INVESTIGATION OF INFLUENCE OF MICROALLOYING WITH TITANIUM AND BORON OF WELD METAL ON ITS MECHANICAL PROPERTIES IN UNDERWATER WELDING

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One of the negative consequences of effect of extreme conditions of underwater welding is a low level of properties of welded joints, in the first turn, of ductility. Traditionally, this task is solved by optimization of microstructure of weld metal due to rational alloying. The purpose of this work was to establish the influence of microalloying of weld metal with titanium and boron on its mechanical properties in underwater welding using flux-cored wire. The structure of metal formed as a result of microalloying was investigated, and values of mechanical properties of deposited metal were determined. Optimal proportions of microalloying were established, at which high values of elongation of weld metal are provided. It is shown that its mechanical properties meet the requirements of A class of Specification on underwater welding ANSI/AWS D3.6. 5 Ref., 2 Tables, 7 Figures.

Keywords: *underwater welding, flux-cored wire, weld metal, microalloying, structure, mechanical properties*

Extreme conditions of underwater welding negatively influence the properties of welded joints. Traditionally, to improve mechanical properties of weld metal the purposeful alloying is used, thus optimizing its microstructure. Microstructure, which shows the optimum values of combination of strength and ductility of welded joints of low-carbon structural steels, is considered to be acicular ferrite (AF).

Figure 1 presents the schematic diagram of transformations at continuous cooling for wet underwater welding using electrode consumables, providing weld metal of ferrite type. The main structural components in weld metal are grain-boundary ferrite and ferrite with the second phase, which are characterized by low ductile properties. According to the results of investigation of microstructure of welds, performed under water using electrodes of the type E6013 under the conditions of Mexican Gulf, it was recommended to increase the content both of oxygen and also manganese in metal to increase the volume of AF (Figure 2).

As an alternative to adding of manganese the authors of work [2] used additions of titanium and boron to the charge of flux-cored wire having obtained more than 90 % of AC in weld metal during welding in air, here the content of boron and titanium was in the limits of 0.004–0.008

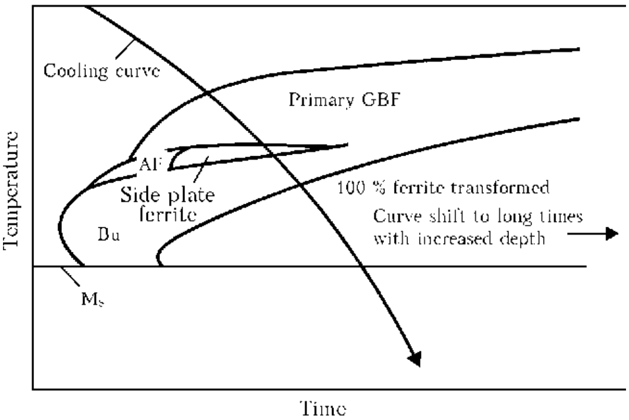

Figure 1. Schematic thermokinetic diagram for underwater welding [1]

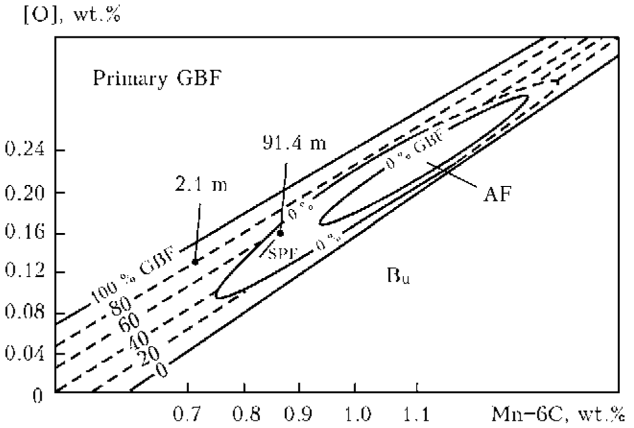

Figure 2. Predicted formation of structural components in wet underwater welding [1] at different depth

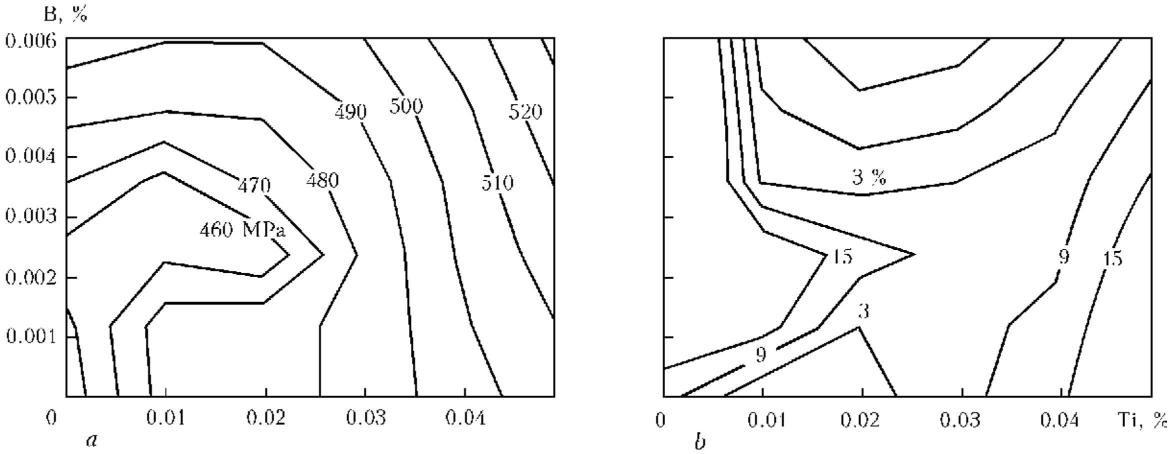

Figure 3. Influence of content of titanium and boron in weld metal on tensile strength (*a*) and elongation (*b*)

and 0.04–0.08 %, respectively. Titanium was added to form the inclusions, which serve as nuclei to AF formation. Besides, titanium as a potential deoxidizer protects alloying elements including boron from burning out. Boron facilitates also the formation of inclusions, which are mainly accumulated along the boundaries of austenite grains and hinder the formation of hypoeutectoid phases, for example, grain-boundary ferrite. Under the conditions of manual wet underwater welding the maximum attainable amount of AF (about 60 %) is formed at the lower level of alloying, such as 0.03 % Ti and 0.0015 % B [3]. The authors of work [3] explain this by the fact that necessity in titanium and boron for optimization of AF content is decreased as a result of increase in crystallization rate during welding in water environment. Close results were obtained also during use of flux-cored wire, in particular, two regions with maximum amount of AF at the level of 56–57 % were revealed. Moreover, the content of titanium and boron in weld metal for the first region amounts to 0.023–0.027 and to 0.0002 %, and for the second one — 0.030–0.032 and 0.0016–0.0023 %, respectively [4].

The aim of this work was to determine the efficiency of influence of microalloying with titanium and boron on mechanical properties of weld metal in underwater welding using flux-cored wire.

To conduct the investigations, a batch of flux-cored wires of the type PPS-AN1 of 1.6 mm diameter with additions of titanium and boron to the charge due to decrease of amount of iron powder was manufactured. Titanium and boron were added as FeTi and FeB in the amount of 10, 20 and 2, 4 %, respectively, both separately as well as together. To obtain specimens of deposited metal, the multipass welding of butt joints of steel St3 of 14 mm thickness was performed in laboratory pool at the depth of 1 m under the conditions: U_a = 30–32 V; I_w = 160–180 A, the polarity is reverse.

Of each butt joint the sections and specimens for mechanical tests in accordance to the requirements of A class of Specifications on underwater welding ANSI/AWS D3.6 [5] were manufactured. Chemical composition of weld metal is given in Table 1, the results of mechanical tests — in Table 2.

Table 1. Chemical composition of weld metal made by Ti- and B-containing flux-cored wire under water

Number of sample	Elements, wt.%						
	C	Si	Mn	S	P	Ti	B
1	0.026	0.013	0.20	0.016	0.018	–	–
2	0.013	0.004	0.17	0.022	0.015	0.003	0.002
3	0.015	0.004	0.20	0.022	0.019	< 0.002	0.002
4	0.017	0.005	0.23	0.021	0.014	0.005	< 0.002
5	0.031	0.106	0.47	0.021	0.021	0.032	< 0.002
6	0.039	0.017	0.37	0.023	0.021	0.007	0.0033
7	0.038	0.114	0.58	0.030	0.018	0.0053	0.005
8	0.024	0.020	0.28	0.024	0.023	0.006	0.002
9	0.044	0.080	0.62	0.027	0.018	0.049	0.006

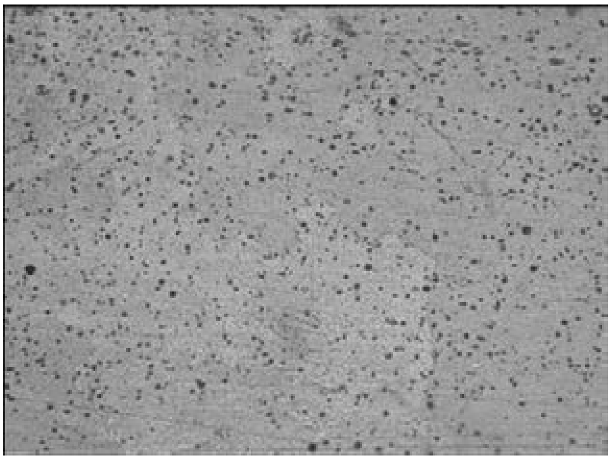

Figure 4. Microstructure (×500) of weld metal without alloying

Table 2. Results of mechanical tests of welds

Number of specimen	σ_y, MPa	σ_t, MPa	δ, %	ψ, %	α_{bend}, deg
1	333.0	440.0	11.3	22.0	50
2	381.6	459.6	12.3	22.0	90
3	374.6	458.6	17.7	35.8	180
4	393.2	469.8	10.7	18.7	69
5	447.5	485.6	7.0	16.0	61
6	342.5	466.3	7.0	16.0	31
7	450.9	485.6	3.7	15.4	135
8	392.1	468.6	16.0	28.2	81
9	494.1	532.4	6.3	12.9	50

As is seen from the given data, alloying with titanium and boron in all cases leads to negligible increase in strength properties of weld metal. Regarding ductility, their influence bears ambiguous nature. For the convenience of the analysis of the obtained results using the specialized package of programs (Origin 7, Statistica 6) polynominal interpolation of experimental data was performed, and distribution of values of elongation and tensile strength depending on boron and titanium content in weld metal was obtained (Figure 3). It was established that the compositions, providing the highest ductile properties, are in the limits of 0.0015–0.0025 % B and to 0.01 % Ti.

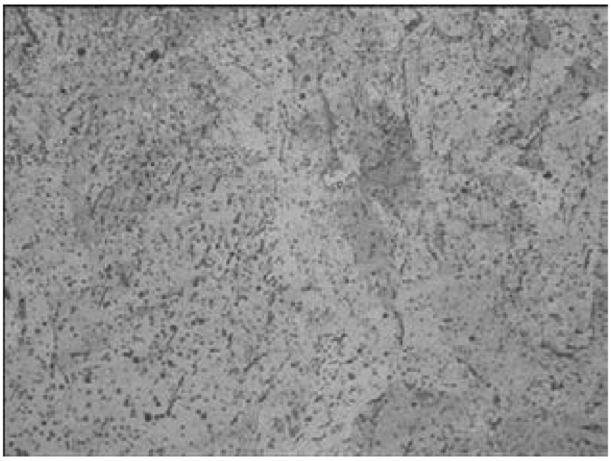

Figure 5. Microstructure (×500) of weld metal alloyed with boron

Metallographic investigations were carried out using microscopes Polyvar and Neophot-32. The hardness was measured in the durometer M-400 (LECO). Digital image of the structure was obtained using digital camera Olympus.

The structure of weld metal produced with the wire PPS-AN1 (specimen 1) represents ferrite matrix and fine carbides, precipitated both in the body of crystallites, as well as along their boundaries (Figure 4). Microhardness of metal of the last pass amounts to $HV1$ = 1880–2130 MPa. During adding of boron the amount of carbides is decreased, which results in decrease of microhardness down to $HV1$ = 1760–1810 MPa in the specimen 2 and $HV1$ = = 1870 MPa in the specimen 3. The structure of

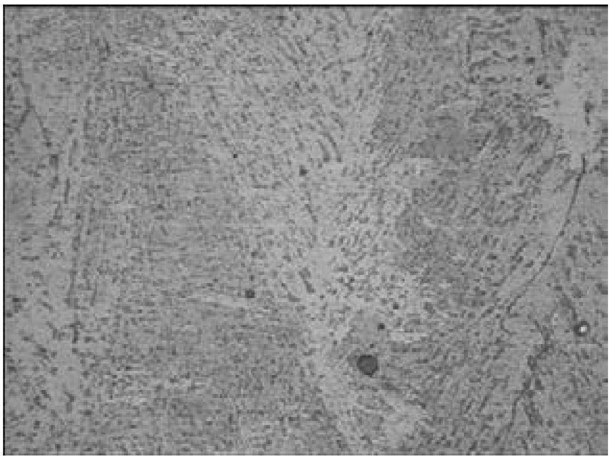

Figure 6. Microstructure (×500) of weld metal alloyed with titanium

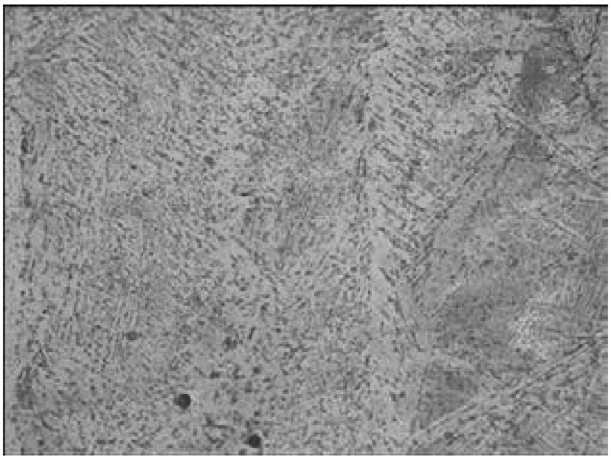

Figure 7. Microstructure (×500) of weld metal alloyed with titanium and boron

weld metal represents ferrite-carbide mixture (Figure 5).

In the welds alloyed with titanium (specimen 4), the structure is composed of ferrite of different modifications: with ordered and non-ordered second phase, polygonal ferrite and small amount of AF areas and bainite (Figure 6). The hardness of metal increases to $HV1$ = 2430–2850 MPa. At increase of titanium content (specimen 5) the size of polygonal ferrite precipitates was increased, AF was not detected. The hardness of weld metal was somewhat decreased — to $HV1$ = = 2300–2450 MPa.

Combined adding of titanium and boron does not lead to such noticeable changes in structure of weld metal as in separate alloying. Depending on the ratio of content of alloying elements the ratio of amount of ferrite with the ordered and non-ordered second phase is changed (Figure 7), and at maximum level of alloying (specimen 9) the areas of bainite with increased hardness ($HV1$ = 2970 MPa) are revealed.

The analysis of results of metallographic investigations shows that the areas with the best ductile properties and maximum amount of AF do not coincide. The highest ductility is observed in welds with ferrite-carbide structure. The appearance of structure components of AF type and upper bainite results in decrease of elongation and increase of strength. To explain the mechanism of influence of microalloying of weld metal with titanium and boron on its properties the additional more profound investigations are required.

As to optimization of content of titanium and boron in weld metal, then several batches of flux-cored wires, providing alloying in above-set limits, were manufactured and tested for this purpose. The following mean values of mechanical properties were obtained: σ_t = 469 MPa, $\sigma_{0.2}$ = = 378.2 MPa, δ = 20.8 %, α_{bend} = 180°. Thus, rational alloying with titanium and boron provides increase in elongation of weld metal by 1.8 times at negligible increase in tensile strength. By its mechanical properties the weld metal meets the requirements of class A of Specifications on underwater welding ANSI/AWS D3.6.

Conclusion

1. Microalloying with titanium and boron of metal of welds, performed under water using flux-cored wire, allows efficient controlling of their ductile properties.

2. The limits for titanium and boron content (0.005–0.010 and 0.0015–0.0025 %, respectively) were established, at which the elongation of welds metal of low-alloyed steels of strength class K40 is 1.8 times increased at negligible increase in tensile strength.

3. The region with the best ductile properties does not coincide with the region of maximum amount of AF. To specify the mechanism of influence of microalloying of weld metal with titanium and boron on its properties in the conditions of underwater welding, the more comprehensive investigations are required.

1. Ibarra, S., Grabbs, C., Olson, D.L. (1988) Fundamental approaches to underwater welding metallurgy. *J. of Metals*, **12**, 8–10.
2. Oh, D.W., Olson, D.L. (1990) The influence of boron and titanium on low carbon steel weld metal. *Welding J.*, **4**, 151–158.
3. Sanchez-Osio, A., Liu, S., Olson, D.L. et al. (1993) Underwater wet welding consumables for offshore applications. In: *Proc. of 12th Int. Conf. on Offshore Mechanics and Arctic Engineering*, Vol. 3, Pt A, 119–128.
4. Maksimov, S.Yu., Krazhanovsky, D.V. (2006) Content of acicular ferrite in weld metal in wet welding. *The Paton Welding J.*, **1**, 45–47.
5. *ANSI/AWS. D3.6*: Specification for underwater welding.

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