Research of Micro-alloyed Microstructure and Composition in X80 Pipeline Steel for High Heat Input Welding

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Abstract. The characteristic of chemical composition of X80 pipeline steel, the microstructure and the existing problems under the condition of high heat input welding were introduced in this paper. The micro-alloyed process of Nb, Ti, V elements in X80 pipeline steel and the influence on the mechanical properties were respectively discussed. In addition, the reasons of the grain coarsening in the welding heat affected zone, the softening and embrittlement in partial microstructure were explored and the corresponding solutions were presented. For X80 pipeline steel, we can see that high strength and high toughness microstructure can be obtained not only by micro-alloyed, but also through the optimization of rolling process and the regulation of cooling rate after hot rolling. X80 pipeline steel with low carbon content and the appropriate micro-alloying, coupled with modern controlled rolling and controlled cooling technology, will have very high strength and toughness. Scholars mainly studied on the composite micro-alloying of Nb and Ti, Al, Ti, Mg, Zr alloy oxides and complex oxide micro-alloying and Ca treatment desulfurization technology, and so on.

Introduction

Pipeline transport is an economic, safe and efficient mode of transport, it can not only transport coal and other solid materials, but also can transport oil and natural gas [1]. And the demand for oil and natural gas is increasing with the rapid development of the national economy, so the demand of pipeline steel as transportation vector is also increasing. By the end of 2010, the total length of oil and gas pipelines is 85,000 km in our country, nearly 80% of onshore crude oil, 20% of refined oil and more than 95% of natural gas are transported through pipelines. In the coming years, with the Northwest, Northeast, Southwest, maritime ‘four strategic lines of oil and gas resources’ to be built [2-4], China’s oil and gas transport industry also will usher in a boom in the spring. The research and development of pipeline steel is toward high levels development of large-diameter, high pressure and automation with the increase of oil and natural gas transportation capacity and transport distance [5].

This paper describes the research and application of X80 pipeline steel, which is widely used in the "West-East Gas Project" in recent years. The characteristic of chemical composition of X80 pipeline steel, the microstructure and the existing problems under the condition of high heat input welding were introduced in this paper. The micro-alloyed process of Nb, Ti, V elements in X80 pipeline steel and the influence on the mechanical properties were respectively discussed. In addition, the reasons of the grain coarsening in the welding heat affected zone, the softening and brittlement in partial microstructure were explored and the corresponding solutions were presented.

Characteristics of the Chemical Composition of X80 Pipeline Steel

Typical carbon content of X80 pipeline steel is 0.04% to 0.08%, however in some special cases,

carbon content can reach the levels of 0.02%. In dealing with offshore, under extremely adverse natural conditions, such as polar, X80 pipeline steel must have low carbon equivalent, so that in the welding process, welding without preheating and post weld heat treatment are performed, and that also can ensure good toughness of welded joints, in order to prevent cracking caused by sulfur compounds. In this way, the decrease of carbon content will inevitably lead to the decrease of the mechanical properties of steel, such as hardness and yield strength.

Modern micro-alloyed technology is a micro-alloying of Mn alloying elements in X80 pipeline steel to compensate for the reduction of mechanical properties due to reduced carbon content. The principle is mainly that the lattice distortion caused by Mn element is larger than carbon in the pipeline steel, so Mn has the better solid solution strengthening effect than carbon. However, too much Mn content will accelerate the center segregation of X80 pipeline steel during hot rolling. Therefore, depending on the different thickness and strength, Mn content is generally controlled from 1.1% to 2.0% in the micro-alloying process [6].

Micro-alloying elements of pipeline steel are mainly the strong nitride-forming elements of Nb, Ti, V, and so on. Its main function is to prevent the growth of austenite grain in the steel plate controlled rolling process and to delay the recrystallization of austenite grain in the process of rolling steel [7]. Nb is not only one of the leading fine-grain strengthening elements, but also have the role of moderate precipitation hardening and reducing the ductile-brittle transition temperature of steels. Therefore they added appropriately a small amount of Nb in HSLA steels. However, the studies [8] on the precipitates dissolution and grain growth in the HAZ for HSLA-100 steel indicated that Nb (C, N) has started to dissolve at 1200℃, austenite grain coarsening occurs, and dissolved a lot at 1300-1400℃, austenite grain coarsening significantly. Therefore, the high strength micro-alloyed steel single used Nb is difficult to stand high heat input welding. For this reason many scholars are studying on Nb and Ti micro-alloying HSLA. The addition of Ti element into steel can form stable nitrides, such as TiN, in the welding peak temperatures. TiN of fine distribution in the HAZ can prevent austenite coarsening, accelerate the formation of acicular ferrite, refine HAZ transformation product and improve the strength and toughness of HAZ. As same as Ti, V is one of the main strengthening elements in steel. However, the ductile-brittle transition temperature of steels containing V is usually higher than that of steel containing Nb and Ti, So V as micro-alloying element is not often used individually in steel, and it is used generally with Nb and Ti simultaneously. VN is formed in steel, the interfacial energy between VN and the ferrite is lower, that is conducive to the nucleation of acicular ferrite and grain refinement, and that can improve the mechanical properties of steel.

X80 pipeline steel belongs to a high degree of ‘clean steel’. Modern metallurgical techniques have been developed to ensure that the contents of impurities and gases are at a low or ultra-low level. This production level is closely related to the development of metallurgy and a variety of new technologies, such as hot metal pretreatment, BOF refining, ladle metallurgy, continuous casting, etc.

Tables 1 and 2 [9] introduced the specific conditions of the chemical composition and mechanical properties of X80 pipeline steel on ‘West-East Gas Project’. Table 2 shows that the conditions of the low carbon content and the right amount of micro-alloying elements, together with the controlled rolling and controlled cooling technology, can make steel with high strength and toughness, which is unavailable on the condition of the traditional alloying process with hot rolling.

Tab. 1 Chemical compositions of X80 pipeline steel (wt %)

C	Si	Mn	P	S	Cr	Mo	Ni	Nb
≤0.09	≤0.42	≤1.85	≤0.022	≤0.005	≤0.45	≤0.35	≤0.50	≤0.11
V	Ti	Cu	B	Al	N	V+Nb+Ti	Pcm	CE
≤0.06	≤0.025	≤0.30	≤0.0005	≤0.06	≤0.008	≤0.15	≤0.23	≤0.43

Note: Pcm=C+Si/30+(Mn+Cu+Cr)/20+Ni/60+Mo/15+V/10+5B
CE=C+Mn/6+(Cr+Mo+V)/5+(Cu+Ni)/15

Tab. 2 Mechanical properties of X80 pipeline steel

Tensile properties				Charpy impact toughness		DWTT
R_m / MPa	$R_{t0.5}$ / MPa	A / %	$R_{t0.5}$ / R_m	A_{kv} / J	SA / %	SA / %
625~825	555~690	≥16	≤0.93	≥240	≥90	≥85

Microstructure and Structure of X80 Pipeline Steel

Fig.1 shows the microstructure of X80 pipeline steel [10]. This microstructure is obtained by controlled rolling and accelerated cooling process. The microstructure of X80 pipeline steels is polygonal ferrite and acicular ferrite. X80 pipeline steel obtained general through controlled rolling and cooling has high toughness and strength [11]. The reason is that the ferrite microstructure has high dislocation density, especially the acicular ferrite has the higher dislocation density, and the ultrafine dispersion phases are precipitated on the ferrite matrix and nanoscale precipitates were produced at dislocation tangles. In addition, the cooling rate after hot rolling will have a significant impact on the microstructure and mechanical properties of X80 pipeline steel. When the cooling rate is slower, granular bainite transformation occurs and the strengthening phases are formed. When the cooling rate is faster, the fine grain strengthening effect will produce. With increasing cooling rate after rolling, the hardness of materials is increasing. For X80 pipeline steel, we can see that high strength and high toughness microstructure can be obtained not only by micro-alloyed, but also through the optimization of rolling process and the regulation of cooling rate after hot rolling, so as to obtain the best mechanical properties.

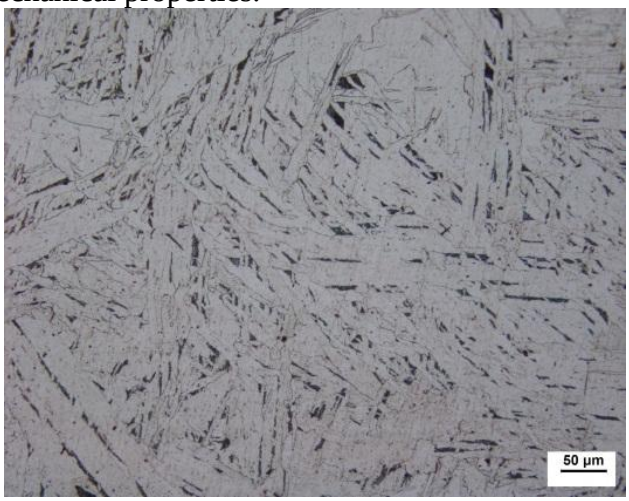

Fig. 1 Microstructure of X80 pipeline steel

X80 pipeline steel with low carbon content and the appropriate micro-alloying, coupled with modern controlled rolling and controlled cooling technology, will have very high strength and toughness. The corresponding solutions to the softening and embrittlement in partial microstructure in the high heat input welding process were presented. Scholars mainly explored the following aspects, such as composite micro-alloying of Nb and Ti, Al, Ti, Mg, Zr alloy oxides and complex oxide micro-alloying and Ca treatment desulfurization technology, and so on.

Conclusions

The characteristic of chemical composition of X80 pipeline steel, the microstructure and the existing problems under the condition of high heat input welding were introduced in this paper. The micro-alloyed process of Nb, Ti, V elements in X80 pipeline steel and the influence on the mechanical properties were respectively discussed. In addition, the reasons of the grain coarsening in the welding heat affected zone, the softening and embrittlement in partial microstructure were explored and the

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(1) For X80 pipeline steel, we can see that high strength and high toughness microstructure can be obtained not only by micro-alloyed, but also through the optimization of rolling process and the regulation of cooling rate after hot rolling.

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