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Research Article

Investigating the Effect of Saw Parameters on Hardness of Weld Metal

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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. The objective of the present work is to evaluate the effect of SAW parameters for hardness of weld bead. The response function of the trial conditions would be match the constituents of transfer elements with the base metal. In the beginning of D.O.E phase, pilot experiments will be performed for preliminary study. The various parameters, their ranges and levels will be selected based on results of the pilot study. The results are expected to show that the response variables (output parameters) will be strongly influenced by the control factors (input parameters). So, the results which are obtained after experimentation shall be analyzed and modeled for their application in manufacturing industry. The purposed work is to evaluate the effect of SAW parameters for hardness of weld bead. In this work the experimentation is done to analyze that which factor is most contributing towards the various element transfers in weld bead. The results and analysis shows that the current is most contributing factors for most of the element transfer. After that with the help of graph plot from Minitab software, the optimized combinations were obtained for different elements.

Keywords: *SMAW, GMAW, DOE etc.*

1. Introduction

1.1. Submerged Arc Welding

The SAW process is frequently preferred because it offers high production rate, high melting efficiency, simplicity of automation and low operator skill requirement. It was first used in industries in the mid 1930's as a single-wire welding system. The operating variables used in the SAW process results in varying heat input in the element. The effect of this is the deterioration of the chemical constituents of the weld bead. Therefore, the properties of the parent metal cannot sufficiently match those of the element to make sure good performance in service, especially in low temperature services. An arc is maintained between the end of a bare wire electrode and the work. As the electrode is melted, it is fed into the arc by a set of rolls, driven by a governed motor. Wire feed speed is automatically controlled to equal the rate at which the electrode is melted, thus arc length is constant (similar to mig/mag - constant voltage). The arc operates under a layer of granular flux, hence submerged arc. Some of the flux melts to provide a protective blanket over the weld pool. The rest of the flux is unaffected and can be recovered and re-used, provided it is dry and not contaminated. A semi-automatic version is available in which the operator has control of a welding gun that carries a small quantity of flux in a hopper

2.2 Literature

1980: H.W. Ebert & F. Winsor have studied on Carbon Steel Submerged Arc Welds-tensile strength vs corrosion resistance such as manganese, silicon, carbon and sulphur. They have concluded that Some carbon steel SAW electrodes may not consistently provide weld metal with required minimum strengths when post weld heat treatment (PWHT) is specified, and controlled alloying with Mn and Mo will achieve minimum tensile and maximum hardness limits although, with welds not subject to PWHT, Mn and Mo additions may at times be undesirable for adequate corrosion resistance.

1989: S.I. Roklin and A.C. Guu have studied on control of SAW penetration by using radiographic means in this the benefit of this technique are on line testing of weld penetration and the possibility of using this information for welding current control. They concluded that the change of welding parameters such as current, voltage and welding speed can affect the

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thickness and width of the weld reinforcement and penetration.

1992: B. Chan, R.S. Chandel, L.J. Yang, & M.J. Bibby have studied on software system for anticipating the size and shape of submerged arc welds. They concluded that a software system for predicting the weld size and shape has been presented. The software components are special user interface design for welding engineers. The software for storing the welding parameters and pictorial graphics for presenting weld size and shape. This system can be used to calculated heat affected zone hardness, pre heat temperatures and weld size and shape.

1993: N. Murugan, R.S. Parmar & S.K. Sud have studied on submerged arc process variables on dilution and bead geometry in single wire surfacing. They concluded that

1. The voltage has no significant effect on penetration, reinforcement decreases with increasing the value of voltage but when the reverse of this is not true with the width.
2. Penetration, reinforcement and dilution increase with increasing the value feed rate but width decreases after reaching an optimum value. Penetration and width decreases with increase the speed but reinforcement decreases to an optimum value with increase in speed.
3. Nozzle to plate distance has no effect on reinforcement and width but penetration and dilution decreases with increases the nozzle to plate distance.

1994: N.D Pandey, A. Bharti & R.S. Gupta 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.. 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.

1996: H.L Tsai, Y.L Tarng & C.M Tseng have done optimisation of submerged arc welding process parameters in hard facing. In this they used a neutral network approach for modeling and optimization of SAW process. i.e a free forward neutral network to construct the SAW process model. 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 hard facing of steel mill roll can be improved.

1997a: V. Gunaraj & N. Murugan have studied on application of response surface methodology for predicting weld bead quality in SAW pipes they concluded that

1. RSM can be used in analyzing the cause and effect of process parameter response. This technique is also used to draw contour graph for various response to show their interaction effect on different process parameters.
2. When the welding speed increases the all response penetration, reinforcement, width and dilution decreases.

1997b: Chandel R.S, Seow H P 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.

1997c: Khallaf M E, Ibrahim M A, El-Mahallawy N A and Taha M 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.

1998: R. S. Chandel, H. P. Seow, F. L. Cheong 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.

1999: Gunaraj & Murugan 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.

2000: Y.S Tarng, W.H Yang & S.C Juang have Used Fuzzy Logic in the Taguchi Method for the Optimization 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.

2001a: Vera Lu´ cia Othe´ro de Brito, Herman Jacobus Cornelis Voorwald. The aim of their work is to evaluate the effect of a post weld heat treatment (PWHT) on the microstructure and mechanical properties of the base metal, heat-affected zone (HAZ) and weld metal of an submerged arc welded pressure vessel steel. The material used was ASTM A537 C1 steel. From this study they concluded that

1. Reduced tensile properties for the base metal. However both yield strength and tensile strength

were slightly above the lower limits established by ASTM.
2. Higher toughness for the weld metal and a reduction of this property for the HAZ and base metal.

2001b: H.C. Wikle, S. Kottilingam, R.H Zee. 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.

2001c: Wen SW, Hilton P and Farrugia D C J 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.

2002: Y.S. Tarng, S.C. Juang, C.H. Chang have used grey-based Taguchi methods to determine submerged arc welding process parameters 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 harness, dilution and deposition rate are improved together by using grey relation.

2003: Ana Ma. Paniagua-Mercado, Paulino Estrada-Diaz, Victor M. Lo´pez-Hirata A 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.

2004: Pandey S 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.

2005a: N. Murugan, V. Gunaraj. Through their study on prediction and control of weld bead geometry and shape relationships in submerged arc welding of pipes they concluded that

1. 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.
2. 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.

2005b: P. Kanjilal, T.K. Pal, & S.K. Majumdar have studied on combined effect of flux and welding parameters on chemical composition and mechanical property of submerged arc weld metal. They concluded that

1. With increase in welding speed carbon increases but sulphur, phosphorous and nickel decreases. The dilution plays very important role here. As the welding speed increases heat input decreases and less dilution occurs. Carbon, sulphur & phosphorous more in base metal.
2. The manganese and nickel content in weld metal decreases with increase in current and voltage.

2006a: S.D. Bhole, J.B. Nemade, L. Collins, Cheng Liu 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.

2006b: T. Kannan, N. Murugan with the hep 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.

2006c: Saurav Datta, Asish Bandyopadhay, & Pardip kumar pal have studied on solving multi criteria optimization problem in SAW consuming a mixture of fresh flux and fused slag. It has been seen that 10% slag mix should be used to achieve good quality weld in term of bead geometry. It also find that the use of slag mix up to 20% does not impose any adverse effect on weld quality of bead geometry and HAZ. And concluded that slag mix percentage 0-20% does not statistically influence the quality of welding.

2006d: Abhay Sharma, Navneet arora & Bhanu K, Mishra have studied on practical approach towards mathematical modeling of deposition rate during twin wire SAW. They concluded that –

1. The deposition rate can be mathematically modeled with the use of welding parameters and involved metal loss can be traced.
2. The close proximity, lead and trail wires act in union and both the wire have identical behavior during melting.

2007a: S Kumanan, J Edwin Raja Dhas & K Gowthaman 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.

2007b: Shigeo OYAMA, Tadashi KASUYA & Kouichi Shinda have studied on High-speed One-side Submerged Arc Welding Process. They concluded that the high-speed one side submerged arc welding process (NH-HISAW) that dramatically increases the welding speed in the panel assembly process in shipbuilding–at least twice as fast as the conventional process. The authors are confident that the NHHISAW process will contribute to improved productivity and product quality in the shipbuilding industry.

2008a: Saurav Datta, Asish Bandyopadhyay & Pradip Kumar Pal have studied the grey based taguchi method for optimization 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 micro structural changes. The traverse speed is most significant factor to minimize area of HAZ.

2008b: Serdar Karaog˘ lu, Abdullah Sec¸gin 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:

1. Bead width is more sensitive to voltage and speed variations than that of bead height and penetration.
2. In order to decrease the bead height, higher values of voltage and speed can be considered.
3. 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.
4. 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.

2008c: Saurav Datta, Asish Bandyopadhyay & Pradip Kumar Pal 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

1. 10% slag mix can be used to obtain optimum bead width and depth of HAZ.
2. 15 to 20% slag mix for reinforcement and depth of penetration.

2009a: Kook-soo Bang, Chan Park, Hong-chul Jung, and Jong-bong Lee 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

1. Both carbon and manganese show negative quantity in most combinations, indicating transfer from the weld metal to the slag.
2. 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.

2009b: Iwata Shinji, Murayama & Masatoshi Kojima Yuji have studied on Application of Narrow Gap Welding Process with High Speed Rotating Arc to Box Column Joints of Heavy Thick Plates. They concluded that The application of a new welding procedure (high speed rotating arc + submerged arc welding) for corner joints, responding to the use of heavy thick plates and high strength, high quality steel plates in box columns for building structures, was introduced.

2009c: Saurav Datta and Siba Sankar Mahapatra have studied on Multi-Objective Optimization of Submerged Arc Welding Process. They concluded that Weld quality in SAW depends on bead geometry, mechanical-metallurgical characteristics of the weld as well as on weld chemistry. The weld quality development is treated as a multi-factor, multi-objective optimization problem. The practical application of SAW requires efficient optimization methodology because process parameters are expected to interact in a complex manner The developed methodology based on RSM, desirability function and PSO (Particle Swarm Optimization) algorithm can be applied in practice for continuous quality improvement and off-line quality control. RSM has been applied to derive a mathematical model of overall desirability represented as a function of process control parameters. This mathematical model has been optimized within an experimental domain.

2009d: Kulwant Singha & Sunil Pandey have studied on recycling of slag to act as a flux in submerged arc welding. They have concluded that acceptable weld bead geometry can be produce after recycling the slag. And when increase in welding wire feed rate penetration and bead width increased and decreased with increase in travel speed.

2010: Krishankant, Sandeep Jindal & Shashi Kant Shekhar have studied on Determination of Flux Consumption in Submerged arc Welding by the Effect of Welding Parameters by Using R.S.M Techniques. They concluded that

1. RSM can be used efficiently in analyzing the cause and the effect of process parameters on response. The RSM is also used to draw contour graphs for

various responses to show the interaction effects of different process parameters.

2011a: Ghosh A, Chattopadhyaya S, Das R K and Sarkar P K 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.

2011b: Dhas J E R and Kumanan S 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.

3. Experimental Setup

The whole experiment was done on Submerged Arc Welding Machine, Model -Tornado Saw M-800 transformer and FD10-200T welding tractor available at MM University. The electrode is EH14.The experimentation was done on SS 310 plates of dimensions 110mm x 55mm x8mm. The welding current, voltage and welding speed could be regulated, displayed and preset on the panel of the tractor for the convenience of the operator. The polarity is kept positive. The nozzle distance is kept constant i.e 20 cm.

3.1 Work Material

The work material selected for experimentation is SS 310. It is easily available and is very widely used due to good mechanical and chemical properties. The work material is cut into rectangular plates of dimensions.
Length = 110 mm, Breadth = 55 mm, Height = 8 mm
Chemical Composition of Work material

Table 1 Composition of Work Material

C	Percentage by weight	0.18
Mn		1.29
Si		0.24
S		0.018
P		0.022
Cr		24.45
Ni		19.36
Mo		0.1
Cu		0.19

3.2 Overall Methodology of the Study

The overall research work is divided in to four phases.

- Detailed literature survey
- Pilot experimentation
- Design of experiments (D.O.E)
- Experimentation
- Analysis
- Conclusion

3.3 Methodology Used

The full factorial design is referred as the technique of defining and investigating all possible conditions in an experiment involving multiple factors while the fractional factorial design investigates only a fraction of all the possible combinations. Although these approaches are widely used, they have certain limitations: they are inefficient in time and cost when the number of the variables is large; they require strict mathematical treatment in the design of the experiment and in the analysis of the results; the same experiment may have different designs thus produce different results; further, determination of contribution of each factor is normally not permitted in this kind of design (Roy, 1990). The Taguchi method has been proposed to overcome these limitations by simplifying and standardizing the fractional factorial design (Roy, 1990). The methodology involves identification of controllable and uncontrollable parameters and the establishment of a series of experiments to find out the optimum combination of the parameters which has the greatest influence on the performance and the least variation from the target of the design.

Table 2 Factors

S No.	Factors (Units)	Symbols	levels		
1	Current (Amp)	I	300	330	345
2	Voltage (Volt)	V	24	28	32
3	Welding speed (m/h)	ws	30	32	34

Table 3 Observation table for hardness

SNo.	I (Amp)	V(Volt)	ws(m/h)	Hardness (HRC)
	A	B	C	D
1	300	24	30	79.25
2	300	28	32	78.25
3	300	32	34	77.5
4	330	24	32	71.125
5	330	28	34	77
6	330	32	30	74.25
7	345	24	34	80.25
8	345	28	30	80.625
9	345	32	32	78.125

Various graphs and tests have been constructed to determine which factors have a statistically significant effect on the hardness. Analysis of variance for S/N ratios for hardness calculated from software is given in Table 4. The average hardness obtained from the hardness test conducted on 18 specimens sampled out from the nine samples (welded plates) three specimen from each sample using L9 orthogonal array. The hardness range from 71.125 HRC to 80.625 HRC in table 4.1. It has been observed that with the increase of welding current from 300A to 330A hardness decreases but after that with increase in current from 330A to 345A hardness increases. Table 4 show the S/N ratio of hardness.

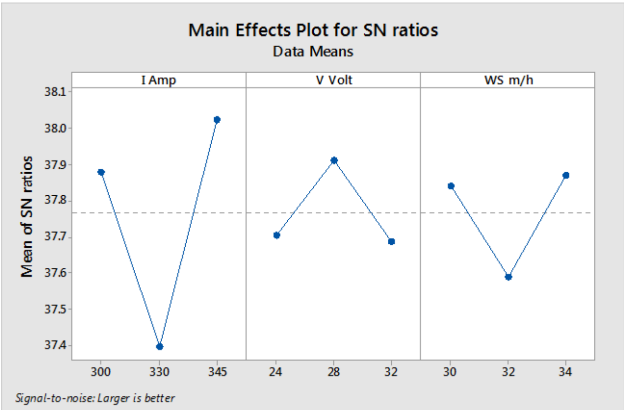

Figure 1 Main Plots

Table 4 S/N ratio of hardness

Source	DF	Seq SS	Adj SS	Adj MS	F	P
I(Amp)	2	50.198	50.198	25.099	10.98	0.083
V(Volt)	2	7.125	7.125	3.562	1.56	0.391
ws(m/h)	2	10.760	10.760	5.380	2.35	0.298
Residual Error	2	4.573	4.573	2.286		
Total	8	72.656				

Conclusion

It is concluded that for Hardness be maximum factor I(Amp) has to be at high level 3, V(Volt) has to be at high level 2 & Ws(m/h) has to be at high level 3. As shown in table below.

Table 5 Optimal combination for hardness

Physical	Optimal Combination		
Requirements	I(Amp)	V(Volt)	ws(m/h)
Maximum Hardness	345	28	34
	Level-3	Level-2	Level-3

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