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Effect of boron addition on the toughness and the microstructure of high strength linepipe seam weld metal †

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Abstract

The effect of boron addition on the toughness and microstructure of seam weld metal was investigated in tensile strength range from 700 to 1100 MPa. Two types of weld metal were produced in this study. Type A weld metal was produced with boron added through the flux. Type B weld metal was produced by boron free flux. In the tensile strength range less than 800MPa, type B weld metal showed lower absorbed energies than type A because of grain boundary ferrite formation. In the tensile strength range of 800MPa or more, type B weld metal showed greater absorbed energies than type A. In this tensile strength range, some acicular ferrite is replaced with bainite or bainite/martensite and the absorbed energy decreases with increasing tensile strength. The type B weld metal had more acicular ferrite and greater absorbed energy than type A in this tensile strength range.

KEY WORDS: (Weld Metal) (Boron) (Toughness) (High Strength Steel) (Line Pipe) (Acicular Ferrite)

1. Introduction

Natural gas is one of the most promising energy sources from the viewpoint of environmental load reduction. The demand for natural gas is growing worldwide. In order to meet future demand, remotely located resources must be made economical. Natural gas is often transported through long distance pipelines using large diameter UOE pipes. The gas transmission pipelines must be operated at high pressure for long distances and must be constructed with less steel. To maximize economic advantages, the use of higher-strength steels (X80 and over) in pipeline systems has been investigated [1][2] . X80 grade steels have been developed and utilized for gas pipelines. Regarding X100, this steel has been developed and the characterization of prototype pipes has been extensively studied by pipe manufacturers [3]-[6] and by a joint industry project of major oil companies [7]. In the case of X120 grade steel, a basic concept has been developed [8] and prototype pipes have been developed and evaluated[9]-[12].

In development of high strength UOE pipes, development of the longitudinal seam weld metal is one of important issues. Generally, weld metal toughness is obtained by controlling the microstructure to fine acicular ferrite. Acicular ferrite is a kind of intragranular bainitic ferrite. Thus acicular ferrite must have an upper limit of tensile strength, although is the tensile strength limit not well understood. On the other hand, in the case of the seam weld metal of X80 grade or less, a small amount of boron is added into the weld metal to prevent the precipitation of grain boundary ferrite. Seam weld metals of X100 and X120 grade must have rich chemistry to achieve high strength. In these kinds of weld metal with rich chemistry, it is expected that the precipitation of grain boundary ferrite can be eliminated without boron addition.

This report describes the influence of B addition on toughness and microstructure of weld metal with tensile strength of 700 MPa or greater. This investigation has been conducted for the development of longitudinal seam weld metal in X100 and X120 grade UOE pipe.

2. Weld metal chemistry and properties

Numerous seam welds were made in the laboratory using candidate X100 and X120 plates and many wire combinations. Steel plates with wall thickness of 20 and 25 mm were used as base metal. The weld heat input was controlled at about 3kJ/mm for 20mm wall thickness plates, and 4.5kJ/mm for 25mm. The four electrodes (DC-AC-AC-AC) submerged arc welding process was applied to simulate the longitudinal seam welding of

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Table 1 Chemical composition of welding flux (mass%)

Mark	SiO2	MnO	CaO	CaF2	B2O3	Others	*BI
Flux A	20	3.5	16	37	0.4	Al2O3, TiO2, BaO	2.5
Flux B	20	3.5	16	37	<0.1	Al2O3, TiO2, BaO	2.5

*BI(Basicity Index)=(CaO+MgO+BaO+CaF2+0.5(MnO+FeO))/(SiO2+0.5(Al2O3+TiO2+ZrO)

UOE pipe manufacturing. In order to change the boron content of weld metal, two kinds of welding flux were prepared. Both fluxes were the fused type flux with high basicity of 2.5 to obtain a weld metal with low oxygen content. For the purpose of boron addition to weld metal, B_2O_3 was blended with Flux A. Chemistry of welding flux is shown in table 1.

Boron content of the weld metal produced using flux A (type A weld metal) was from 0.0025 to 0.0034mass%. On the other hand, boron content of weld metal produced using Flux B (type B weld metal) was 0.0015mass% or less. The boron appearing in type B weld metal arises because B_2O_3 occurs in flux B as impurities and base metal dilution. (Some steel plates used as the base metal contain boron.) Oxygen contents were similar level in both Type A and B weld metals, oxygen contents ranged from 0.024 to 0.032%. All weld metals contained a small amount of titanium in the range from 0.01 to 0.02 mass%. Carbon content was almost constant at 0.06 to 0.07%.

3. Relationship between weld tensile strength and weld metal chemistry

Figure 1 shows the relationship between weld tensile strength and Pcm value of weld metal. Weld tensile strength increases with increasing Pcm value when Pcm value is 0.33 mass% or less. This figure also indicated that tensile strength saturated at around 1100 MPa by applying a Pcm value

of greater than about 0.33 mass%. It was considered that the cause of tensile strength saturation was microstructural change from bainite or bainite/martensite to martensite. Some researchers have reported that the hardness of martensite depends on the carbon content and it can be expressed by the equation (1). There is a little difference in a coefficient (A and B in the equation (1)) proposed by the researchers, although the predicted results are in general agreement. The martensite hardness of 0.07 mass% C steel is predicted to be Hv 340/353. The estimated martensite hardness showed good agreement with 1100MPa which is the saturated level.

Hardness (Hv) of martensite = A x (carbon content(mass%)) + B (1)

M. Becker et al.[13] : A=939, B=284, Hv(martensite)=340

T. Terasaki et al.[14] and N. Yurioka et al.[15]: A=812, B=293, Hv(martensite)=342

K. Lorenz et al.[16] : A=802, B=305, Hv(martensite)=353

The result which plotted tensile strength of weld metal against Ceq (IIW) is shown in figure 2. Tensile strength increases with increasing Ceq (IIW), like the relationship between Pcm and tensile strength. When Ceq (IIW) increases exceeding 0.8 mass%, a maximum of tensile strength is reached.

In both figure 1 and 2, the data plots of type A and B weld metal were distributed in the same bands. This indicated that boron content had little effect on the weld metal tensile strength.

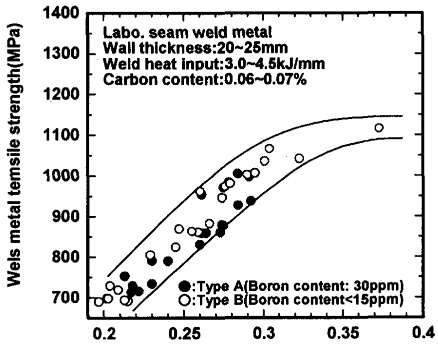

Fig. 1 Relationship between the weld metal tensile strength and Pcm value.

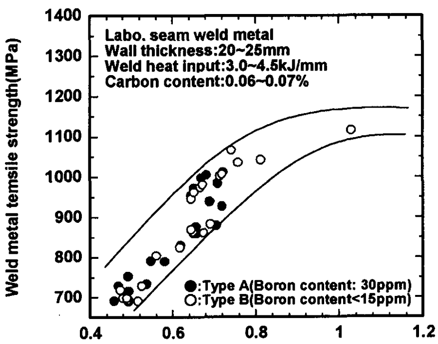

Fig. 2 Relationship between the weld metal tensile strength and Ceq(IIW)

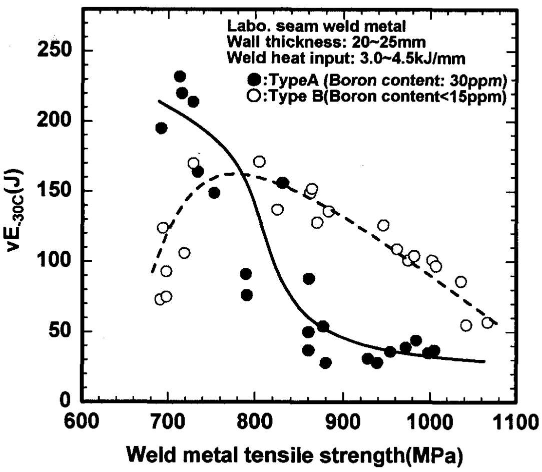

Fig.3 Relationship between Charpy absorbed energyat -30°C and weld metal tensile strength

4. Effect of boron addition on the Charpy V Notch (CVN) properties

Figure3 shows the relationship between Charpy absorbed energy at -30°C (vE-30°C) and weld metal tensile strength. Type A weld metal had a boron content around 30ppm. This type of weld metal had high vE-30°C when tensile strength was around 700MPa. With this type of weld metal, vE-30°C decreased with increasing weld tensile strength and vE-30°C decreased to less than 50J at strengths greater than 900MPa.

At strengths of about 700MPa, type B weld metal had lower vE-30°C than type A. With type B weld metal, as strength increased from 700 to 800 MPa, vE-30°C increased to about 150J. As strength of type B was further increased to above 800MPa, vE-30°C decreased with increasing weld tensile strength. At tensile strengths from 850 to 1000MPa, type B produced greater absorbed energy than type A.

Three Charpy curves of type A weld metal are shown in figure 4. Weld metal A3 with tensile strength of 713MPa had good toughness. Upper shelf energy was 230J and Charpy transition temperature (vTrs) was lower than -60 °C. Weld metal A7 had greater tensile strength and smaller upper shelf energy than A3. Upper shelf energy decreased to 163J and vTrs rose up to around -30 °C. In the case of weld metal A20, weld tensile strength increased to 998MPa and the vTrs rose up to around 10 °C.

In figure 5 Charpy curves of type B weld metal are shown. Weld metal B5 had tensile strength of 719MPa and upper shelf energy of 215J, those values were similar to A3. Although B5 had vTrs of -20°C, it was much higher than vTrs of A3. Thus absorbed energy at -30 °C

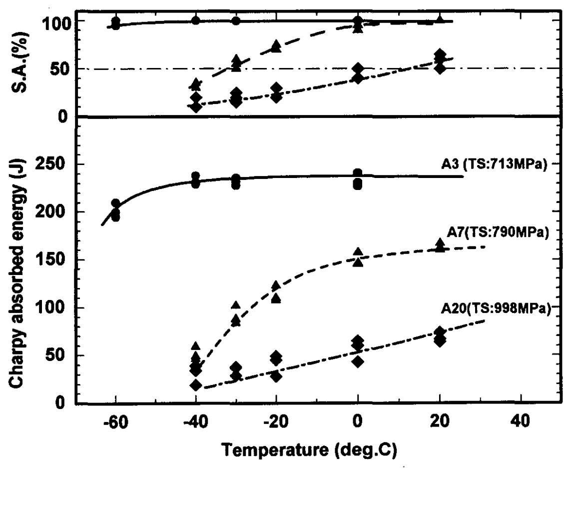

Fig.4 Examples of Charpy curves of type A weld metal

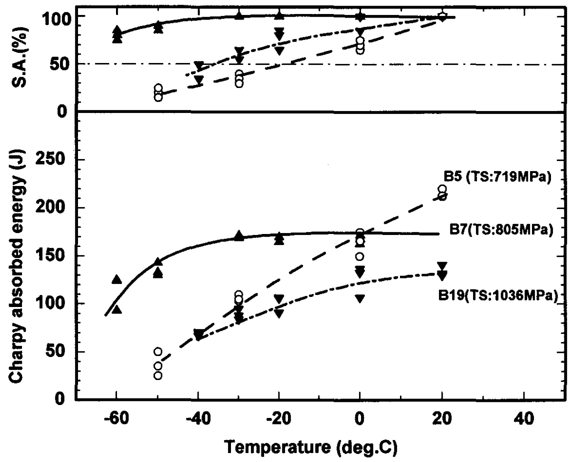

Fig.5 Examples of Charpy curves of type B weld metal

of B5 was lower than that of A3. B7 with tensile strength of 805MPa had upper shelf energy of 169J and vTrs lower than -60 °C. Because of low transition temperature B7 had greater Charpy absorbed energy at -30 °C than B5. With increasing tensile strength from 805 to 1036 MPa, from B7 to B19, the vTrs rose to about -40°C and upper shelf energy decreased to 135J.

As shown above, increasing weld tensile strength decreases the upper shelf energy in both type A and B weld metal. From a viewpoint of vTrs, there is a difference between type A and type B. The Charpy transition temperature of type A rose with increasing tensile strength from 700 to 1000 MPa. Type A weld metal with the tensile strength around 1000MPa had the Charpy transition temperature of 0°C or higher. On the other hand, vTrs of type B went down from -20 to less than -60 °C, when the tensile strength increased from 700

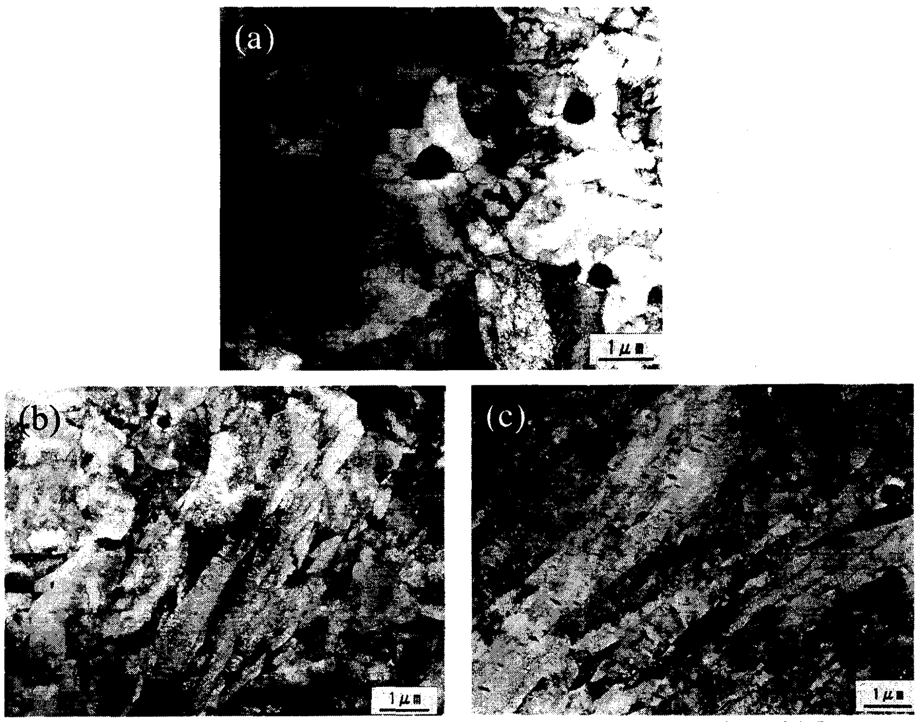

Fig.6 Microstructure of type A weld metal, (a) A3, Tensile strength=713 MPa, vE-30°C =232J, (b) A12, Tensile strength= 861 MPa, vE-30°C =88J, (c) A20, Tensile strength=998MPa, vE-30°C =35J

to 800 MPa. When tensile strength increased exceeding 800 MPa, the transition temperature went up as in type A. Although compared with type A, the rise of transition temperature in type B was small and the transition temperature was -30 °C or less at the tensile strength of 1000MPa. It is considered that the difference in the behavior of Charpy transition temperature accompanying the increase of tensile strength in type A and B weld metal originates from the difference in microstructure.

5. Effect of boron addition on microstructure

In the type A weld metal, the microstructure was dominated by fine acicular ferrite when the tensile strength around 700 MPa as shown in figure 6-(a). Some of the acicular ferrite is coarsened or replaced with bainite or bainite/martensite with increasing tensile strength, and

the microstructure changes to bainite/martensite at strengths greater than 900MPa. Typical microstructures of type A weld metal with tensile strengths are shown in figure 6.

Within the type B weld metal, when the tensile strength was around 700MPa, insufficient amounts of grain boundary ferrite precipitated. As strength increases from 700 to 800 MPa, grain boundary ferrite is eliminated. As the strength of type B is further increased above 800MPa, some of the acicular ferrite is coarsened or replaced with bainite or bainite/martensite as in type A weld metal. At tensile strengths greater than 900MPa, type A weld metal contains a bainite/martensite microstructure whereas type B still retains a significant amount of acicular ferrite as shown in figure 7.

It was considered that weld metal with tensile strength of 800MPa or higher had enough hardenabilty to eliminate grain boundary ferrite without boron addition. In this high strength range, increasing the boron content causes an increase in Charpy transition temperature by accelerating the change of microstructure from acicular ferrite to bainite/martensite and lowering the transformation temperature.

As shown in figure 3, in the tensile strength range from 700 to 1000 MPa, weld metal can show Charpy absorbed energies at -30°C more than 100J by optimizing the boron content. Regarding X100, the weld tensile strength range from 800 to 850 MPa must be suitable to consider the over-matching concept and field weldability. In this weld tensile strength range, a boron content less than 15ppm was acceptable.

In the case of X120, tensile strength of 931MPa and Charpy absorbed energy at -30°C of 84J were set . Some welds with lean boron content can meet the development target of X120. Although the balance between the toughness and tensile strength of weld metal is marginal for the target properties, it is difficult to keep the over-matching concept. Upper shelf energy relates to true fracture strain and it can increase by decreasing tensile strength or decreasing of the amount of inclusions [17]. In submerged arc weld metal the main inclusions are oxides. Thus optimum oxygen levels for the high strength weld metal should be established as well as how to produce weld metal with low oxygen content in mass production. Transition temperature mainly depends on microstructure. It was confirmed that acicular ferrite can be formed and improve transition temperature at tensile strengths around 1000MPa and boron content influenced the amount of acicular ferrite retained in the high strength range. The effect of other elements on acicular ferrite formation should also be studied.

6. Conclusions

The influence of boron addition on toughness and microstructure of weld metal which has tensile strength of 700 or more was investigated by laboratory scale tests.

At tensile strengths of 800 MPa or less, boron addition improved weld metal toughness because of the elimination of grain boundary ferrite. At tensile strengths exceeding 800MPa, boron addition promoted the

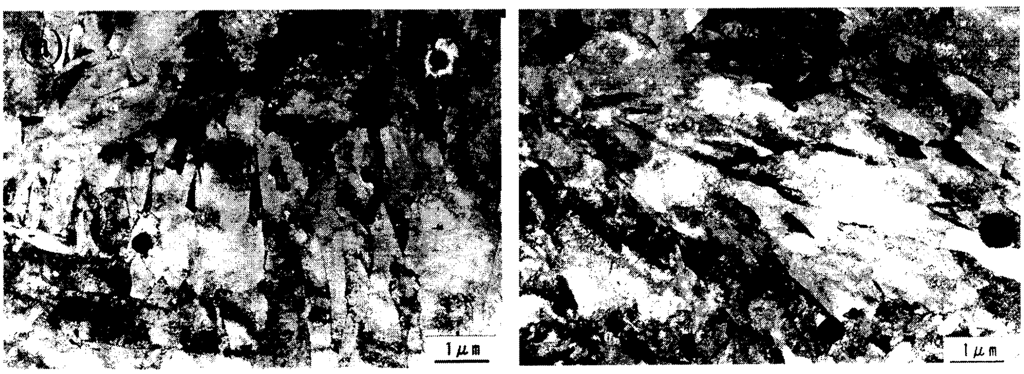

Fig.7 Microstructure of type B weld metal, (a) B11, Tensile strength=870 MPa, vE-30°C=128J, (b) B16, Tensile strength= 982 MPa, vE-30°C=104J,

microstructural change from acicular ferrite to bainite/martensite and had bad influences on toughness.

It was confirmed that acicular ferrite can be formed and improve transition temperature at tensile strengths around 1000MPa and boron content influenced the amount of acicular ferrite retained in the high strength range.

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