Properties and Behaviour of MMA Welding Slag

Dr. S. Bhattacharya,

Introduction

In the competitive world of welding consumables market the basic properties of the weld deposit like chemical and mechanical properties do not differ considerably to influence selection of a specific brand over the other. Selection is often decided on the basis of ease of welding, aesthetic aspects, reliability of the product etc., besides economic considerations. The ease of welding that is slag detachability, ease of striking and restriking of arc, capacity to absorb fluctuations in welding parameters etc., thus assumes high commercial importance.

In the early seventies the research activities[1, 2] were directed towards the study of properties of slag in steel making were taken but it was soon recognised that there exists few basic differences in conditions between the slags of steel making and MMA welding. The most significant amongst them are the time element and the cooling rate. The properties which were of interest to a welder were its (slag) easy detachability from the weldmetal and manoeuvarability during welding. Both these properties has been attributed to chemical composition and morphology of the slag.[3]

Detachability of slag has been classified[4] according to its nature of detachment viz, homogenous and heterogeneous. Homogenous detachment is one in which with slight hammering or without any hammering (self lilting type) the slag comes out and does not leave any amount at the sides whereas in the heterogeneous one even after slight hammering the slag remains attached to the surface of the weldmetal only to the sides. To study detachability let us first analyse the causes which make the slag attached to the weld metal.

Author is with ESAB INDIA LIMITED, Thane.

A weld deposit could be divided broadly into three layers:-

— weld metal
— interface between the weld metal and the slag
— slag layer

Attachment of slag to the weldmetal is due to three forces :-

— Vander Waals forces
— Chemical interaction and
— Surface tension.

The first type of force is one to two magnitude less than the second type and plays lesser role in slag detachment. The second category of forces arises due to the chemical interaction between the weldmetal and the slag and hence depends on the chemistry of the weld deposit as well. It has been reported[4] that the elements which form spinel with cubic structure similar to α - Fe or Fe_3O_4 slag detachment will be diffcult. It has also been reported that pressure of NiO in the slag makes it diffcult to detach whereas presence of Cr content in the $FeTiO_3$ base slag, favour slag removal. In highly alloyed base metals adherence of this film of oxide layer which has similar structure as that of the slag will also make the detachability poor.

The most crucial property under discussion is the interface layer and it emerges from the influence of adjacent layers i.e. weld metal and the slag layer. The influence of weld metal has already been discussed, whereas that of the slag layer is more intricate due to complex chemical composition and interaction between the constituents. Any factor which reduce the affinity between the weld metal and the slag or increases stress between the weld metal and the slag shall improve slag detachability. The importance of controlling physical properties of slag thus assumes importance and this work attempts to establish any correction between chemical composition and physical properties of slag to this effect.

Experiment

The detachability is usually preceived subjectively and is based on hammering strength and visual inspection. The present experimentation was devised to eliminate these two subjective parameters. In es nce the set up was a modified version of impact testing machine. A fixed load was taken and allowed to strike a welded piece with slag. The area freed from slag was measured. On the basis of this a factor 'a' as described by Pokhodnya[3] et al, was calculated.

Six MMA electrodes were selected from well known Indian and foreign brands. Care was taken to select these electrodes from different formulation base. The type of coating and welding parameters are summarised in Table 1. Welding was carried out on boiler quality plate for unalloyed electrodes and stainless steel plates of matching chemistry for alloyed types. The plates were 20 mm thick to prevent any distortion of the plates. D.C. electrode +ve was used for all the types of electrodes.

TABLE 1 Experiment Parameters & Results

Electrode No.	Type of coating	Welding Current Amp.	a Kgm/cm^2	Slag detachability
1	Basic	160	12.6703	Hard
2	Ilmenite	150	10.9618	Slightly hard
3	Rutile basic	130	10.7509	Fair
4	Rutile Acid	130	10.7412	Easy
5	Rutile	165	10.7412	Easy
6	Rutile high deposition	190	10.7402	Very easy

The slags of all the electrodes were analysed for its major constituents and have been presented in Table II as percentage. The factor 'b' has been calculated to indicate basicity using the following simplified formula :

$$b = \frac{(CaO + CaF_2)}{1/2\,(TiO_2 + Al_2O_3 + ZrO_2 + Cr_2O_3 + FeO + MnO) + SiO_2}$$

all representing their respective perçentage in the slag.

Discussion

It has already been indicated that the slag detachment is significantly influenced by the forces acting at the slag metal interface. The resultant force between the one which heops to detach the slag and the one which helps to adhere the slag to the weld metal is the one which determines the slag detachability properties. The force which shall affect the slag detachability properties most significantly shall be generating from the difference in contraction during cooling between the weld metal and the slag. The following Table III gives an idea of the co-efficient of linear thermal expansion of the slag forming constituents, iron and AISI 308.

Table II Major Constituents of Slags (%)

Elec. No.	TiO_2	SiO_2	AlO_2	CaO	CaF_2	FeO	Cr_2O_3	Fe_2O_3	b
1	2.78	25.28	1.51	24.30	29.79	3.48	–	–	1.855
2	33.42	31.07	5.27	2.67	–	–	–	15.03	0.052
3	37.94	25.85	5.83	5.31	11.31	–	3.54	–	0.376
4	42.86	25.96	5.74	6.68	4.13	–	4.26	–	0.246
5	56.74	18.27	6.70	7.25	–	–	–	–	0.206
6	29.25	31.96	7.61	2.28	–	6.04	–	–	0.053

Table III Co-efficient of thermal linear expansion

Item	Constituent	Value µm/m x $10^{-6}/^{o}C$
Pyrophyllite	$Al_2O_3SiO_2$	3.3
Magnesia	MgO	1.3
Steatite	$MgOSiO_2$	8.5
Aluminia	Al_2O_3	7.0 to 8.9
Zirconia	ZrO2	9.0 to 10.0
Titania	TiO2	8.8
Iron (0.06%C)	Fe	14.2
AISI 308	–	18.4

The above table (Table III) gives an idea of which type of slag would be best from the point of view of detachability. From the point of view of thermal expansion data alone it appears that a slag having higher content of a constituent which has wider difference of the co-efficient of thermal expansion between it and the base metal shall have favourable influence. Consequently, if a slag is predominantly formed of MgO the detachability would be the best followed by Pyrophyllite (Al_2O_3 SiO_2). Again Table I shows that higher basicity (electrode No. 1) act adversely and slag detachment becomes difficult.

In the case of electrode No. 2 the chemical analysis indicates presence of large quantity of iron oxide. (In the analysis presence of ferrous oxide was also observed but has however been indicated as ferric oxide). Possibly presence of iron oxide in such large quantity may have caused a slag with co-efficient of linear expansion close to that of the parent metal or forming of a thin layer of FeO at the slag metal interface and thus producing a common phase between the two. Such common phase are known to be adherent.

Considering these properties a slag containing magnesia is not much favoured whereas slag containing Pyrophyllite would be favoured. The Table II again shows that slags containing high alumina (Al_2O_3) and presumably higher pyrophyllite have better slag detachability property.

Conclusions

The results of the above work gives a guideline to look towards the factors which would significantly influence the slag detachability properties. The factors like chemical composition and consequently the basicity of the slag are often not the only properties which directly influence slag detachability.

The difference of co-efficient of thermal expansion between the slag and the base metal should be given more importance and thus slags with magnesium oxide base may form the basis of future MMA electrodes.

Acknowledgement

The author acknowledges the kind permission granted by the management of ESAB INDIA LIMITED for the publication of this paper.

References

1. Pokhodnya I.K. et.al. Mechanism of Slag crust adhesion to weld metal. Avta. Svarka (5), 1977.
2. Pokhodnya I.K. et.al. 'Kinetics of the formation of intermediate layer between weld metal and slag crust'. Avta. svarka (2), 1977, 1.4.
3. Pokhodnya I.K. et.al. The interaction of molten slag with weld pool metal and the peculiarities of the slag crust adhesion mechanism. Weld Pool chemistry and Matallurgy, International Conference, London 15-17, April 1980. The Welding Institute Paper No. 22.
4. Wittung L. Some physical and chemical properties of welding slags and their influence on slag detachability. ibid Paper No. 35.

AME - IIW Examination

The last AME-IIW examination was held on 17-21 July, 1989 at four centres - Cochin, Bombay, Visakhapatnam and Calcutta. All together 5 candidates appeared in this session.

The next examination will be held on and from 22 January, 1990 at four centres Cochin, Madras, Bombay and Calcutta. Around 10 candidates are expected to appear in this session.

The Ministry of Technical Education, Govt. of India, has been approached for recognition of the AME-IIW examination.

Reported by : Mr. N.K. Sarkar
Chairman
Welding Education Sub-Committee IIW