Seam Welding of High Strength UOE Line Pipe

1. Introduction

For long-distance natural gas pipelines, there is growing demand for stronger UO pipe which permits cutting the cost of transportation by higher top-pressure operation or the cost of pipeline construction by reduction of the pipe diameter/wall thickness[1]. Nippon Steel Corporation has developed a high-strength UO pipe X120 (Specified minimum yield strength: 827 MPa, Specified minimum tensile strength: 931 MPa) that affords far superior strength to X80, which has already been put into practical use. The company is evaluating the new UO pipe with the aim of putting it into practical use[2].

UO pipe is manufactured by welding steel plate formed into a cylinder by a C press, a U press and an O press. (The welding process used to manufacture UO pipe is hereinafter referred to as seam welding.) Needless to say, the seam weld metal is required to have the same mechanical properties as those required of the base metal. In developing a high-strength UO pipe, therefore, it is absolutely necessary to design a weld metal which is compatible with the base metal. As a matter of fact, weld metal design is an indispensable element in the development of any new UO pipe. This paper describes seam welding of high-strength UO pipes represented by X120.

2. Seam Welding of UO Pipes

Seam welding the DSAW (Double SAW) method in which the seam is first tacked by gas shielded metal arc welding and then joined by submerged arc welding (SAW) from the inside and outside of the pipe. From a productivity standpoint, the tack welding needs to be carried out speedily. However, since sufficient strength is required of the tack weld, various welding conditions are studied and the optimum ones are adopted. The tack weld is completely removed by the subsequent SAW. Ultimately, therefore, the UO pipe seam weld is composed of one layer on each side. **Fig. 1** schematically shows the UO pipe seam welding process. First, steel plate is formed into a pipe and the seam is tack-welded from the outside. Next, SAW is applied to the pipe from the inside. The figure shows as if the SAW were applied in an overhead position. Actually, however, the pipe is turned 180 degrees and the SAW is performed in a downward position. Then, the pipe is turned 180 degrees again and subjected to SAW from the outside. **Fig. 2** shows an example of a DSAW weld prepared in the laboratory simulating a UO pipe seam weld.

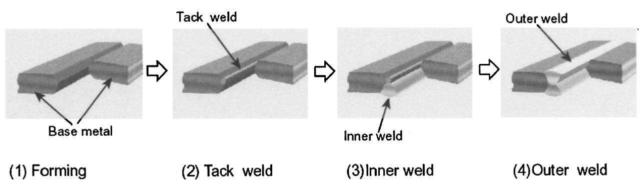


Fig. 1 Schematic illustrations of seam welding process of UO pipe

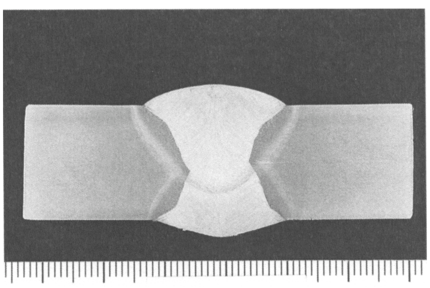


Fig. 2 Macro-appearance of DSA weld

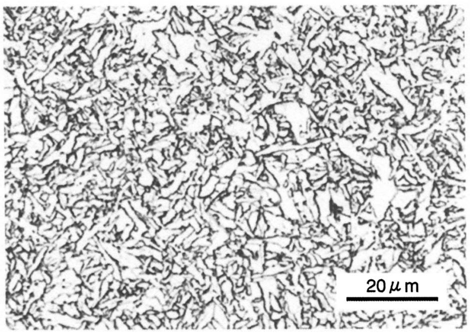
3. Design of Seam Weld Metal Chemical Composition

In the seam welding of UO pipes, multi-electrode SAW, or SAW using multiple welding wires, is applied. Ordinarily, the seam weld metal is used as welded. Therefore, the mechanical properties of seam weld metal are determined largely by the chemical composition of the weld metal. On the other hand, the weld metal chemical composition is strongly influenced by the base metal since the base metal dilution rate in SAW is high. Therefore, in designing the chemical composition of weld metal, consideration is given not only to the chemical composition of the welding material but also to that of the base metal, and an alloy wire which offers optimum weld metal chemical composition is adopted. Ordinarily, the oxygen content of SAW weld metal is kept low so as to ensure sufficient toughness of the weld metal. In the seam welding of high-strength UO pipe too, the oxygen content of the weld metal is kept low for the same purpose. In SAW, the oxygen content of the weld metal is adjusted by the flux. For high-strength UO pipe, a low-oxygen-based flux is used.

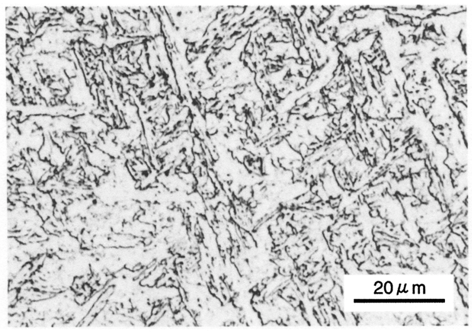
4. Characteristics of Seam Weld Metal

The microstructure of the seam weld metal of UO pipes is determined largely by the alloy content, and the strength of the seam weld metal is determined largely by the microstructure. With the increase in strength, the weld metal microstructure changes from acicular ferrite to bainite, which changes to martensite when the alloy content is increased further. **Fig. 3** shows the microstructures of two different weld metals; one having a tensile strength of 717 MPa and the other having a tensile strength of 970 MPa. The weld metal having a tensile strength of 717 MPa presents an acicular ferrite structure, whereas the weld metal having a tensile strength of 970 MPa presents a bainite structure. **Fig. 4** shows an SEM image of high-strength SAW metal having a tensile strength of 970 MPa. X120 has been subjected to composition adjustment so that the microstructure of its seam weld metal becomes bainite.

The seam weld of UO pipes is required to have both strength and low temperature toughness. Generally speaking, however, strength and toughness are incompatible with each other. **Fig. 5** shows the relationship between tensile strength and absorbed energy at −20℃ obtained with low-oxygen weld metal. In the figure, each absorbed energy value is the average of values obtained at three points. As shown in Fig. 5, there is a tendency that the energy absorbed by the weld metal decreases with the increase in weld metal strength.



(a) TS : 717MPa



(b) TS:970MPa

Fig. 3 Micro-structures of SA seam weld metal

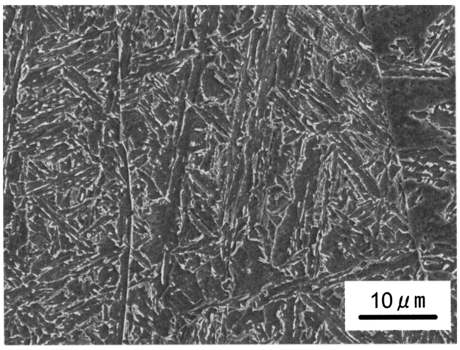


Fig. 4 Microstructure of SA seam weld metal (TS: 970MPa)

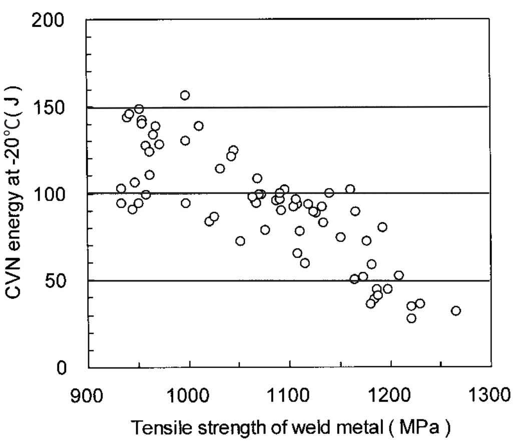


Fig. 5 Relationship between tensile strength and CVN energy of SA seam weld metal

Table 1 Typical chemical compositions of X120 SA seam weld metal

	Chemical composition (mass%)							
	C	Si	Mn	Ni	Mo	Cr		P_{cm}
O/W	0.051	0.23	1.63	2.2	0.92	1.0	Others	0.306
I/W	0.051	0.18	1.69	2.3	0.98	1.1	Others	0.315

O/W: outer weld, I/W: inner weld

Table 2 Typical mechanical properties of high strength SA seam weld metals

Grade		TS (MPa)	El (%)	Ave. of CVN Energy at –30℃ (J)
X80	O/W	717	21	192
X100	O/W	875	22	183
X120	O/W	1008	20	135
	I/W	958	21	

O/W: outer weld, I/W: inner weld

However, even when the weld metal strength remains unchanged, the energy absorbed by the weld metal varies slightly. A study showed that the variation was due to the difference in trace elements other than oxygen. It was found that toughness of the weld metal could be stabilized by optimizing the content of those elements.

Table 1 shows typical chemical compositions of seam weld metal of X120-equivalent prepared in the laboratory. **Table 2** shows typical mechanical properties of weld metals of X80-, X100- and X120-equivalent also prepared in the laboratory. As in the case shown in Fig. 5, the energy absorbed by the weld metal at − 30℃ decreases with the increase in weld metal strength. However, even with X120-equivalent having a tensile strength of 1,008 MPa (the outer weld metal), it was possible to obtain high energy absorption – 135 J on average – by optimizing the weld metal’s chemical composition. In the case of X120 pipe, the development targets for the weld metal are a tensile strength exceeding 931 MPa and an absorbed energy of 84 J on average. Those targets have been attained.

5. Conclusion

The high strength UO pipe, X120, has been co-developed by Nippon Steel and ExxonMobil. It is being put into practical use through comprehensive research and development in the fields of material design, steelmaking, casting, plate production and pipe-making. As part of the R&D, we implemented composition design of weld metal for high-strength UO pipe which renders strength and toughness compatible with each other. As a result, it was possible to successfully develop a high-strength weld metal which meets the above requirement with a good balance between strength and toughness.

References

1) Corbett. K.T. et al.: Proceedings of the International Offshore and Polar Engineering Conference. 2003, p.105
2) Asahi, H. et al.: Shinnittetsu Giho. (380), 70 (2004)

For further information, contact
Steel Research Laboratories