Niobium Bearing Structural Steels
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OVERVIEW ON THE NB-ADDED HSLA STEELS FOR PRESSURE VESSELS IN CHINA

Qin Xiazhong[1], Li Shurui[2], Guo Aimin[2], Gu Xianshan[3], Xi Tianhui[2]

1 China National General Machinery Engineering Corporation
2 R&D Center WISCO, China
3 Hefei General Machinery Research Institute, China

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Abstract

This paper discusses the impact of the 11th Five-Year Development Plans of China's Energy & Petrochemical Industry on the Pressure Vessel Industry. The paper provides a brief introduction to the key areas, requirements and presents the current status of pressure vessel development and associated steel grade developments. Covering a range of topics from new materials requirements, storage-transport vessels, and heat exchangers through to the present status of steel requirements for coal gasification, the paper concludes with an examination of the future requirements for pressure vessel steels.

Introduction

Steels for pressure vessels have received more attention in the world compared with steels for other end uses. This is no exception in China. However, there are a few grades for pressure vessel fabrication that can be manufactured in the Chinese steel works because of the limitation of the steelmaking process and equipment until the early 1990s. Moreover, the commercial steel plates usually exhibit poor toughness or weldability for engineering applications. With the metallurgical technique progress that has been made in China, a series of steel grades for pressure vessels has been developed and will be applied in the next decade. The product performance has also improved. Today, the steels for pressure vessels in China are built to some Chinese mandatory standards, i.e. GB713- *Steel Plates for Boilers and Pressure Vessels*, GB3531- *Low Alloying Steel Plates for Low Temperature Pressure Vessels*, and GB19189- *Quenched and Tempered High Strength Steel Plates for Pressure Vessels*.

To review the evolution of the steels for pressure vessels in China, it is noticed that micro-alloying technique, especially for niobium micro-alloying, acted as an essential function all along. For the early few grades, based on C-Mn alloying design, known as 16MnR in China, the main effort was to guarantee strength by increasing C, Mn content because of lack of other effective methods. Therefore, the impact toughness and weldability of the plates would be decreased to a poor level. With adopting Nb, V, Ti micro-alloying design concept, it became achievable by grain-fined strengthening and precipitate strengthening [1,2,3]. Furthermore, the

decrease in C content to a reasonable level leads to the achievement of high toughness and good weldability. Among the modern steels listed in the above standards, the mandatory requirement to make Nb additions can be found in different grades.

In this paper, several typical Nb-added HSLA steels for pressure vessels in China, corresponding to different grades and application conditions, chemical composition, mechanical properties, and weldability, are introduced. The prospective applications of Nb alloying steel for pressure vessels in China are also briefly discussed.

YS 370MPa grade steel plates for pressure vessels

There were three main aims to develop the yield strength 370MPa grade steel plates for pressure vessels. The first was to increase strength to satisfy the demand of reducing the vessel's shell thickness. The second was to improve Charpy V-notch impact energy at -20°C to meet the safety requirement. The third was to achieve favourable weldability simultaneously to make engineering fabrication more flexible. This grade of steel was first developed by WISCO, known as WH530 or 15MnNbR, and now it is listed in GB713 mandatory standard. Also, this grade steel plate has been the most popular material for LPG, or propylene spherical pressure vessels building in China, where the maximum normal volume can be 3000m^3.

Table 1 shows the chemical composition for heat analysis and the mechanical properties for plates according to the GB713 standard. From an alloying design perspective, the addition of Nb is a mandatory requirement with the maximum C content decreasing to 0.18% (in wt.) compared to the conventional grade where it can be 0.25%C. The equivalent carbon content (CE), an index to evaluate weldability of C-Mn steels, had also been decreased. Consequentially, the target temperature for plate Charpy impact test had been lowered from room temperature to -20°C.

Table 1. Chemical composition and mechanical properties Q370R steel.

Chemical composition (wt. %)	C	Si	Mn	Nb	P	S
	≤0.18	≤0.55	1.20-1.60	0.015-0.050	≤0.025	≤0.015
Mechanical properties	Tensile test			Charpy V-notch impact test		
	YS (MPa)	UTS (MPa)	El. (%)	Temp. (℃)	Energy (J)	
	≥370	530～630	≥20	-20	≥34	

During the steelmaking process, secondary refining and normalizing heat treatment after hot rolling is always needed to attain high internal cleanness in the slab and achievement of a stable microstructure in the plate. Table 2 summarizes some test results on plates and weldments, which is referenced in Chinese publications [4,5].

. Table 2. Mechanical properties of Q370R steel plates and weldments.

	Thickness (mm)	Tensile test			Charpy V-notch impact test	
		YS (MPa)	UTS (MPa)	El. (%)	Temp. (℃)	Energy (J)
Base Plates	24	415	580	27	-20	145
	48	400	565	29	-20	106
Weldments	24	--	595	--	-20	142(HAZ)
	48	--	565	--	-20	114(HAZ)
	44	--	540	--	-20	110(HAZ)

Nb-added HSLA steels for low temperature pressure vessels

Development of steels for low temperature pressure vessels based on C-Mn alloying design and Ni content not exceeding 1.0% wt. has been Chinese researcher's road-map from the beginning, where the service temperature can be between -70°C to -40°C. The main microstructure of finished plates must be ferrite and pearlite because of the post weld heat treatment. The good balance between strength and low temperature toughness must be kept because the structure must maintain low temperature integrity. To achieve such performance targets, it is no doubt that micro-alloying and grain-refining is the key metallurgical approach to use.

In the GB3531 Chinese mandatory standard, there were several HSLA steels specified for low temperature pressure vessels, with yield strengths from 295MPa to 345MPa and service temperatures of -70°C to -40°C. These steels basically meet the domestic engineering demands for low temperature applications.

Here is another steel for low temperature pressure vessels developed and manufactured by WISCO recently, and not listed in GB3531 yet. Table 3 and Table 4 show the technical requirements on chemical composition and mechanical properties, and properties tested on industrial plates and weldments, respectively[6,7]. This is the same strength grade steel as Q370R mentioned above except that the required Charpy V-notch impact test temperature is 50°C instead of 20°C. Approximately 5000 tons of plates have been produced by WISCO. There have been 17 sets of spherical tanks for low temperature ethylene storage fabricated from these plates in China, where the normal volume of the tanks were all 2000m^3.

Table 3. Chemical composition and mechanical properties of 15MnNiNbDR steel.

Chemical composition (wt. %)	C	Si	Mn	Ni	Nb	P	S
	≤0.18	≤0.55	1.20□1.60	0.30□0.70	0.015□0.050	≤0.020	≤0.010

Mechanical properties	Tensile test			Charpy V-notch impact test	
	YS (MPa)	UTS (MPa)	El. (%)	Temp. (℃)	Energy (J)
	≥370	530～630	≥20	-50	≥60

Table 4. Mechanical properties of 15MnNiNbDR steel plates and weldments.

	Thickness (mm)	Tensile test			Charpy V-notch impact test	
		YS (MPa)	UTS (MPa)	El. (%)	Temp. (℃)	Energy (J)
Base Plates	24	410	550	28	-50	140
	48	390	540	30	-50	161
Weldments	24	--	560	--	-50	96 (HAZ)
	48	--	560	--	-50	165 (HAZ)

Nb-added forging steels for pressure vessels

The components of pressure vessels, such as flanges, manholes, usually have heavy sections with thickness over 100mm. Rolled plates by slabs or ingots do not meet such purposes with too low of a reduction ratio for the finished shape of the component. The forging process is commonly applied in this area. Same as the rolled plate, Nb microalloying principle was the effective methodology to achieve a good matched strength and toughness on the forging components. Table 5 shows two kinds of Nb-added forging steels for pressure vessels in China.

Table 5. Chemical composition and mechanical properties of forging steels

	Grade	C	Si	Mn	Mo	Ni	Nb	P	S
Chemical composition (wt. %)	09MnNiD	≤0.12	≤0.35	1.20-1.60	--	0.45-.85	≤ 0.050	≤ 0.020	≤ 0.010
	20MnMoNb	≤0.15	≤0.50	1.20-1.60	0.20-0.40	--	0.005 □0.020	≤ 0.025	≤ 0.010

	Grade	Thickness (mm)	Tensile test			Charpy V-notch impact test	
			YS (MPa)	UTS (MPa)	El. (%)	Temp. (℃)	Energy (J)
Mechanical properties	09MnNiD	≤300	≥260	430-580	≥23	-70	≥60
	20MnMoNb	≤300	≥470	620-790	≥16	0	≥41
		>300-500	≥460	610-780	≥16	0	≥41

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