APPLICATION OF HIGH STRENGTH STEELS IN CIVIL CONSTRUCTION IN SEISMIC AREAS

Sung Doo Hwang, Hee Woong Lee, Sang Gi Ko and Jong Man Han

Plate R&D Team, Hyundai-Steel Company; 167-32 Kodae-Ri Songak-Eup; Dang Jin City, Chungnam, 343-800, Korea

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Abstract

In recent years, high strength and good weldability of steels have been required for building structures. Hyundai Steel Company has developed a series of construction steels ranging from 550 to 800 MPa tensile strength class, with 450 to 650 MPa yield strength. A microstructure of low-C bainite was obtained by using thermomechanical controlled rolling with accelerated cooling. These steels achieved the required mechanical properties (high strength, low yield/UTS ratio) and demonstrated satisfactory weldability up to 100 mm thickness. In 2012, these steels were successfully used in the construction of the “Federation of Korean Industries” building.

Introduction

Over the last several years, increasing attention has been paid, in both the steel and construction industry, to the importance of developing higher strength steel for constructing high-rise buildings. Meanwhile, the ability to produce heavier plate for structural parts has become another important issue, especially for structural steels, for which it has been regulated in certain standards that they possess a low yield ratio (yield/tensile strength) as a safeguard against seismic activity.

In Japan, the earthquake which took place in Kobe inspired interest in seismic design using structural steels. Furthermore, it has now been stipulated in Japanese Industrial Standards to produce anti-seismic steels to safeguard buildings from unforeseen disasters.

Since the year 2000, the Korean Standards body (KS) has applied similar rules to the SN series of steels used for building construction. On the back of the efforts above, KS has carried out an examination of high performance rolled steels for building structures (KS D 5994), as used in constructing higher skyscrapers.

Responding to this demand, Hyundai Steel Company has successfully deployed, on a commercial scale, an anti-seismic steel with an SMYS (Specified Minimum Yield Strength) in the range 325-355 MPa. In addition to that, a YP 450 MPa grade steel, with excellent toughness and weldability, has been used in constructing the “Federation of Korean Industries” building (Figure 1). Additionally, YP 650 MPa grade structural steels are under development to use in constructing higher skyscrapers.

Figure 1. “Federation of Korean Industries” building.

Development of YP 450 MPa Grade Steel

Development Concept

Table I shows the chemical composition of the developed YP 450 MPa grade steel.

Table I. Chemical Composition of YP 450 MPa Grade Steel

Thickness (mm)	Chemical Composition (wt.%)						
	C	Si	Mn	P	S	Ceq	Others
100	≤0.06	≤0.30	≤1.60	≤0.020	≤0.006	0.39	Cu, Ni, Nb, Ti, B

Table II. Mechanical Properties of YP 450 MPa Grade Steel

Location	YP (MPa)	TS (MPa)	YR (%)	El. (%)	vE-5°C (J)
1/4t	511	654	78	27	278
1/2t	482	633	76	26	227

The alloy composition was designed to give an optimum value of high strength with good toughness and weldability and was based on a low C-Si-Mn composition with microalloying.

For the purpose of improving mechanical properties, TMCP was applied in the production of the steel. TMCP is a well known process used to attain high strength and good toughness for steel plates with a lean alloy composition [1-4]. The excellent properties of the TMCP steel resulted from a fine microstructure obtained by controlled rolling and accelerated cooling. By using the TMCP process, a microstructure was produced which exhibited a low yield/tensile ratio and continuous yielding behavior [5].

Mechanical Properties of Base Material

Table II shows the mechanical properties of the base material, YP 450 grade steel. Similar to SM570 as specified in KS, the yield and tensile strength of the steel are in the range 482-511 MPa and 633-654 MPa respectively. In the case of Charpy V-notch energy (Figure 2), values above 200 J at -5 °C were attained. A low yield ratio of 76-78% was also achieved. The microstructure of the high strength steel, YP 450 MPa grade, is illustrated in Figure 3. The developed steel is made up of mostly bainitic ferrite with other components, such as MA constituent. The low yield ratio is achieved by the presence of these MA islands resulting in continuous yielding behavior [6-8].

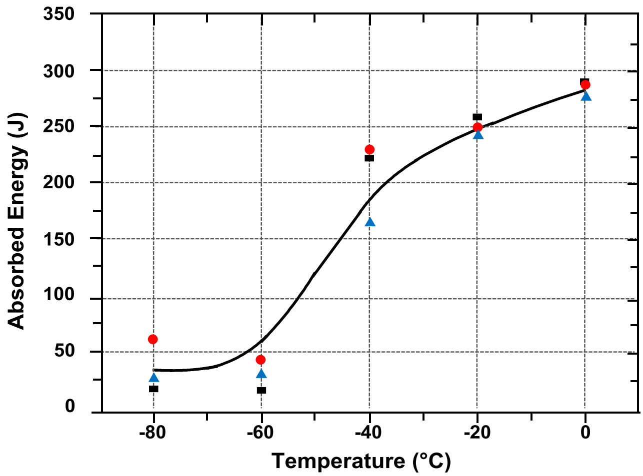

Figure 2. Charpy transition curve of YP 450 MPa steel.
(Points represent individual values and the line represents the average.)

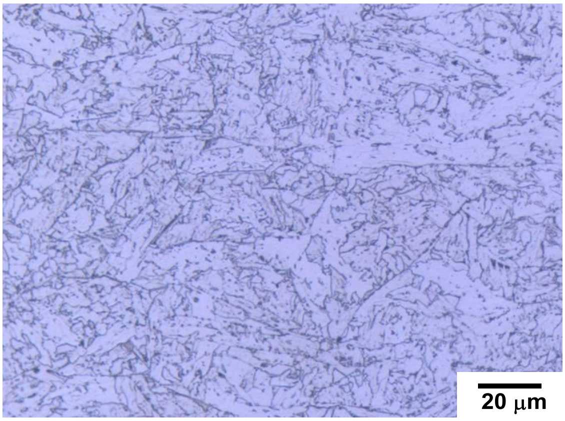

Figure 3. Microstructure of YP 450 MPa steel.

Weldability and Properties of Developed Steel

The welding processes used to test the weldability of the developed steel were FCAW (Flux Cored Arc Welding) and SAW (Submerged Arc Welding). The test plate was welded at a heat input of 19.2 kJ/cm (FCAW) and 46.1 kJ/cm (SAW). Table III shows the welding conditions used for each welding method and Figure 4 shows the Charpy impact values of the heat affected zone for each welding process.

The Charpy impact test results from the heat affected zone were all over 80 J at -5 °C. The maximum hardness value of the weld zone was 258 HV for the FCAW or SAW welding process. The overall results show that the developed steel has good weldability.

Table III. Welding Conditions for each Welding Method

Thickness (mm)	Welding	Angle	Groove Type	Consumable	Current Amps	Voltage Volts	Speed cm/min	Heat Input kJ/cm
100	FCAW	60°	X	Supercored 81K2 (Ø1.4 mm)	280	32	28	19.2
	SAW	60°	X	Superflux 600/A-3 (Ø3.2 mm)	700	34	31	46.1

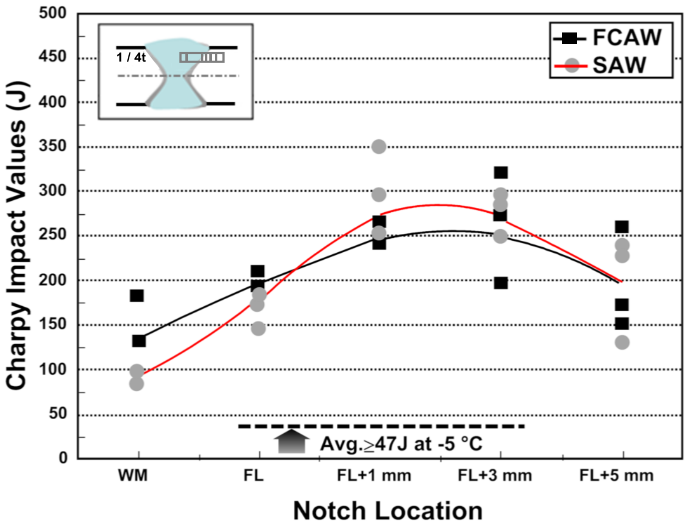

Figure 4. Charpy impact energy values of Weld Metal and Heat Affected Zone.

Application of the Developed Steel

The developed YP 450 MPa grade steel was used for constructing the "Federation of Korean Industries" building (Figure 1), scheduled for completion in 2013. The plates were used for the belt truss and outrigger of the building with a thickness of 100 mm with approximately 1,300 tons of plates used.

Development of YP 650 MPa Grade Steel

Development Concept

Table IV shows the chemical composition of the developed YP 650 MPa grade steel. With the addition of Mo and Mn, the strength was increased by approximately 200 MPa in comparison to the YP 450 MPa steel grade.

The YP 650 MPa steel was developed with a well designed low C-microalloyed chemistry and TMCP+AC technology, to have high strength with good toughness and weldability.

Table IV. Chemical Composition of YP 650 MPa Grade Steel

Thickness (mm)	Chemical Composition (wt.%)						
	C	Si	Mn	P	S	Ceq	Others
50	≤0.08	≤0.30	≤2.00	≤0.020	≤0.006	0.55	Cu,Ni,Nb,Ti,B,Mo

Mechanical Properties of Base Material

Table V shows the mechanical properties of the YP 650 MPa structural steel: Yield strengths of 690-744 MPa, tensile strengths of 859-905 MPa and favorable yield/tensile ratios (80-82%) were obtained. Moreover, Charpy V-notch absorbed energies above 230 J at -5 °C, according to KS HSA800 were attained (Figure 5). The microstructure of the developed steel (Figure 6) is composed of mainly bainite and a small amount of MA constituent.

Table V. Mechanical Properties of YP 650 MPa Grade Steel

Location	YP (MPa)	TS (MPa)	YR (%)	El. (%)	vE -5 °C (J)
1/4t	744	905	82	20	236
1/2t	690	859	80	20	253

In general, if the percentage of martensite or MA increases, the yield ratio rises simultaneously due to the continuous yielding phenomenon. Thus, a low yield ratio could be maintained by controlling the amount of MA constituent.

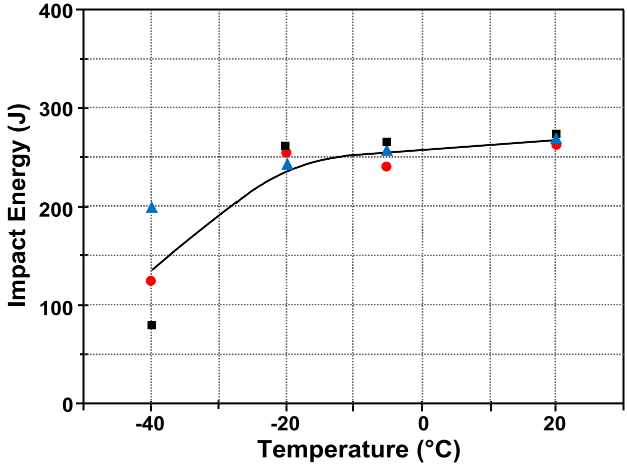

Figure 5. Charpy transition curve of YP 650 MPa steel.
(Points represent individual values and the line represents the average.)

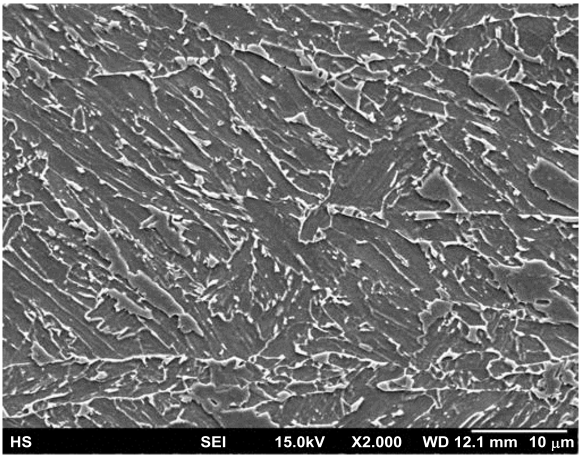

Figure 6. SEM image of YP 650 MPa steel.

Conclusions

1. The Hyundai Steel Company has developed an anti-seismic steel having a SMYS (Specified Minimum Yield Strength) of 450 MPa and TS of 650 MPa by adopting TMCP technology with an optimized alloy design.

2. High strength with a low YR, good impact toughness and good weldability can be obtained by controlling the ratio of bainite, ferrite and MA and by utilization of TMCP.

3. The YP 450 MPa grade steel was used in the construction of the "Federation of Korean Industries" building and the YP 650 MPa grade steel will be applied to higher skyscrapers as a construction material.

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