Submerged Arc Welding Fluxes

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Welding fluxes used in submerged arc welding have essentially the same functions to perform as the flux coating in arc welding electrodes. The flux influences the process physically and metallurgically. Physically it protects the deposited weld bead from atmospheric attacks, helps to form a bead of the right shape and prevents rapid cooling of the weld deposit. Metallurgically the fluxes, through their alloying elements, replace or add the elements lost through burning or volatalisation in the arc. The metallurgical conditions of the weld deposit are also influenced by the base plate as well as the wire used and hence it is necessary to correlate all the three factors.

A good submerged arc welding flux should have the following characteristics so that it fulfills all chemical and metallurgical requirements :

(a) It should guarantee arc stability during the entire process of welding. A submerged arc welding flux for A.C. welding should possess this property particularly when the current cycle passes through zero phase.

(b) The weld deposit should give the required chemical analysis and also the desired mechanical properties.

(c) The weld deposit and the weld joints should be free from defects like cracks, porosity etc.

(d) The slag must detach easily from the surface of the weld bead, particularly from root runs of Vee joints.

(e) The slag must have a good rate of reaction, so that the various reactions between solid, liquid and gaseous phases are completed within a very short time before the weld deposit solidifies.

and (f) The flux should have a good shelf life and should absorb as little moisture as possible.

These factors can naturally be fulfilled only when base metal and filler material are correctly chosen and the correct welding technique is adopted.

Fluxes for submerged arc welding can be classified into various groups as follows :—

(a) *Based on method of manufacture :*

(i) Fused fluxes
(ii) Sintered fluxes
(iii) Agglomerated fluxes

(b) *Based on the welding technique :*

(i) For high speed welding
(ii) For deep penetration
(iii) For thin sheet welding
(iv) For hardfacing

(c) *Based on their chemical nature :*

(i) Acid fluxes
(ii) Neutral fluxes
(iii) Basic fluxes

(d) *Based on their manganese content :*

(i) Fluxes with high manganese
(ii) Fluxes with medium manganese
(iii) Fluxes free of manganese

The slag produced by submerged arc welding fluxes may be either viscous or fluid. For high speed welding a flux with a less viscous slag can be used while for welding on curved surfaces fluxes with a more viscous slag is preferred, so that it does not flood the weld. On rusted plates, a flux with highly de-oxidising properties is to be used to reduce considerably chances of porosity. Also the ease with which the slag can be detached is a very important factor. In multi-run welding which is normally adopted in pressure vessels, the slag must detach very easily from the weld joints.

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The various welding fluxes are quite different in their chemical composition as well as in their metallurgical reaction. They are developed mostly with specific applications in view. Even as there are no universal electrodes for hand welding, it is difficult to have universal fluxes for submerged arc welding. A flux for thin sheet welding has necessarily to weld at high welding speeds. A flux for use in fillet welds should be highly resistant to porosity because in steel construction, the plates used are often rusted and they can be cleaned fully only with high wastage of time and money. Fuxes for pressure vessels must have very good mechanical properties and also give X-ray deposits but the speed of welding is only of secondary importance. For multi-run welding, it is essential that cleaning of the slag between runs is quite easy so that excessive use of hand chipping and pneumatic tools can be avoided.

It is worth noting that submerged arc welding fluxes contain a high percentage of SiO_2. This constituent imparts definite physical and chemical characteristics to the flux. It is an important raw material for increasing the fluidity of the slag.

Another important constituent of submerged arc welding fluxes is MnO. Particularly in fused fluxes it plays a very important part for ensuring the quality of the weld deposit. Fluxes for high speed welding or fluxes with a high de-oxidation capacity can never be made without a high MnO content but with increased MnO contents the maximum currents at which these fluxes can be used are reduced. The fluxes used for high current applications in industry usually have a high SiO_2 and CaO content without any MnO at all. Table 1 gives a rough idea of the chemical analysis and the range of application of a few typical fluxes.

TABLE 1

Chemical Composition of Different Submerged Arc Welding Fluxes

Applications	*Method of Manufacture*	*Wire required for use with the flux*	*Chemical composition of the flux*					
			SIO_2	*MnO*	*CaO*	*CaF_2*	*MgO*	*Al_2O_3*
For high current use (upto 4000 Amps)	By fusion	High manganese wire 2.8 to 3.2% Mn	50%	—	30%	6%	10%	4%
Multi-purpose flux (a) for fusion welding & hardfacing applications (b) for single and multi-run welding upto 1500 Amps	By fusion	Medium manganese wire 1.3 to 2.2% Mn with or without 0.5% Mo content	38%	7%	22%	6%	10%	15%
Multi-purpose flux (a) for fusion welding and hardfacing applications (b) for single and multi-run welding upto 1000 Amps	By fusion	Lower manganese wire (0.8 to 1.7% Mn)	33%	28%	7%	5%	2%	20%
Multi-purpose flux (a) thin plate welding (b) high speed welding (c) for resistance to rust (d) for hardfacing	By fusion or agglomeration	Lower manganese wire (0.8 to 1.2% Mn)	34%	40%	5%	4%	Traces	—
Multi-purpose flux (a) for fusion welding and hardfacing (b) single and multi-run welding (c) highly basic	By agglomeration	Lower manganese wire (0.4 to 1.2% Mn)	24%	8%	18%	9%	Traces	40%

The high SiO_2 (MnO free) fluxes are sensitive to the presence of rust and scale in the joints. Hence the joints have to be thoroughly cleaned before welding. The speed of welding with such fluxes is naturally slow. For the intermediate current range, the middle and high MnO content fluxes are well suited. They are recommended for multi-run welds but they can also be used for two run welds if current density is not very high. These fluxes can be used for a wide range of applications if the right combinations of wire and flux are chosen. Within certain limits these can be used for thin sheet and high speed welding. In combination with high manganese wire they can also be used for hardfacing applications. The high MnO fluxes are comparatively resistant to unclean joints. This does not mean that plates in a highly rusted condition can be used and the best results expected still.

We shall now discuss briefly the methods of manufacture of submerged arc welding fluxes and the quality control measures adopted.

Manufacture of Fused Fluxes

The fused fluxes are normally melted silicates which are prepared just like glass. They are known from the earliest days of submerged arc welding, but quite a lot of research work had to be carried out for a long time to determine the correct melting characteristics.

For fused fluxes, the classic raw materials like Quartz, Manganese Ore (Manganese Slag) Dolomite, K Felspar, Fluorspar and Clay are used. The raw materials in the required quantity are well mixed in the melting oven. For fusion an electric furnace or gas fired furnace can be used. The impurities in the raw materials used must be controlled within definite limits. Impurities like sulphur and phosphorus must be kept to very low limits. Because of the difference in crushing strength of the various materials, they should be ground separately. The mesh size of raw materials will depend on the nature of the melting oven, being between 2 to 4 mm size for electric ovens and a little smaller for the gas fired furnaces. Since the fines obtained during the process of grinding exert a bad influence, they should be removed. Also the oversize raw materials which lead to increase in melting time should also be eliminated. The proportion of raw materials selected should be based on the chemical analysis of the fluxes required. When these proportions are calculated, the melting losses should also be taken into account.

The melting capacity of an oven depends on the holding capacity of the oven and the required energy. A gas fired oven with a base area of 4 Sq. metres has a melting capacity of 300 kg of liquid slag per hour. The capacity of an electric oven in which the melt is to be removed through a hole at the bottom lies between 300-800 kg/hr. For melting in an electric oven graphite electrodes are used which are fed from a transformer. With big furnaces, the currents used are in the range of 1000—1100 Amps.

The melting process is so arranged, that initially a small quantity of raw material is melted by the arc of the graphite electrode. In this melt, the electrode is dipped and the arc is extinguished. During the process of melting, the melted flux acts as a conductor of electricity. The regulation of the melting process is done by the up and down movement of the electrode. The working temperature of the oven lies between 1500 to 1600°C.

The melting time required is calculated on the basis of the colour of the melt and its analysis. The estimation based on colour is done only for high manganese fluxes, while the low manganese fluxes are checked by means of a quick analysis. Overheated melts must be powdered and a performance test carried out. If this is found unsatisfactory, the whole melt will have to be rejected.

There are two methods of granulation of fused fluxes viz, the dry method and the wet method. In the dry method, the hot melt is dropped on to a steel plate cooled by water. The melt is cooled very suddenly and breaks into small bits. The bigger pieces are broken by a hammer. The mesh control is then done in the usual manner of grinding and sieving. For the purpose of grinding, hammer mills are preferred to ball mills because of less fines in this process.

The other method which is more widely used is called the 'Wet Method'. Here the melt is poured in a thin stream into a big container of water. Due to sudden cooling and the consequent forces, the slag is broken into small parts, which conform very nearly to the mesh size required. These are then dried in hot air ovens and sieved to required dimensions.

The fluxes are packed in paper bags or drums for onward despatch to customers.

In the wet method of granulation, one can influence the structure of the powder as desired. Besides the crystalline powder, one can also prepare a flux with porous structure. They differ not only in their structure but also exhibit an entirely different behaviour in the process of welding. For the preparation of this porous structure, suitable adjustment of the following variables is necessary :—

(a) The melting temperature

(b) The size of stream and height of fall

(c) The temperature of water in the container

Manufacture of Sintered Powder

Sintered powders are prepared in gas fired ovens. The raw materials are first ground together and then pressed into very small balls and the oven is filled with these. The working temperature of the oven is between 1000 and 1100°C. The raw materials are pressed into a solid mass at this temperature range. After this process, the same method as for fused fluxes is followed. The sieve control is closely maintained till the flux gives very good results in welding.

Manufacture of Agglomerated Fluxes

By the term agglomeration, one understands the technique of joining and holding together of different raw materials. An agglomerated flux consists of a mixture of different raw materials which have been agglomerated into fine balls. Each individual part of this agglomerated flux consists of silicates, fluorides, iron oxide, carbonates and others which have to fulfil the physical and metallurgical requirements of the flux, like slag formation, deoxidation, ionisation of the arc and alloying the weld metal. Through a binding material these raw materials are mixed in a gradual manner to form agglomerates of uniform size, weight and shape. These agglomerates are immediately dried and baked to remove all traces of moisture. The baking temperature should be kept lower than the minimum temperature at which any of the chemical constituents will disintegrate. After this baking process, the fluxes are sieved to the required mesh size. Since the individual agglomerates have a porous outer surface and pick up moisture, it is necessary to pack these fluxes into plastic bags which keep out the moisture.

Before despatch of these fluxes their performance is checked thoroughly.

Quality Control of Fluxes

The quality of a submerged arc weld depends to a very great extent on the quality of the flux used. This is why strict quality control is essential before a batch of flux produced is released for use in the market.

The melting time in the oven has a great influence on the chemical composition and the structure of a fused flux. In case the melting time is increased or the melting temperature is high, the quality of the flux gets impaired. Also irregularity in the structure of these fluxes is introduced if a definite cooling speed is not maintained. For good quality control of the flux, besides the chemical analysis, careful control of the moisture content is essential. Although fused fluxes are not directly hygroscopic due to the crystalline nature of their structure, during long storage, moisture can penetrate into their structure. For this reason, one should always store these fluxes in a clean dry room. It is a bit different for sintered and agglomerated fluxes. Due to the porous surface of the individual agglomerates, they are prone to higher moisture pick up.

As for low hydrogen electrodes, gas or electrically operated drying ovens are used for drying these fluxes at about 300°C for 3 hrs just before use. In case the fluxes are used in moisture laden condition, porosity will definitely result. Therefore, it is essential that only perfectly dried fluxes are used to get best results in submerged arc welding.

The fused submerged arc fluxes are supplied in various grain sizes depending on the nature of welding. Hence good quality control depends on good mesh control. The agglomerated fluxes on the other hand are supplied in one mesh size and this fulfills the various chemical and metallurgical functions. The best measure of quality for any flux is its performance characteristics. Out of one charge, small portions are taken from different places, mixed thoroughly and a fillet weld is made with no gap between the plates. A fillet weld is an ideal test for quality of any flux produced.

There are various ways of testing the metallurgical behaviour of submerged arc welding fluxes. In such tests one should always bear in mind that the analysis of a weld deposit depends on the quality of base material, flux and wire used.

A simpler and more accurate study of the chemical character of a flux can be made by building up on a plate, a six-layer weld pad using the flux and a wire having 0.05% Mn. On the top layer there is no dilution from the parent plate and the true influence of the flux on the chemical composition may be studied.

In conclusion it can be said that the six layer deposit analysis gives a very good method of metallurgical control of the quality of submerged arc welding fluxes. From this it can be concluded that in the middle and top layers of a multilayer weld, weld metal without any dilution of the base material is deposited and hence the wire flux combinations should be so chosen that in these portions the desired chemical analysis is obtained. In case there is loss of manganese in the weld deposit, it should be compensated for by choosing a wire with a higher manganese content. In weld deposits, which become thoroughly diluted with base material containing manganese, the manganese content is naturally high. This is the case with root runs in V or Y or X—preparations of base plates. However, the middle layers will contain a lower manganese content and hence it is necessary in such cases to choose a wire with a slightly higher manganese.

Advantages of Agglomerated Fluxes

Agglomerated fluxes present a new field of development in the manufacture of submerged arc welding fluxes and a brief description has already been given earlier of their method of manufacture. Three main advantages are claimed for these fluxes.

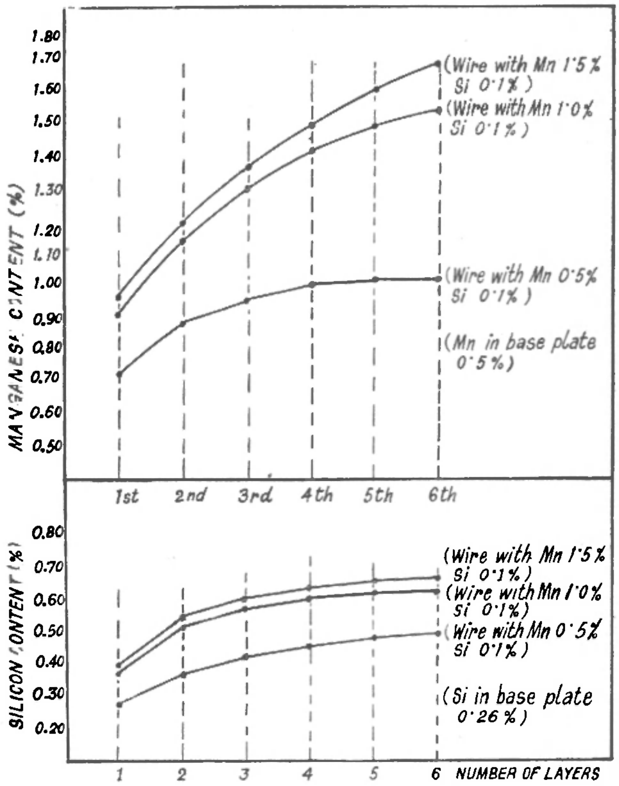
(i) The ease of manufacture of these fluxes

(ii) An unalloyed wire may be used as the alloying elements can be transferred to the weld metal from agglomerated fluxes. Such fluxes are manufactured in our country. They can give rise to an increase in the manganese content of the weld metal to about 1.2% when used with an electrode quality mild steel wire (Mn between 0.4 and 0.6%). If with the same fluxes a wire having higher manganese is used (with 1.2 to 1.6% Mn) the manganese content in the weld deposit increases considerably. The Si and Mn transfer obtained using such a flux and wires of varying manganese contents is shown in Chart I.

These figures show that in the 4th layer, the manganese content has reached 1% with a wire of 0.5% manganese. The higher the manganese in the wire, the higher is the manganese content in the weld deposit. The higher manganese recovery through the flux is an important factor in the economics of welding. Since a wire with lower manganese is cheaper than a wire with higher manganese and since with these fluxes a good manganese content results in the

CHART I

Manganese and Silicon Recovery with Agglomerated Flux and Wires of Various Compositions.



weld deposit, the use of the more expensive higher alloy wire may be dispensed with. If at all higher tensile is required a wire with a small addition of molybdenum may be used.

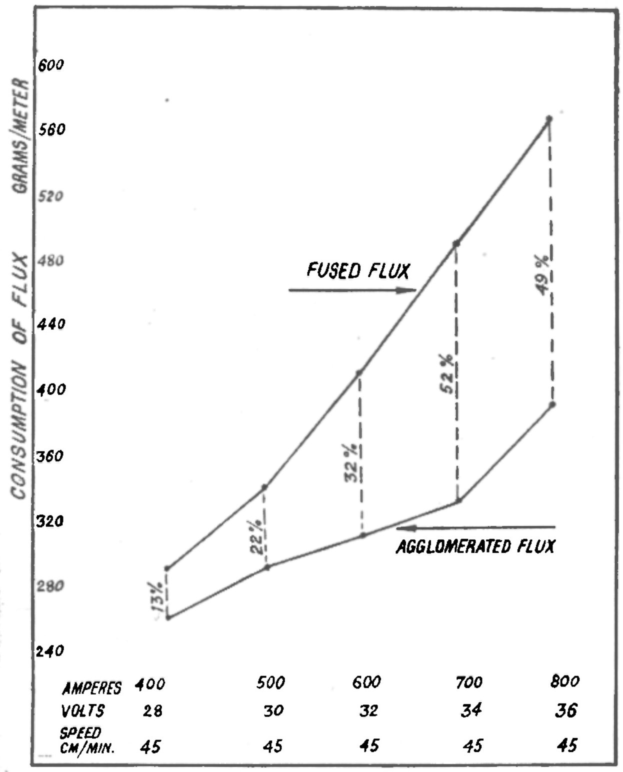
The silicon pick up of the weld deposit is equally interesting. Till the 4th layer is reached the silicon content increases and thereafter it remains practically unaltered. This is very good from a metallurgical view point, because an increase in the silicon content beyond a certain limit impairs the mechanical properties of the weld metal.

Because of the basic nature of slag, the sulphur and phosphorus contents of the weld deposit are very low and this contributes to its very good impact properties.

(iii) Another great advantage of agglomerated fluxes is their lower bulk density. This has the advantage that under identical conditions of current and voltage, less flux is melted and forms a slag as compared to fused fluxes. Comparative figures for agglomerated flux consumption and fused flux consumption for different current settings are indicated in Chart II.

CHART II

Comparison of Consumption of Fused and Agglomerated Fluxes.



The fear that agglomerated fluxes separate out and consistent results can not obtained is also not correct. Some German investigators have concluded after extensive research that even in multilayer welds with as many as 75 runs, the weld deposit reveals a very consistent deposit analysis in various layers.

The use of agglomerated fluxes affords the greatest advantage for hard-facing applications. Ferroalloys can be very easily mixed with agglomerated fluxes and significant alloying effects can be obtained. Thus, deposits of varying hardnesses can be obtained by using a simple mild steel wire in combination with different agglomerated fluxes. But with fused fluxes alloy wires invariably have to be used.

Basically, the principle of alloy addition through fluxes is the same as that employed with conventional hand welding electrodes. For manual arc welding low alloy steels and for hardfacing, the electrode core wire is usually low carbon mild steel and the necessary alloys are introduced into the deposit from the electrode coating. Similarly in submerged arc welding, the coiled electrode wire is of mild steel and the alloys are added to the deposit through the agglomerated flux covering the arc.

In welding low alloy steels and in hardfacing, the employment of the alloy flux produces consistently excellent welds, for a wide range of service conditions. The amount of alloys is dependably consistent in the weld deposit and is easily controlled by standardised welding procedures. The use of alloy fluxes is the most economical method for depositing hardfacing materials of the higher alloy types.

Equipment such as tractor rollers and idlers, must withstand considerable impact. In hardfacing these parts the material used should not be so hard as to wear away the track links. For this purpose a rather low alloy flux is used which is cheaper than buying an alloy electrode. To ensure a softer deposit with an alloy flux, the first few passes can be laid at a low arc voltage resulting in melting less flux and thus introducing less alloy in the deposit. It will thus be possible to control the chemical composition of the build up for several layers without imparting undue hardness or chances of spalling. Then the finishing layers can be laid with a higher voltage to increase the alloy pick up and thus the wear resistance.

This paper deals with, in detail, the nature of the flux behaviour during submerged arc welding. There are quite a number of process variables in submerged arc welding like arc voltage, welding current, speed of welding, polarity, size of wire used etc which also influence the alloy transfer and thus the chemical characteristics of weld deposits. These aspects are outside the scope of this paper.