY IMPACT AND CTOD TEST AT GIRTH WELDED PORTION

Charpy impact and CTOD tests with the notch located weld center line and fusion line (50:50 portion) were conducted. Charpy test results were shown in Fig. 12 Charpy energy at fusion line more than 100 J was obtained at -60 deg. C. The ductile brittle transition temperature was -53 deg. C. Charpy energy at weld center line was lower than that at fusion line. Charpy energy at weld center line more than 100 J was obtained at -50 deg. C. The ductile brittle transition temperature was lower than -60 deg. C at weld center line. The transition temperature at weld center line is lower than that at fusion line. Low energy level at weld center line must be provided by low upper shelf energy because of high oxygen content of 0.03 mass %.

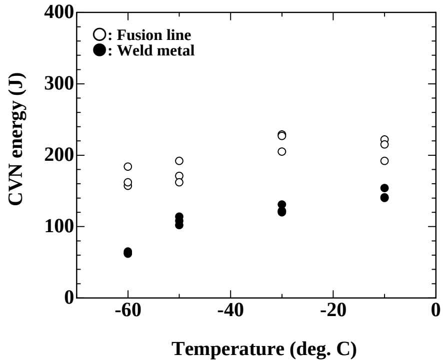

Fig. 12 Charpy impact test results at welded portion

CTOD test conducted at -10 deg. C by using Bx2B specimens with a/W of 0.5. The CTOD test results were listed in Table 6. CTOD values at weld center line were 0.32, 0.35and 0.33 mm. CTOD values at fusion line (50:50 portion) were 0.40, 0.61 and 0.34 mm. All specimens both weld center and fusion line were fractured in ductile manner.

Table 6 CTOD test results at welded portion

Notch location	Temp. deg. C	CTOD value mm
Weld center line	-10	0.32, 0.35, 0.33
Fusion line	-10	0.40, 0.61, 0.34

PIPE BENDING TEST

Full scale pipe bending test was conducted by using X80 SAW pipes with girth weld. To avoid the effect of misalignment at girth welded portion, the pipe was cut and welded as shown in Fig. 13.The test was conducted under the internal pressure of 20.3 MPa. The internal pressure was decided as 72 % specified minimum yield strength of X80. Schematic illustration of the pipe bending equipment is shown in Fig. 14. The lengths of the pipe and a moment arm are 4880 mm (8 OD) and 2000 mm, respectively. The pipe was set up as the seam weld position of the pipe was corresponding to the neutral position. The pipe was bended by a hydraulic jack and the bending load was measured by a load cell. A stroke of the moment arm and a moment length were measured by a wire gage, and angle meters were set to moment arms to evaluate bending angle of the pipe. The internal pressure was loaded by water pressure, and the adjustment of the internal pressure was executed during the test to keep a prescribed value. In this equipment, the pipe was capped at the pipe ends, the pipe was applied axial force induced by the end cap effect.

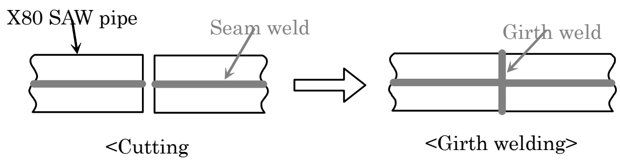

Fig 13 Cutting and welding orientation of the pipe

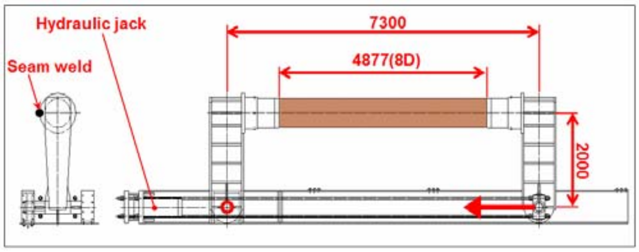

Fig. 14 Schematic illustration of the pipe bending equipment

The pipe deformation shape after rupture is shown in Fig. 15. The pipe fractured at tensile side in base metal remote from girth wed portion. It was confirmed that buckling occurred at compressive side. Figure 16 shows the pipe bending test results as a relationship between bending angle and bending moment. The bending moment increased with increasing of the bending angle. And then the bending moment had peak value when the bending moment was 18.5 degree. After the peak bending moment decreased with increasing of the bending angle. The dropping of after the peak was provided the buckling occurrence. The bending test results mentioned above indicated that the buckling occurred before tensile rupture, tensile rupture finally occurred in the base metal under this test conditions.

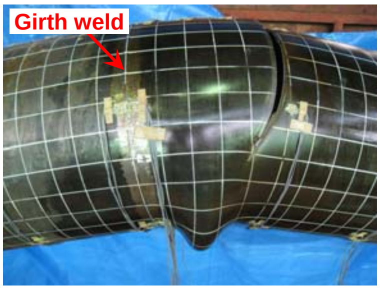

Fig. 15 Pipe deformation shape after rupture

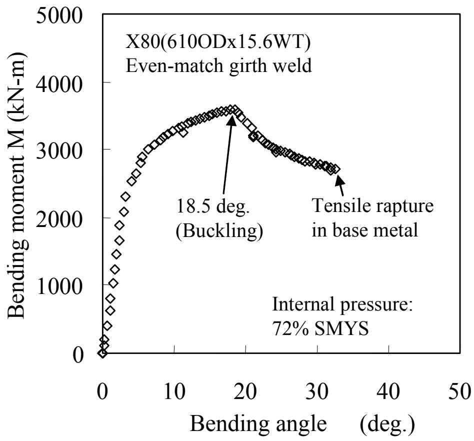

Fig. 16 Pipe bending test results as a relationship between the bending angle and the bending moment

CONCLUSIONS

A welding procedure was developed to produce even-match weld metal for X80 grade line pipe. It was demonstrated that the X80 pipes welded under the developed procedure fractured in base metal remote from girth welded portion by full scale pipe bending test conducted under the internal pressure of 72 % SMYS of X80.

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