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Review Article

Submerged Arc Welding: A Review

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Abstract

In industries and research organizations most widely used welding methods are shield metal arc welding (SMAW), gas metal arc welding (GMAW), gas tungsten arc welding (GTAW) and submerged arc welding (SAW). The SAW process is often preferred because it offers high production rate, high melting efficiency, ease of automation and low operator skill requirement. This review will be very helpful for providing the details for future work. This study expose the different works have been done in the past for improving different properties of welded material. This study also exhibits the effect of different welding process parameters that affect the weld chemistry. Depending upon the requirement the details of past work will we easily obtained for future work with the help of this study.

Keywords: *Submerged arc welding, chemical composition, Taguchi design of experiment, S/N ratio.*

1. Introduction

In industries and research organizations most widely used welding methods are shield metal arc welding (SMAW), gas metal arc welding (GMAW), gas tungsten arc welding (GTAW) and submerged arc welding (SAW). The SAW process is often preferred because it offers high production rate, high melting efficiency, ease of automation and low operator skill requirement. It was first used in industries in the mid 1930's as a single-wire welding system (Parmar, 1992). The operating variables used in the SAW process results in varying heat input in the weldment The consequence of this is the deterioration of the chemical constituents of the weld bead. Therefore, the properties of the parent metal cannot adequately match those of the weldment to ensure good performance in service, especially in low temperature services.

1.2 Control Parameters

1.2.1 Welding Current: It controls the melting rate of the electrode and thereby the weld deposition rate. It also controls the depth of penetration and thereby the extent of dilution of the weld metal by the base metal. Too high a current causes excessive weld reinforcement which is wasteful, and burn-through in the case of thinner plates or in badly fitted joints, which are not provided with proper backing.

1.2.2Arc-Voltage: Arc voltage, also called welding voltage, means the electrical potential difference between the electrode wire tip and the surface of the molten weld puddle.

1.2.3 Weld Speed: For a given combination of welding current and voltage, increase in the welding speed or the speed of arc travel results in lesser penetration, lesser weld reinforcement and lower heat input per unit length of weld.

2. Literature review

(Pandey, et al, 1994), have studied the influence of submerged arc welding (SAW) parameters and flux basicity index on the weld chemistry and transfer of elements such as manganese, silicon, carbon and sulphur. They have used five fluxes and different values of the welding parameters; the welding speed was being kept constant to produce weld bead on a mild-steel plate. The study was mainly aimed at studying whether welding parameters or fluxes were more effective on the element transfer and weld composition. From the study; finally it was concluded that:
1. For controlling the weld-metal composition, welding voltage was more effective than is welding current.
2. The basicity index value of fluxes had a definite relationship with silicon but the same cannot be correlated with the weld-metal manganese, carbon and sulphur contents.
3. The weld-metal composition showed, in general, gain of silicon and loss of carbon, manganese and sulphur elements. The results showed that welding current and voltage have an appreciable influence on element transfer, as well as on weld composition.

(H.L Tsai et al, 1996) has done optimisation of submerged arc welding process parameters in hardfacing. In this they used a neutral network approach for modeling and optimisation of SAW process. i.e a freeforward neutral network to construct the SAW process model.

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They have used a 30mm thick plate of mild steel of dimensions 120x 80mm. Before use the flux baked at 523 K for two hours. They admitted that complicated relationship can be obtained between the process parameters and welding performance. The efficiency of determining optimal SAW process parameter in hardfacing of steel mill roll can be improved.

(Chandel et al, 1997) With the help of their study showed the theoretical predictions of the effect of current, electrode polarity, electrode diameter and electrode extension on the melting rate , bead height, bead width and weld penetration, in submerged arc welding.

(Khallaf et al, 1997) through their study they described cracking behaviour during the submerged arc welding of medium carbon steel plates and found that the cracking susceptibility increases with an increase in the welding current and decreases with an increase in the welding speed or the electrode wire feed rate. It also increases with increases in the plate rolling reduction ratio and with decrease in the plate thickness.

(Chandel et al, 1998) through their study on mild steel plates 350x220x25mm as test material, showed that The impact properties of welds made with powder addition are superior. The weld metal is stronger and tougher than the base metal.

(Gunaraj et al, 1999) studied the effect of controllable process variables on the heat input and the area of the heat-affected zone (HAZ) for bead-on-plate and bead-on joint welding using mathematical models developed for the submerged arc welding of pipes. A comparative study of the area of the heat-effected zone between bead-on-plate and bead-on-joint welding was then carried out.

(Tarng et al, 2000) have used fuzzy Logic in the Taguchi Method for the Optimisation of the Submerged Arc Welding Process. They have used L_8 in this study which means 9 runs and the levels are 3. They have used a mild steel plate of 24mm. having dimensions 120mm x 60 mm. Through their study they show that the performance characteristics of the Saw process such as deposition rate, dilution and hardness are improved together by using grey-relation.

(Vera et al, 2001) The aim of their work is to evaluate the effect of a postweld heat treatment (PWHT) on the microstructure and mechanical properties of the base metal, heat-affected zone (HAZ) and weld metal of a submerged arc welded pressure vessel steel. The material used was ASTM A537 C1 steel. From this study they concluded that-

- Reduced tensile properties for the base metal. However both yield strength and tensile strength were slightly above the lower limits established by ASTM.
- Higher toughness for the weld metal and a reduction of this property for the HAZ and base metal.

(Wikle et al, 2001) Through their study by doing experimentation on plain carbon steel as test material they showed that variation in the plate gap resulted in depressions where both the weld bead height and width varies significantly.

(Wen et al, 2001) A multi wire SAW process was modeled using a general purpose finite element package for thick wall line pipes. It was shown that the geometric distortion and residual stresses and strains can be minimized through process optimization.

(Tarng et al, 2002) have used grey-based Taguchi methods to determine submerged arc welding process parameters in hardfacing. For Experimentation they deposited a martensitic stainless steel hardfacing 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 harness, dilution and deposition rate are improved together by using grey relation.

(Ana Ma et al, 2003) they have done study of chemical and structural characterization of fluxes for submerged-arc welding was conducted. Three flux formulations were prepared using mineral oxides for agglomerating and sintering processes. A commercial agglomerated and sintered flux was used for comparison. The four fluxes were then analyzed chemically by atomic absorption and X-ray diffraction to determinate the quantity and type of oxides formed. Differential thermal analysis was carried out from 1000 to 1350 ^{0}C in order to determine the temperatures for phase transformations and melting of the different compounds formed in the sintering process. From this study they concluded that:-

- The determination of various phases in fluxes helps to identify the different type of oxides and radicals formed during sintering of intial materials. This quantification makes it possible to know which anions and cations would be present in the electric arc.

(Pandey, 2004) proposed a relationship between welding current and direct SAW process parameters using two level half factorial design. Interactive effects of direct parameters were also studied.

(Murugan et al, 2005) Through their study on prediction and control of weld bead geometry and shape relationships in submerged arc welding of pipes. They concluded that-

Arc voltage had a less significant negative effect on penetration and reinforcement but had a positive effect on bead width, penetration size factor and reinforcement form factor.

Wire feed rate had a significant positive effect but welding speed had an appreciable negative effect on most of the important bead parameters. Penetration increased by about 1.3mm as wire feed rate was increased from −2 to +2 limit whereas penetration decreased by about 1mm as welding speed was increased from −2 to +2 limit.

(Kanjilal et al, 2006) have studied the combined effect of flux and welding parameters on chemical composition and mechanical properties of submerged arc weld metal. For experimentation they have used low carbon steel plate of 18mm thickness. The test regarding weld metal composition is done. Also the behavior of mechanical property was also studied. From this study they concluded that:-

- Among the welding parameters, polarity has a profound influence on weld metal chemical composition.

- Welding speed influences weld metal carbon content through oxidation reaction; whereas weld metal sulphur and phosphorous content are affected by dilution of weld deposit.

Welding current influences weld metal manganese content through slag–metal reaction.

Transfer of nickel from flux to weld, is found to be impeded by oxides formed during slag–metal reaction.

Weld metal yield strength and hardness are mainly determined by welding parameters; whereas the impact toughness is determined by flux mixtures variables.

(Bhole et al, 2006) through their study they showed that the addition of Mo in the range 0.817–0.881 wt.% resulted in a decrease of fracture appearance transition temperature (FATT) and an increase of impact toughness. When Ni is added alone in the range of 2.03–3.75 wt.%, the weld metal shows a lower toughness and an increased FATT.

(Kannan et al, 2006) with the help of their experimentation they have concluded that Dilution increases with the rise in welding current and welding speed and decreases with the rise in nozzle-to-plate distance and welding torch angle. Weld bead width increases with the rise in welding current. Penetration increases with the rise in welding current and welding speed and decreases with the rise in nozzle-to-plate distance and welding torch angle. Bead width increases with the increase in welding current at all levels of welding speed.

(Kumanan et al, 2007) have studied the determination of submerged arc welding process parameters using taguchi method & regression analysis. The test material was mild steel plates of 500x50x6mm dimensions. Using multiple regression analysis they concluded that Welding current and arc voltage are significant welding process parameters that affect the bead width.

(Saurav Datta et al, 2008a) have studied the grey based taguchi method for optimisaion of bead geometry in submerged arc bead on plate welding. They have used L_{25} orthogonal array on the test material of mild steel plates of 100x40x10mm.with the grey relation and Analysis of variance they concluded that the area of HAZ must be minimum to avoid microstructural changes. The traverse speed is most significant factor to minimize area of HAZ.

(Serdar Karaog et al, 2008) have done Sensitivity analysis of submerged arc welding process parameters. The material used for testing is mild steel plate of 108x80x10mm size. The mathematical models were constructed using regression analysis. After carrying out a sensitivity analysis using developed empirical equations, relative effects of input parameters on output parameters are obtained. Effects of all three design parameters on the bead width and bead height show that even small changes in these parameters play an important role in the quality of welding operation. From this study they concluded that:-

Bead width is more sensitive to voltage and speed variations than that of bead height and penetration.

In order to decrease the bead height, higher values of voltage and speed can be considered.

Current is the most important parameter in determining the penetration. Penetration is almost non-sensitive to variations in voltage and speed. Therefore, voltage and speed cannot be effectively used to control penetration.

At maximum heat input level (higher levels of current and voltage, and lower level of welding speed), current sensitivity of penetration, and speed sensitivity of bead width reach their maximum values.

(Saurav Datta et al, 2008b) have used application of taguchi philosophy for parametric optimization of bead geometry and HAZ width in submerged arc welding using mixture of fresh flux and fused flux. The experiment was performed on mild steel plate of 100x40x12mm using L_9 orthogonal array. From this they concluded that 10% slag mix can be used to obtain optimum bead width and depth of HAZ. 15 to 20% slag mix for reinforcement and depth of penetration.

(Kook-soo Bang et al, 2009) have studied Effect of Flux Composition on the Element Transfer and Mechanical Properties of Weld Metal in Submerged Arc Welding. Experimentation is done by single and multi pass welds. The test material was low carbon steel plate of 300x500x34mm. The single V- groove welds were made with gauge length of 24mm.Pcm index of each weld metal is calculated to compare the chemical composition. From this study they concluded that:-

Both carbon and manganese show negative quantity in most combinations, indicating transfer from the weld metal to the slag. The impact toughness of the weld metal increases with an increase of flux basicity through a reduction of the oxygen content in the weld metal.

(Ghosh et al, 2011a) addressed the issue associated with the uncertainties involved with the heat affected zone (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 by means of digital image processing techniques. It was concluded that the grains are predominantly of smaller variety and the counts for larger grain are almost negligible. The absence of larger size grains in the image vouch for the soundness of the weld in comparison to the competing welding methodologies of structural steel plates.

(Dhas et al, 2011) used Taguchi's design of experiments and regression analysis 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 genetic algorithm (GA) and particle swarm optimization (PSO) algorithm to determine optimal weld parameters.

(Ghosh et al, 2011b) used graphical technique to predict submerged arc welding yield parameters and studied the effect of main factors, viz. current, wire feed rate, travel speed and stick out and the interactions among the main factors on the welding bead parameters. The interactions depicted the level of confounded character of the main factors with respect to the significant yield parameters of the process.

(Bhattacharya et al, 2012) has done experimental investigation for multi response optimization on plain carbon steel 200x75x12mm as test material. The multi response from the observation was converted to grey analysis using MATLAB code. Finally they concluded that Welding current is most significant for maximizing Depth of penetration & Minimizing Bead height and bead width.

(Shen et al, 2012) A series of measurements was carried out on specimens of submerged arc welded plates of ASTM A709 Grade 50 steel. The bead reinforcement, bead width, penetration depth, HAZ size, deposition area and penetration area increased with increasing heat input but the bead contact angle decreased with it. The electrode melting efficiency increased initially and then decreased with increasing heat input but the plate melting efficiency and percentage dilution changed only slightly with it. Cooling time exhibited a very good linear relationship with the total nugget area, heat transfer boundary length, and nugget parameter.

(Hari Om et al, 2013) have shown from their work that HAZ width rises more effectively with wire feed rate. With negative polarity dilution rate decrease more than 20%. HAZ area varies linearly with heat input.

(Brijpal Singh et al, 2013) they have done a review study on effect of flux composition on its behavior and bead geometry. With the help of their detailed review they showed 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

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