EFFECT OF ALUMINIUM ON THE TOUGHNESS OF SUBMERTED ARC WELD METAL

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INTRODUCTION

The toughness of weld metal is a factor of critical importance that governs the safety of welded structures. Considering that the trend is towards higher heat input in welding and that environmental and use conditions of structures are becoming increasingly severe, it is imperative to take comprehensive measures to improve the toughness of the weld metal.

Submerged Arc Welding (SAW) is generally credited for high productivity due to its high deposition rate compared with other major arc welding processes viz. Shield Metal Arc, Gas Metal Arc and Flux Cored Arc Welding. SAW is, therefore, the method of choice where technically possible. Its productivity, however, is often limited because of its relatively high heat input, which tends to impair joint toughness at low temperatures. Compliance with toughness requirements, therefore, often sets limits on heat input levels, resulting in a reduction of productivity.

Metallurgical and technical solutions have received considerable attention in recent years to overcome the dilema faced between productivity and toughness when using SAW.

Studies were conducted by different investigators [1, 2] to improve the toughness of submerged arc weld metal by addition of Ti, B, etc. and the excellent toughness of weld metal derived from Ti or Ti - B addition has been established. Both Ti and B have strong affinity to oxygen and nitrogen and they can exert a remarkable effect, whether beneficial or deleterious, on its morphology [1, 3]. Since Al also has strong affinity to oxygen and nitogen as Ti and B do, it is imperative to study their interactions on weld metal microstructure which in turn may affect the toughness. Earlier works on the implications of Al additions on weld metal toughness revealed different opinions. For example, Hannerz and Werlefors [4] observed a detrimental effect on toughness of aluminium in the range of 0.006 to 0.07%. North et al. [5] found the optimum upper shelf charpy toughness with 0.02% Al. Suzuki et al. [6] also observed a detrimental effect on submerged arc weld toughness with 0.035% Al.

With this background the present experimental work was initiated to investigate the effect of aluminium on the toughness of submerged arc weld metal in order to obtain a better understanding on the role of aluminium in relation to the toughness of weld metal.

Experimental Procedure

Materials :

Low Carbon Steel Plates of dimensions 300 x 75 x 19 mm were used. Welds were deposited in milled V - grooves of 60° angle and 4.5 mm deep in the plates using AWS type E 70S - 3 mild steel wire **(Fig. 1)**. The composition of base plate and welding wire are shown in **Table 1**.

Flux Preparation :

Reagent grade SiO2, MgO, CaF_2, Al_2O_3 powders were used to produce the welding fluxes. A total of three

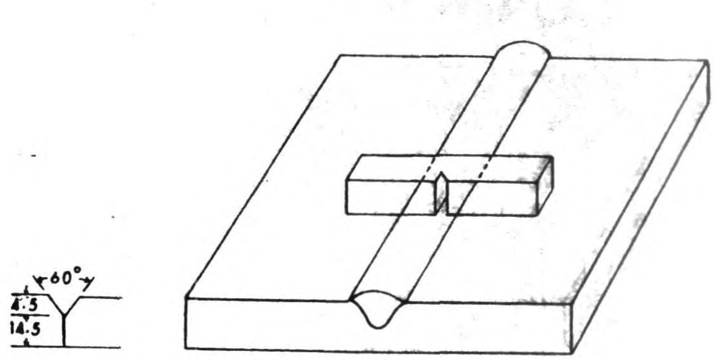

Fig. 1 : Schematic drawing showing the position of charpy impact specimens.

Table 1 : Base Mtetal and Filler Metal Compositions

Material	Composition (wt%)				
	C	Mn	Si	S	P
Base metal	0.22	1.44	0.53	0.02	0.03
Filler metal	0.10	0.85	0.05	0.02	0.02

Table 2 : Flux matrix composition (wt%) and basicity indeces

Flux number	SiO_2	MgO	CaF_2	Al_2O_3	B. I.
Fl	40	20	18	22	0.74
F2	30	30	26	14	1.51
F3	25	40	23	12	2.03

different flux compositions listed in **Table 2,** were used in this study. Each of the four major ingredients were varied to obtain different basicity index of the flux.

Submerged Arc Welding :
An automatic machine (Auto Weld Major AM/380) of constant voltage power supply was employed and the current was controlled by the wire feed rate control unit. The wire feeder and flux hopper rode on a stationary track. These arrangements made it possible to maintain constant welding current, voltage, travel speed, flux depth etc. Single - pass welds were made using DC electrode positive at a current of 610A, voltage of 37.5 V and welding speed of 208 mm/min. All the welds were, therefore, made with a heat input of 6.7 kJ/mm.

Chemical Analysis of Weld Metal :
Weld metals were subject to chemical analysis. Carbon, silicon, manganese and aluminium were analysed by Atomic Absorption Spectrometer. Oxygen and nitrogen content was measured with a Leco analyser. Sulpher and phosphorus were measured by wet analysis method.

Charpy V - Notch Impact Test :

The charpty impact testing with the standard V - notch made perpendicular to the weld axis was tested at - 20°C.

Mettalographic Examination :

The microstructure of weld metal was observed under optical microscope. A few samples were observed under TEM. Non-metallic inclusions of selected specimens were measured directly on the microscope. A minimum od 100 particles were examined from each specimen.

Results

Weld metal chemistry :
Typical chemical compositions of the weld deposits are given in **Table 3**. Aluminium content of weld metal was varied from about 0.015 to 0.085% for each type of flux. The oxygen content significantly varies with the flux basicity. However, other elements remain more or less same.

Fig. 2 : Microstructure of weld metal (W8) showing mostly fine acicular ferrite.

Fig. 3 : Microstructure of weld metal (W10) showing mostly bainite.

Table 3 : Chemical composision of Weld Metal									
Weld Number	Flux Number	C(%)	Si(%)	Mn(%)	S(%)	P(%)	Al(%)	O(P.P.M)	Charpy Impact Toughness at 20°C, J
W1		0.15	0.35	1.27	0.03	0.03	0.015	870	10.0
W2	F1	0.14	0.38	1.29	0.03	0.03	0.023	890	10.8
w3		0.15	0.36	1.26	0.03	0.03	0.037	873	14.0
w4		0.014	0.35	1.28	0.03	0.03	0.066	862	18.0
w5		0.14	0.37	1.26	0.03	0.03	0.085	850	8.0
w6		0.16	0.37	1.29	0.03	0.03	0.017	630	9.8
w7	F2	0.15	0.36	1.27	0.028	0.03	0.029	621	13.7
w8		0.16	0.35	1.26	0.03	0.03	0.035	617	22.0
w9		0.16	0.37	1.28	0.03	0.03	0.062	622	10.0
w10		0.15	0.38	1.28	0.029	0.03	0.084	605	8.5
w11		0.17	0.40	1.30	0.027	0.03	0.013	478	11.0
w12		0.17	0.39	1.29	0.027	0.03	0.025	471	24.0
w13	F3	0.16	0.40	1.31	0.028	0.03	0.038	452	14.1
w14		0.16	0.38	1.30	0.030	0.03	0.060	460	9.7
W15		0.17	0.40	1.30	0.029	0.03	0.080	457	9.0

Weld metal microstructure :

Typical microstructure of weld metal at two different aluminium contents are shown in **Fig. 2** and **3**. The microsrtructure of weld deposit at 0.035% aluminium is characterised by more or less uniform acicular ferrite. On the other hand, the increase in aluminium content (at 0.084%) gives rise to bainite as the main structure. The transmission electron micrographs of these two microstructures are shown in **Fig. 4**. With low aluminium content, Fig. **4(a)**, the island-like structure surrounded by ferrite is a ferrite - cementite aggregate, while with high Al content, **Fig. 4(b)**, the martensite - austenite constituent is present.

Non-metallic inclusions :

Most of the non-metallic inclusions examined in all the weld deposits are spherical. The inclusion size not only depends on the oxygen level of the welds, but also on the aluminium content. Coarse inclusions are present in high oxygen and high aluminium welds. The inclusion size distribution is shown in **Fig. 5**.

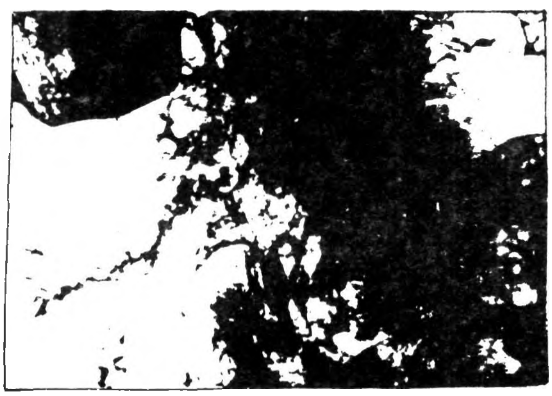

Fig. 4a : Transmission electron micrographs of weld metal (W8) showing cementite aggregate

Fig. 4b : Transmission electron micrographs of weld metal (W10) showing martensite austenite constituent.

Fig. 5a : Inclusion morphologies of weld metal W8

Fig. 5b : Inclusion morphologies of weld metal W10

Weld metal toughness :

The effect of aluminium on the toughness of weld metal are shown in Table 3. Optimum toughness values obtained vary with the type of flux viz. basicity of the flux. Moreover the level of aluminium required in the weld metal to give maximum charpy impact toughness decreased with increasing flux basicity.

DISCUSSIONS

The present study has shown that the addition of aluminium to the weld metal in C - Mn steel has considerable effect on charpy impact toughness. The level of aluminium required in the weld metal to give maximum charpy impact toughness decreased with increasing flux basicity (Table 3). The improvement in toughness is usually associated with the favourable microstructure.

In SAW process, the greatest oxygen contribution comes from the fluxes, and fluxes with high basicity reduce weld metal oxygen levels and improve the indices toughness [7, 8]. The influence of oxygen on weld metal toughness has been closely related with presence of non-metallic inclusions in the weld metal. Aluminium preferentially combine with the oxygen and the deoxidation products of weld metals in C - Mn steels normally occur as roughly spherical inclusions which are primarily oxides. With low oxygen and aluminium content in the weld metal, it is apparent that the volume fraction of inclusiion will be at a lower level and will induce maximum toughness. The results, however, show that the maximum charpy impact toughness for a given oxygen content of the weld metal does not correspond to the *lowest level of aluminium content.* These suggests that aluminium plays a critical role with oxygen in modifying the microstructure and therefore the impact properties.

In the present study the improvement in toughness of weld metal is associated with a change in the microstructure from one consisting primarily of grain boundary ferrite to one consisting primarily of acicular ferrite. Many authors [9, 10, 11] concluded that the microstructure of weld deposits is governed by the non-metallic inclusions and that the efficacy of inclusions as nucleants for acicular ferrite varies with inclusion composition and with size. Though inclusion composition has not been measured in the present study, it has been reported that the composition of inclusion e.g., the amount of Al_2O_3 in the inclusion increase with aluminium addition, while other oxides such as SiO_2, MnO decrease [12]. The inclusion size distribution at two different level of aluminium addition e.g. 0.035% Al and 0.084% Al is shown in **Fig. 6**. These welds exhibited higher amount of acicular ferrite than the other welds, which seems to agree with the finding of *Terashima and* Hart [13] that inclusions with a mean diameter of < 0.56 um are too small and those with a mean diameter of > 1.81 um are too large to nucleate acicular ferrite in submerged arc weld.

However, with further increase in aluminium in the weld metal e.g., with increasing Al_2O_3 increasing difficulty in promoting acicular ferrite has been noted [14]. In the present study, acicular ferrite was replaced by bainite. These could be due to increase in hardenability of the weld metal as a result of uncombined

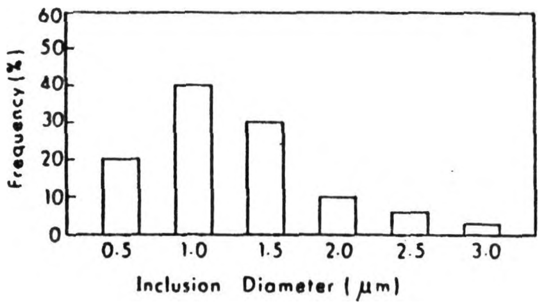

Fig. 6a : Inclusion size distribution as a function of weld metal aluminium content 0.035% Al.

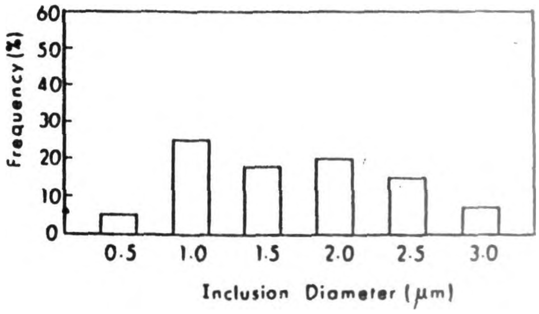

Fig. 6a : Inclusion size distribution as a function of weld metal aluminium content 0.084% Al.

manganese and silicon in the weld metal.

CONCLUSIONS

The results of the present investigation led to the following conclusions

1. The effect of aluminium on submerged arc weld toughness is dependent on the flux type.
2. The level of aluminium required in the weld metal to give maximum charpy impact toughness increased with decreasing flux basicity.
3. The beneficial effect of aluminium is associated with an increase in the proportion of acicular ferrite and refinement of the grain structure.
4. The deleterious effect of aluminium is attributed to the reduction of the proportion of acicular ferrite and increase of the proportion of bainite.

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