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Study of Various Process Parameters, Defects and Their Control in Submerged Arc Welding - Review

Sahil Thappa[1], Pranav Dev Srivyas[2], Sahil Singh[3], Sarbjeet Singh[4]
[1]MBSCET, Jammu, India
[2, 3, 4]GCET, Jammu, India
Email address: sahilthappa1122@gmail.com[1], devpranav.srivyas@gmail.com[2], sahilsingh4244@gmail.com[3], sarabjeet.gcet@gmail.com[4]

***Abstract*—** Submerged arc welding (SAW) is known for high reliability, smooth finishing and good quality weld formation especially for welding of heavy pipe lines and boilers and is used widely throughout the world. It is a process of selecting proper process parameters such as welding temperature, bead width, weld timing etc. The flux used in this process, while transportation and handling, gets converted into dust like fine particles called as slag, which if not removed before using the flux in welding process, can result into many defects in the joint made by submerged arc welding, and dumping the waste flux into open air can cause pollution too. Some of the defects in submerged arc welding include porosity, surface pitting improper penetration, arc blows, undercut, slag sticking etc. A study to control the various costs involved in submerged arc welding such as welding cost, disposal of the waste flux and also reduction of pollution due to waste flux has been done. This study also encompasses the re-use of waste flux, in order to reduce the cost up to some extent. This study also shows how the re-use of waste flux reduces the cost of welding and also reduces the pollution. To study the defects, cost reduction and reduction in pollution in involved in submerged arc welding, a review of past few years has been made. This study also covers various process parameters involved in the submerged arc welding required to be followed for better results.

***Keywords*—** Bead geometry, defects, HAZ, melt-through, SAW, waste flux.

I. INTRODUCTION

Welding is a process of joining two or more metal pieces together as like riveting which is time consuming process. Submerged arc welding (SAW), also called as submerged melt welding is much reliable process. It was introduced in 1930's as one of the automatic welding process to provide high quality weld. The method of submerged arc welding is to struck the metal electrode with the work piece. Both the electrode and work piece are made in contact under a layer of granular flux, which helps in minimizing the spatter, flash and smoke outside the flux. It also makes the welding arc invisible. It is compulsory to use appropriate flux and electrode combination to produce a weld, such that it meets the minimum requirements of the base metal which is to be joined. Submerged arc welding (SAW) is widely used throughout the world in industrial arc welding processes, ship building, structural components and bridges as the deposition rate of SAW is high. It is reliable process but at the same time it needs more monitoring of its process parameters. It is very necessary to predict the process parameters before starting the welding process, as the welding is to be done on various wall thicknesses. Commonly it is found that the defects in weld due to bad bead geometry, quality of flux used and the flux consumption rate, i.e. if bead penetration is not proper or is more than the requirement it will cause the weld to be weak for obvious reasons. Over-melt can also be there if the time requirements are not met properly. It is necessary that only the portion of metals which are to be joined is in the heat affected zone (HAZ). The consumption of the flux depends upon the welding rate i.e. the length of metal joint in given time. It is used in the fabrication processes of pressure vessels, heavy machine parts, construction and many more.

Submerged Arc welding Process:

Submerged arc welding process is shown in the fig. 1. SAW includes a continuously –fed bare wire electrode and work piece. The process of submerged arc welding is done at a high temperature as to initiate the process a high resistance conducting material is required, so the temperature at the welding area is very high. The high resistance conducting material like steel wool or carbon between the electrode and the work piece.

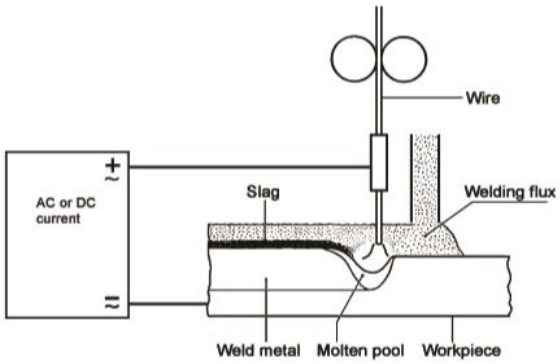

Fig. 1. Submerged arc welding process.

When the current is made to flow through the electrode, steel wool and the work piece the intense heat produced due to the resistance offered by the steel wool melts the metal, which forms a weld pool. The weld formation takes place when the molten filler displaces the liquid flux and fuses with the molten base metal. Now the molten flux moves above the molten metal pool and forms a blanket like cover surface and

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gets hardened. This flux coating also makes sure that the newly welded zone which can easily be oxidized is not open to air, so reducing the chances of oxidization and spattering of arc. The molten weld metal and molten flux is cooled to normal temperature beneath the layer of unused flux coating. This unused flux is little porous, brittle slag layer which can easily be removed.

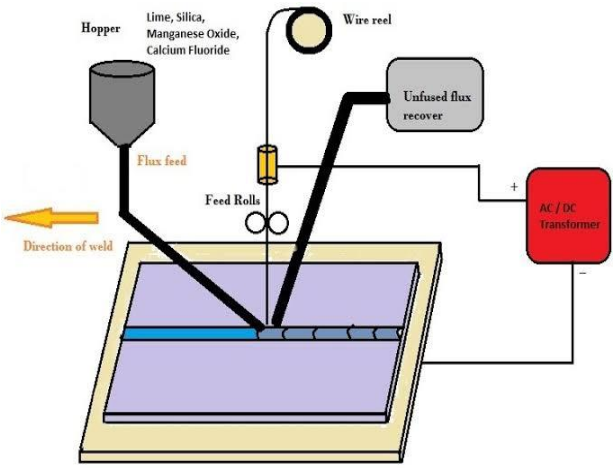

Fig. 2. SAW operation.

MOARREFZADEH et. al*[9] investigated the Numerical simulation of welding process in SIMPELC method and ANSYS software to find copper temperature field gained in the process in SAW. A complete model describing the 3D mathematical model in metal transfer in SAW process is developed in this paper. The results computed that the Gaussian assumption for the distributions of the arc pressure, heat flux, and current density on the work piece surface did not represent of the real situation.

DALLAM et. al*[16] studied the Flux Composition Dependence of Microstructure and Toughness of Submerged Arc weldments. In an attempt to study the chemical and crystalline nature of the particles, an acid dissolution technique was used.

OMI et. al*[5] This work investigates the effect of polarity and other SAW parameters on HAZ size and dilution. It also establishes their correlations. Using statistical technique empirical models have been developed. This investigation is an attempt to quantify the effect of SAW parameters on heat input, HAZ size and dilution.

EBERT et. al*[17] tests performed to check the effect of post weld heat treatment on the strength and hardness of various types of carbon steel. Tests revealed that the commonly employed carbon steel SAW electrodes may not consistently provide weld metal required for minimum tensile strength when the heat treatment is specified.

AMANIE et. al*[11] carried his investigation in about the influence of submerged arc welding (SAW) process parameters on the microstructure of SA516 grade 70 steel weld metal (WM). The results showed that the WM grain structure coarsened but the grain width of prior austenite grains decreased with increasing heat input. Also, the proportion of acicular ferrite (AF) in the WM increased initially, while the volume fractions of grain boundary ferrite and Widmanstatten ferrite decreased with increasing welding current. The weld nugget area decreased with increasing welding speed at all currents, but did not affect the amount of AF produced.

SINGH et. al*[10] studied the effect of waste flux and its effect on the environment. This poses the problem of storage, disposal, and environmental pollution and needs landfill space apart from exhaust of non-renewable resources. He concluded that if the waste slag is reused, it will solve the problem. In this investigation an attempt has been made to reuse the submerged arc welding slag as flux in the submerged arc welding process. Results after the case study were reduced cost, arc stability and reduced pollution.

DAS et. al investigated about the ANFIS for prediction of weld bead width in a submerged arc welding process. This Paper propose an intelligent technique, Adaptive Neuro-Fuzzy Inference System (ANFIS) , to predict the weld bead width in the submerged arc welding (SAW) process for a fiven set of welding parameters. Experiments are designed according to Taguchi's principles and its results are used to develop a multiple regression model.

KRISHANKANT et. al*[8] designed an experiment based on a five level factorial central composite rotatable design with full replication . The experimental calculations and results graph was conducted as per the design matrix using Design Expert Software. The analysis of variance (ANOVA) was applied to study the effect of input parameters on the flux consumption. In this study, the effect of welding current, arc voltage, welding speed and distance between tip of nozzle & work piece on the flux consumption. Finally the results revealed that the flux consumption increased with the increase in open circuit voltage and very small increases with increases in current.

EAGAR et. al*[16] in this work examined about the oxygen level of submerged arc weld metal is controlled by Si02 decomposition in most acidic fluxes whereas the oxygen level of basic fluxes is controlled by the oxygen potential of the slag as determined by the FeO content of the slag. However, with current trends toward lower carbon steels, Si levels might be effectively increased without either reducing tough ness or exceeding acceptable carbon equivalents. Many current specifications do not allow this freedom in alloy design. A number of experiments have been performed which confirm that higher Si in the base metal does not harm metal toughness.

GUNARAJ et. al*[13] performed a study and analysis on the effects of process parameters on weld bead volume in submerged arc welding (SAW) of pipes, mathematical models were developed to relate the process parameters and the weld bead quality parameters. The mathematical models thus developed for optimization are also helpful in predicting the weld bead quality parameters and in setting process parameters at optimum values to achieve the desirable weld bead quality at a relatively low cost with a high degree of repeatability and increased production rate. Sensitivity

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Analysis was also carried out to predict the direct and few interaction effects of important bead parameters on the total

volume of the weld bead, and the results are resented in graphical form. The results of the sensitivity analysis are very useful in understanding the interdependence of various weld bead quality parameters in controlling the volume of the weld bead, to improve weld quality, to increase productivity with the available welding facilities and to minimize the total welding cost.

Advantages of Submerged Arc Welding

1. Suitable for welding in thicker sections as the heat generated can melt the metal.
2. Much faster than other methods of welding.
3. Almost no distortion in the metals joined together because heat concentration is higher.
4. Single pass welds can be formed and so metal deposition can be moderated easily.
5. SAW is a welding process which forms a smooth weld joint of uniform pattern and good quality.
6. This process is corrosion resistant and spatters-less, with no flashes and sparkles.

Disadvantages of Submerged Arc Welding

1. The unused flux needs to be removed at the same time while the process is going on.
2. Only applicable in thicker metals usually more than 4.8 mm thick, as if the metal to be welded with SAW is below 4.8 mm it may get vaporised with the high heat involved in the process.
3. Easily done on flat welds and not suitable for overhead welding and vertical welding.
4. The flux can spill into the gap in-between. And that can cause the edges of the metal burnt by the arc.
5. Since the flux is open to atmosphere, it can be contaminated so many defects can arise after welding if precautions are not taken before initiating the process.
6. Many metals & alloys like Cast iron, Al alloys, Mg alloys, Pb and Zn cannot be welded by this process.

II. Effect of Process Parameters on Bead Geometry

In submerged arc welding the various properties of a weld are always affected by the composition of the base metal and it also depends on the weld bead shape and geometry. Welding bead geometry is affected by the process parameters like welding speed, welding current etc. A lot of researchers have studied the effect of parameters on the bead geometry. The study of factors affecting bead geometry are widely studied as they are directly or indirectly involved in the bead geometry formation.

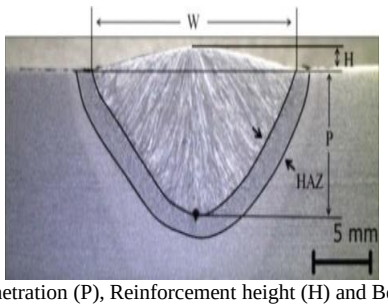

Fig. 3. HAZ, Penetration (P), Reinforcement height (H) and Bead width (W).

Effect of Process Parameters on Mechanical Properties

It is studied that if the process parameters like electrode stick-out, welding speed, wire feed rate, voltage and current, which can be moderated individually can result a lot on the mechanical properties of the weldment. The mechanical properties are hardness, toughness brittleness, tensile strength etc. In the study it was found that if the electrode stick-out increases, the weldment becomes hard and its yield strength decreases. Similarly it was studied that if the welding speed is more than the required speed, the joint will be porous and will offer less toughness and yield strength. If the wire feed rate is not as per requirement there will be a fragile joint formation thus insufficient strength in the weldment. If the voltage and current are kept constant, there will be an increase in tensile strength otherwise it can enhance its brittle properties.

Effect of Process Parameters on Heat Affected Zone

Heat Affected Zone (HAZ) is a surrounding area near the welding bead on the metal to be joined where the heat generated during the welding process can cause any change in its properties. HAZ is shown in fig. 4 below from which it is much clear to understand the affected zone. Heat Affected Zone (HAZ) is a layer like formation on the metal after welding. The number of layers increase or decrease with increase or decrease in voltage and current parameters used in the welding process.

Fig. 4. Heat affected zone (HAZ).

It is necessary to predict appropriate process variables in order to control the Heat Affected Zone (HAZ) in Submerged Arc Welding (SAW). While going through the literature it was found that if voltage and current inputs vary a lot, it can cause the HAZ to expand or to restrict in smaller area. Study shows that to get a required bead size along with good penetration the process variables i.e. voltage and current are to be kept at an appropriate value. The selection of voltage and current range depends upon the thickness of the metal to be joined and thus the HAZ can be controlled.

Submerged Arc Welding Defects

Defect in a welding joint in a submerged arc welding process can be like insufficient penetration, rough bead geometry, hardness in joint, melt-through, undercut etc. All these defects can be due to one or more reason like variation in process parameters such as to much voltage or less voltage. Some of the defects may be due to current variation and some due to welding speed. If the flux is not distributed properly on the part which is to be joined, it can result into spattering in the welding process and this can be harmful for the work piece as well as operator. The study of defects in the literature of last few years has been made in this review paper. Various defects commonly found in a submerged arc welding are given as under: -

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- Insufficient penetration: - Low current and high voltage in a welding process with a high travel speed can result into insufficient penetration i.e. the bead is formed on the surface of the joint but internally the joint is not that much reliable.
- Melt-through: - It occurs when the voltage is much more than the requirement and sometimes if the work piece is much thinner and the parameters used during the welding process. It can be resolved if welding voltage is decreased and welding speed is increased.
- Surface pock marks: - This defect is found in the welding joint when the flux used is either moist or out-dated.
- Porosity: - It is the defect found in the welding joint due to the impurities present in the flux or due to the contamination of the flux in open air. Sometimes it is due to the high moisture content in the atmosphere where the welding is to be done. This problem can be solved by pre-heating the flux in order to remove the moisture content.
- Slag sticking: - This type of defect is commonly found in welds of concave shape. This defect involves the sticking of slag in a deep groove. If voltage is reduced and the travel speed is increased, this defect can be omitted.
- Arc Blow: - If the DC current is very high the arc blow comes into picture. It occurs in case when there is large magnetic field imbalance in the surrounding area of weldment.
- Bead rollover: -This defect occurs when there is high current, low voltage, or when the travel speed is low.
- Undercut: - This defect is commonly found in many welding joints. This type of defect is found in the welding when the weld pool created by the high voltage is not filled completely with the molten metal added into it. This defect can be omitted if the travel speed is reduced with increase in metal feed. In order to minimise this defect reducing the intensity of voltage can also help.

Recycling of Waste Flux Comparison with the Fresh Flux

The flux used in the submerged arc welding process to facilitate the welding, is more than actually required to get settled down. The waste flux which has formed a blanket type solid layer around the welded joint can be recycled and used as newly made flux. It involves the refining of slag for which first of all it is necessary to do the crushing and then sieving of the hardened flux. Crushing makes the granules of the hardened slag and then the sieving helps to form a fine particle of uniform size.

Fig. 5. Waste flux.

Cost Reduction and Pollution Control

The slag recycling itself is reducing the cost of welding ultimately and the cost involved in the processing of the waste slag and refining it into new flux is minute and it can be made to be ignored if the recycling of waste flux is increased. The waste slag is easily available in industries and recycling it will reduce the chances to cause pollution the environment as it can cause pollution to environment if dumped in open.

III. CONCLUSION

From the literature and the discussed pros and cons of the submerged arc welding, it can be concluded that, no doubt the SAW process is reliable, quick, spatter less, flash less and spark less process even then there are some gaps where the submerged arc welding in still lagging behind. Some of the main points that should be quoted as the reason for the lagging of SAW process are bead geometry, arc blow, undercut, slag sticking, porosity due to impurities in flux, surface marks, melt through and insufficient penetration. From the literature, it can also concluded that many of its defects and cons can be minimized by moderating the process parameters like voltage, current, welding speed and travel length. Also the recycling and reusing flux can reduce the overall cost of the process with a reduction of pollution as a side product.

IV. IDENTIFICATION OF PROBLEM OR GAP

The paper gives the literature review up to few years back and it is clear that the defects are caused due to one or more reasons regarding the process parameters. Some of the gaps which are highlighted are:-

1) Submerged arc welding can only be used in thick sheets.
2) SAW process is limited to flat surfaces only.
3) Submerged arc welding needs the flux in excess to get a welding environment.
4) The extra flux, after use needs to be collected along with the moving electrode, which is not applicable for all types of surfaces to be welded.

It is possible to carry this investigation further by taking any of the above said gaps. Solving these gaps may result the betterment of the SAW process.

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