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Review on effect of flux composition on its behavior and bead geometry in submerged arc welding (SAW)

Brijpal Singh[1], Zahid Akthar Khan[2] and Arshad Noor Siddiquee[2]

[1]Department of Mechanical Engineering, Maharaja Surajmal Institute of Technology, C-4, Janakpuri, New Delhi, 110058, India.

[2]Department of Mechanical Engineering, Jamia Millia Islamia University, Jamia Nagar, New Delhi, 110025, India.

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Performance of a welding flux is decided by the physical and chemical properties of its constituents. The flux selected should show a good welding behavior and the required weld bead geometry. The mechanical properties of a joint are not only decided by its composition but these also depends on bead geometry, dimensions and physico-chemical properties of fluxes. These properties include surface tension, viscosity, heat capacity, thermal coefficients of expansion, grain size etc. These properties of fluxes primarily affect the flux behavior, bead shape and size, welding speed, current carrying capacity, protection of molten metal, arc stability, slag detachability, capillarity, surface tension and viscosity. Various constituents of a welding flux have major influence on the performance of welding processes and weld bead dimensions. We need to understand the physical properties and behavior of fluxes during submerged arc welding. The influence of specific flux additions on arc stability, viscosity, capillarity, slag detachability and weld bead shape need to be better characterized. It can be inferred that we cannot obtain the weld of desired geometry and composition until we consider the physico-chemical characteristics of flux like slag viscosity, surface tension, arc stability and slag detachability, capillarity and weld penetration. So, while designing the flux or during selection of welding process parameters the above characteristics should be carefully controlled or selected.

Key words: Submerged arc welding, bead width, reinforcement, weld penetration, bead morphology.

INTRODUCTION

Weld bead shape is an indication of bead geometry, which affects the load carrying capacity of the weldments (Baach et al., 1981; Samiti, 1986). The bead geometry is specified by bead width, reinforcement, penetration size factor and reinforcement factor.

A flux may serve a number of essential functions, which include metal refinement, atmospheric protection, stabilization of arc, and improvement of the bead morphology. With increase in mechanization and automation, the selection of flux and welding procedures must be more specific to ensure adequate weld bead quality is obtained (Mcglone, 1982). The bead profile determines to a large extent the stress carrying capacity of the welded joint (Gupta and Parmar, 1986). The variations in the behavior of commercial flux are found depending upon their geological origin, chemical composition and method of manufacturing. These variables affect the physical and chemical behavior of fluxes. The increasing demand of high quality joints, deep penetration, smooth finish etc requires better control of chemical content and the welding process parameters. With increasing use of automated welding systems, precise control over chemical content and selection of process variables in submerged arc welding (SAW)

*Corresponding author. E-mail: brijpalsingh101@gmail.com.

becomes important. These two together decides the bead geometry. In order to have better control of the chemical content, it is essential to understand the flux behavior. The behavior of the flux is reported to be associated with basicity, viscosity, slag detachability, arc stability, weld penetration and bead shape. Most of the researchers have discussed the effect of process parameters on weld bead geometry but the effect of flux composition has been discussed very little so this literature review will provide a base for the researchers in the field of SAW (Chandel et al., 1997; Murugan and Gunaraj, 2005).

This review aims to draw the attention of the researchers to correlate the physical properties with the flux behavior and bead shape so that the load carrying capacity of the welded joint may be increased.

FLUX BEHAVIOR

Arc stability

Arc instability is commonly measured as the average voltage variation around the set potential during welding. It is also being measured as the distance that an electrode can be pulled away from the work and still maintain the arc.

Flux can affect arc stability by containing materials of various ionization potential. Materials which are added to the flux to produce vapors alone with low ionization potential are classified as arc stabilizers. Schwemmer et al. (1979) discussed the effect of flux properties on weld bead dimensions. The arc stability has a profound effect on weld bead shape and penetration. The atoms of low ionization potential which improve arc plasma, conduction and reignition characteristic are often related to overall improvement in arc stability.

Schwemmer et al. (1979) stated that FeO, CaO improves arc stability due to the presence of more easily ionized atoms however beyond a certain limit determined by other constituents it makes the viscosity of the slag too low. It also makes the flux more sensitive to moisture pick up, which causes porosity. MnO improves arc stability, due to increased oxygen potential in the arc cavity and as a result of change in oxide activity of slag. It favors high welding speed and deep penetration and decreases the sensitivity to rust and porosity. On the other hand it decreases the current capacity.

FeO addition to the flux has a more marked influence on arc stability, basicity. Arc stability depends upon availability of active oxygen at the cathode surface. Higher oxygen potential of gas over the flux improves arc stability and leads to deeper penetration (Patchett and Dancy, 1980).

Davidenko (1938) has reported that acidic fluxes require a higher arc voltage than basic fluxes. The non-stabilizing behavior of SiO_2 has been confirmed by Russanevitz (1938). He also reported that the alkali and alkaline earth oxides produce vapors that are easily ionized and therefore stabilize the arc. FeO, NiO, CuO and TiO_2 produce vapors that have a medium ionization potential and they have a little effect on arc stability. Also Al_2O_3 and Cr_2O_3 are reported to decrease the arc stability.

Hazett (1957) has found that when using single component compounds, CaO produces a more stable arc than SiO_2 or MnO. It is reported that CaO improves the arc stability more than MnO.

Arc stability data have been reported for various flux compositions (Russanevitz, 1938). Various contaminant level additions to a flux have been found to influence the arc behavior (Sorokin and Sidlin, 1981). Good correlation between arc instability and ionization potential has been reported (Olson and Indacochea, 1983). The arc instability may also be influenced by the specific alloying additions in the weld pool.

Understanding the nature of arc stability in welding arc is important to the development of welding consumables for advanced welding systems where the control is based on electric sensing of arc and feedback. A new generation of welding fluxes behaviors needs to be developed.

Viscosity

Viscosity is being reported as a function of basicity and flux composition (Ferrera and Olson, 1975). An increase in acidic component of a basic flux decreases the fluidity or increase the viscosity. The reason is that the viscosity increases as SiO_2 is a network former and it forms covalent bonds and these bonds close the silica network (Sims, 1963). When basic components like CaO or MnO is added to the network, the numbers of Si-O bonds are decreased. The viscosity is greater for $MnO\text{-}SiO_2\text{-}CaO$ flux system than for $MnO\text{-}SiO_2$ for the same basicity. This indicates that Cao is not as effective a network former as is MnO, because when some of MnO is replaced by CaO the actual viscosity increases (Sims, 1963).

Diffusion, reaction rates and heat transfer during welding process are dependent on the viscosity of flux (Belton et al., 1963). If the viscosity of the flux is high, the gas atoms cannot diffuse rapidly through the flux and reach the flux metal interface before the flux solidification.

The flux must have a low enough viscosity to dissolve the gases entrapped between the molten flux and metal (Butler and Jackson, 1967). The molten flux should spread over the total surface of the weld bead to provide the protection for the weld. It has been reported that the viscosity of a basic flux is decreased when CaO, MnO, Fe_2O_3, CaF_2 content is increased.

For proper flux coverage the flux should melt at a temperature approximately two hundred degree Celsius below that at which the alloy melts. The mass transport behavior of a flux is a function of both the temperature and flux composition and can be correlated to the viscosity. Attempts have been made to determine the ionic properties responsible for changes in manganese silicate fluxes. For the group of similar cations there is a modest increase in viscosity with increasing ionic characteristic (Olson, 1989).

Valance has a strong effect on viscosity. It is well known that ions with a high valance are more likely to act as network formers and forms silicates of high viscosity. Iwamoto et al. (1976) and Jackson (1960) reported that the viscosities range at 1400°C should be from 2 to 7 Poise.

The viscosities of various welding fluxes and oxides have been reported (Mills, 1977). Even the small concentration of impurities may degrade the performance of the flux.

It has been reported that if the viscosity of manganese silicate fluxes is above 7 Poise a definite increase in weld surface pocking will occur. Pock marks have been associated with easily reducible oxides in the flux, which contribute oxygen to the weld pool. The weld pool reacts with carbon to form carbon monoxide, which cannot be transported through a high viscosity flux and is trapped at the liquid metal/flux interface. The result is a weld metal surface blemished by pocks. As viscosity is sensitive to temperature and thus heat input, pocking can be the evidence that a flux formulated, for high current welding is being used at too low current or at too great travel speed. Slag viscosity also affects the shape of the weld deposit and must be carefully controlled when covered electrodes are used out of position. The higher the slag viscosity, the greater is the weld penetration in submerged arc welding. However this benefit must be balanced, because if the viscosity is too high the gaseous products cannot escape the weld pool and creates porosity. This can be monitored by observing the density of pores in the underside of detached slag.

Viscosity and interfacial tension influence the smoothness of the weld bead surface and the reinforcement angle. CaF_2 increases interfacial tension (Palm, 1972) and improves the impact strength.

A low interfacial tension will promote a concave bead, while a high interfacial tension will produce convex bead (Linnert, 1995). It was shown by Joublanc (1938) that if the viscosity of the flux is too high, there could be depressions on the surface, and the edges of the weld bead would not be parallel. The reason for this is that the highly viscous flux impedes uniform solidification and does not allow the gases to escape. Hazett (1957) has observed some contradictory behavior in weld width and penetration.

Slag detachability

Slag detachability a serious productivity concern for steel manufacturers. Residual slag on the weld deposit promotes slag stringers in multi pass weldments, limits the effective use of narrow gap flux related welding processes. It also reduces the corrosion resistance of the weldments.

Welding flux formulations have modified flux compositions to reduce this problem (Olson et al., 1993). Slag detachability has been related to both the physical and chemical properties of the flux. These properties include the differences between the thermal expansion coefficients of the slag and the metal, and the phase transformations in the slag during cooling.

Poor slag removal has been reported to occur when the flux contains fluorite. Slags containing spinels generally have been found to attach tenaciously to the weld deposit. Slags with cordierite, and [Cr, Mn, Mg]O, [Cr, Mn, Al]$_2$O$_3$ type spinel phases have been reported to be difficult to remove. It has also been reported that if CaO_2, SiO_2, Cr_2TiO_2 are present slag readily detaches from the weld deposit. Increasing the Al_2O_3 content in the flux has demonstrated improved slag detachability.

Capillarity

The interfacial tension between the molten flux and the weld metal has been found to be a function of flux composition. Keene (1979) reported that small variations in surface active components could have significant effects on interfacial properties. The interfacial tension associated with slag metal reactions influence the weld pool morphology. Weld bead morphology correlates better with capillary considerations than with kinetic functions such as melting temperature and viscosity (Hazett, 1957). As the MnO content increases the tendency of under cutting is observed because the interfacial tension is changed by changing the constituents of flux.

Current carrying capacity, welding speed and moisture pick up

Each component of flux makes its own contribution to the behavior of flux. SiO_2 is added to a flux to adjust viscosity and increase the current capacity (Sparagen and Claussen, 1939). Grain size of the flux particles also increases the current carrying capacity (Patchett, 1983). There is in fact very little information on weld bead formation. MnO is added to a flux to decrease the sensitivity of the flux to rust. MnO also allows welding speed to be increased at a constant voltage and wire feed rate. CaO increases the efficiency to remove sulfur and phosphorus, to improve arc stability. However CaO also increases the sensitivity of the flux to pick up moisture from the atmosphere (Palm, 1972).

Bead width and weld reinforcement

Weld bead width is the maximum width of the weld metal deposited on base plate. It increases flux consumption rate and affects chemistry of weld metal. Weld width and reinforcement are important physical properties of a weldment as they help in determining the strength of a welded joint (Thodeti, 1992). According to Tregelsky (1968), reinforcement should usually be 20% of plate thickness. Excessive reinforcement does not improve the strength of the weld but increases weld consumption. Yang et al. (1992) investigated that bead width was not significantly affected by the type of power sources when acidic fluxes are used, however constant current source gives large bead width. When using basic fluxes. Various welding parameters such as heat input, welding speed, polarity, arc length, metal transfer etc seem to affect the weld width and reinforcement (Gurev and Stout, 1963). The B.I has no significant effect on bead width; however reinforcement decreases with increase in basicity index (Kumar, 2011).

Weld penetration

Weld penetration is the maximum distance between the base plate top surface and depth to which the fusion has taken place. The more the penetration, the lesser the number of passes required to complete the weld and consequently the higher production rate. The penetration is influenced by flux composition, welding speed, polarity, arc travel speed, electrode stickout, basicity index and physical properties of the flux.

The influence of welding flux on weld bead penetration has been investigated. A linear relationship between penetration and the physical characteristics [viscosity, capillarity and arc stability] of the submerged arc welding has been reported. Arc penetration has been found to vary with heat input and flux composition (Renwick and Patchett, 1976). An equation for arc penetration was reported by Jackson and Shrubsall (1953) to be

$$P = k(I^4/SE^2) \quad (1)$$

Where P is the penetration, I is the current, S is the travel speed, E is the input voltage and k is a constant which would be expected to be dependent on composition of flux and base metal. Hazett (1957) has shown that single pure flux components cause different amounts of penetration. He showed that pure $CaCO_3$, K_2CO_3 and CaF_2 produce shallow penetration, while MgO, SiO_2, Na_2CO_3, MnO_2, Al_2O_3 shows medium penetration. Deep penetration was reported by the use of $MgCO_3$. It has been reported by others that the addition of MnO improves arc penetration. A modified Jackson Shrubsall equation of the general form has been suggested.

$$P = k(\gamma fl - \gamma fm)\eta\Delta v(I^4/SE^2)^{1/3} + c \quad (2)$$

Where η is the viscosity, Δv is the arc instability and are flux solid metal interfacial tensions, I is the current, E is the arc potential, S is the travel speed and c, k are constants. All the parameters used in the above equation [viscosity, surface tension and voltage instability] have been shown to be dependent on FeO levels in the flux, but there is no causal relationship between the above parameters and weld penetration (Patchett and Dancy, 1980).

The width to depth of penetration ratio is a measurement of the confining effect of flux. A low number for this ratio indicates that the energy or heat from the electric arc has been confined by the flux to a narrow region. Belton et al. (1963) has reported that as the amount of SiO_2 decreases the width to depth of penetration ratio increases. Width to depth of penetration ratio is found to be slightly dependent on basicity. Caddell (1967) reported that the penetration increases with decreasing thermal conductivity of the base metal.

The improved arc stability automatically leads to deeper penetration simply because the wander is minimized allowing the more efficient transfer of heat. It is hazardous to link increased penetration with increased viscosity. The effect of viscosity on penetration is likely small compared with the effect of arc stability. Surface tension or interfacial energy is also unlikely to have a primary effect on penetration.

It is generally recognized that penetration is influenced by current, voltage and travel speed, while other factors are thermal conductivity, arc length and arc force. The higher the thermal conductivity of the work material, the shallower will be the penetration. Too small arc may also give rise to poorer penetration (Austin, 1956). Ishizaki (1966) made a detailed study on the mechanism of penetration from the point of view of interfacial tension theory and found that arc force played an important role in determining the contour of the surface of penetration.

The researchers in their old research have used the thermodynamics that decides equilibrium of a chemical reaction to discuss the effect of flux composition on flux behavior. The new researchers are using mathematical modeling, algorithms, regression analysis to correlate bead geometry with welding process parameters.

RESULTS

Results of this review show physical properties of fluxes and their factors.

i) Arc stability: Ionization potential of flux, oxygen, B.I oxygen Potential of gases over the flux, alloying additions, contaminant, flux composition.

ii) Viscosity: Diffusion, reaction rate and heat transfer during welding.

iii) Interfacial tension: Mass transport behavior of flux, valancy and chemical composition.

iv) Slag detachability: Physical and chemical properties of flux, thermal coefficients of slag, phase transformed during cooling.

v) Capillarity: Interfacial tension, chemical composition of flux.

vi) Current carrying capacity, welding speed, moisture pickup: Grain size of flux, chemical composition of flux.

vii) Penetration: Flux composition, current, travel speed, viscosity, arc length, thermal conductivity.

CONCLUSIONS

With the discussions on the above it is found that flux constituents has a major effect on flux behavior and bead shape geometry. The load carrying capacity of the welded joint does not only depend on microstructure but it is also affected by the physical behavior of the flux, and bead geometry. The main characteristics which are affected by flux constituents are arc stability, slag detachability, capillarity, viscosity and basicity index. These above characteristics of the flux also affect the bead geometry parameters like weld width, reinforcement, penetration and dilution. To make a strong joint in submerged arc welding the above characteristics of the flux should be considered and for this a scientific methodology is to be adopted for designing the fluxes. Research to determine the physical behaviors of welding flux that can be sensed to control consumable welding process behavior and to determine the physical property data necessary to model consumable welding process behavior is required.

REFERENCES

Austin JB (1956). Electric ARC welding. American Tech. Soc., Chicago, pp. 61-62.

Baach H, Nadkarni SV, Vishvanasth PS (1981). Submerged arc welding: Combined increased deposition rates with improved mechanical properties. Proceedings of the National Conference, Trichi, India.

Belton GR, Moore TJ, Tankins ES (1963). Slag metal reactions in submerged arc welding. Weld. Res. Suppl. 42(7):289-297.

Butler CA, Jackson CE (1967). Submerged arc welding characteristics of the $CaO–TiO_2–SiO_2$ systems. Weld. Res. Suppl. 46(10):448-456.

Caddell RM (1967). The influence of physical properties on penetration in arc welding. Trans. ASME J. Engg. Ind. pp. 328-332.

Chandel RS, Seoe HP, Cheong FL (1997). Effect of increasing deposition rate on weld bead geometry of submerged arc welds. J. Mater. Process. Tech. 72:124-128.

Ferrera KP, Olson DL (1975). Performance of the $MnO–SiO_2–CaO$ system as a welding flux. Weld. Res. Suppl. pp. 211-215.

Gupta VK, Parmar RS (1986). Fractional factorial technique to predict dimensions of weld bead in automatic submerged arc welding. J. Inst. Engr., India, 70:67-71.

Gurev HS, Stout RD (1963). Solidification phenomenon in inert gas metal arc-welds. Weld. J. 42(7): 298-310.

Hazlett TH (1957). Coatings ingredients influence on surface tension, arc stability and bead shapes. Weld. Res. Suppl. 36(1):18-23.

Ishizaki K (1966). Interfacial tension theory of the phenomena of arc welding - Mechanism penetration. In Proceeding of the Symposium on Physics of the Weld. Arc. The Institute of Weld., London, pp.195-209.

Iwamoto N, Tsunawaki Y, Nakagawa H, Yoshimmua T, Wakabayashi N (1976). Spectral chemistry of green glass-bearing 15426 regolith. Trans. J. Weld. Res. Inst. 5:101.

Jackson CE (1960). The science of arc welding part-1. Weld. Res. Suppl. 39(4):129-140.

Jackson CE, Shrubsall AE (1953). Control of penetration and melting ratio with welding techniques. Weld. Res. Suppl. 32(4):172-178.

Kumar V (2011). Development and characterization of fluxes for submerged arc welding. Shodhganga. http://shodhganga.inflibnet.ac.in/handle/10603/2065. 16 May 2011.

Linnert G (1995). Weld Metallurgy. American Welding Society, New York.

Mcglone JC (1982). Weld bead geometry prediction - A review. Metal Const., pp. 378-384.

Murugan N, Gunaraj V (2005). Prediction and control of weld bead geometry and shape relationship in submerged arc welding of pipes. J. Mater. Process. Tech. 168:478-487.

Olson DL (1989). Keynote address - The fundamentals of welding consumables. Proceedings of 2nd International Conference on Trends in Welding Research, Gatliburg, Tennessee, USA, pp. 551-562.

Olson DL, Indacochea JE (1983). Relationship of weld metal microstructure and penetration to weld metal oxygen content. J. Mater. Energy Syst. ASM Int. 5(3):139-148.

Olson DL, Liu S, Frost RH, Edwards GR, Fleming DA (1993). Nature and Behavior of fluxes used for Welding. ASM Handbook 6(10):55-63.

Palm JH (1972). How fluxes determine the metallurgical properties of submerged arc welds. Weld. Res. Suppl., 51(7):358-360.

Patchett BM (1983). Some effects of flux physical properties on Weld-Bead formation in the SAW process." J. Mater. Energy Syst. 5(3):165-166.

Patchett BM, Dancy EA (1980). Discussion on the relationship of weld penetration to the welding flux. Weld. Res. Suppl. 13:36.

Renwick BG, Patchett BM (1976). Operating characteristics of sub merged arc processes. Weld. Res. Suppl. 35(3):69-76.

Samiti Z (1986). Automatic pulsed MIG welding. Metal Constr. 1:38R-33R.

Schwemmer DD, Olson DL, Williamson DL (1979). The relationship of weld penetration to the welding flux. Weld. Res. Suppl. 59(5):153-160.

Sims CE (1963). Theory and fundamentals of Electrical furnace steelmaking. AIME vol. 2.

Sparagen W, Claussen WG (1939). Coating and fluxes in welding of Steels. Weld. Res. Suppl. 18(5):153-165.

Thodeti S (1992). Submerged arc welding of high strength LOW alloy steels. Ph.D. Dissertation. IIT, Delhi, India.

Tregelsky V (1968). The electric welder. Foreign Languages pub. House, Moscow.

Yang LJ, Chandel RS, Bibby MJ (1992). The effects of process variables on the bead width of submerged-arc weld deposits. J. Mater. Process. Tech. 29(1):133-144.