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BOX-BEHNKEN BASED ANALYSIS OF SLAG CONSUMPTION IN SUBMERGED ARC WELDING OF HIGH STRENGTH LOW ALLOY STEEL

The present research work involves the placing of a small quantity of molten steel into the gap among the components to be connected, subsequently positioning them together during solidification. The heat sources utilized in the welding process include the electric arc. The result is a variant of arc welding in which the cost is determined by the flux utilized during the process. The submerged arc welding technique (SAW) technique has been utilized for the rapid process that involves physical, mechanical, and chemical interactions. When the metal arc is shielded, the spatter from the arc is contained by granular fusible material, which safeguards the weld from ambient contamination. Flux plays a major role in SAW welding and welding cost depends upon recycled slag as recycled slag as flux consumption. This flux gets converted into a shielded layer as slag on the weld bead after solidification. The slag from submerged arc welding is thrown away as trash. According to the investigation, this welding is based on factors such as welding current, speed voltage, and stick out depending on the consumption of recycled slag. The box-Behnken-based designed experimental model has been used while RSM has been effectively employed to examine the causation and influence of process elements on responses for optimization. For the model to be deemed significant, its calculated F-ratio must surpass the standard tabulated F-ratio for a specified confidence level (i.e., 95%). In submerged arc welding, the consumption of slag flux escalates with an increase in current and voltage. As welding speed and nozzle-to-plate distance increase, the consumption of slag as flux diminishes. A weighing machine has been utilized to measure the recycled flux consumption before and after each weld bead. Even yet, extensive research has been done on the physical and chemical characteristics of welding fluxes as well as the factors that influence their use.

Keywords: Welding parameters; Submerged arc welding; Response surface methodology; High strength alloy steel

1. Introduction

The Response Surface Methodology (RSM) is a technique for figuring out and expressing as a two- or three-dimensional surface the cause and relationship between real mean responses and input parameters or control variables that affect the responses [1]. The most significant benefit of this method is the simultaneous analysis of a large number of factors, which allows for a more thorough understanding of the combined impact of the parameters on the response [2,3]. Due to its ease of use and precise productivity, the submerged-arc welding method (SAW) is extensively utilized in the metal-mechanic sector [4]. The current study effort has looked at how recycled slag consumption is affected by range voltage, range of welding current, Range of welding speed, and stick out [5-7]. Consumption of recycled slag as flux for each bead was weighted. To forecast and manage the recycled slag as well as recycled slag as flux consumption within the parameters, a response surface approach was used [8-10]. It was discovered that slag consumption rises with rising operating voltage and falls with rising gap of the nozzle-to-each material plate separation and welding speed [11-13]. The use of RSM in creating mathematical models is covered in this study. By using computer software to produce contour graphs connecting the welding parameters in the SAW, researchers can determine how different parameters affect the consumption of recycled slag and flux [14-17]. The overall cost

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of welding in submerged arc welding (SAW) relies on the consumption of the flux and where slag is disposed of as garbage, its price [18-21]. To shield the welding region from ambient contaminates or other contaminants, flux is used as a shielding agent [22-26]. It also protects against arc splatter. Each bead's recycled slag consumption was measured and weighed. After completing the investigation and testing, we discovered that slag consumption rises as operating voltage rises, and falls when welding speed and nozzle-to-plate distance rises. This study applies the RSM to the creation of mathematical models and the drawing of contour graphs linking significant input process parameters. Only the flux that melts during the SAW process is consumed. Separated from the slag, the flux's unused fraction is then utilized again. The melting of the flux is necessary for its utilization. Slag recycling Researchers have previously attempted to create several techniques for recycling or reusing slag debris. To explore the potential of blending pure flux consumption with consumed pulverized slag at the right range, several levels of experiments were undertaken. Typically, adding 15% to 30% of slag mixture to building materials won't degrade their quality. It has been demonstrated in a separate study that recycled slag grows as welding current increases up to a certain instantaneous limit before beginning to drop. The current study addresses a literature gap about the insufficient research on optimizing slag use through statistical design methodologies, specifically for High Strength Low Alloy (HSLA) steels. Although various research has investigated the influence of process parameters on weld quality, bead shape, and mechanical qualities in Submerged Arc Welding (SAW), few have specifically focused on slag consumption as a response variable [30,31]. Moreover, the majority of current studies depend on trial-and-error approaches or conventional experimental designs, which lack the accuracy and efficacy of contemporary response surface procedures. A deficiency exists in systematic research utilizing the Box-Behnken Design (BBD) to predict and optimize process parameters aimed at reducing slag production. This study addresses the deficiency by offering a quantitative, statistically-based framework to minimize slag waste, optimize material efficiency, and augment the sustainability of Submerged Arc Welding operations with High-Strength Low-Alloy steel.

The principal focus of the current study is to optimize welding process parameters to reduce slag consumption while maintaining weld quality. This work utilizes the Box-Behnken Design (BBD) in Response Surface Methodology (RSM) to systematically assess the impact of critical welding parameters—namely voltage, wire feed rate, and travel speed—on slag production. This has significant implications for industrial fabrication and manufacturing sectors, especially those utilizing high-strength low alloy (HSLA) steels, by facilitating cost reduction, enhancing material efficiency, and promoting environmentally sustainable welding practices through diminished waste and improved operational control.

2. Literature review

A multitude of studies have been conducted in the field of submerged arc welding. The literature reviews seek to elucidate the specified domain. Gunaraj and Murugan investigated the use of RSM to predict weld bead excellence in submerged arc welding of pipes, selecting five process parameters at two levels. RSM techniques were utilized to ensure an accurate estimation of the true mean response and to establish a mathematical model that generates the desired outcomes. The trial was executed permitting the design matrix. Submerged arc welding apparatus and inspection were disclosed. The RSM technique is excellent for analyzing the causes and effects of process factors; as the nozzle-to-plate distance rises, penetration, speed, voltage, and feed rate decrease, but reinforcement increases. Chandel examined the influence of process factors on flux usage in submerged arc welding. This research involved the selection of four process parameters at two levels. The Taguchi method was used to optimize the chosen process parameters, and the base metal was applied. ASTM A36 mild steel and a 3.2 mm diameter C-Mn electrode were utilized with a fused flux. The Linde-24 finding indicated that an elevation in arc voltage and electrode extension enriches flux consumption. In order to manage the dimensions of the heat-affected zone (HAZ) and achieve the required bead size and quality, Gunraj and Murugan investigated the importance of choosing the right process variable values to forecast the features of the HAZ in submerged arc welding of structural steel pipes. Second-order quadratic mathematical models are useful for predicting and controlling the dimensions of discrete parts of the heat-affected zone (HAZ) of a weldment. These models were created to investigate how heat input and process factors affect different metallurgical features. Using the factorial design approach, Kim et al. investigated sensitivity research of process parameters in GMA welding, concentrating on the geometric factors of bead width-penetration and bead height. The optimal bead geometry was ascertained using the factorial design, and a mathematical model was created to investigate the relationships among process variables and the bead's geometry and to forecast bead dimensions with a 0-25% precision rate. Gupta and Manohar investigated the response surface methodology for assessing failure probability and important measures in relation to the limit surface situated inside two hyperspheres of specified radii. This problem's significance in structural reliability analysis pertains to performance functions featuring multiple design points and/or regions that substantially influence failure probability, as well as proposed global sensitivity measures of failure probability in relation to fundamental random variables. The efficacy of the proposed enhancements was assessed by juxtaposing simulation-derived outcomes with those obtained from the suggested methodology concerning two particular structural reliability analysis issues. TABLE 1 illustrates the literature review of recent advancements in the current subject.

TABLE 1

Literature Review Table

Authors	Topics	Work Done	Materials Used	Techniques Implemented	Parameters	Conclusion
1	2	3	4	5	6	7
Chandel et al., 1997	Impact of accelerating the rate of deposition on SAW weld bead shape	Bead width & weld penetration	HSLA & HY Steels	Mcglone's Model	Polarity, Current, Electrode melting rate, Bead width, Penetration	With a straight polarity electrode, high current can accelerate the melting rate.
Chandel, 1998	Impact of process factors on flux utilization in the SAW process	Flux consumption	ASTM Mild Steel A-36	R&P	Welding current, Voltage, Wire melt rate, Bead profile	Flux consumption increases when increases current &voltage.
Murugan, andGunaraj, 1999	RSM is used to predict the quality of the weld beads in pipes that are submerged arc welded.	Central composite design	I.S. 2062 Carbon Steel 6 MM Thick	Response Surface Methodology	Welding speed, voltage, wire feed rate, and distance from nozzle to tip	All the responses P,W,W, decrease with increased welding speed & nozzle-to-tip distance.
Kim et al., 2003	Sensitivity analysis of GMA welding process factors using the E.D. technique	Process parameters, Bead geometry, bead width	200×75×12 mm Mild Steel AS1204	Factorial design method	Current, Electrode extension,Welding speed, Welding voltage	To investigate the connection between bead geometry and process parameters in order to forecast the bead dimensions with an accuracy of 0-25%.
Murugan, and Gunaraj, 2005	Predicting and controlling the shape and structure of the weld beads in pipes welded by submerged arc	Weld bead geometry	IS:2062 Steel Plate 6 MM Thick	Response Surface Methodology	Nozzle-to-plate distance, welding speed, wire feed rate, and arc voltage	Prediction bead dimensions and shape relationship and welding speed increases –2 to +2
Kim et al., 2005	An inquiry into the method for forecasting bead shape in Gas Metal Arc Welding	Intelligent system, Multiple regression, Neutral network	Mild Steel AS1204	Factorial design method	Bead height, width, penetration form, welding speed, current and voltage	The prediction of the bead geometry factors varies the ranges of parameters in GMA welding.
Datta et al., 2006	Addressing a multi-criteria optimization challenge in submerged arc welding uses a combination of fused slag and fresh flux.	Multiple Criteria Optimization	HAZ	Taguchi Method	flux basicity index and welding current	The optimal quantity of slag mix that can be utilized in the SAW process without adversely affecting the typical aspects of weldment quality regarding bead shape.
Kumanan et al., 2007	SAW process parameters are identified using regression analysis and the Taguchi method.	Regression Analysis	Mild Steel Plates	Taguchi Method	Electrode protrusion, welding speed, voltage, and welding current.	To anticipate the bead geometry, a mathematical model is constructed, and statistical software is used for MRA.
Datta et al., 2008	Slag recycling in submerged arc welding (SAW) and how it affects the excellence of the weld beads for parametric optimization.	Parametric Optimization	Mild Steel Plates	Taguchi Method	Wire feed rate, Stick out, Voltage, Transverse Speed	It has been discovered that consuming 20% of the slag mix can produce optimization beads without having an adverse influence on the geometry of the beads.
Ghaderi et al., 2015	Optimizing the deposition rate in a submerged arc welding procedure with TiO_2 nanoparticles by applying an imperialist competitive algorithm	Regression Analysis and Optimization	Mild Steel and TiO_2 Nanoparticle	Rotatable central composite design (RCCD)	The thickness of the TiO2 nanoparticle coating on the mild steel plates, welding speed, contact tip-to-plate distance, welding current, and arc voltage	ICA was used to determine the input variable levels needed to reach the maximum deposition rate.

TABLE 1. Continued

1	2	3	4	5	6	7
Sharma et al., 2016	Optimizing Bead Configuration for Steel Submerged Arc Welding Employing an RSM-Fuzzy Method [27]	Optimization	API X80 steel	RSM-Fuzzy	Heating the environment, wire-rate of feed, interaction tube for working distance, voltage in the open circuit, and trolley velocity	As compared to triangular MF, the use of trapezoidal MF has given more logical and better-optimized results for bead geometry parameters
Rivas et al., 2020	Multi-Objective Optimization Investigation of an Immersed Arc Welding Technology[28]	Optimization	JIS 3116 sheet	Optimization with a posteriori method	The factors include the depth of cut, feed, and slicing velocity, while in heat treatment, the temperature, duration, and cooling agent should be selected.	In comparison to the presently used welding factors, the calculated optimal solution enhances economic and environmental sustainability while maintaining equivalent social impact.
Thakar et al., 2023	Optimization of performance and analysis of metal-cored filler lines for exceptionally strong steel in welding using gas metal arcs [29]	Parametric Optimization	S690QL Steel	Response Surface Methodology (RSM)	Gas flow rate voltage, current, width, reinforcement(R), width of the heat-affected zone(W), depth of diffusion(D)	The single-objective optimization outcomes demonstrated an upper limit R of 5.3873 mm, peak W of 12.258 mm, greatest D of 3.4494 mm, and a lowest of 1.5674 mm.
Abhishek et al., 2024	Eco-friendly welding of low alloy steel using metal drilled filler wire	Parametric Optimization	ASME SA387 Gr.11 Cl.2 steel	Taguchi Method	gas flow rate, voltage, and current	In the average S/N response table, voltage stood out as the peak influential component, underscoring its major role in influencing weld quality.
Lostado-Lorza et al., 2024	The way to Use FEM and RSM to Find the Thermal Fields in Shielded Metal Arc Welding (SMAW)	Parametric Optimization	Material of electrode has been used	SMAW Technique	surface angle, current during welding, and velocity of travel	The welding current ranges from 105 to 140 amperes, the groove angle from 0 to 45 degrees, and the travel speed from 4.16 to 5.97 mm per second.

3. Methodology

The Design Expert Software (Box-Behnken Method) discovered the weld beads' numerous experimental ranges and restrictions utilizing versions of State Ease 6.0. The experimentation levels were carried out within the bounds of the TORNANDO SAW M800 welding machine was done. Each specimen used in the experiment was a 150 mm by 100 mm HSLA plate with a 10 mm thickness. ESAB SA1 (E8) copper-coated wire with a 4 mm diameter was utilized as the electrode. Five samples were sliced at once to create beads for the experiment, which involved drawing bead profiles on each plate using a selective-type profile projector. An exact digital plan meter was used to measure the bead profile characteristics [8]. Measure the weight of the slag both before and after the weld bead as a way to determine how much slag is used for each bead. Fig. 1 depicts the flowchart for the proposed model.

3.1. Various Strategies Used in the Investigations

The research was designed to continue in subsequent phases, such as determining the welding parameters. 30 trials have been conducted by the design matrix. Checking appropriateness and mathematical models have been developed. The following actions were intended to be taken in research as depicted in Fig. 1.

3.2. Finding the Control Variable's Upper and Lower Bounds

One of the process parameters was changed throughout trial runs, while the other parameters remained at fixed levels. By checking the bead for smoothness and the lack of any obvious flaws, the operating range was established. A factor's lower and upper limits were recorded as –2 and +2, respectively, based on the following relationship [1].

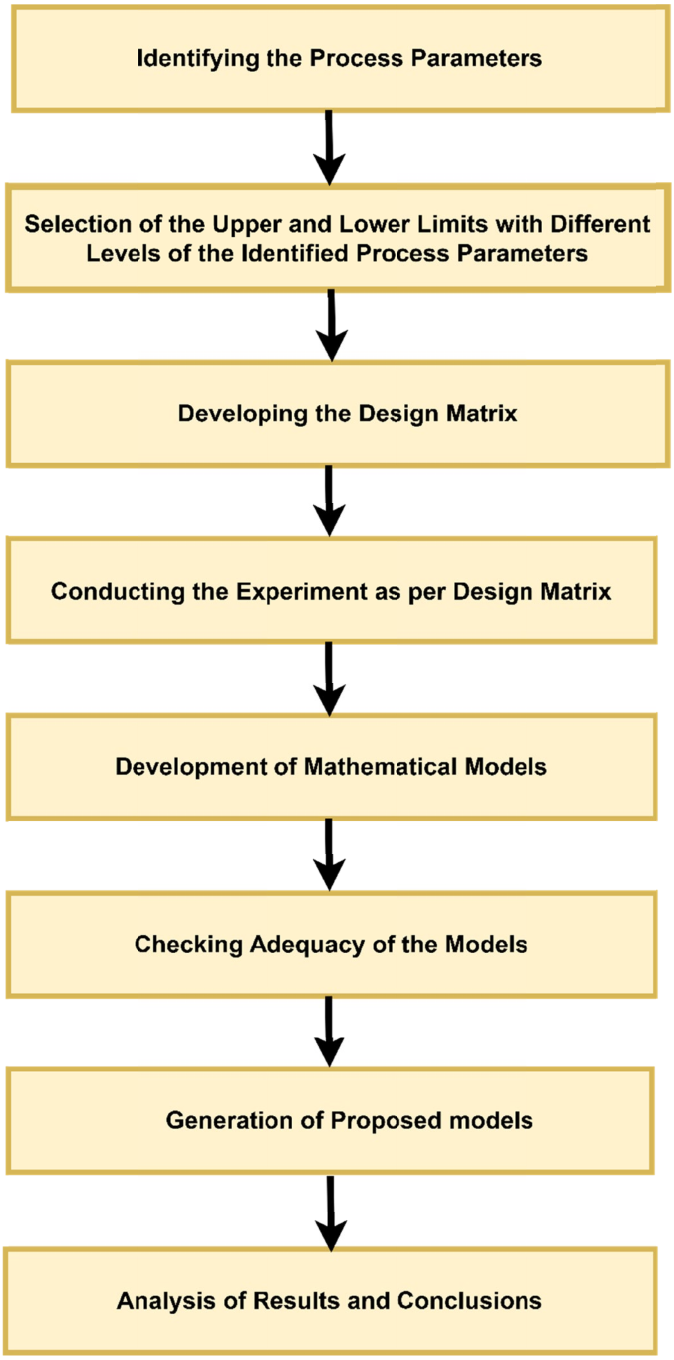

Fig. 1. Flowchart for the Proposed Model

3.3. Mixing of Slag

The appropriate ratio of combining slag with new flux has been taken to determine the proper weld bead and its effects on the material. In the current study, blended pure flux and 30% recycled slag for the trial runs have been taken.

3.4. Experiments Performed by the Design Matrix

The chosen design matrix was a central composite rotatable factorial design with 30 sets of coded environments. Eight-star points, seven center points, and a complete replication of 24 (=16) factorial designs are all included. While all welding factors at the intermediate level (0) make up the center points, the star points are produced by the combinations of each welding variable at its minimum (–2) or maximum (+2) levels as well as the other three variables at intermediate levels [8]. Thus, the 31 trial runs facilitated the assessment of the linear, quadratic, and two-way interactive impacts of the process factors on bead geometry. Creating the design matrix and applying it to the experiments. Thirty sets of experimental ranges in a central composite rotatable factorial design make up the chosen design matrix. Eight-star points and seven center points are included, along with a complete replication of the 24 = 16 factorial design [2]. The star points are made up of whole welding factors at the intermediate level points and how they combine with the other three welding variables at the intermediate levels. Consequently, the 30 experimental runs made it possible to assess how the process factors affected the linear, quadratic, and two-way interactions. The parameters of a design matrix should be selected so that the predicting accuracy of the values of the optimization variable is the same at equal distances from the centers of the experiment. The table below lists the 30 experimental conditions or designs. The fourth column was created by combining the factor interactions of b1, b2, and b3 with the main impact b4, such that b4 = (b1.b2.b3).To prevent the chance of systematic mistakes entering the system, the tests were passed out as per the design matrix at random. A common statistical method for examining the impact of various parameter combinations on the response or output parameter is the factorial design. The number of parameters that are concurrently investigated for a more thorough understanding of the combined impact of the factors on the response is the design's peak significant benefit. TABLE 2 shows the design matrix of experimentation. Fig. 2 shows the weld bead formation.

TABLE 2

Welding Factors Limit and Response Factor

Experiment Number	Welding Factors				Response
	Current (C)	**Voltage (V)**	**Speed of weld bead (S)**	**Stick out (D)**	**Recycled slag**
Sr. No.	**(a)**	**(v)**	**(m/hr)**	**(mm)**	**(gms)**
1	**2**	**3**	**4**	**5**	**6**
1	300	25	23	26	24
2	400	25	23	26	45
3	300	35	23	26	44
4	400	35	23	26	53
5	300	25	27	26	38
6	400	25	27	26	51
7	300	35	27	26	42
8	400	35	27	26	54
9	300	25	23	30	22
10	400	25	23	30	48
11	300	35	23	30	47
12	400	35	23	30	52
13	300	25	27	30	27

TABLE 2. Continued.

1	2	3	4	5	6
14	400	25	27	30	49
15	300	35	27	30	47
16	400	35	27	30	48
17	250	30	25	28	25
18	450	30	25	28	56
19	350	20	25	28	33
20	350	40	25	28	52
21	350	30	21	28	38
22	350	30	29	28	37
23	350	30	25	24	46
24	350	30	25	32	39
25	350	30	25	28	36
26	350	30	25	28	43
27	350	30	25	28	35
28	350	30	25	28	38
29	350	30	25	28	39
30	350	30	25	28	45

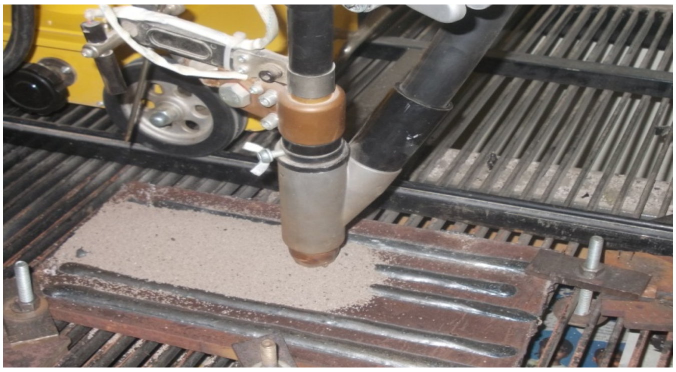

Fig. 2. Formation of Weld Bead

3.5. Evaluating the Suitability and Advancement of Mathematical Models

Any dimensions of the weld bead can be conveyed using the response function. The correlation among several independent variables, wherein the response variable Y, representing flux consumption, is ascertained through a mathematical construct known as a regression model when more than two independent variables are involved. Fig. 3 shows the total thirty weld beads formed as per the design matrix. Slag as flow consumption regression equation in terms of coded factors. RSM problems utilize either one or a combination of both the first and second models, wherein the levels of every factor remain free of the levels of various other factors. The second-order model encompasses all terms from the first-order model, in addition to all quadratic terms in the equation.

$$\text{Slag as Flux Consumption} = -982.7142 + 0.40214\ C + 46.69\ V + 21.50\ S - 7.96\ N - 1.33\ C2 - 0.458\ V2 + 0.407\ S2 + 0.291\ N2 + 0.02\ C * V - 0.024\ C * S - 9.375\ E\text{-}003\ C * D - 1.031\ V * S + 0.203 V * D - 0.239\ S * D$$

The relationship chosen has the following expression, which is a second-degree response surface.

Fig. 3. Total 30 Beads as per Design Matrix

4. Results and discussion

ANOVA was utilized to examine the impact of input factors on flux intake [4]. The analysis indicated that the quadratic model is the most recommended model. Furthermore, the adequacy of the quadratic model was assessed using the ‘lack of fit test’ [8]. The “Prob> F” for all these tests exceeded 0.001, indicating that the lack of fit is negligible. This model was utilized for subsequent analysis. Ultimate tensile strength (UTS) rises with a rise in background current, however, it diminishes with an increase in ultimate current and pulse frequency. Yield strength diminishes with a rise in ultimate current, pulse frequency, and duration of ultimate current. Elongation rises with growth in ultimate current, however it diminishes with an increase in pulse frequency and peak current duration. Interaction effects significantly impact mechanical qualities and must not be overlooked. All relationships are linear and can be efficiently employed to optimize circumstances. The ultimate tensile strength diminishes as the basicity index rises. The presence of Rutile, or TiO_2, enhances the ultimate tensile strength. Augmenting the quantity of CaF_2 enhances the impact strength of the weld joint. The effect of input factors on flux consumption was examined by analysis of variance (ANOVA) [4]. The “Prob> F” for all these tests exceeded 0.001, indicating that the lack of fit is negligible. This model was utilized for subsequent analysis. When background current increases, ultimate tensile strength (UTS) increases; yet, when peak current and pulse frequency increase, UTS decreases. As peak current, pulse frequency, and peak current duration increase, yield strength decreases. Peak current causes elongation to increase, whereas pulse frequency and peak current duration cause it to decrease. Mechanical properties are greatly impacted by interaction effects, which should not be disregarded. Every relationship is linear and can be effectively used to maximize conditions. As the basicity index rises, the ultimate tensile strength decreases. The presence of Rutile, or TiO_2, enhances the ultimate tensile strength. Augmenting the quantity of CaF_2 enhances the impact strength of the weld joint. ANOVA is presented in TABLE 3.

TABLE 3

ANOVA Table

Terms	**Sum of Squares**	**DOF**	**Mean Sum of Squares**	**F-Value**	**Probability**	
Model	3976.07	14	284.05	49.74	0.0001	significant
A	234.375	1	234.37	41.05	0.0001	
B	1276.04	1	1276.04	223.5	0.0001	
C	925.04	1	925.04	162.02	0.0001	
D	18.37	1	18.375	3.21	0.0917	
A2	3.205	1	3.22	0.56	0.4645	
B2	96.26	1	96.26	16.8	0.0008	
C2	384.14	1	384.14	67.28	0.0001	
D2	38.82	1	38.82	6.8	0.019	
AB	68.06	1	68.062	11.9	0.0033	
AC	217.56	1	217.56	38.10	0.0001	
AD	14.06	1	14.06	2.4	0.1361	
BC	612.56	1	612.56	107.2	0.0001	
BD	10.56	1	10.56	1.8	0.1926	
CD	33.06	1	33.06	5.7	0.0285	
Residual	91.345	16	5.7			
Lack of Fit	17.916	10	1.791	0.1464008	0.9957	not significant
Pure Error	73.42	6	12.2			
Cor Total	4067.4	30				

4.1. Effect of Welding Parameters on Flux Composition

Effect of various factors on the flux compositions such as Voltage's impact, travel speed, and welding current. The direct effects of welding voltage on the flux consumption are shown in Fig. 4a. The value of voltage increases according to experiment run order selecting the range/level of voltage varies from 25-35 volts and the values of flux consumption vary from

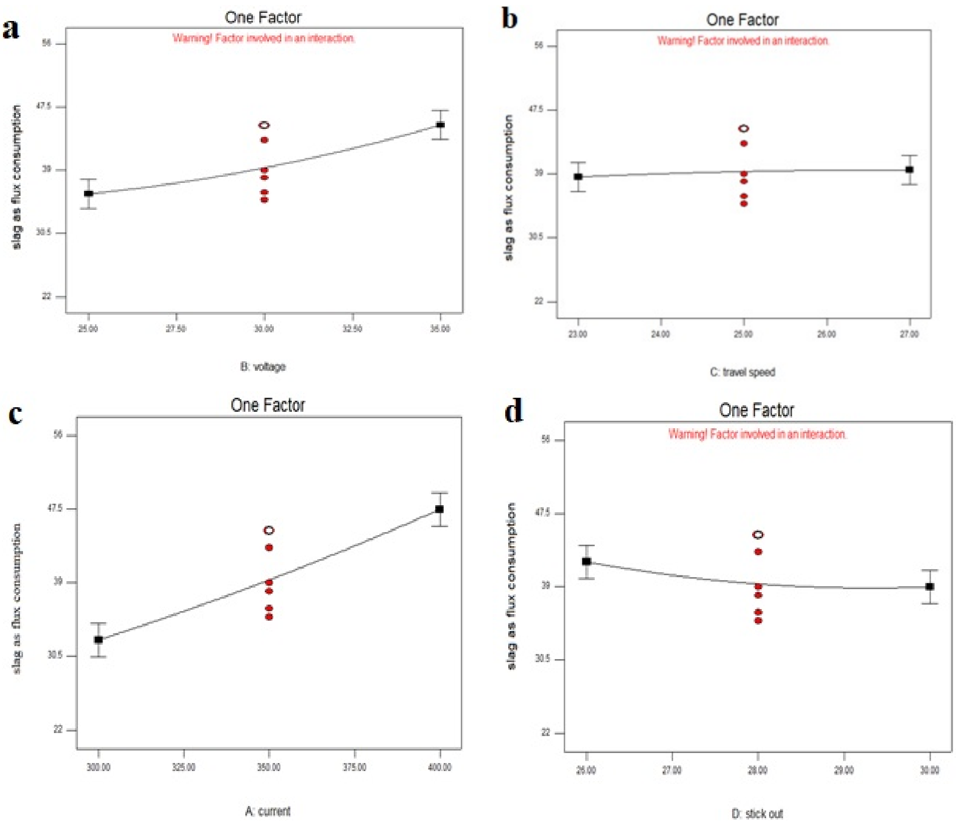

Fig. 4. Effect of Welding Parameters on Flux Composition; (a) Effect of Voltage; (b) Effect of Travel Speed; (c) Effect of Welding Current; (d) Effect of Consuming Stick Out on Flux

36 minimum consumptions 46 maximum consumption. Direct effects of welding speed on the flux consumption as depicted in Fig. 4b the value of speed increases according to experiment run order selecting the range/level of voltage varies from 23-27 m/hr and the values of flux consumption vary from 40 minimum consumptions 41 maximum consumption so that increases the speed then flux consumption increases slightly in this range while the actual parameters vary accordingly. But if the speed increases more than this limit then flux consumption decreases. The direct effects of welding current on the flux consumption as shown in Fig. 4c. The value of current increases according to the experiment run order selecting the range/level of current varies from 300-400 amp and the values of flux consumption vary from 33 minimum consumptions to 48 maximum consumption so that increases the current then flux consumption also increases while the actual parameters vary accordingly. Direct effects of stick out on the flux consumption as depicted in Fig. 4d. The value of electrode extension increases according to experiment run order selecting the range/level of voltage varies from 26-30 mm and the values of flux consumption vary from 42 minimum consumptions 39 maximum consumption so that increases the nozzle to plate distance then flux consumption decreases while the actual parameters vary accordingly. The variation in the influence of one factor when a second factor is altered from one level to another is referred to as the interaction effect. Analysis of the interplay between process factors and their impact on flux consumption. This analysis exclusively examines the two-way interaction impact of the factors to reduce complexity. Fig. 5 illustrates that flux consumption decreases with increasing welding speed and nozzle -to-plate distance. Fig. 6 illustrates the fluctuations in flux consumption according to variations in welding speed and voltage. Accordingly, the design expert plot shows the 3D surface view between voltage and welding speed. Interaction graph the 3D surface view between current and welding speed when welding speed and current increases the flux consumption increases as depicted in Fig. 7. Understanding the behavior of the process is made much easier by the fascinating examination of the interaction effects of procedure factors on bead dimensions.

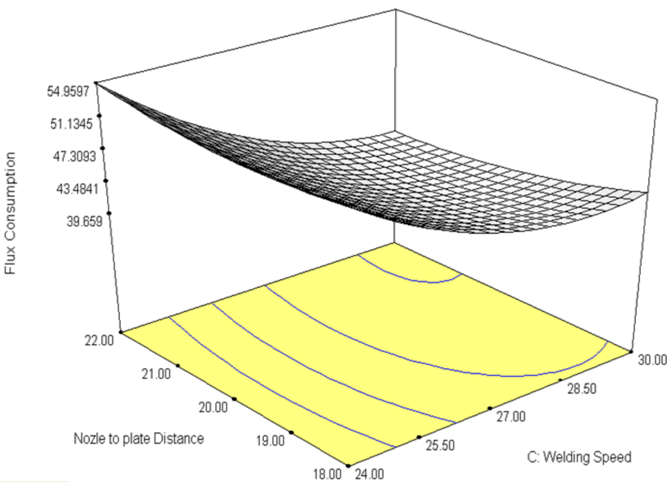

Fig. 5. The Association between Welding Speed and the Distance between the Nozzle and the Plate

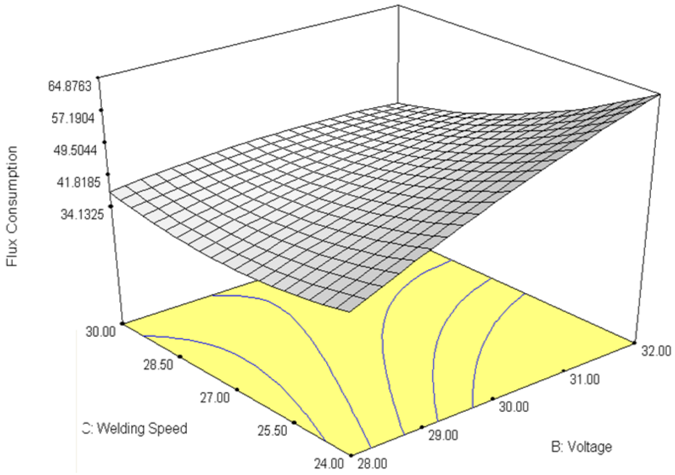

Fig. 6. Interaction among Voltage and Welding Speed

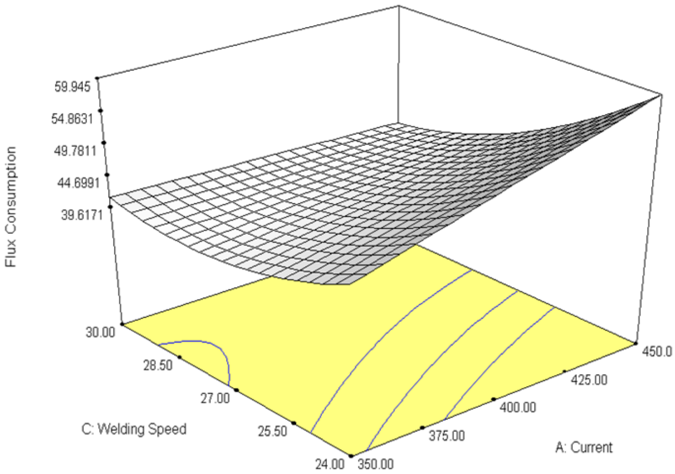

Fig. 7. Interaction among Current and Welding Speed

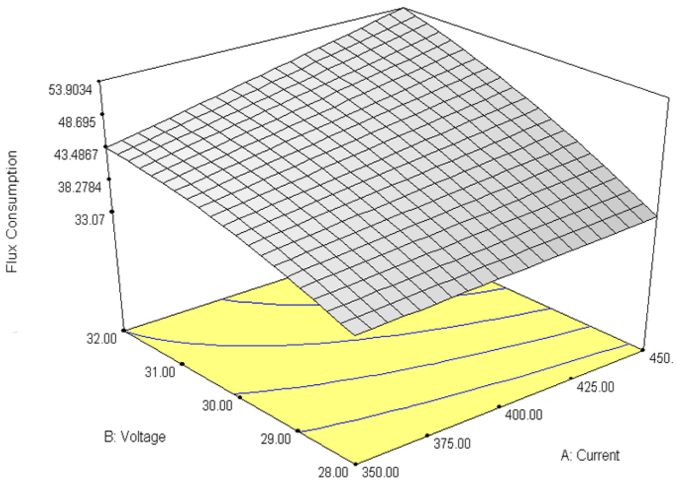

Fig. 8. Effects of Voltage and Current Interactions

The influence of one variable when a second variable is altered from one level to another is referred to as the interaction effect. Fig. 8 demonstrates the utilization of two-way interacting effects of the variables to mitigate complexity in this study. As voltage and current escalate, flux consumption also rises.

5. Conclusions

The current study reveals that response surface methodology (RSM) has been employed to evaluate the influence of process parameters on responses and their fundamental causes. Furthermore, contour graphs for various reactions are generated utilizing RSM to illustrate the relationships among different process parameters. Flux consumption increased somewhat with rising current and marginally with increasing open circuit voltage. The consumption of flux is adversely affected by the speed of welding. The flux consumption gradually decreases with increasing distance between the plate and the nozzle. The flux consumption for forecasting weld-bead geometry within the feasible zone of control various factors in the SAW may be readily found using the five-level factorial technique. The ANOVA method was used to verify the models' competence. RSM has been used successfully to analyze the cause and impact of process factors on response. For the model to be considered significant, its computed F-ratio value must exceed the typical tabulated F-ratio value for a given degree of confidence (i.e. 95%). In Submerged arc welding slag flux consumption increases when current & voltage increase. As welding speed and nozzle-to-plate distance increase, slag as flux usage falls. Two-way interactive effects of the factors were used in this study to reduce complexity. This study examines four welding parameters that influence flux usage. During the welding process, consider additional factors such as electrode extension, electrode polarity, heat input, various fluxes, and others for future scope. Substitute materials may be employed instead of high-strength alloy steel. Slag, as a fused flux, can also serve as a flux in welding processes.

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