

# Effect of B<sub>2</sub>O<sub>3</sub> containing fluxes on the microstructure and mechanical properties in submerged arc welded mild steel plates

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**Abstract.** This paper represents a study on the effect of B<sub>2</sub>O<sub>3</sub> additions in fluxes on the microstructure and mechanical properties of the weld metal formed during Submerged Arc Welding of Mild Steel plates. Five fluxes with about 2.5, 5, 7.5, 10 and 12.5% B<sub>2</sub>O<sub>3</sub> were used with a low carbon electrode. Welding process parameters were kept constant for all the conditions. The microstructure of weld metal for each flux consisted mainly of acicular ferrite, polygonal ferrite, grain boundary ferrites and equiaxed pearlite. It was noted that the Vicker's hardness value was a function of boron content and shows a mixed trend. Impact Energy and Tensile Strength were increased with the increase in boron content in welds this can be attributed to relation with the higher acicular ferrite percentage. However an optimum level of toughness and tensile strength was available with 7.5% and 5% of B<sub>2</sub>O<sub>3</sub> respectively. A qualitative comparison has also been done with fresh flux by means of full metallography and mechanically.

## 1. Introduction

Among the several arc welding methods, the submerged arc welding is the preferred method for welding thick sections in the industry because of its several advantages which include high production rates, good weld quality, ease of automation and minimum operator skill requirement [1]. Despite their numerous advantages, welded joints can often act as sources of weakness leading to catastrophic structural failures such as boiler explosion, pipeline crack or bridge collapse [2]. The mechanical properties of weld metal are strongly dependent on the microstructure developed during solidification and cooling of the weld pool and also depend on the weld metal chemical composition and cooling rate [3]. It has been reported that acicular ferrite can help in getting excellent mechanical strength and toughness. Weld metal of steel with a microstructure formed predominantly by acicular ferrite (AF) has high mechanical properties for both notch toughness and strength. This is attributed to the very fine grain size of the acicular ferrite (1-3 µm) as well as its high boundary angle and high dislocation density, reducing crack propagation [3]. A method for promoting the formation of acicular ferrite consists of the additions of oxides into the flux, such as boron oxide, zirconium oxide, vanadium oxide and titanium oxide [4]. The oxides in the flux may contribute to different metallic element dissolution



and oxygen into the weld. These elements may react to form oxide inclusions, which are trapped into the weld and facilitate the nucleation of acicular ferrite during the weld cooling [5].

Ana Ma et al [6] the oxides in the flux may contribute to different metallic element dissolution and oxygen content in to the weld. These elements may react to form oxide inclusions, which are trapped in to the weld and facilitate the formation of AF during the weld cooling. Koukabi et al [7] the chemical composition of weld metal is determined by the dilution of base metal, electrode wire chemical composition and any pyro-metallurgical chemical reactions in the weld arc.

The objective of the present investigation was to see the effect of boron trioxide on microstructure and mechanical properties of mild steel. Mechanical investigation of welds was carried out using hardness test, tensile testing and Charpy impact testing.

## 2. Experimental procedure

Submerged arc welding was carried out in mild steel parent metals in flat position with single pass welding. Copper coated mild steel electrode wire [AWS A/S 5.17: EH 14] was used which was supplied by ADOR welding ltd. Wire diameter was 3.15 mm and its chemical composition of parent material and electrode wire is given in Table 2. Five fluxes containing 2.5, 5, 7.5, 10 and 12.5% of  $B_2O_3$  were prepared by mechanical mixing of a commercial flux with fresh flux, designated as A, B, C, D and E respectively. A fused flux [AUTOMELT A55] of grain size 0.2 to 1.6 mm with basicity index 1.6 was used to perform the welding. Chemical composition of flux was  $SiO_2+TiO_2=30\%$ ;  $CaO+MgO=10\%$ ;  $Al_2O_3+MnO=45\%$ ;  $CaF_2=15\%$ . AISI 1013 low carbon steel plates with square butt joint welded using SAW process with standard process parameter and the same has been kept constant for all welding condition their numeric values are shown in Table 1. Welding was conducted in a submerged arc welding machine model: ADOR WELDING LIMITED, INDIA; Model- MAESTRO 1200 (F), available in the NIT Agartala.

**Table 1.** Process parameters of welding process

Parameters	Units	Notation
Wire feed rate	200 mm/min	$W_f$
Stick out	28 mm	$S_o$
Traverse speed	0.45 m/min	$T_s$
Voltage	34 volts	V
Current	625 amp	I

**Table 2.** Chemical composition of parent metal and electrode wire

Element	C	Mn	Si	P	S	$C_{eq}$
Base Metal	0.16	0.4	0.05	0.03	0.05	0.35
Electrode	0.043	0.412	0.05	0.019		

Weld samples were polished using emery papers and diamond paste by following standard procedure. Metallographic study was carried out after etching using Light optical microscopy. Etching of samples were performed by 2% Nital solution (2 volume %  $\text{HNO}_3$  and 98 volume % ethyl alcohol) for 10-15seconds duration. The chemical tests were performed in an optical emission spectroscopy machine for all welding conditions. Hardness was carried out in a straight line 2 mm below and parallel to the surface of base plate with a constant load of 2 kgf and dwell time 10 Sec. The standard for hardness testing was according to the ASTM E 92 and readings were taken 0.5 steps throughout the WM, HAZ and part of the base material. The specimens were also machined to prepare a round sample transverse to the welding direction according to ASTM E8. For impact testing CVN impact toughness samples were prepared according to the ASTM E23 standard.

### 3. Result and discussion

#### 3.1 Weld metal chemical composition

Table 3 shows the chemical composition of the weld metals with fresh flux and also corresponding to the fluxes A, B, C, D and E. It can be noticed that the amount of Boron content increased with the increase in Boron trioxide content in the fluxes which has been mentioned in the last column Boron variation was observed from 0 to 0.0066 wt%. The Mn content was almost the same for the five welds. The S content was almost the same for the welds and it showed good agreement with the S content for the electrode material.

**Table 3.** Weld metal Chemical composition with addition of  $\text{B}_2\text{O}_3$

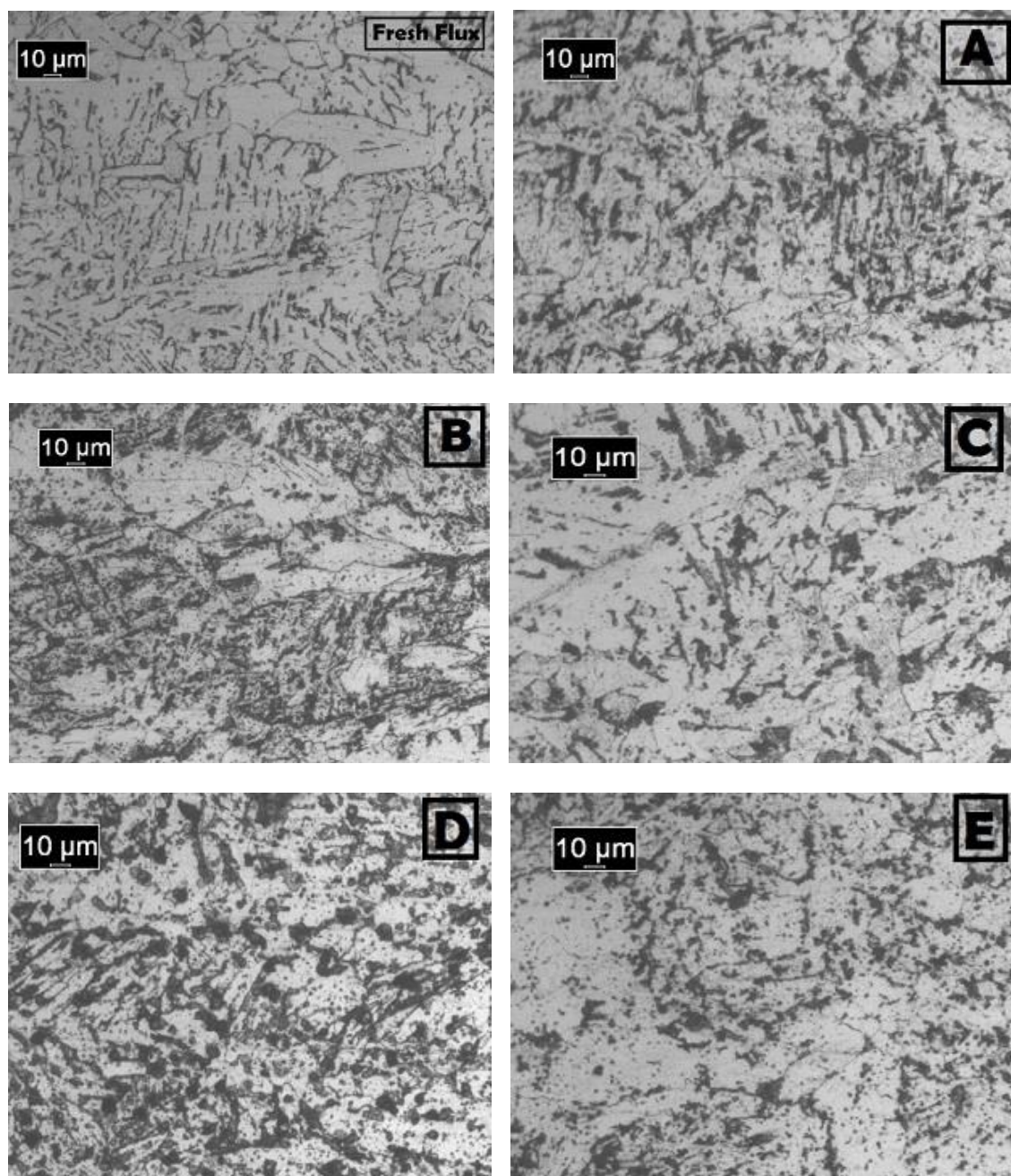
Element	C	Mn	Si	P	S	Al	B
<b>Fresh Flux</b>	0.156	1.35	0.48	0.019	0.013	0.033	<b>0.00</b>
<b>A</b>	0.153	1.32	0.52	0.021	0.012	0.026	<b>0.0025</b>
<b>B</b>	0.155	1.35	0.56	0.018	0.0098	0.024	<b>0.0036</b>
<b>C</b>	0.157	1.37	0.53	0.022	0.011	0.023	<b>0.0048</b>
<b>D</b>	0.162	1.33	0.66	0.021	0.010	0.022	<b>0.0053</b>
<b>E</b>	0.165	1.30	0.62	0.023	0.014	0.021	<b>0.0066</b>

#### 3.2. Microstructural characterization

Figure 1 shows the light optical micrograph of the welded steels corresponding to fluxes A, B, C, D and E. The microstructure of the weld metal for each flux consisted mainly of equiaxed pearlite, acicular ferrite, polygonal ferrite, grain boundary ferrite etc. Those pearlite colonies can be seen in form of darker or blackish region. It has been noted that the microstructures in all weld metal were somewhat changes as going from 2.5% to 12.5% of borontrioxide addition that appeared to be typically acicular and others possibly polygonal ferrite. The grain boundaries between the ferrite grains can be seen quite clearly. It is made up from a fine mixture of ferrite and iron carbide, which can be seen as a "wormy" texture.

However, the main constituent was the acicular ferrite, forming a "wicker basket" structure or having needle type shape which was responsible for optimum mechanical properties. The microstructural evidence that acicular ferrite forms a maximum in flux C and the impact energy shown in Figure 3 are consistent with the suggestion that acicular ferrite promotes the toughness. The lowest and highest formation of acicular ferrite was correspondence to C and E fluxes which was done on the basis of mechanical testing. In fluxes B the pearlite formation was more and the pearlite percentage in welds seems to be responsible for the higher strength and hardness. With low levels of carbon, the

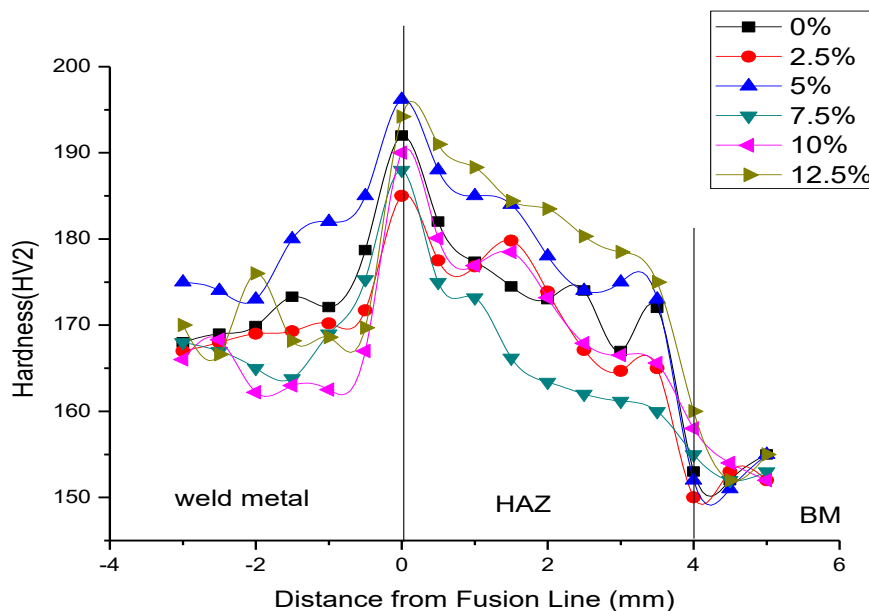
carbide may precipitate as discrete particles, following the path of the ferrite/austenite interface [8]. However, the overall mechanism of bainite formation is independent of carbon content in the main. The appearance of bainite strongly resembles that of martensite corresponding to fluxes D and E. This was, however, difficult to confirm or quantify with any certainty by optical means only at the same time it was very difficult to distinguish between different types of boundary ferrite as optical microscopy does not reveal such intricate structural features because of a lack of resolution of visible boundaries.



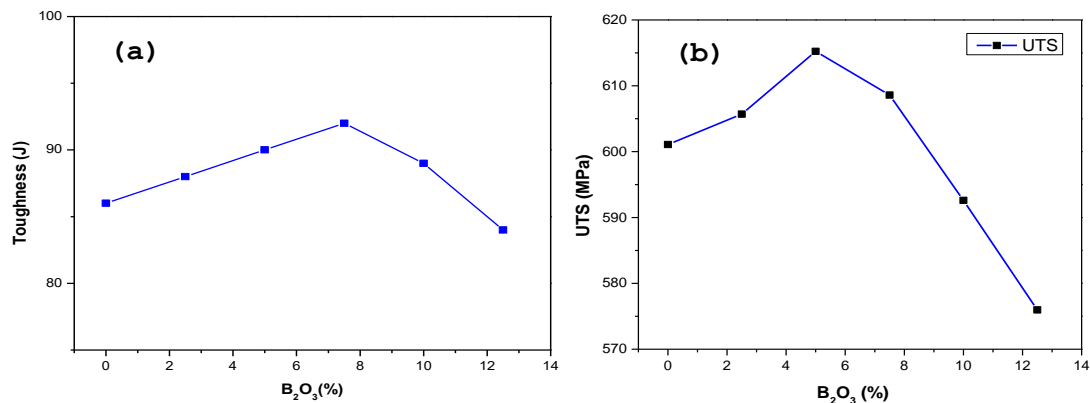
**Figure 1.** Light optical Micrograph of weld metals corresponding to the fresh flux, A, B, C, D and E fluxes.

### 3.3 Mechanical properties

Figure 2, 3 (a) and (b) shows the Vickers hardness, toughness and tensile properties for the weld metals at room temperature respectively. It was noted that the vicker hardness value was a function of boron content and shows a mixed trend since boron is a powerful hardenability element so it has promoted the hardness but some weld metal experience a decrease in hardenability due the formation of borocarbides, which act as the preferential nucleation sites for the austenite to ferrite transformation at prior austenite grain boundaries. Boron possesses a high affinity for nitrogen and forms nitrides already in the liquid phase then it is not contained in the solid solution and does not increase the hardenability of the steel [9]. Impact Energy and Tensile Strength were increased with the increase in boron content in welds this can be attributed to relation with the higher acicular ferrite percentage shown in Figure 3. The highest toughness detected by the largest area under the engineering stress-strain curve, corresponded to the weld metals containing 7.5 % of  $B_2O_3$  this can be credited to their higher content of acicular ferrite, which is known to improve the steel toughness because of its fine size which has a higher resistance to the crack propagation. However an optimum level of toughness and tensile strength was available with 7.5% and 5% of  $B_2O_3$  respectively after that percentage appreciable decrease in toughness have been notice and this can be attributed to the fact that boron addition inhibits intragranular transformation and promotes formation of lath microstructure which have a detrimental effect on toughness.



**Figure 2.** Hardness profile for weld metals with addition of boron trioxide



**Figure 3. (a) Impact Energy and (b) Tensile Strength of weld metals with addition of B<sub>2</sub>O<sub>3</sub>**

#### 4. Conclusions

A study of the effect of boron trioxide enriched flux composition on microstructure and mechanical properties of the submerged arc welded mild steel was pursued and the following conclusion were observed:

- Microstructure formed with fresh flux was mainly consists of ferrite and pearlite in wormy texture however after addition of boron probable microstructure for weld metals was the dominating of ferrite like acicular ferrite, grain boundary ferrite, polygonal ferrite. However presence of other phases like M-A constituent was low compare to the general weld metal microstructure.
- Vicker hardness value was a function of boron content and shows a mixed trend having higher hardness in 12.5% while lower hardness was observed in 7.5%.
- Optimum toughness was available with 7.5% B<sub>2</sub>O<sub>3</sub> in weld metal and with further increase in boron were seems to be incapable of improving it further due to formation of lath microstructure.
- The higher tensile strength was obtained with 5% B<sub>2</sub>O<sub>3</sub> in weld metal respectively due to formation of acicular ferrite and decreased with the further addition because of higher oxygen content.

#### 5. References

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