

Arc welding processes (SMAW)

This chapter presents the basic principle of arc welding processes with focus on shielded metal arc welding. Further, the influence of welding parameters on performance of weld joint and the role of coating on electrode have been described.

Keywords: Arc welding, shielded metal arc welding, shielding in SMAW, electrode coating, welding current, electrode size

11.1 Arc Welding Process

All arc welding processes apply heat generated by an electric arc for melting the faying surfaces of the base metal to develop a weld joint (Fig. 11.1). Common arc welding processes are manual metal or shielded metal arc welding (MMA or SMA), metal inert gas arc (MIG), tungsten inert gas (TIG), submerged arc (SA), plasma arc (PA), carbon arc (CA) selding etc.

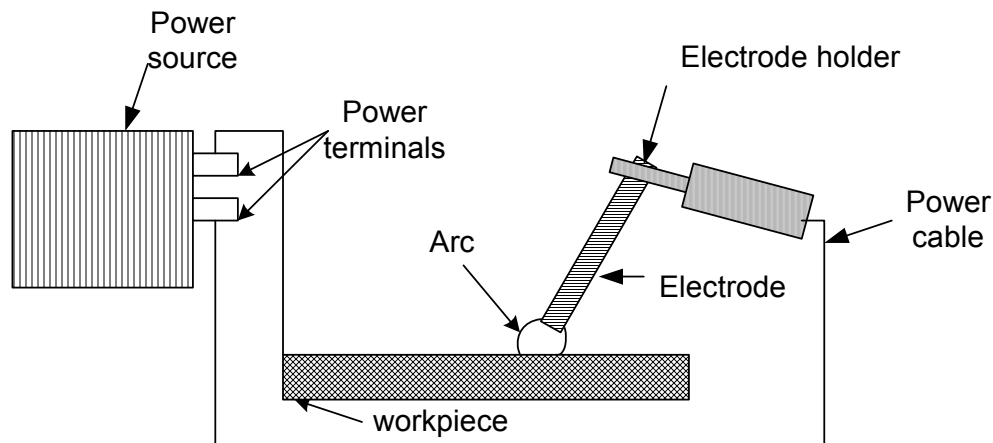


Fig. 11.1 Schematic diagram showing various elements of SMA welding system

11.2 Shielded Metal Arc Welding (SMAW)

In this process, the heat is generated by an electric arc between base metal and a consumable electrode. In this process electrode movement is manually controlled hence it is termed as manual metal arc welding. This process is extensively used for depositing weld metal because it is easy to deposit the molten weld metal at right place where it is required and it doesn't need separate shielding. This process is commonly used for welding of the metals, which are comparatively less sensitive to the atmospheric gases.

This process can use both AC and DC. The constant current DC power source is invariably used with all types of electrode (basic, rutile and cellulosic) irrespective of

base metal (ferrous and non-ferrous). However, AC can be unsuitable for certain types of electrodes and base materials. Therefore, AC should be used in light of manufacturer's recommendations for the electrode application. In case of DC welding, heat liberated at anode is generally greater than the arc column and cathode side. The amount of heat generated at the anode and cathode may differ appreciably depending upon the flux composition of coating, base metal, polarity and the nature of arc plasma. In case of DC welding, polarity determines the distribution of the heat generated at the cathode and anode and accordingly the melting rate of electrode and penetration into the base metal are affected.

Heat generated by a welding arc (J) = Arc voltage (V) X Arc current (A) X Welding time (s)-----(equation 11.1)

If arc is moving at speed S (mm/min) then net heat input is calculated as:

$H_{net} = VI (60)/(S \times 1000)$ kJ/mm.....(equation 11.2)

11.3 Shielding in SMA welding

To avoid contamination of the molten weld metal from atmospheric gases present in and around the welding arc, protective environment must be provided. In different arc welding processes, this protection is provided using different approaches (Table 1). In case of shielded metal arc welding, the protection to the weld pool is provided by covering of a) slag formed over the surface of weld pool/metal and b) inactive gases generated through thermal decomposition of flux/coating materials on the electrode (Fig. 11.2). However, relative effect of above two on the protection of the weld metal depends on type of flux coating. Few fluxes (like cellulosic coating) provide large amount of inactive gases for shielding of weld while other fluxes form slag in ample amount to cover the weld pool. Shielding of the weld pool by inactive gases in SMAW is not found very effective due to two reasons a) gases generated by thermal decomposition of coating materials don't necessarily form proper cover around the arc and welding pool and b) continuous movement of arc and varying arc gap during welding further decreases the effectiveness of shielding gas. Therefore, SMAW weld joints are often contaminated and are not very clean for their possible application to develop critical joints. Hence, it is not usually recommended for developing weld joints of reactive metals like Al, Mg, Ti, Cr and stainless steel. These reactive metal systems are therefore commonly welded using welding processes like GTAW, GMAW etc. that provide more effective shielding to the weld pool from atmospheric contamination.

11.4 Coating on electrode

The welding electrodes used in shielded metal arc welding process are called by different names like stick electrode, covered electrode and coated electrode. Coating or cover on the electrode core wire is provided with various hydrocarbons, compound and elements to perform specific roles. Coating on the core wire is made of hydrocarbons, low ionization potential element, binders etc. Na and K silicates are invariably used as binders in all kinds of electrode coatings. Coating on the electrode for SMAW is provided to perform some of the following objectives:

- ❖ To increase the arc stability with the help of low ionization potential elements like Na, K
- ❖ To provide protective shielding gas environment to the arc zone and weld pool with the help of inactive gases (like carbon dioxide) generated by thermal decomposition of constituents present in coatings such as hydrocarbon, cellulose, charcoal, cotton, starch, wood flour
- ❖ To remove impurities from the weld pool by forming slag as constituents present in coatings such as titania, fluorspar, china-clay react with impurities and oxides in present weld pool (slag being lighter than weld metal floats over the surface of weld pool which is removed after solidification of weld)
- ❖ Controlled alloying of the weld metal (to achieve specific properties) can be done by incorporating required alloying elements in electrode coatings and during welding these elements get transferred from coating to the weld pool. However, element transfer efficiency from coating to weld pool is influenced by the welding parameter and process itself especially in respect of shielding of molten weld pool.
- ❖ To deoxidize weld metal and clean the weld metal: Elements oxidized in the weld pool may act as inclusions and deteriorate the performance of the weld joint. Therefore, metal oxides and other impurities present in weld metal are removed by de-oxidation and slag formation. For this purpose, deoxidizers like Ferro-Mn, silicates of Mg and Al are frequently incorporated in the coating material.
- ❖ To increase viscosity of the molten metal and slag so as to reduce tendency of falling down of molten weld metal in horizontal, overhead and vertical welding. This is done by adding constituents like TiO_2 and CaF_2 in the coating material. These constituents increase the viscosity of the slag.

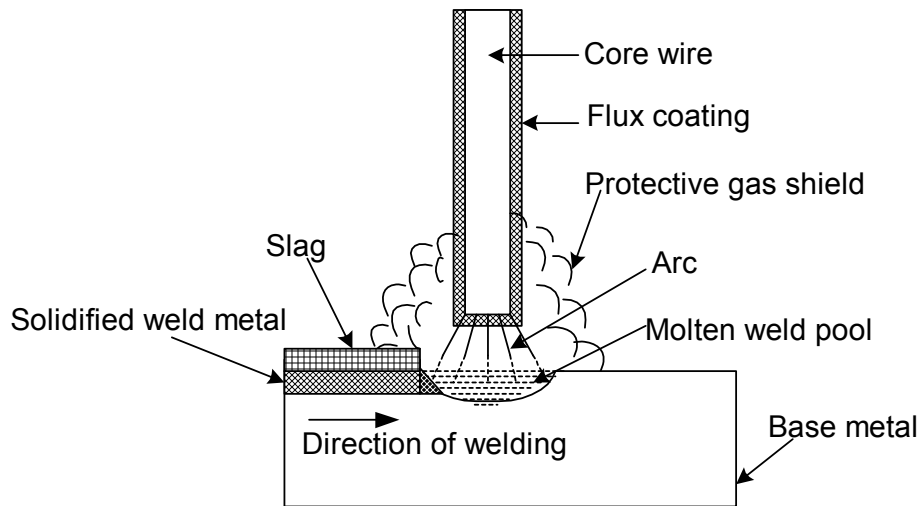


Fig. 11.2 Schematic diagram showing constituents of SMAW

Role of common constituents added in flux of SMAW electrode is given below.

[Technical document, MMAW, Aachen, ISF, Germany, (2005)]

| Constituent in flux | Role on welding arc features |
|--|--|
| Quartz (SiO_2) | Increases current-carrying capacity |
| Rutile (TiO_2) | Increases slag viscosity, good re-striking |
| Magnetite (Fe_3O_4) | Refines transfer of droplets through the arc |
| Calcareous spar (CaCO_3) | Reduces arc voltage, produces inactive shielding gas, slag formation |
| Fluorspar (CaF_2) | Increases slag viscosity of basic electrodes, decreases ionization |
| Calcareous- fluorspar ($\text{K}_2\text{O Al}_2\text{O}_3 6\text{SiO}_2$) | Improves arc stability by easy ionization |
| Ferro-manganese and ferro-silicon | Acts as deoxidant |
| Cellulose | Produces inactive shielding gas |
| Potassium Sodium Silicate ($\text{K}_2\text{SiO}_3 / \text{Na}_2\text{SiO}_3$) | Acts as a bonding agent |

11.5 Common types of SMAW electrodes

The steel electrode of a given composition is made available with different types of flux coating in order to make them suitable for different arc characteristics, welding position, welding speed, deposition rate, weld metal recovery, weld metal properties and variety of quality requirements. The selection of correct type of electrode coating results in weld metal with desired quality characteristics at low cost. In general,

welding electrode is selected in such a way that characteristics of weld metal are similar to or better than the base material while keeping in mind the welding position and weld joints design as they significantly affect the properties of the weld.

11.5.1 Rutile electrode

These electrodes predominantly contain rutile (TiO_2) besides other constituents and are known to offer almost 100% weld metal recovery, easy arc striking and re-striking. These are found suitable for a) fillet welds, b) welding of sheet metal, c) good gap bridging capability, d) free from spatter losses and e) all position welding. These are recommended for welding low strength steel (<440 MPa). For welding of high strength steel (>440 MPa) generally weld metal should have low hydrogen level and therefore weld joints is developed using basic, rutile, basic-rutile and Zircon-based electrode.

11.5.2 Cellulosic electrodes

These electrodes are composed of large amount of hydrocarbon compounds and calcium carbonates besides other constituents and are found suitable for a) all welding positions especially for vertical and overhead welding position and b) realizing high mechanical properties in a weld metal of radiographic quality. These are preferred for vertical downward welding. However, these produce high hydrogen content in weld metal besides deep penetration.

11.5.3 Acidic electrode

Acidic electrodes offer a) easier arc striking than basic electrodes but poorer arc striking than rutile electrodes, b) moderate welding speed, c) smooth weld bead d) good slag detachability. However, acidic electrode has been replaced by rutile electrode and basic electrode for flat and positional welding respectively. The ductility and toughness weld metal developed by acidic electrode are better than those developed from rutile electrodes however yield and ultimate tensile strength are found inferior. This type of electrode results in minimal penetration which is good for very thin sheet but these are sensitive to moisture pick up.

11.5.4 Basic electrode

These electrodes have basic (alkali) coatings containing calcium carbonate / calcium fluoride. The basic electrodes are preferred over other electrode for developing weld joints of high strength steel (480-550 MPa) with weld metal having a) low hydrogen, b) good low temperature toughness, c) resistance to hot and cold cracking. However, these electrodes suffer from comparatively poor slag detachability. The welding speed and deposition rate offered by the basic electrodes especially in vertical welding position is much higher than the rutile and acidic electrode. Basic electrodes can sustain higher welding current even in vertical welding position.

11.5.5 Basic-rutile electrode

This type of electrode combines positives of both basic as well as rutile electrodes and therefore recommended for horizontal-vertical fillet welds of high strength steels.

11.6 Welding parameters for SMAW

SMA welding normally uses constant current type of power source with welding current 50-600A and voltage 20-80V at 60% duty cycle. Welding transformer (AC welding) and generator or rectifiers (DC welding) are commonly used as welding power sources. In case of AC welding, open circuit voltage (OCV) is usually kept 10-20% higher than that for DC welding to overcome the arc un-stability related problems due to fact that in case AC both current magnitude and direction changes in every half cycle while those remain constant in DC. OCV setting is primarily determined by factors like type of welding current and electrode composition which significantly affect the arc stability. Presence of low ionization potential elements (Ca, K) in coating and reduce the OCV required for stable arc.

Importance of welding current

Selection of welding current required for developing a sound weld joints is primarily determined by the thickness of base metal to be welded. In general, increase in thickness of plate to be welded increases the requirement of heat input to ensure proper melting, penetration and deposition rate. This increased requirement of heat input is fulfilled using higher welding current. Thus, need of high welding current dictates use of large diameter electrode. SMAW electrode are commercially available in different sizes and generally found in a range from 1-12.5 mm in steps like 1.25, 1.6, 2, 2.5, 3.15, 4, 5, 6.3, 8 and 10 mm.

Upper and lower limits of welding current for SMAW are determined by possibility of thermal decomposition of electrode coating material and arc stability respectively. Welding current (A) is generally selected in range of 40-60 times of electrode diameter (mm). Too high current creates problem of damage to the electrode coating material due to thermal decomposition caused by electrical resistance heating of the core wire besides turbulence in the arc. Turbulence in the arc zone can lead to spatter and entrainment atmospheric gases. On other hand low current setting makes the arc unstable, poor penetration and low fluidity of molten weld metal. All these tend to develop discontinuities in weld joints.

In shielded metal arc welding process, lower limit of current is decided on the basis of requirement for stable arc, smooth metal transfer and penetration whereas higher limit of current is decided on the basis of extent of overheating of core wire that an electrode coating can bear without any thermal damage. High current coupled with long electrode extension causes overheating of core wire of electrode due to electrical resistive heating. Excessive heating may cause the combustion/decomposition of flux much earlier than when it is required to provide inactive shielding gases for protecting the weld pool and arc. Therefore, large diameter electrodes are selected for welding of thick sections as they can work with high welding current. Large diameter electrodes allow high current setting without any adverse effect on electrode coating materials because increased cross sectional area of electrode reduces resistance to the flow of current and so the electrical resistance heating of the core wire is reduced.

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