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AN OVERVIEW OF NEW DEVELOPMENTS ON LINEPIPE STEELS AND OFFSHORE STRUCTURAL STEELS AT POSCO

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Key Words: The High heat input, TiN particle, Ship building, Offshore structure, CTOD, Linepipe

Abstract

An overview of the development of linepipe and offshore structural steel manufacturing technology at POSCO is presented. As more energy production sites are being developed under the constrained conditions, there is currently a strong need for linepipe steels that can withstand severe conditions, such as extreme cold, deep seabed and corrosive environments.

To meet current market needs, POSCO has developed API-X80/X100/sour X70 grade hot rolled strip and plates with low temperature toughness for energy transportation. Several mill trials with multiple process variables have been performed to optimize the production processes of high strength/high toughness linepipe steel, such as reheating/rolling/cooling conditions. API 2W Gr. 50 and 60 class steel plates have also been developed using TMCP techniques for offshore structures. Steel composition and manufacturing parameter were optimized to obtain high strength and good weldability.

POSCO has now established an API Steel Application Center to provide total solutions for pipe manufacturers, energy firms, and construction companies. The API Steel Application Center consists of three laboratories, each specializing in pipe forming, pipe corrosion evaluation and welding research. Especially, in the forming laboratory, the world's first UOE simulator is installed with several evaluation facilities for full-scale pipes. The UOE simulator can carry out U-ing, O-ing and expansion at the same machine.

The present review describes the recent POSCO activity for new development of linepipe and offshore structural steels and briefly introduces the API Steel Application Center

Introduction

The required performance of gas and oil transmission pipelines has steadily become more strict over the past few decades. Moreover, transportation efficiency has been improved by using high strength steel pipelines allowing higher operating pressure and gas transmission rate. API-X80 steels have been widely applied in several pipeline projects during the last decades and the required level of toughness and weldability have been increased as the transport environment becomes more and more hostile. Recently, large-scale natural gas pipeline projects are being planned and constructed in North America and Northeast Asia (Klatt, 2000 & Asakura, 2000). In order to respond the needs for high strength linepipe steel for these natural gas pipeline projects, POSCO has developed API-X80 grade steels with enhanced low temperature toughness and good weldability.

Also, the offshore oil and gas industry has been demanding high performance steel plates with high strength, heavy thickness and good toughness of the base metal and welded joints. Good toughness of the HAZ is one of the most important properties of steel plate for offshore structures for safety assurance of the weld structure (Salama, Peterson and Thomason, 1988; Hart 1988). Also, good weldability for low preheat temperature during welding can improve the efficiency of fabrication of offshore structures. Lowering the carbon equivalent (Ceq) is essential for good toughness of the HAZ and improved weldability but it is not commonly compatible with the needs for high strength with heavy thickness.

In the present paper, API-X80/100 grade linepipe steel plates and the possibility for the application of high strength steel strip such as grade X65/70 for sour service are discussed. The weld joint performance of API-2W Gr. 50 and 60 class steel plates for offshore application developed by optimizing chemical compositions and applying TMCP are described. And finally, the API Steel Application Center of POSCO is introduced.

Results and Discussions

API-X80/100 Grade Plate - Properties of Base Plate

API-X80 steel was designed to have an acicular ferrite microstructure of carbide-free cells of bainite grouped in domains with islands of dispersed martensite/austenite (MA) consisting of. The addition of manganese nickel, and molybdenum is effective for stimulating the formation of acicular ferrite. To obtain high toughness, carbon content is kept at about 0.07% or less. Table I shows the chemical composition of X80 steel plate. Plates having 15.6mm thickness with 2,900mm width were manufactured from 250mm thickness slabs. Figure 1 and Table II show the typical microstructure and the mechanical properties of base plate, respectively

Table I. Chemical composition of API-X80 plate (wt. %)

C	Si	Mn	P	S	Others	Ceq	Pcm
0.07	0.33	1.78	≤0.015	≤0.003	Nb, Cr, Mo, Ni, Cu	0.45	0.20

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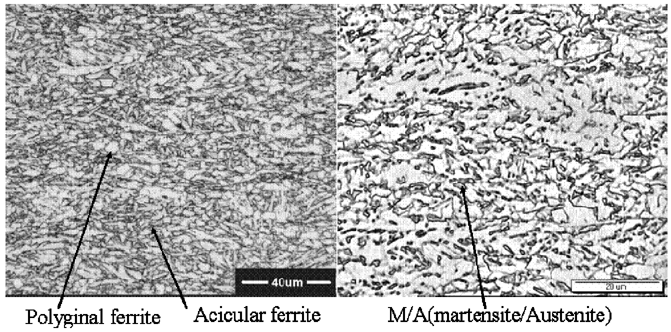


Figure 1. Microstructure of X80 steel plate.

Table II. Summary of mechanical properties of X80 plate

Design	YS (MPa)	TS (MPa)	YR (%)	DWTT SA at -40°C(%)	CVN Energy at -40°C (J)
Target	552~670	620~827	≤ 93	≥ 85	≥ 110
Result	571~591	681~724	81~87	96~99	300~350

Seam SAW Joint Properties

To ensure that the 15.6mm thick X80 steel plate has adequate seam weld properties needed for X80 steel pipe, the plate was welded by 2-wire submerged arc welding(SAW). The SAW conditions used for seam producing are listed in Table III. Heat inputs for inside and outside welding were all about 2.7kJ/mm. SAW wire and flux equivalent to the grade of AWS A5.23 F8A4-EA3-G were used and wire diameter was 4.0mm. A macrograph of a weld section is shown in Figure 2. The full thickness of 15.6mm plate could be fully joined with the applied heat input.

Table III.. Seam SAW conditions

Side	Polarity		Current (A)	Voltage (V)	Speed (cm/min)	Heat Input (kJ/mm)	Interpass temp. (°C)
Inside	L	DC	700	35	100	2.73	Max. 150
	T	AC	600	35			
Outside	L	DC	685	35	102	2.72	
	T	AC	585	38			

* SAW wire: A-3(ϕ4.0), flux: S-777MXH

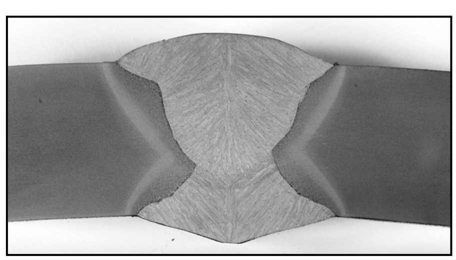


Figure 2. Macrograph of seam weld cross section

Figure 3 shows the hardness distributions across the base metal, heat affected zone, and weld metal of a SAW weld joint. There is no hardening near the fusion line in the HAZ, whereas there is a slight softening in the fine grained HAZ. The maximum hardness of the HAZ is below Hv 250. The weld metal hardness is not higher than that of the base metal.

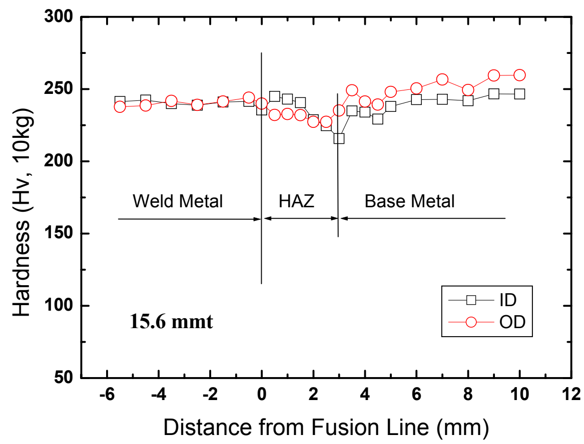


Figure 3. Hardness distributions of SAW weld seam

Figure 4 shows the location of rupture during tensile test of the SAW joint. The fracture occurred in the weld metal. This is attributed to the relatively low hardness of the weld metal. Although the fracture occurred in the weld metal, the tensile strength of the weld joint is sufficiently high to meet specified strength requirements, as shown in Figure 5. The average tensile strength is about 712MPa. Note that elongation of the SAW joint is lower than expected. This seems to be due to the narrow width of the weld metal which has lower hardness than base metal.

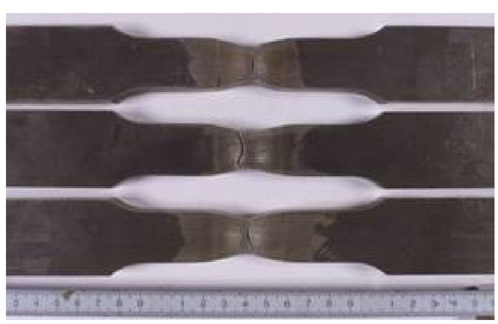


Figure 4. Fractured appearances of tensile test specimens

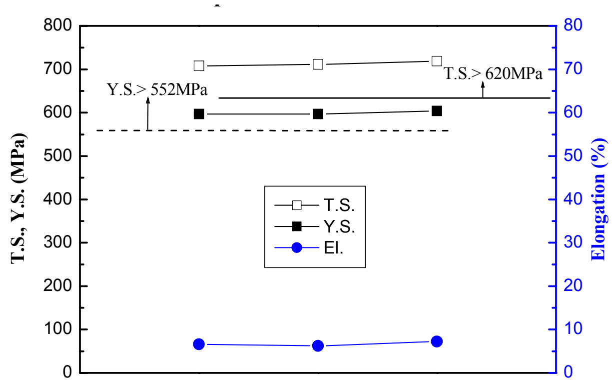


Figure 5. Tensile properties of SAW joint

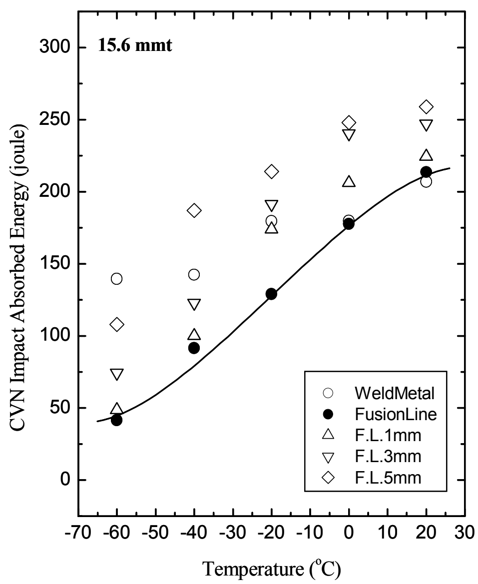


Figure 6. Charpy V-notch impact toughness of SAW joint

Figure 6 shows the Charpy V-notch impact toughness of SAW joints. As is well-known from previous papers, the lowest impact toughness of the weld joint is at the fusion line of the in HAZ. However, the impact toughness of the fusion line of X80 steel is about 129J at -20°C. Even at -40°C, the fusion line has an impact toughness of about 90J. These toughness levels are adequate for the most linepipe projects. Weld metal formed by the mixture of base metal, welding wire and flux also has high impact toughness at low temperatures. In the range of heat input from 2.5 to 3.0kJ/mm, the impact toughness of the X80 plate showed sufficient values.

Girth GMAW Joint Properties

To confirm that the X80 steel plate has adequate girth weld properties for producing X80 pipe, test plate was welded by mechanized gas metal arc welding (GMAW). GMAW conditions used for girth welding are listed in Table 4. GMAW wire of 1.2mm diameter, equivalent to the grade of AWS A5.29 E91T1-K2, was used to make the test welds. A macrograph of a GMAW weld section is shown in Figure 7.

Table IV. Mechanized GMAW conditions

Welding Parameters	**Welding Conditions**
Welding Method	GMAW (FCAW)
Welding Wire	SC-91K2 Cored
Shielding Gas	100% CO_2
Gas Flow (l/min.)	20
Polarity	DC+
Initial Temperature (°C)	20
Arc Voltage (V)	26
Welding Current (A)	230
Welding Speed (cm/min.)	32
Heat Input (kJ/mm)	1.12

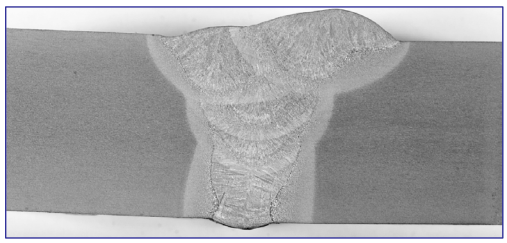


Figure 7. Macrograph of girth GMAW joint

The hardness distribution of GMAW joints is shown in Figure 8. Due to the relatively low heat input compared to SAW, the GMAW HAZ shows more hardening near the fusion line whereas no softening occurs in the base metal side of HAZ. The weld metal hardness is slightly higher than that of the base metal.

Figure 9 shows the location of rupture in tensile test specimens of girth GMAW joints. Fractures occurred in the base metal due to the higher hardness of the weld joint. The average tensile strength is about 659MPa, satisfying specification requirement, as shown in Figure 10.

Figure 11 shows the Charpy V-notch impact of the toughness of GMAW joints. The impact toughness of the fusion line is about 134J at -20°C and 82J at -40°C. HAZ toughness in the GMAW need is nearly the same as that of a SAW joint. This toughness level of the GMAW joint also is high enough for most linepipe projects. Weld metal toughness, however, is lower than that of the HAZ, about 68J at -20°C. This difference can be attributed to the different welding consumables.The heat input of GMAW was also varied in the range of 0.5~1.5kJ/mm and the toughness was sufficient for the heat inputs tested.

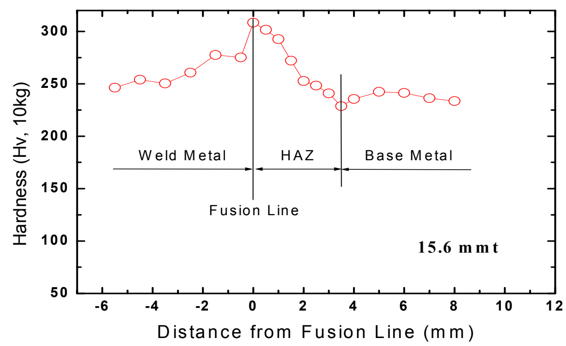


Figure 8. Hardness distribution of GMAW joint

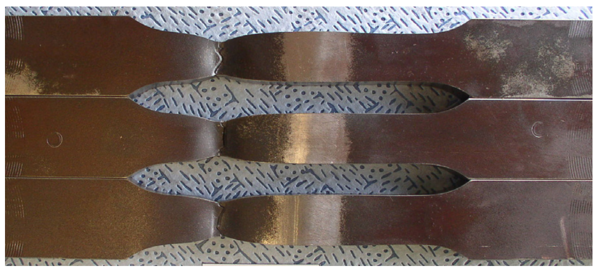


Figure 9. Fracture appearance of tensile test specimens

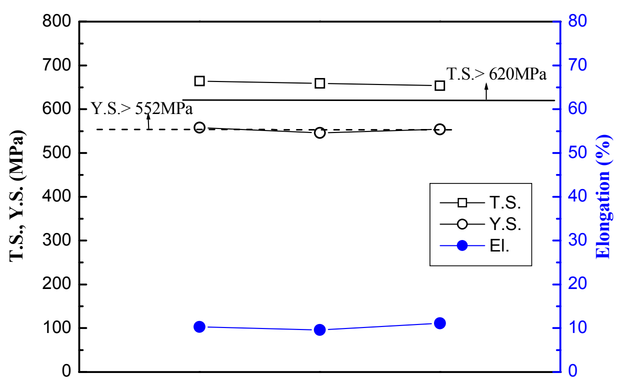


Figure10. Tensile properties of a GMAW joint

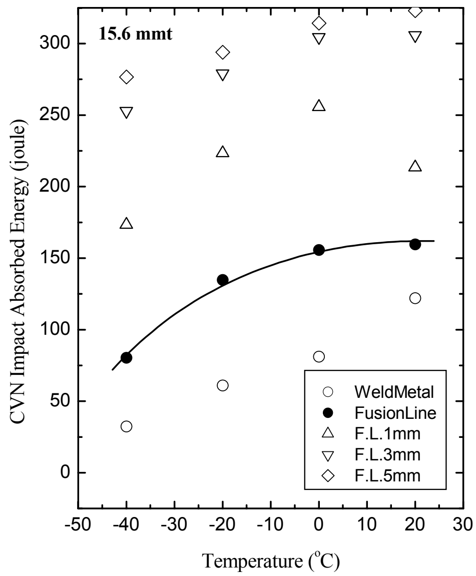
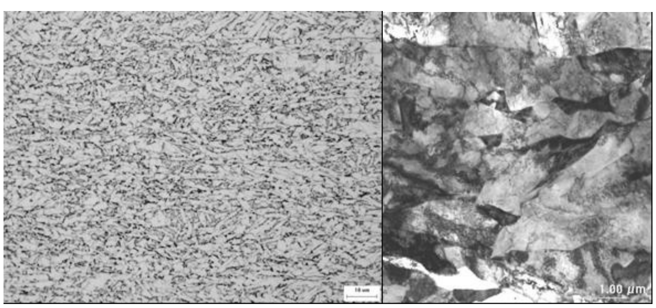


Figure11. Charpy V-notch impact toughness of a GMAW joint

Properties of X100 Plate

Plates having 19mm thickness and 2,900mm width were manufactured from 250mm thickness slabs. Figure 12 shows the typical microstructure and the mechanical properties of the base plate.The microstructure consists of degenerate upper bainite and martensite with 9 percent MA(Martensite/Austenite Constituent).



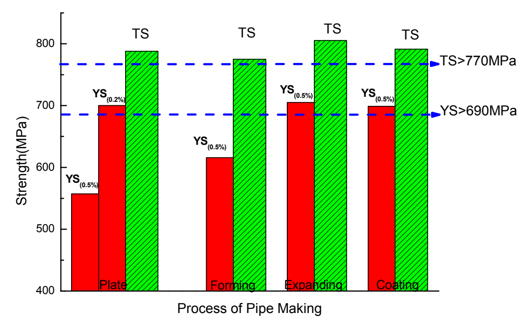


Figure 12. Microstructures and mechanical properties of X100 steel plate.

There's little different in alloy design and microstructures when, comparing X80, X70 and X100 plate. It is to precisely control low temperature phases such as bainite and martensite. X100 steel was our most recent challenge necessary and POSCO is very close to be ready to supply X100 plate.

API-X70 for Sour Service

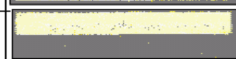
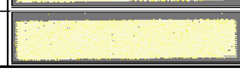
Table V shows the chemical composition of X70 for sour service. It is characterized by low Ceq. chromium and molybdeaum are added to increase strength. Also, these alloying elements have a role to play in reducing centerline segregation in slab formation due to solidification in the delta-ferrite temperature region and thus they increase the HIC and SSCC resistance.

The HIC and SSCC properties of the test materials with various microstructures were examined in NACE Solution A, and the results are shown in Table VI. The steel has high sour service resistance, which may be due to the uniform microstructure with almost no inclusions.

Table V. Chemical composition of API-X70 for sour service (wt. %)

C	Si	Mn	Others	Ceq
0.04	0.25	1.3	Nb, Cr, Mo, Ni, Cu	0.32

Table VI. HIC properties of test materials in NACE solution A

Pipe	Position	HIC Test @ NACE Solution A			
		Ultrasonic Test		Max CAR, %	Max CLR, %
		Inspection Drection	C sanc Image		
ERW 20" 12.7mmt	0°	A		0	0
		B		0	0
	90°	A		0.0	0
	180°	A		0.3	<10%
	270°	A		0.0	0

Trial production results of API X70 ERW Pipe for sour service

Low temperature toughness of ERW pipe was very good as shown in Figure 13. The Charpy V-notch impact test showed that the transition temperature of the ERW pipe is around -60°C, while the hot strip showed ductile fracture to -80°C. For the ERW matrial, the Charpy energy of the bond line was lower than that of the HAZ but was still relatively good.

Figure 14 shows the plot of hardness traverses in the ERW weld region. The hardness values of 240Hv (500g) were almost the same as the base metal. No cracking was observe in the hot rolled coil and ERW pipe according to NACE TM0284 tes.

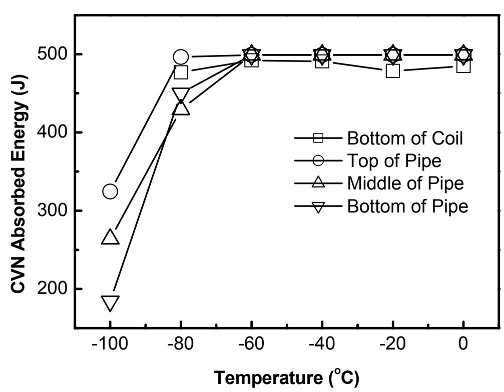


Figure 13. Charpy V-notch impact energy of ERW pipe material according to the sequence of pipe making process

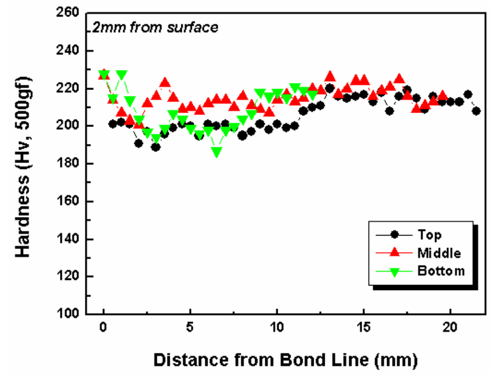


Figure 14. Hardness distributions near the ERW bond line

API-2W GR.50/60 Steel Plate

Properties of Base Plate

Table VII shows chemical compositions of API-2W Gr. 50 and 60 produced at POSCO's plate mill. The alloy composition was designed based on simulated evaluation at laboratory. Phosphorus and sulfur levels were sufficiently reduced in the molten steel and slabs were continuously cast into 280mm thickness. The slabs were reheated to a moderately high temperature and then rolled in two stages of recrystallized austenite region and non-recrystallized region. The hot rolled plates were directly cooled with MULPIC system. Table VIII shows the results of tensile tests and Charpy V notch impact tests in the transverse direction. The base plates satisfy the requirements for strength and Charpy impact energy for API-2W Gr. 50 and 60 at quarter thickness and central region. The DBTT of the Charpy energy is lower than -95^{o}C at quarter thickness and lower than -64^{o}C even in the central region, respectively. The through-thickness direction tensile properties were also measured. The reduction of area in the through-thickness direction is over 70%. This good through-thickness property, implying a good resistance to lamellar tearing, can be attributed to a low sulfur content and heavy reductions during plate rolling.

Welding Conditions

Welding was carried out by multi-pass submerged arc welding(SAW) with heat inputs of 3.0 and 4.5 kJ/mm. Also flux-cored arc welding(FCAW) with an heat input of 0.7 kJ/mm was also employed. Detailed welding conditions are summarized in Table IX. All specimens were welded using a single bevel with a groove angle of 4^{o}. Welding process parameters and bead placement were selected to produce a straight fusion line and generate the required unrefined columnar weld metal along the straight fusion line to maximize the CGHAZ microstructure.

Basic Properties of Welded Joints

The results of tensile and Charpy impact tests of welded joints are summarized in Table X. Complete Charpy transition curves were obtained for coarse grain(CG) and unaltered subcritical (SC) HAZ locations at quarter thickness and root position as specified in API RP2Z. The tensile strengths of all the weld joints of Steel A show higher values than the requirement of API-2W Gr. 50. The Charpy absorbed energy is over 136J at -60°C. The DBTT ranges between -49 and -130°C and the absorbed energy levels at the DBTT are about 200J for each weld. It can be said from the results that the HAZ of the developed steel plates has excellent Charpy impact properties.

CTOD Properties of Weld Joints

Rectangular (B x B) CTOD specimens were extracted from the weld joint of Steel A. The test was performed at -10°C in accordance with BS 7448 as specified in API RP2Z. Prior to fatigue precracking, the unnotched ligament of each specimen was laterally compressed to nominally 0.4% of the specimen thickness on each side to promote crack front straightness (Dawes, Pisarski, and Squirrell, 1988). Specimens according to BS 7448 were sectioned near the fatigue crack tip to assess the HAZ microstructures after completion of the fracture toughness tests. Microstructure validation was performed according to the specified requirement for sampling HAZ microstructure in API RP2Z.

The results of the HAZ CTOD test whose validity was confirmed by the assessment of the HAZ microstructure are shown in Figure 9. The test results indicate that the HAZ of the developed steel plate has excellent CTOD toughness at the required welding heat input levels. All HAZ CTOD values exceed the minimum requirement of API RP2Z, 0.38mm.\, by a large margin.

Also, CTOD tests of the base metal and weld metal were carried out and the results are shown in Figure 15. As shown in Figure 16, the CTOD value of the base metal is higher than 1.76mm at -10°C and -40°C and the weld metal shows higher values than 1.14mm at -10°C. Excellent toughness could be obtained in both base plate and weld metal.

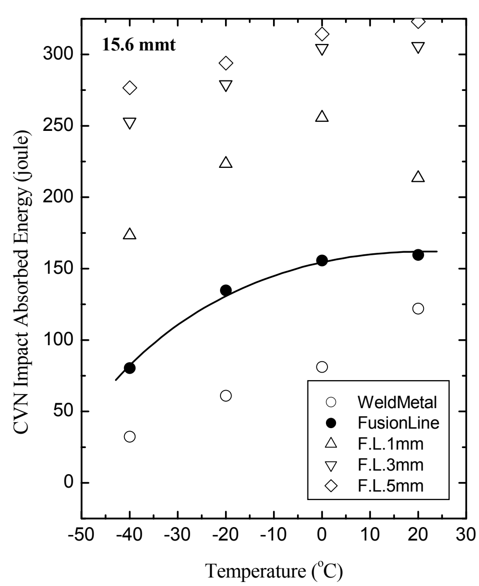


Figure 15. Charpy V-notch impact toughness of GMAW joint

Table VII. Chemical compositions of API-2W Gr. 50 and 60 plates (wt%)

Steel	C	Si	Mn	P	S	Sol. Al	Others	Ceq	Pcm
A (Gr.50)	0.08	0.25	1.45	0.004	0.002	0.028	Cu, Ni, Nb, Ti	0.38	0.18
B(Gr.60)	0.08	0.15	1.58	0.008	0.001	0.037	Cu, Ni, Nb, Ti	0.39	0.19

Table VIII. Mechanical properties of API-2W Gr. 50 and 60 plates

Steel	Thickness (mm)	Location	Tensile properties			Charpy impact properties	
			YS (MPa)	TS (MPa)	EL (%)	Absorbed energy at -60^oC (J)	DBTT (^oC)
A (Gr. 50)	70.0	1/4t	364	463	39	344	-104
		1/2t	352	451	38	212	-72
	90.0	1/4t	392	502	38	421	-112
		1/2t	374	490	37	409	-82
B (Gr. 60)	50.0	1/4t	438	575	32	346	-95
		1/2t	437	579	31	173	-64
	76.5	1/4t	443	550	34	349	-98
		1/2t	435	548	30	153	-68

Table IX. Welding condition for API-2W Gr. 50 and 60 plates

Welding Method	Filler Metal	Flux	Current (A)	Voltage (V)	Speed (cm/min.)	Heat input (kJ/mm)	Preheat Temp. (^oC)	Interpass Temp (^oC)
FCAW	DW-55L	-	210	30	55	0.7	Ambient	Max. 100
SAW	US-36	PFH-55LT	550	32	35	3.0	100	Max. 150
			650	32	28	4.5	Min. 250	Min. 250

Table X. Mechanical properties of weld joints of API-2W Gr. 50 and 60 plates

Steel	Heat Input (kJ/mm)	Tensile properties		Absorbed energy at -60^oC				DBTT			
		TS (MPa)	Location of rupture	1/4t		Root		1/4t		Root	
				CGHAZ	SCHAZ	CGHAZ	SCHAZ	CGHAZ	SCHAZ	CGHAZ	SCHAZ
A (Gr.50)	0.7	548	BM	136	168	151	225	-49	-55	-52	-63
	3.0	533	BM	407	407	367	407	-107	-103	-84	-84
	4.5	498	BM	346	393	155	353	-84	-130	-49	-98
B (Gr.60)	0.7	-	-	228	194	227	261	-70	-89	-96	-94
	4.5	-	-	213	306	206	328	-80	-105	-76	-98

POSCO API Steel Application Center

POSCO has established an API Steel Application Center to provide total solutions for pipe manufacturers, energy firms, and construction companies by implementing a comprehensive research plan for steel manufacturing, pipe forming and welding. The API Steel Application Center (ASAC) consists of three laboratories, each specializing in pipe forming, evaluation and welding research. The forming laboratory possesses the world's first UOE simulator (Figure 16) and the various pipe welders that are used for performing research tasks on pipe manufacturing and quality evaluation, while the Center's large-scale tensile testing machine can evaluate the performance and construction-readiness of fabricated, full-scale pipes.

The evaluation laboratory is equipped with a full scale corrosion tester, HIC, and SSCC testers (Figure 17) that measure the corrosion resistance of full-scale pipes. The latest ERW simulator is installed in the Welding laboratory, in which research activities ranging from test welding to the selection of welding consumables are carried out.

We are confident that ASAC will provide the means to swiftly meet ever-changing requirements of the global API steel market through the development of high-strength, high-performance API steel and new welding technologies, which would in turn provide customers with differentiated technologies.

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Figure 16. UOE simulator

Figure 17. Sulfide Stress Corrosion Cracking Test System

Summary

In the present paper, three representative API POSCO plate products including their welding performance plus the API product research Center have been briefly introduced. These are API X80/100 plate for high strength pipeline, API 70 for sour service, and API-2W Gr 50/60 class plates for offshore structure

API-X80/100 grade hot rolled steel plates with thickness of 19mm have been developed. This X80 grade plates satisfy the API requirements for strength and toughness for commercial applications. The DWTT transition temperatures of 15.6mm thick X80 steel plate and pipe are -55℃ and -45℃, respectively. A combination of high strength and good toughness of POSCO's X80 grade plates was obtained through the control of microstructure of the plate. Seam SAW and girth GMAW joints have sufficiently high tensile strength and impact toughness at low temperatures.

API-2W Gr. 50 plate of 90mm thickness and Gr. 60 plate of 76.5mm thickness were developed for offshore application by optimizing alloy composition and applying TMCP technology with a heavy reduction and accelerated cooling. The base plates and weld joints of API-2W Gr. 50 and 60 product have been evaluated and the performance satisfied the requirement of API RP2Z.

POSCO is dedicated to creating value-added product for to its customers and leading future-oriented technologies through the API Steel Manufacturing Research Center.

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