Microstructure and Mechanical Impact Behavior of Ultra-Low Carbon Microalloyed Pipeline Steel Used in Chemical Pipeline during Welding Heat Treatment

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Abstract: Through optical microscopy, scanning electron microscopy, transmission electron microscopy and impact testing machine and other equipment, this paper study the microstructures and impact properties of ultra-low carbon microalloyed pipeline steel. The results show that the base metal of ultra-low carbon microalloyed pipeline steel is mainly composed of granular bainite and bainite ferrite. The coarse grain structure of HAZ in welded joints mainly includes bainite ferrite, granular bainite, a small amount of polygonal ferrite and fine M-A island, and the grain size is coarse. The acicular ferrite in the weld is mainly induced by complex oxides of titanium, aluminium, silicon and manganese. And the organizational structure is interlaced with the basket weaving structure. The microstructures of weld zone and heat affected zone of ultra-low carbon microalloyed pipeline steel are obviously different.

1. Introduction

With the development of economy, the demand for energy is increasing all over the world. At present, pipeline transportation is the most economical and applicable transportation method for natural gas and oil. Energy enterprises reduce the cost of pipeline transportation by continuously increasing the working pressure of pipelines. The power of pipeline steel development also comes from the increasingly stringent requirements of pipeline engineering for pipe materials. With the development of polar, remote, acidic and offshore oil and gas fields, pipeline engineering is facing the challenges of low temperature, large displacement, acidic medium, deep sea and other harsh environments. In order to ensure the economy and safety of pipeline construction, pipeline steel gradually requires high strength and toughness, high corrosion resistance, large deformation, thick wall, good weldability and other characteristics. Since the 1950s, microalloyed steel has been applied to chemical pipelines. Microalloyed pipeline steel has been studied and produced for 50 years internationally. Especially since 1990s, some world-class super-large oil and gas fields have been discovered successively. Therefore, the pipeline industry has entered a new period of development. Therefore, ultra-low carbon microalloyed pipeline steel has entered a new stage of development.

2. Weldability of pipeline steel

2.1 Welding method of pipeline steel

Oil and gas pipeline engineering is a large-scale welding forming and long-distance welding installation process. The main welding methods of pipeline steel are pipe forming welding and on-site girth welding. At present, in the manufacture of welded pipe, the main welded pipes for pipelines at home and abroad are LSAW pipe, LSAW high frequency resistance welded pipe and spiral submerged arc welded pipe. Longitudinal submerged arc welded steel pipe can be divided into RBE, UOE and JCOE according to its forming method. RBE is to roll and bend the steel plate, and then expand the diameter. UOE is formed in the order of U-O in the forming die, and the diameter is enlarged after welding. JCOE is formed in the order of J-C-O in the forming die and enlarged after welding. At present, UOE steel pipe is used in the main long-distance pipelines abroad. The forming and welding of UOE steel pipe are different at the same time. The welding quality is easy to control and the performance reliability is high.

2.2 Weldability of pipeline steel

Successful laying of pipeline steel pipe requires good field weldability, which requires that the carbon equivalent of pipeline steel should be as low as possible. Welding brittleness is related to carbon content and alloy content in steel. The greater the carbon equivalent, the easier the welding cracking will occur. Carbon equivalent (CEnw) is used to indicate the effect of carbon and alloy elements on the cracking trend after welding. The relationship between CEnw and weldability is shown in Figure 1.

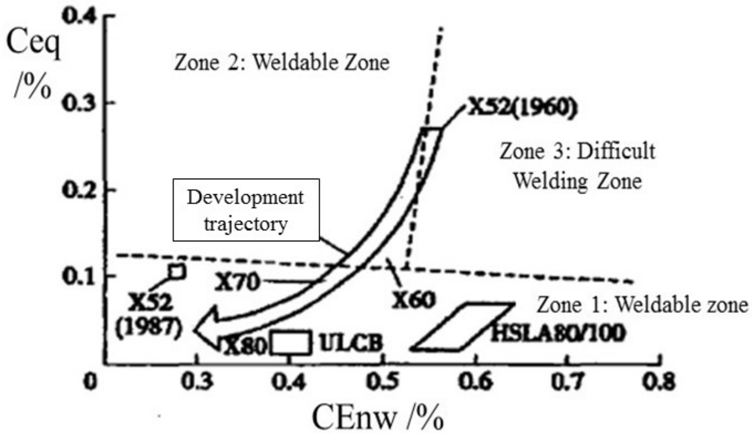

Figure 1 Relation Diagram of Ceq, CEnw and Weldability of Steel

International Welding Society (IIW) uses Ceq formula to calculate Cenw.

$Ceq=C+Mn/6+(Ni+Cu)/15+(Cr+Mo+V)/5$

3. Test methods

Ultra-low carbon microalloyed pipeline steel from a domestic plant was selected in this test. The thickness is 15.0 mm. Its chemical composition is 0.044C, 0.2Si, 1.95Mn, 0.011P, 0.002S, 0.39Ni, 0.28Cr, 0.21Cu, 0.07Nb, 0.01V, 0.014Ti, 0.25Mo, 0.03Al, 0.0003B. Its carbon equivalent is 0.52 and the welding crack sensitivity index Pcm is 0.2. Its mechanical properties are shown in Table 1.

Table 1 Mechanical properties of pipeline steel

Tensile strength R_m /MPa	Yield strength $R_{p0.2}$/Mpa	Elongation after breaking A /%	HV10	Shock Absorption Power KV (-20^oC)/J
930	800	15.5	290	201

GLC403 QUINTO double wire gas shielded welding machine manufactured by Cloos Company of Germany was used in this test. According to the principle of "low strength matching", flux-cored wire of type TWE-110K3 and diameter of 1.2 mm is used for welding material. The preheating temperature is 120 C, and the interlayer temperature is controlled between 150 and 200 C.

4. Test results and discussion

4.1 Microstructure of welding

As can be seen from Figure 2, the the base metal microstructures of ultra-low carbon microalloyed pipeline steel are mainly composed of granular bainite (GB) and bainite ferrite (BF). GB is mainly elongated strip with small angle between strips. This kind of grain boundary with small angle is not easy to corrode and appears as irregular small pieces under the microscope. BF slab is long and narrow, and its boundary is clear. Proper BF can improve the toughness and plastic toughness of steel. In pipeline steel, both GB and BF belong to acicular ferrite (AF), but their morphologies are different. AF has irregular non-equiaxed morphology and high density dislocations in ferrite.

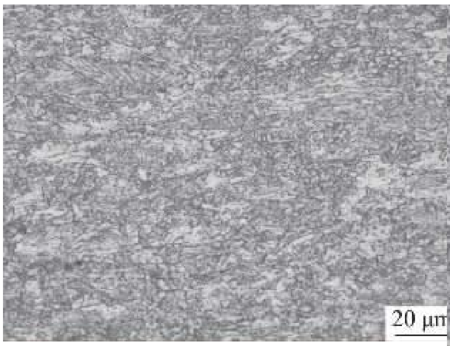

Figure 2 Microstructure of base metal

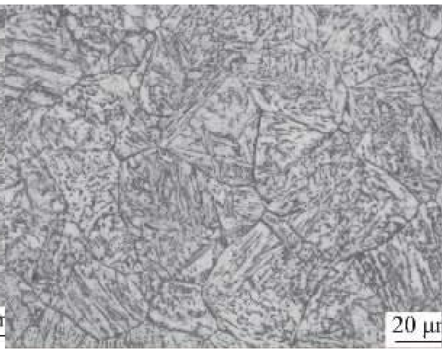

Figure 3 Microstructure of HAZ

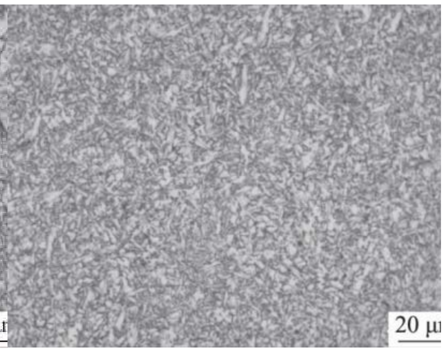

Figure 4 Microstructure of weld seam

After welding heat treatment, we get Figure 3. The structure of coarse grained zone in HAZ is larger than that of base metal, which indicates that the grains grow rapidly under the action of welding thermal cycle. With the coarsening of the material structure, the material will become more brittle. Its microstructures are mainly BF and GB, and a small amount of polygonal ferrite (PF). BF grows from the original austenite grain boundaries to the grains with parallel slabs. Some BF slab bundles penetrate the original austenite grain. The original austenite grains are divided into different regions by BF beams in different orientations. The grain boundaries of primary austenite are clearly visible.

Ultra-low carbon microalloyed pipeline steel contains relatively high content of alloy strengthening elements, such as manganese, chromium, nickel, molybdenum and other alloy elements. In the welding process, we can inhibit the precipitation of pre-eutectoid ferrite, which will obtain the weld structure mainly composed of GB and AF and a very small number of M-A islands. Details are shown in Figure 4. This kind of AF is different from that in the base metal. The AF formed in the welding process is mainly induced by inclusions and nucleated in the crystal.

4.2 Impact toughness analysis

Impact toughness is an important index for testing mechanical properties of metal materials, which can well reflect the resistance of metal materials to external impact load. The impact toughness can also reflect the resistance of different regions of the joint to external impact load. The impact test results of CO^2 welding joints of pipeline steel at room temperature (20^{o}C) and low temperature (-20^{o}C) are shown in Figure 5.

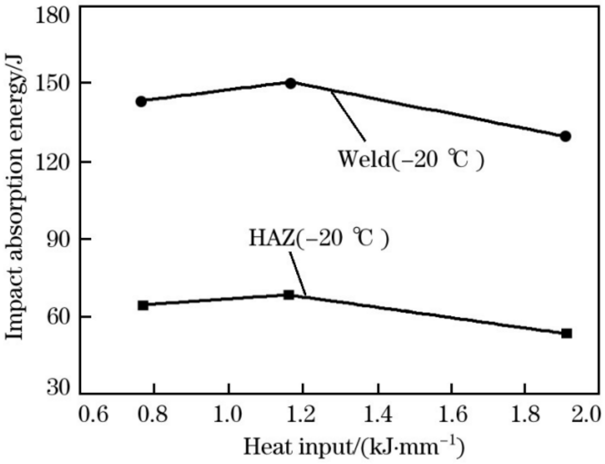

Figure 5 Effect of heat inputs on impact toughness of carbon dioxide arc weld joints

5. Conclusions

The inclusion inducing acicular ferrite nucleation is a composite oxide containing Ti, Al, Si and Mn elements, which plays an important role in the formation of acicular ferrite. The impact property of the weld zone of low carbon microalloyed pipeline steel is very good. With the increase of welding heat input, the tensile strength and yield strength of welded joints decrease. However, the maximum strength-plastic product is obtained when the heat input is 1.17 kJ/mm. The low-temperature shock absorption energy at weld and HAZ increases first and then decreases. On the whole, we can use 1.17 kJ/mm as the best heat input for CO2 welding of pipeline steel.

References

[1] Li Jihong, Yang Liang. Microstructure and impact properties of welded joints of ultra-low carbon microalloyed pipeline steel [J]. Mechanical engineering materials, 2014, 38 (6): 75-78.

[2] Yang Huihui. Effect of heat treatment process on the structure and properties of investment casting die steel [J]. Casting technology, 2014, 35 (7): 1453-1455.

[3] Yang Xisheng, Yang Bin, Peng Yun, et al. Study on Welding Softening Behavior of Low Alloy Quenched and Tempered High Strength Steel [J]. Hot Processing Technology, 2013, 42 (17): 32-36.

[4] Chen Huaizhong, Xu Xuegui, Huang Fang. Study on weldability of steel pipe girth based on PLC [J]. Military Material Science and Engineering, 2014 (3): 41-44.