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FACTORS INFLUENCING SUBMERGED ARC WELDING ON STAINLESS STEEL - A REVIEW

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ABSTRACT

Stainless Steel have functional characteristics in wide variety of applications such as nuclear reactor vessels, heat exchangers, oil industry tubulars and components of chemical processing units. Components have been used in such industries often required joining of materials with high thickness. There are many welding methods reliable for stainless steel welding. Among various welding methods, Submerged Arc Welding technique is familiar for high thickness welding .In this paper, Submerged Arc welding process and the effect of process parameter on quality of welding have been reviewed with various researches and discussed in detail because of its inherent benefits such as higher metal deposition rate, good strength of the joint and good surface appearance. Due to the above said desired properties, this welding process is extensively used in the fabrication of pressure vessels, pipe lines and off-shore structures. Welding flux constitutes nearly half of the cost in Submerged Arc Welding process. This welding process is often preferred because it offers high production rate, high melting efficiency and ease of automation. The review is concerned with factors influencing the quality of weld in stainless steel by Submerged Arc Welding and hope that it is very helpful for predicting the best welding conditions for stainless steel.

Keywords: submerged arc welding, stainless steel and flux.

INTRODUCTION

In Submerged Arc Welding (SAW) process, the arc and the molten weld metal are shielded by a covering envelope of molten flux and a layer of unfused granular flux particles. The arc is literally submerged in flux, thus the process is relatively free of intense radiation of heat and light in most typical open arc welding processes and the resulting welds are very clean. Like Gas Metal Arc Welding (GMAW) process, SAW process employs continuous solid wire electrode that is consumed to produce filler metal.

The arc currents are generally very high (500A to 2000A). The efficiency of transfer of energy from electrode source to work piece is very high (usually over 90%), since losses from radiation, convection and spatter are minimal. The deposition rate is high and weld reliability is good.

Cost reduction and productivity improvement in welding operations can therefore generate considerable impact on competitiveness of various manufacturing industries. Welding time, joint preparation and arc efficiency are the most important factors dominating the cost and productivity of the weld. The desired amount of weld penetration should be achieved in a single pass the welding speed will be the major factor that determines the welding time. The arc efficiency determines proper penetration as well as productivity of quality welds. Thickness of the part is also important in developing the desired penetration.

Principle of SAW Process

Figure-1 indicates the main principles of SAW in schematic form. The filler material is an uncoated, continuous wire electrode, applied to the joint together with a flow of fine-grained flux, which is supplied from a flux hopper via a tube. The electrical resistance of the electrode should be as low as possible to facilitate welding at a high current and so the welding current is supplied to the electrode through contacts very close to the arc and immediately above it. The arc burns in a cavity, which is apart from the arc itself, is filled with gas and metal vapour. The top of the cavity is formed by molten flux. Figure-2 shows the solidified weld and the solidified flux, which covers the weld in a thin layer and which must subsequently be removed. Not all of the flux supplied is used up. The excess flux can be sucked up and used again. The flux also has a thermal insulating effect and thus reduces heat losses from the arc. As a result, more of the input energy is available for the actual welding process itself. The thermal efficiency is greater and the rate of welding is faster. It has been found that submerged arc welding has higher thermal efficiency than Shield Metal Arc Welding (SMAW).

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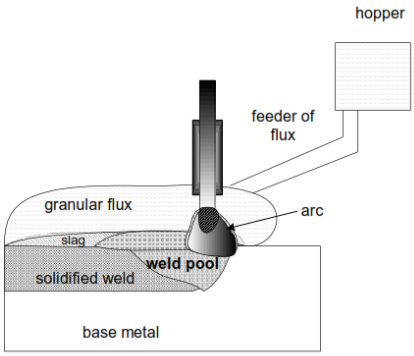

Figure-1. Schematic of SAW process.

Stainless Steel

In general, they are alloyed with a number of other elements that make them resistive to a variety of different environments such as corrosive and oxidative environments. These elements also modify the microstructure of the alloy, which in turn has a distinct influence on their mechanical properties and weldability. Stainless steels can be broadly classified into five groups as detailed below:

Austenitic stainless steels, which contain 12-27% chromium and 7-25% nickel.

- Ferritic stainless steels, which contain 12-30% chromium with a carbon content below 0.1%.
- Martensitic stainless steels, which have chromium content between 12 and 18% with 0.15-0.30% carbon.
- Ferritic-austenitic (Duplex) stainless steels, which contain 18-25% chromium, 3-5% nickel and up to 3% molybdenum.
- Martensitic-austenitic steels, which have 13-16% chromium, 5-6% nickel and 1-2% molybdenum.

SAW with Stainless Steel

The procedure for welding stainless steel does not differ greatly from that of welding mild steel. The material being handled is expensive and exacting conditions of service are usually required necessitating extra precautions and attention to detail. Stainless steel can be welded using either AC or DC with as short an arc as possible to overcome any possibility of alloy loss across the arc. When using AC, a slightly higher current setting maybe required. When welding in the flat position, stringer beads should be used and, if weaving is required, this should be limited to two times the electrode diameter. The heat input, which can adversely affect corrosion resistance and lead to excessive distortion, should be limited by using the correct electrode diameter to give the required bead profile and properties at the maximum travel speed.

Welding Electrode

The diameter of electrodes used in submerged arc welding generally ranges from 1-5 mm. The electrode wire is fed from the spool through a contact tube connected to the power source. Electrode wire of steel is generally copper coated for two reasons a) to protect it from atmospheric corrosion and b) to increase their current carrying capacity.

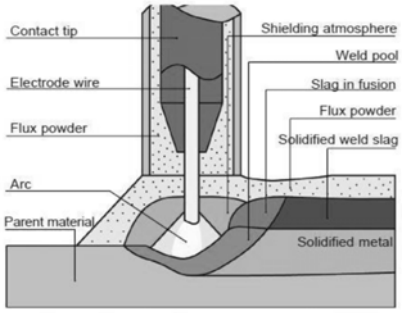

Figure-2. Sectional view of SAW process.

SAW Flux

Role of fluxes in SAW is largely similar that of coating in stick electrodes of SMAW i.e. protection of weld pool from inactive shielding gases generated by thermal decomposition of coating material. SAW fluxes can influence the weld metal composition appreciably in the form of addition or loss of alloying elements through gas metal and slag metal reactions. Few hygroscopic fluxes are baked (at 250-300°C for 1-2 hours) to remove the moisture. There are four types of common SAW fluxes.

Manufacturing steps of these fluxes are given below.

- Fused fluxes: raw constituents-mixed-melted-quenched-crushed screened-graded
- Bonded fluxes: raw constituents-powdered-dry mixed-bonded using K/Na silicates-wet mixed-pelletized-crushed-screened
- Agglomerated fluxes: made in similar way to bonded fluxes but ceramic binder replaces silicate binder
- Mechanically mixed fluxes: mix any two or three type of above fluxes in desired ratios.

The fused and agglomerated types of fluxes usually consist of different types of oxides and halides such as MnO, SiO2, CaO, MgO, Al2O3, TiO2, FeO, CaF and Sodium/Potassium Silicate. Halide fluxes are used for high quality weld joints of high strength steel to be used for critical applications while oxide fluxes are used for developing weld joints of non-critical applications. Some of oxides such as CaO, MgO, BaO, CaF_2 , Na_2O, KO, MnO etc. are basic in nature (donors of oxygen) and few others such as SiO_2, TiO_2 , Al_2O are acidic (acceptors of oxygen). Depending upon relative amount of these acidic

and basic fluxes, the basicity index of flux is decided. The basicity index of flux is calculated by the ratio of the sum of (wt. %) all basic oxides to all non-basic oxides.

LITERATURE REVIEW

Austin J.B reported that the penetration is influenced by current, voltage and travel speed, 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. Caddell also found that the penetration increases with decreasing thermal conductivity of the base metal. [1, 3]

Belton *et al.* (1963) has revealed 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. [2]

Daemen *et al*. concluded that at 850° C the transformation of ferrite to austenite phase occurs very rapidly in the alloys 316L. Taking in account both the slow cooling rates during strip welding and the fact that the ferrite pools have smaller dimensions in a weld metal than in the cast or forged steels, it is possible to justify the presence of sigma phase in as deposited weld metal. In order to avoid this type of transformation which is detrimental for the corrosion resistance of the alloys, the welding consumables must be specially designed. The σ-γ mixture which is formed in the sites of the original ferrite proved to be very corrosion sensitive. All the etchants are likely to produce very pronounced corrosion effects on those areas. As a result, the higher corrosion rates observed on σ - 316L low ferrite alloys [4]. Renwick *et al*. studied the characteristics of the weld bead penetration, melting rate under variable operating current conditions and found that those increased with the increase in current. They also investigated that increase in welding voltage produced flatter and wider bead and increased flux consumption. [5].

Bailey N *et al*. postulated that trans-varestraint test has been used to directly assess the effects of compositional factors on solidification cracking of submerged arc welds. Good correlations have been obtained between compositionally based crack susceptibility values and the cracking of actual welds in C and C-Mn steels made with a range of weld compositions. The test cannot be used to investigate the effects of factors which change the weld shape since such changes alter the test conditions. Provided certain limitations are accepted, corrections can be made to compare Transvarestraint results obtained from tests giving different weld shapes. Measures recommended to minimize solidification cracking include gap filling techniques, using filler metals with low C, S and P contents and the proper use of multi power techniques to maintain or increase deposition rates while avoiding the detrimental effects of large dilutions and high depth/width ratios. [6]

Schwemmer *et al*, had shown that a flux with higher viscosity would tend to confine the molten weld pool, thus increasing the heat input for a given area and resulting into deeper penetration. [7]. Fleck *et al*. found that filler material and flux composition in SAW would influence the growth of austenite considerably. [8] Gowrisankar *et al*. revealed that an increase in the number of passes during welding results in an increase in the minimum delta-ferrite content in the root region of the weld, and a decrease in the difference between the delta ferrite contents at the surface and root of the weld. Furthermore, a systematic increase in the hardness and tensile strength properties and a decrease in the ductility and impact properties of the weld metal have been observed with an increase in the number of passes during welding. [9]

Yang *et al*. reported that for a particular electrode diameter and extension, the bead width increases initially as the current is increased up to a maximum after while it decreases as the welding current is increased further [10]. Gupta *et al*. used five different commercial fluxes in their investigation of submerged arc welding of mild steel, and found that the welding parameters and the flux basicity appreciably affected the depth of penetration and width of the weld bead. The reinforcement was also influenced by welding parameters, but not appreciably by flux basicity. With respect to Heat Affected Zone (HAZ) width, the authors observed lower values with highly basic fluxes as compared to lower basicity fluxes, at lower welding current range. The investigators, however, could not find any definite trend of HAZ width with reference to flux basicity and felt that different widths of HAZ obtained with different fluxes (other welding parameters being kept constant) might be due to different proportions of heat shared by the molten flux and the weld metal [11].

Tsai *et al*. have used grey-based Taguchi methods to determine optimum process parameters for submerged arc welding in hard facing. For Experimentation they deposited a martensitic stainless steel hard facing layer on 30x80x120mm mild steel plate by SAW process. Using grey relation they have done evaluations on dilution rate, hardness and deposition rate, finally done the analysis of variance. From this study they concluded that the performance characteristics such as hardness, dilution and deposition rate are improved together by using grey relation [12].

Murugan *et al* concluded that either high voltage and high welding speed or low voltage and low welding speed produced low dilution. Cladding surfaced at low dilution conditions possessed good ductility and resistance to intergranular corrosion [13]. Lee *et al* reported that for a given heat input, the HAZ-to-bead size ration decreases as the welding current increases. Although the weld bead size and HAZ size increase with the increasing welding current, there is a greater increase in the bead size compared to the HAZ size [14].

Malin conducted experiments employing modified refractory flux welding and studied the effects of welding variables on formation of root (backside) welds, including the root bead (deposit inside the groove) and

root reinforcement (deposit outside the groove). The work also revealed that welding variables produced profound and sometimes conflicting effects on the root weld‟s shape. For example, increasing the current increased the deposition rate and the depth of joint penetration; however, root bead shape deteriorated and slag pockets formed, which might provoke defects in the weld. [15-16]

Jerzy Nowacki *et al*. had studied that the influence of the heat input on submerged arc welding (SAW) of duplex steel UNS S31803. As a result of the tests, it can be stated that increase of plate thickness increases weld defectiveness of duplex steel. Increase of welding heat input reduces the occurrence of inadmissible welding imperfections in joints, which reduces the costs of testing and repairs [17]. Ana *et al*. conducted a study for chemical and structural characterization of fluxes used in submerged arc welding process, which enabled one to quantify the ions that might be present in the plasma arc due to the fluxes. Their analysis was capable of predicting reactions that occur in the weld pool [18].

Chi *et al*, reported that welding of 316LN stainless steel with a single sided single pass submerged arc welding process was satisfactorily undertaken up to 20 mm plate thickness without preheat or postweld heat treatment. The ability to achieve this resulted in significant economic savings within the process for ship panel production combined with satisfactory weld metal properties [19]. Ghosh *et al*. addressed the issue associated with the uncertainties involved with the HAZ in and around the weldment produced by SAW process. The most intriguing issue is about HAZ softening that imparts some uncertainties in the welded quality. It increases the probability of fatigue failures at the weakest zones caused by the heating and cooling cycle of the weld zone. They assessed the heat affected zone of submerged arc welding of structural steel plates through the analysis of the grain structure. [20-21]

Pranesh *et al*. found that increase in welding current increases the depth of penetration. It is known that molten metal droplets transferring from the electrode to the plate are strongly overheated. It can be reasonably assumed that this extra heat contributes to more melting of the work piece. As current increases the temperature of the droplets and hence the heat content of the droplets increases which results in more heat being transferred to the base plate. Increase in current reduces the size but increases the momentum of the droplets which on striking the weld pool causes a deeper penetration or indentation. The increase in penetration as current increased could also be attributed to the fact that enhanced arc force and heat input per unit length of the weld bead resulted in higher current density that caused melting a larger volume of the base metal and hence deeper penetration [22].

CONCLUSIONS

After reviewing the various research papers, much useful information about the Submerged Arc Welding process and its process parameters have been collected. This review paper would be helpful for the ongoing researches on improving the production quality and optimization of process parameters of SAW on stainless steel.

i. The SAW process is applicable to the welding of stainless steels where the higher heat input and slower solidification are tolerable. With submerged arc welding, depending upon the flux chosen, the silicon content may be much higher than with other processes.
ii. The submerged arc process is not recommended where a weld deposit is needed that is fully austenitic or is controlled to low ferrite content (below 4%). However, high quality welds may be produced for applications in which more than 4% ferrite in weld deposits are allowable.
iii. For stainless steel welding, DC power is mostly used on thin sections. Either AC or DC may be used on heavier pieces but DC is often preferred.
iv. Number of passes has greater influence on mechanical properties. Increased Number of passes resulting in superior mechanical properties such as tensile and hardness by developing incomplete transformation of delta ferrite to austenite. It is occurred due to differential heating and cooling rates per pass.

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