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라인파이프용 고강도 열연강판의 기계적 성질

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Mechanical Properties of High Strength Hot Strips For Line Pipe Application

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Abstract

The purpose of this study was to investigate the effects of alloying and rolling condition on the mechanical properties and to develop high strength line pipe steels with good toughness. Tests were carried out by the laboratory experiments followed by mill trials and mass production. It was found that a small addition of microalloying elements, such as Nb, V with Mo or Ti remarkably increased the strength and toughness of hot strips. The optimum condition of thermomechanical rolling on low carbon microalloyed steel improved the toughness through the formation of a fine and uniform microstructure. Based on this mill trials following the fundamental research, the production technology of line pipe steels, grade X70～X100 with high toughness, has been established. These grade steels exhibit excellent low temperature toughness (vTs= under −80℃) and sufficient strength in both the base metal and the ERW seam weld position, respectively.

Keywords : Linepipe, X70 ~X100, microalloying elements, Low temperature toughness, ERW

1. Introduction

In recent year, requirements for line pipe steels have become progressively sophisticated in order to cope with severe environments such as arctic weather conditions. Hot strips for HFERW pipes are required to have high strength but also low temperature toughness and superior field weldability. Especially in case of arctic region, there is a need to get higher strength pipes with excellent low temperature toughness to transport more oil economically. In order to manufacture the high quality HFERW, material design, steel making and hot rolling technologies are indispensable as well as pipe welding, inspect, and heat treatment technologies. On the other hand, production experience and technologies were extended up to 80Ksi(API～X80) for HFERW manufacturing process. This report describes the technology of manufacturing hot strips graded from X70 to X100 for HFERW pipes with high strength and high toughness, in POSCO Lab trials and hot strip mill trials, and mass production.

2. Laboratory experiments (for API-X100)

2.1 Experimental procedures

The base chemical composition of steel in this study is 0.05%C-0.25%Si- 1.55%Mn. Nine steels with various alloy additions, such as Ti (0.028～0.064%), Nb (0.041～0.072%),Ni (0.18～0.79%), Mo (0.28～0.38%), Cu (1.0～1.73%) were prepared by vaccum-induction melting and casting. The ingots were initially hot rolled to 35mm thick bars to break cast structure. These bars were reheated at 1250℃ for 1 hour, and then hot rolled to a thickness of 7mm sheets by 3 pass reduction. The finish rolling was performed in the temperature range of 800～900℃. The hot rolled sheets were cooled at a cooling rate of 20℃/sec to coiling temperature (CT). The CT were changed in the temperature range of 540～660℃ and coiling simulation was carried out by keeping the sheets for 1hr at given CT. The various mechanical properties such as tensile properties, Charpy impact toughness, and the fractions of shear area by drop weight tear test (DWTT) were measured.

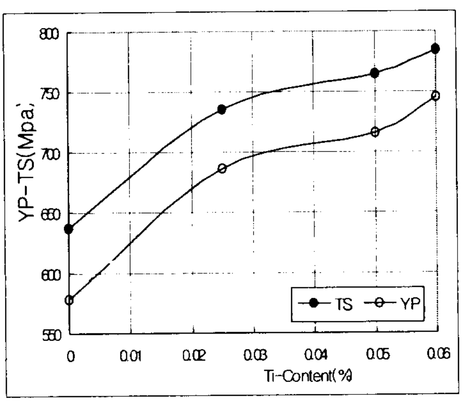
Table 1. Rolling conditions

Heating	Rolling			Cooling	
Temp	Bar	FDT	Thickness	C/R	CT
1250℃	35mm	800-900℃	7mm	20℃/S	540-640℃

* FDT : Finishing Deliverly Temperature, C/R : Cooling Rate, CT:Coiling Temperature

2.2 Results and Discussion

Fig.1 shows the effect of Ti content on the mechanical properties of hot rolled sheets coiled at 600℃. Base composition is 0.05%C-1.50%Mn-0.045%Nb-0.30%Mo. It showed that strength was increased remarkably but low temperature toughness was decreased as the content of Ti was increased. The strength for API-X100 grade was achieved when Ti was added over 0.040% with Nb. The low temperature toughness was



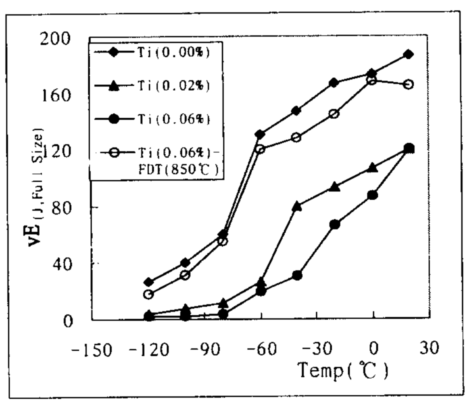


Fig.1 The effect of Ti content on the tensile strength and low temperature toughness.

[CT:600℃,FDT:800℃, 0.05%C-1.50%Mn-0.045%Nb-0.30%Mo]

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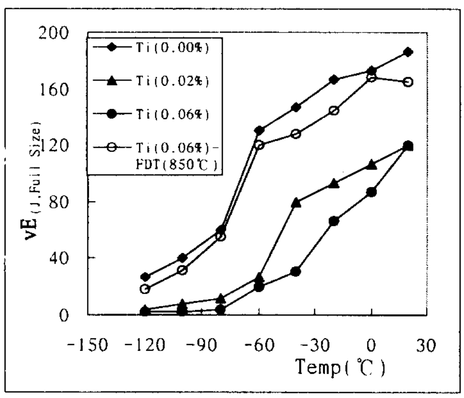


Fig.1 The effect of Ti content on the tensile strength and low temperature toughness.

[CT:600℃,FDT:800℃, 0.05%C-1.50%Mn-0.045%Nb-0.30%Mo] deteriorated as the content of Ti was increased. However, this deteriorating toughness was improved when the Finishing Delivery Temperature (FDT) was decreased. The ductile brittle transition temperature(DBTT) was decreased from -30℃ to -60℃ as the FDT was decreased from 850℃ to 800℃. The improvement of low temperature toughness is achieved due to the refinement of ferrite and the fine dispersion of the second phase.

3. Mill Trials and Mass Production

3.1 API-X100 (Mill Trials)

Based on the results of fundamental research for X100 grade line pipe steels, Mill trial tests were carried out. Table.2 shows the processing conditions. The total reduction at the finishing train was varied from 65%-80%, and CT was in the range of 550-650℃. The various mechanical properties such as tensile properties, Charpy impact toughness, and the fraction of shear area by the DWTT were measured.

Table 2. Processing Conditions

Heating		Rolling				Cooling	
Temp	Hold Time	Bar	FET	FDT	Thickness	C/R	CT
1250℃	230min	32-40mm	950℃	780-860℃	8.6mm	20℃/S	550-650℃

(1). The Effect of FDT and CT.

Fig. 2 shows the effect of CT on the mechanical properties and the low temperature toughness. As CT was decreased from 650℃ to 550℃, the yield strength was increased from 550Mpa to 740Mpa,

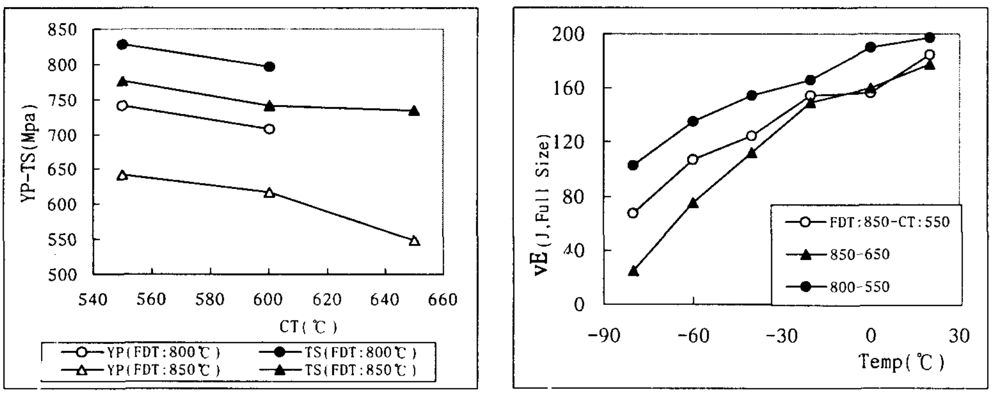


Fig 2. Effects of CT and FDT on the tensile strength and toughness.

(a) FDT:850℃-CT:650℃ (b) FDT:800℃-CT:550℃

and the DBTT was increased from Under -80℃ to -70℃. Photo 1. shows the optical microstructure of the hot rolled steel (The base composition of which is 0.08%C-1.5%Mn-0.05%V-0.3%Mo-0.2%Ni-0.05%Ti) coiled at

650℃ and 550℃. The coarse accicular ferrite was changed to the fine bainitic ferrite as CT was decreased. The DBTT was decreased from -70℃ to -110℃ as FDT was decreased from 850℃ to 800℃.

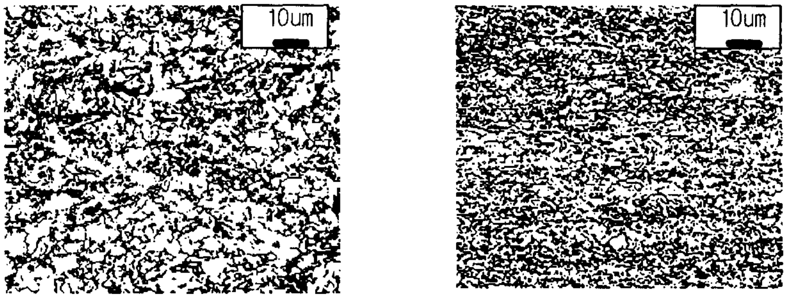


Photo 1. Microstructure of hot rolled coils.

(2) Properties of HFERW pipes

Table 3 shows the mechanical properties of HFERW pipes. Impact energy of X100 grade steels was obtained with absorbed energy 87Joule at -60℃.

Table 3. Mechanical Properties of manufactured HFERW pipes.

Pipe Size		Tensile Strength				Charpy Impact(Full size)			DWTT
		Base			Weld,Joint	Base		Weld, Joint	Base
O.D	W.T	YP	TS	El	TS	vTs	vE(-60℃)	vE(-60℃)	S.A(-60℃)
406mm	8.7mm	732Mpa	892Mpa	23%	882Mpa	<-80(℃)	105J	87J	100%

3.2 Mechanical properties of API-X70～X100 grade line pipe steels

Nb-V, Nb-V-Ti, Nb-V-Mo, Nb-Mo-Ni and Nb-Ti-Mo-Ni (API-X100 grade) steels were produced. The hot coils were reheated to 1150～1250℃, subsequently controlled rolled to the thickness of 8.7～14.3mm (Base;12.5mm), and accelerated cooled 10～30℃/sec. The FET was varied from 920-1030℃ and the FDT was varied from 780-860℃, the total reduction ratio at finishing train was also varied from 60% to 80%.

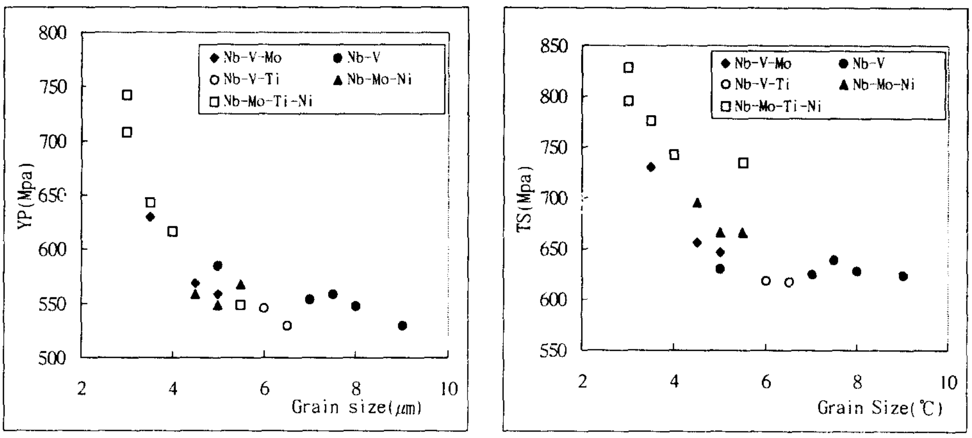
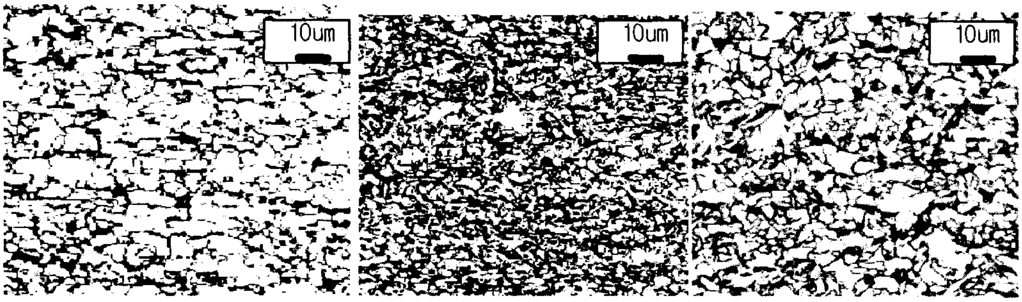


Fig 3. The effect of grain size on the tensile properties.

(1) Tensile strength

Fig.3 shows the effect of grain size on the tensile properties of hot rolled coils. Although the effect of alloying element on yield strength represents slightly different behavior, YS was increased from 540Mpa to 740Mpa as the grain size was reduced from 10μm to 3～4μm. Photo. 2 shows the optical microstructure of the hot-rolled steels 12.5mm in thickness contained Nb-V, Nb-V-Mo or Nb-V-Ti. The microstructures of the Nb-V, Nb-V-Ti (0.015%Ti) steels were ferrite and pearlite, but in case of the steels contained Mo were accicular ferrite and bainite. The mechanical properties of X80 or X100 grade were obtained with the addition of Mo.



(a) Nb-V (b) Nb-V-Mo (C) Nb-V-Ti

Photo. 2 Microstructure of hot rolled coils. (Thickness;12.5mm, FDT;810℃).

(2) Low temperature toughness

Fig. 4 shows the effect of microalloying elements on the low temperature toughness. It was found that Charpy impact energy of Nb-V-Mo and Nb-V-Ti steels was higher 50～100joules than that of Nb-V steel. The DBTT was decreased from under -20℃ to -80℃ as the grain size was reduced from 10um to 3～4um. The DBTT was remarkably deteriorated when FET was higher than 1000℃ and FDT was higher than 850℃.

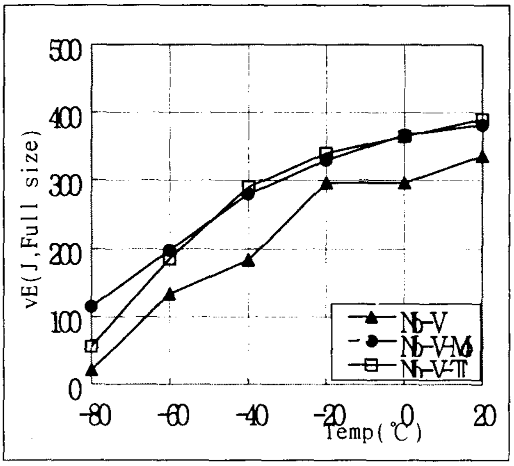


Fig 4. Effect of the microalloying element on the toughness.

(Thickness; 12.5mm, Base composition; 0.05%C- 1.50%Mn)

(3) Properties of HFERW pipes

Table.4 shows the impact energy of seam welded position in X70 grade HFERW pipes. The impact energy of Nb-V, Nb-V-Mo and Nb-V-Ti added steel was represented as 121, 158 and 169J at –60℃, respectively.

Table 4. Mechanical Properties of HFERW pipes.(API-X70～X80)

Items	Pipe Size		Tensile Strength				Charpy Impact, Full size			DWTT
			Base			Weld,Joint	Base		Weld,Joint	Base
	O.D	W.T	YP,Mpa	TS,Mpa	El,%	TS,Mpa	vTs(℃)	vE(-60℃)	vE(-60℃)	S.A(-40℃)
Nb-V	508mm	12.5mm	512	642	41	658	-60	132J	121	85%<
Nb-V-Mo	508mm	12.5mm	618	724	38	713	-80	162J	158	95%<
Nb-V-Ti	508mm	12.5mm	534	632	42	645	-70	167J	169	95%<

4. Summary

In order to improve the low temperature toughness of API-X70～X100 grade steels, lab-scale tests and mill trials, productions were conducted with the Table 4. Mechanical Properties of HFERW pipes.(API-X70～X80) change in hot rolling conditions in combination with the selection of the most suitable chemical compositions.

○ **Tensile strength** ; In order to satisfy the tensile properties higher than API-X80 grade, Mo was indispensable to get the accicular or bainite microstructure. To improve strength, it was necessary to decrease FDT and CT.

○ **Low temperature toughness** ; It was found that Charpy Impact Energy of Nb-V-Mo and Nb-V-Ti steels was higher 50～100 joules than that of Nb-V steel. For improvement of toughness, it was necessary to decrease the FET and FDT with heavy reduction in unrecrystallized region of austenite. A decrease of FDT markedly improved low temperature toughness by grain refinement. These grade steels exhibit excellent low temperature toughness (vTs= under –70℃) and sufficient strength in both the base metal and the ERW seam weld position, respectively.

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