IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 12, Issue 2 Ver. II (Mar - Apr. 2015), PP 39-44
www.iosrjournals.org

Optimization of Submerged Arc Welding Process: A Review

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Abstract: *Welding processes that employ an electric arc are the most prevalent in industry are Shielded Metal Arc Welding, Gas Metal Arc Welding, Flux Cored Arc Welding, Submerged Arc Welding and Gas Tungsten Arc Welding. These processes are associated with molten metal. Molten metal reacts with the atmosphere so that oxides and nitrides are formed. All arc welding processes employ some means of shielding the molten weld pool from the air. The Submerged Arc Welding process is often preferred because it offers high production rate, high melting efficiency, ease of automation and low operator skill requirement. Generally, all welding processes are used with the aim of obtaining a welded joint with the desired weld-bead parameters, excellent mechanical properties with minimum distortion. The Submerged Arc Welding (SAW) process finds wide industrial application due to its easy applicability, high current density and ability to deposit a large amount of weld metal using more than one wire at the same time. The quality of weld depends on bead geometry of the weld which in turn depends on the process variables. Welding input parameters play a very significant role in determining the quality of a weld joint. The joint quality can be assessed in terms of properties such as weld-bead geometry, mechanical properties, and distortion.*

Index Terms**—** *Weld joint, Welding parameters, Wire Shielded Metal Arc Welding, Gas Metal Arc Welding, Flux Cored Arc Welding, Submerged Arc Welding and Gas Tungsten Arc Welding.*

I. Introduction

Submerged arc welding can be employed for an extremely wide range of workpieces. The method is suitable for butt welding and fillet welding of such applications as structural members in ships, manufacture of pressure vessels, bridge beams, massive water pipes, thin sheet shells and so on. In addition, the process is particularly effective for cladding applications, e.g. when surfacing mild carbon steel with stainless steel materials, or when depositing hard materials on a softer substrate. Submerged arc welding is generally performed indoors in fabrication shops. Working outdoors always carries the risk of undesirable levels of moisture finding their way into the joint or flux and resulting in porosity of the weld. If submerged arc welding must be carried out outdoors, special precautions should be taken, such as the construction of a roof over the work area. Submerged arc welding is most efficient if the joint can be filled with as few passes as possible. If, when working in mild steel, the workpiece can be turned over, and if the material is not too thick, a bead is often applied from each side of the joint. If the basic material is alloyed steel, a multi-pass procedure is normally necessary. Admittedly, this results in an increase in process costs, but for many workpieces the economics of the process are still sufficiently attractive for submerged arc welding to be more cost effective than, say, manual welding using coated electrodes. In addition, there will be fewer weld defects with automatic welding.

Principle of submerged arc welding

The diagram below indicates, in schematic form, the main principles of submerged arc welding. 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, apart from the arc itself, is filled with gas and metal vapour. The size of the cavity in front of the arc is delineated by unmelted basic material, and behind it by the molten weld. The top of the cavity is formed by molten flux. The diagram also 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.

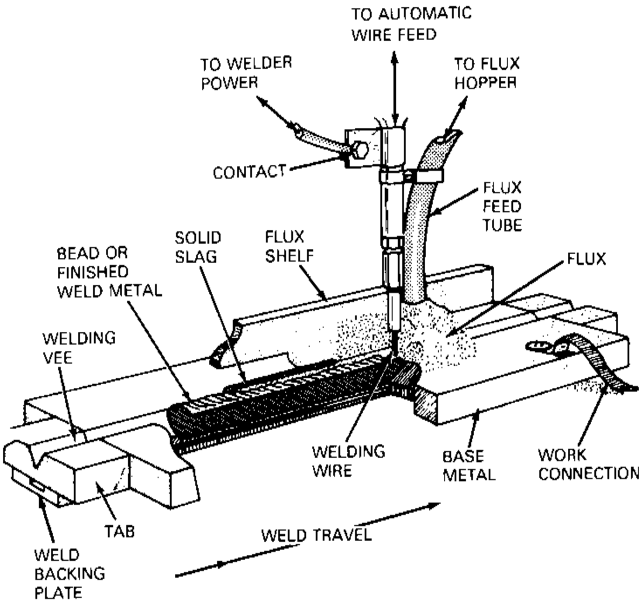

Fig. 1. Submerged Arc Welding

The filler metal is a continuously-fed wire electrode like GMAW and FCAW. However, higher deposition rates can be achieved using SAW by using larger diameter electrodes (up to 1/4”) and higher currents (650-1500 Amperes). Since the process is almost fully mechanized, several variants of the process can be utilized such as multiple torches and narrow gap welding. 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 than is the case with processes involving an exposed arc. The thermal efficiency is greater and the rate of welding is faster. It has been found that submerged arc welding has a thermal efficiency of about 90 %, as against an approximate value of about 75 % for MMA welding. Submerged arc welding can be performed using either DC or AC.

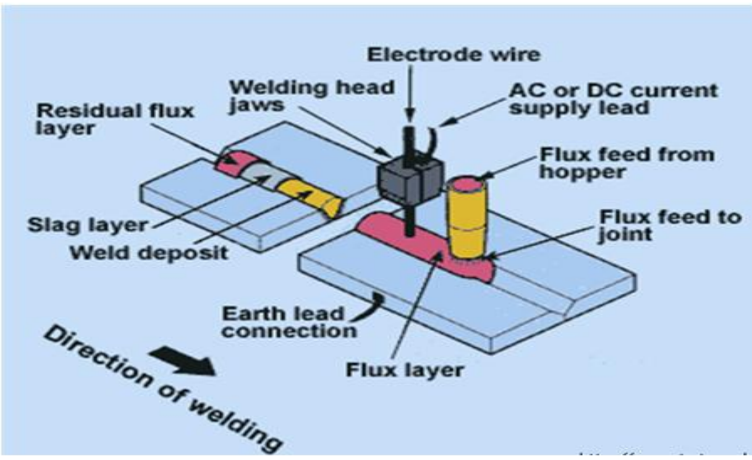

Fig.2. Direction of Welding Process

Important parameters in Submerged Arc Welding

1. Arc voltage

The arc voltage is decisive in determining the shape and width of the arc and, to some degree, also in determining its penetration. Too high an arc voltage in an I-joint in flat sheet will produce a wider weld, while in a V-joint, X-joint and fillet radii it will result in a concave weld, with a risk of undercutting and slag that is difficult to remove. On the other hand, too low an arc voltage will result in a high, round weld in I-joints and V-joints, while in X-joints and fillet radii it will result in a convex weld, and which is also hard to de-slag.

2. Welding current

Welding current is the parameter that is of greatest importance for penetration. The current setting depends on the thickness of the metal and the type of joint. The current has no effect on the width of the bead, but too high a current can result in burn through, while too low a current can result in insufficient penetration with resulting root defects.

3. Welding speed

The welding speed (the linear speed along the line of the weld) also affects the penetration. If the speed is increased relative to the original value, penetration will be decreased and the weld will be narrower. Reducing the speed increases penetration and results in a wider weld (cf. manual welding). However, reducing the welding speed to about 20–25 cm/min (depending on the actual value of the current) can have the opposite effect, i.e. a reduction in penetration, as the arc is prevented from transferring thermal energy to the parent metal by the excessive size of the weld pool. If the welding speed is to be changed while penetration is kept constant, it is necessary to compensate by adjustment of the welding current, i.e. to increase or decrease it.

4. Wire diameter

For a given current, a change in wire size will result in a change in current density. Greater wire diameter results in a reduction in penetration and, to some extent, also the risk of burning through at the bottom of the weld. In addition, the arc will become more difficult to strike and arc stability will be adverse.

Submerged Arc Welding Methods

1. **Single-wire welding:** Filler wires with diameters from 1.2 mm to 6 mm can be used with welding currents of 120–1500 A. Submerged arc welding processes have developed from single-wire welding to higher productivity processes.
2. **Twin-arc welding:** Submerged arc welding with two parallel wires differs more from twin-wire welding with separate welding heads than it does from conventional submerged arc welding having one wire and one welding head. An automatic twin-arc welding machine can be easily produced by fitting a single-wire machine with feed rollers and contact tips for two wires, together with an extra carrier for a second wire bobbin. Double wires have become increasingly common in the interests of higher productivity. Without very much higher capital costs, it is possible to increase the deposition rate by 30–40% in comparison with that of a single-wire machine, as a result of the higher current density that can be carried by two filler wires in parallel. As the equipment uses only a single wire feed unit, the welding current will be shared equally between the two wires.

Wire sizes and types of current:

Wire sizes normally used for butt welding are 2.0, 2.5 and 3.0 mm, with wire separations of about 8 mm. DC welding, with the wire positive relative to the workpiece, is preferable, as this results in the best arc stability and least risk of porosity. When hard facing using tubular wires, it is generally preferable for the wire to be negative, resulting in minimum penetration and highest deposition rate. Commonly used tubular wire diameters are 2.4, 3.0 and 4.0 mm.

Wire angles and positions: advantages and drawbacks

- By varying the angle of the contact tip, the wire angle relative to the joint can be varied.
- With the wires in line with the joint, penetration will be highest and risk of undercutting will be least. This position ensures the least risk of porosity, as the molten weld metal has longer to cool, allowing more time for gas to escape from the weld.
- With the wires perpendicular to the joint, penetration is minimum. This arrangement is preferred in welds in which ordinary root faces for submerged arc welding cannot be used, e.g. corner/fillet welds, and also where wide joint widths need to be covered with one pass or where the edges of the joint are uneven. There is some risk of undercutting at high welding speeds. As, with the wires in this position, very little of the parent metal is melted relative to the amount normally melted in the submerged arc process, resulting in an improved form factor of the weld. This arrangement is also used for welding materials in which there is a risk of thermal cracking.
- A pair of wires arranged diagonally to the weld can be used as a compromise position to obtain the benefits of the two basic positions described above.

II. Literature Survey

Dhas et al.[1] elaborates the study of welding procedures generation for the submerged arc welding process. Several research works have already been carried out in the field of submerged arc welding for parametric optimization.

Biswas et al.[2] studied the effect of process parameters on output features of submerged arc weld by using Taguchi method.

Chang et al.[3] applied grey-based Taguchi methods for optimization of submerged arc welding process parameters in hard facing. They considered multiple weld qualities and determined optimal process parameters based on grey relational grade from grey relational analysis proposed by Taguchi.

K. srinivasulu reddy[4] in his paper presented optimization & prediction of welding parameters and bead geometry in submerged arc welding. He collected data as per Taguchi's Design of Experiments and analysis of variance (ANOVA) and experiment was carried to establish input–output relationships of the process. By this relationship, an attempt was made to minimize weld bead width, a good indicator of bead geometry, using optimization procedures based on the ANN models to determine optimal weld parameters. The optimized values obtained from these techniques were compared with experimental results and presented.

Juang and Tarng [5] have adopted a modified Taguchi method to analyze the effect of each welding process parameter (arc gap, flow rate, welding current and speed) on the weld pool geometry (front and back height, front and back width) and then to determine the TIG welding process parameters combination associated with the optimal weld pool geometry. It was experimentally reported that, the four smaller-the-better quality characteristics, 'four responses' of the weld pool in the TIG welding of S304 stainless steel of 1.5 mm in thickness are greatly improved by using this approach.

Laser butt-welding of a thin plate of magnesium alloy using the Taguchi method has been optimized by **Pan et al. [6].** They studied the effect of Nd-YAG laser welding parameters (shielding gas type, laser energy, conveying speed, laser focus, pulse frequency and pulse shape) on the ultimate tensile stress. Their result indicated that the pulse shape and energy of the laser contributed most to thin plate butt-welding.

Anawa et al. [7] have continued their investigation and studied the effect of the laser welding parameters mentioned above on the impact strength of the same joint at room temperature using the same optimizing technique. The results indicated that the laser power has the most significant effect on the impact strength. Also, it was mentioned that the optimal settings to obtain excellent impact strength were the highest laser power, a welding speed of 750 mm/min and a focus position of -0.5 mm.

Lee et al. [8] have used the Taguchi method and regression analysis in order to optimize Nd-YAG laser welding parameters (nozzle type, rotating speed, title angle, focal position, pumping voltage, pulse frequency and pulse width) to seal an iodine-125 radioisotope seed into a titanium capsule. The accurate control of the melted length of the tube end was the most important to obtain a sound sealed state. It was demonstrated that the laser pulse width and focal position were the laser welding parameters that had the greatest effects on the S/N ratios of the melted length.

Muruganath [9] used Non-dominated Sorting Genetic Algorithms (NSGA) to optimize the contradicting combination of strength and toughness of steel welds.

Gunaraj and Murugan [10] applied Response Surface Methodology (RSM) for prediction and optimization of weld bead quality in submerged arc welding of pipes by establishing mathematical models.

Tarng et al. [11] applied grey based Taguchi method for optimization submerged arc welding process parameters in hard facing.

Datta et al. [12] developed statistical models for predicting bead volume of submerged arc butt-weld.

Patnaik et al. [13] studied the effect of process parameters on output features of submerged arc weld by using Taguchi method. The relationship between control factors and performance outputs was established by means of nonlinear regression analysis, resulting in a valid mathematical model. Finally, Genetic Algorithm (GA) was employed to optimize the welding process with multiple objectives.

Datta et al. [14] applied Taguchi philosophy for parametric optimization of bead geometry and HAZ width in submerged arc weld.

III. Conclusion

Fluxes melt to form a protective slag over the weld pool. Slag keeps oxygen off weld bead during cooling. Flux produces protective gas around weld pool. General purpose welding widely used High speed & quality (4 – 10x SMAW) and 300 – 2000 amps(440 V). The following gaps in literature review have been discovered.

- Very less work has been reported on metal transfer in SAW, which influences the chemical composition and metallurgy of weld metal, arc stability, weld bead geometry as well as strength of the weld.
- Very less work on current voltage transient study in submerged arc welding has been reported as many characteristics are influence by current voltage.
- The study of effect of polarity change affects the amount of heat generated at welding electrode and work piece. Hence influences the metal deposition rate, weld bead, HAZ and mechanical properties of the weld metal.

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