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# Application of Response Surface Methodology for Element Transfer in Submerged Arc Welding using Recycled Slag

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***Abstract: Submerged arc welding process is a process used for manufacturing pipes and pressure vessels of varying diameter and lengths. Challenge faced during the process is the appropriation of an optimal condition of input parameters for achieving the most favourable quality of the weld. This paper attempts to embark the usage of response surface methodology for five level central composite design matrix having four factors as input variables. In this investigation, mathematical models were elaborated to analyse the performance of process variables i.e., wire feed rate, voltage, travel speed and nozzle to plate distance on element transfer of C, Mn, Si, S and P using recycled slag. They help in selecting optimum process parameters for obtaining quality desired and optimize the process.***

***Key words: submerged arc welding, response surface methodology, central composite design, wire feed rate, travel speed, nozzle to plate distance, recycled slag.***

## I. INTRODUCTION

Submerged arc welding is a diverse welding process which involves workpieces to be welded by covering it with a layer of granular flux. This Flux converts into slag after welding and due to its non-biodegradable behaviour is disposed off as a waste. This slag is recycled to be used as flux (www.paton.kiew.ua,2015 ; Beck and Jackson,1996). In order to avoid the problem of slag disposal, recycling technology has been developed to recycle fused slag (Singh and Pandey, 2009). Further, a comparison between flux and slag has been performed by evaluating weld qualification tests as well as bead geometry relationship (Singh et al., 2005; 2006).

Slag once reclaimed proves reliable as it contributes equivalent to that of virgin flux. Few researchers proposed a theory to determine the extent of Mn and Si transfer amid slag metal equilibrium (Chai & Eagar, 1982). It was observed that between slag and weld pool, transfer of Mn and Si takes place along with Cr, P, S, C, Ni and Mo. (Mitra & Eagar, 1984). Study the impact of parameters and flux basicity index on element transfer of Mn, Si, S and P, and have reported the satisfactory result.(Pandey et al., 1994).

The concept of recycling and processing of flux after welding i.e. slag has been investigated so far by few researchers. As to achieve desired features of weldment, parametric optimization is applied. They include multiple regression analysis, response surface methodology (Datta et al., 2008a; 2008b). In another study, welding parameters and flux mixture influence the weld metal configuration and mechanical properties by employing rotatable design based on statistical analysis (Kanjilal et al., 2007).

Response surface technology is an approach to conduct and elucidate the cause and effect relationship of variables influencing the output responses as a two or three-dimensional surface (Chandel, 1998). Careful conception and execution of the experimental method result in adequate and effective experimental procedure (Montgomery, 2006). RSM proves reliable in predicting the weld bead characteristics and achieving optimal process variables (Gunuraj and Murugan, 1997; 1999). This paper deals with developing a mathematical model and drawing a conclusion in graphical form by relating input parameters to the output parameters through the formulation of RSM.

## II. EXPERIMENTAL SETUP

The research was executed at Delhi Technological University, Delhi. They have modern SAW facility with details given below:
Model: QSW800
Current Range: 100 – 800 A
Polarity: Pulsed AC
Input Supply: 200-400 A, 3 phase, 50 Hz supply

The weld specimen is anchored at a specific position, and electrode holder moves back and forth along the guideways, which runs through lateral lane. SAW machine operates at 200 V rated input voltage, filler wire EL-8 having 3.15 mm diameter with flux type F7AZ which generates slag after welding. The flux hopper is adjusted along with the spool holding device.

## III. METHODOLOGY

The research work involves following steps to be carried out

*A.* Reclaimation of slag.
*B.* Identify the input parameters.
*C.* Deciding the working range of the process control variables, viz. wire feed rate (F), voltage (V), travel speed (S) and nozzle to plate distance (N).
*D.* Developing the design matrix.
*E.* Executing the experiments as per the design matrix.
*F.* Observing the responses viz. Element transfer of C, Mn, Si, S and P across molten weld pool.
*G.* Development of mathematical models.
*H.* Analysing the adequacy of the models.
*I.* Finding the significance of co-efficient.
*J.* Developing the final proposed models.
*K.* Graphical representation of process parameters with their main and interaction effects.
*L.* Analysis of results.

## IV. RECLAIMATION OF SLAG

Slag once generated as a scrap is collected from the dump yard of welding laboratory of Delhi Technological University for processing. Once collected, it is crushed and sieved to achieve the granular size equivalent to fresh flux. Welding is carried out using fresh flux and pure slag, and chemical composition of weld metal deposited is compared using spectroscope. On the basis of composition achieved, slag is modified by first crushing it to powder form in ball mill then mixing it with deoxidisers and solution of potassium silicate as a binder. This mixture then pass through 10- 15 mesh size sieve and convert into pellets which are air dried and then baked for 2 hours at 850$^{o}$C. This baked slag is now crushed to the desired size and termed as reclaimed slag. Reclaimed slag is repeatedly examined for chemical composition with the help of spectroscope till the acceptable weld metal chemistry has not achieved as per AWS standards.

### *A. Identify the Input Parameters*

Wire feed rate (F), voltage (V), travel speed (S) and nozzle to plate distance (N) were identified as input process parameters.

### *B. Deciding the Working Range of the Process Control Variables*

Based on the trial runs where varying one parameter and keeping others at a constant value. The upper and lower limit was coded as +2 and -2, the code value calculated as given below:

$$X_i = \frac{2\{2X - (X_{max} + X_{min})\}}{(X_{max} - X_{min})}$$

Where $X_i$ is the code value of variable X,
X is the value for any process variable varying from $X_{min}$ to $X_{max}$.

Table 1 shows the selected parameters with their limits, units and notations.

| Parameters | Units | Notation | limits | | | | |
|---|---|---|---|---|---|---|---|
| | | | -2 | -1 | 0 | +1 | +2 |
| Wire feed rate | mm/min | F | 90 | 107.5 | 125 | 142.5 | 160 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Voltage | Volts | V | 25 | 28.7 | 32.5 | 36.2 | 40 |
| Travelspeed | mm/min | S | 250 | 275 | 300 | 325 | 350 |
| Nozzle to plate distance | mm | N | 20 | 22.5 | 25 | 27.5 | 30 |

### *C. Developing the Design Matrix*

Design matrix selected on the basis of central composite rotatable factorial consist of 31 runs is shown in table 2. It consists of full replication of $2^4$ (=16) runs with seven central points and eight star points. These experimental runs allowed the approximation of varying interactive effects on element transfer.

Table 2. Design Matrix with observed values of response parameters

| S.No | Design Matrix | | | | C | Mn | Si | S | P |
|---|---|---|---|---|---|---|---|---|---|
| 1 | -1 | -1 | -1 | -1 | 0.056 | 0.813 | 0.153 | 0.0185 | 0.0181 |
| 2 | 1 | -1 | -1 | -1 | 0.061 | 0.816 | 0.252 | 0.0252 | 0.0252 |
| 3 | -1 | 1 | -1 | -1 | 0.058 | 0.824 | 0.153 | 0.0244 | 0.0240 |
| 4 | 1 | 1 | -1 | -1 | 0.069 | 0.817 | 0.251 | 0.0289 | 0.0288 |
| 5 | -1 | -1 | 1 | -1 | 0.052 | 0.812 | 0.150 | 0.0173 | 0.0172 |
| 6 | 1 | -1 | 1 | -1 | 0.053 | 0.824 | 0.151 | 0.0245 | 0.0247 |
| 7 | -1 | 1 | 1 | -1 | 0.058 | 0.821 | 0.149 | 0.0208 | 0.0207 |
| 8 | 1 | 1 | 1 | -1 | 0.062 | 0.814 | 0.223 | 0.0297 | 0.0296 |
| 9 | -1 | -1 | -1 | 1 | 0.052 | 0.821 | 0.139 | 0.0153 | 0.0154 |
| 10 | 1 | -1 | -1 | 1 | 0.058 | 0.814 | 0.234 | 0.0222 | 0.0221 |
| 11 | -1 | 1 | -1 | 1 | 0.056 | 0.833 | 0.139 | 0.019 | 0.0187 |
| 12 | 1 | 1 | -1 | 1 | 0.089 | 0.826 | 0.234 | 0.0257 | 0.0259 |
| 13 | -1 | -1 | 1 | 1 | 0.055 | 0.817 | 0.135 | 0.0143 | 0.0140 |
| 14 | 1 | -1 | 1 | 1 | 0.054 | 0.820 | 0.146 | 0.0185 | 0.0186 |
| 15 | -1 | 1 | 1 | 1 | 0.061 | 0.828 | 0.136 | 0.0179 | 0.0178 |
| 16 | 1 | 1 | 1 | 1 | 0.063 | 0.820 | 0.135 | 0.0234 | 0.0235 |
| 17 | -2 | 0 | 0 | 0 | 0.048 | 0.823 | 0.125 | 0.0203 | 0.0202 |
| 18 | 2 | 0 | 0 | 0 | 0.057 | 0.817 | 0.153 | 0.0314 | 0.0313 |
| 19 | 0 | -2 | 0 | 0 | 0.058 | 0.812 | 0.149 | 0.0126 | 0.0127 |
| 20 | 0 | 2 | 0 | 0 | 0.074 | 0.827 | 0.150 | 0.0223 | 0.0220 |
| 21 | 0 | 0 | -2 | 0 | 0.061 | 0.824 | 0.225 | 0.0210 | 0.0209 |
| 22 | 0 | 0 | 2 | 0 | 0.055 | 0.816 | 0.173 | 0.0190 | 0.0190 |
| 23 | 0 | 0 | 0 | -2 | 0.062 | 0.812 | 0.148 | 0.0256 | 0.0258 |
| 24 | 0 | 0 | 0 | 2 | 0.057 | 0.827 | 0.150 | 0.0170 | 0.0168 |
| 25 | 0 | 0 | 0 | 0 | 0.060 | 0.821 | 0.153 | 0.0213 | 0.0212 |
| 26 | 0 | 0 | 0 | 0 | 0.057 | 0.820 | 0.173 | 0.0215 | 0.0215 |
| 27 | 0 | 0 | 0 | 0 | 0.059 | 0.819 | 0.145 | 0.0211 | 0.0213 |
| 28 | 0 | 0 | 0 | 0 | 0.062 | 0.820 | 0.152 | 0.0212 | 0.0214 |
| 29 | 0 | 0 | 0 | 0 | 0.058 | 0.823 | 0.149 | 0.0214 | 0.0212 |
| 30 | 0 | 0 | 0 | 0 | 0.058 | 0.819 | 0.151 | 0.0213 | 0.0210 |
| 31 | 0 | 0 | 0 | 0 | 0.057 | 0.821 | 0.150 | 0.0252 | 0.0255 |
| | | | | | | | | | |

### *D. Executing the Experimentation as per the Design Matrix*

The experiments were executed as per design matrix in order to avoid the chances of systematic errors within the system.

### *E. Observing the Responses*

Mild steel plates were cross-sectioned from middle to obtain two transverse specimens. The observed values of responses i.e., C, Mn, Si, S and P, were given in table 2.

### *F. Development of Mathematical Models*

Y = f (F, V, S, N) expresses the response function for defined mathematical model**.** The relationship for second degree response surface is expressed as:

$$Y = bo + b_1F + b_2V + b_3S + b_4N + b_{11}F^2 + b_{22}V^2 + b_{33}S^2 + b_{44}N^2 + b_{12}FV + b_{13}FS + b_{14}FN + b_{23}VS + b_{24}VN + b_{34}SN$$

### *G. Analysing the Adequacy of the Models*

Analysis of variance technique (ANOVA) was used to test the adequacy of model and according to this technique [ ]:

1) For 95 % level of confidence the value of F ratio $_{\text{calculated}}$ < the value of F ratio $_{\text{tabulated}}$.
2) For the same level of confidence, the model may be considered adequate if value of R ratio $_{\text{calculated}}$ > value of R ratio $_{\text{tabulated}}$.

It was found that the models are adequate as inferred from table 4.

| Element transfer% | First order terms | | Second order terms | | Lack of fit | | Error terms | | F ratio | F tab. | Model adequate |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | S.S | DF | S.S | DF | S.S | DF | S.S | DF | | 4.09 | Yes |
| C | 0.0000473 | 4 | 0.0000242 | 10 | 0.000242 | 10 | 0.0000194 | 6 | 2.88 | 4.09 | Yes |
| Mn | 0.0000048 | 4 | 0.00000727 | 10 | 0.0000727 | 10 | 0.0000117 | 6 | 0.090 | 4.09 | Yes |
| Si | 0.001424 | 4 | 0.000676 | 10 | 0.00675 | 10 | 0.000493 | 6 | 3.14 | 4.09 | Yes |
| S | 0.000188 | 4 | 0.00000104 | 10 | 0.000004 | 10 | 0.0000131 | 6 | 2.7 | 4.09 | Yes |
| P | 0.0000188 | 4 | 0.00000104 | 10 | 0.0000104 | 10 | 0.0000131 | 6 | 0.47 | 4.09 | Yes |

### *H. Finding the Significance of Co-Efficient*

Appraise of regression coefficient gives us a notion of how the control variables affect the responses significantly. It is clearly evident, without sacrificing much of accuracy and reducing mathematical labor the coefficients can be eliminated. For this student's t-test is used and as per this test,

1) Analogous to a coefficient the calculated value of t is compared with tabulated value of t at a specific level of probability.
2) If t $_{\text{calculated}}$ > t $_{\text{tabulated}}$ then at the corresponding level of probability,= the coefficient is said to be significant.

### *I. Developing the Final Proposed Models*

The proposed mathematical model is developed on the basis of 't' test. The developed models are given below:

## V. RESULTS & DISCUSSIONS

Figure 1 described the variation in carbon percentage with respect to voltage and wire feed rate it has been seen that carbon percentage is maximum, i.e. 0.07% at wire feed rate 142.5mm/min and 36.2volts. Figure 2 shows the manganese percentage variations with respect to wire feed rate and voltage. Maximum value of manganese percentage found to be around 0.826% at wire feed rate 107.5mm/min and 36.2volts. Figure 3 shows the silicon percentage variations with respect to wire feed rate and voltage. It has been observed that highest silicon percentage is 0.18% at wire feed rate 142.5mm/min and 36.2volts. Figure 4 illustrates the variation in sulphur percentage 0.027% at wire feed rate 142.5mm/min and 36.2volts. Figure 5 demonstrates the variation in percentage of phosphorous with respect to wire feed rate and wire feed rate. It has been found that 0.027% phosphorous percentage with respect to wire feed rate 142.5mm/min and 36.2volts. at the desirability of 0.874 the optimized value of carbon percentage is 0.083%, manganese percentage is 0.865%, silicon percentage is 0.194%, sulphur percentage is 0.0284%, and phosphorous percentage is 0.0293% with the optimized parameters 36.8volts and 143.6mm/min.

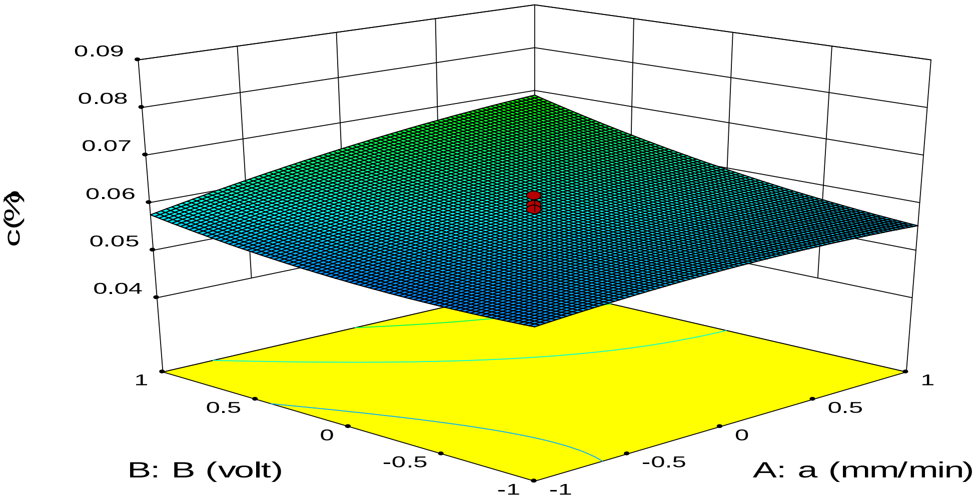

Figure 1. Variation in carbon percentage with voltage and feed rate

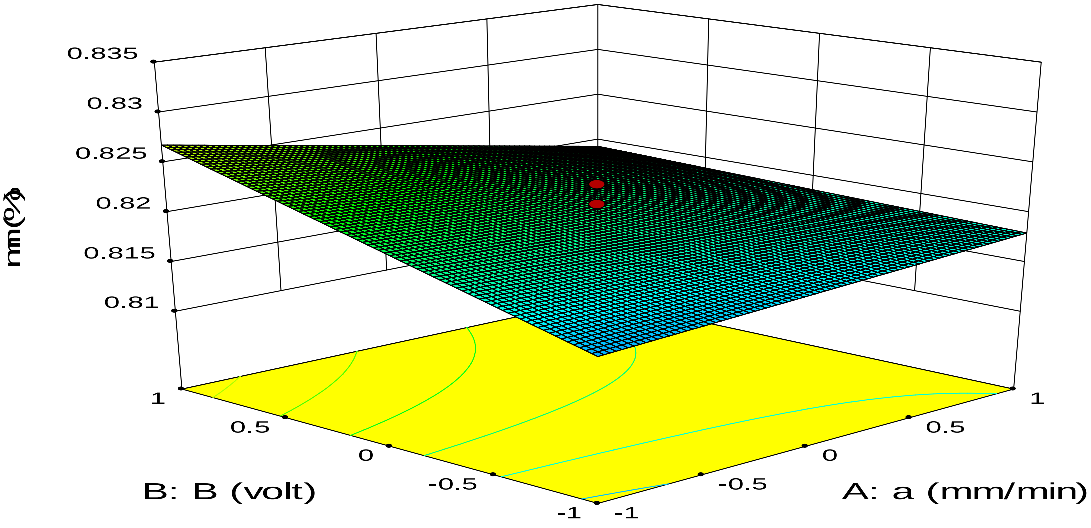

Figure 2 Variation in mangnese percentage with voltage and feed rate

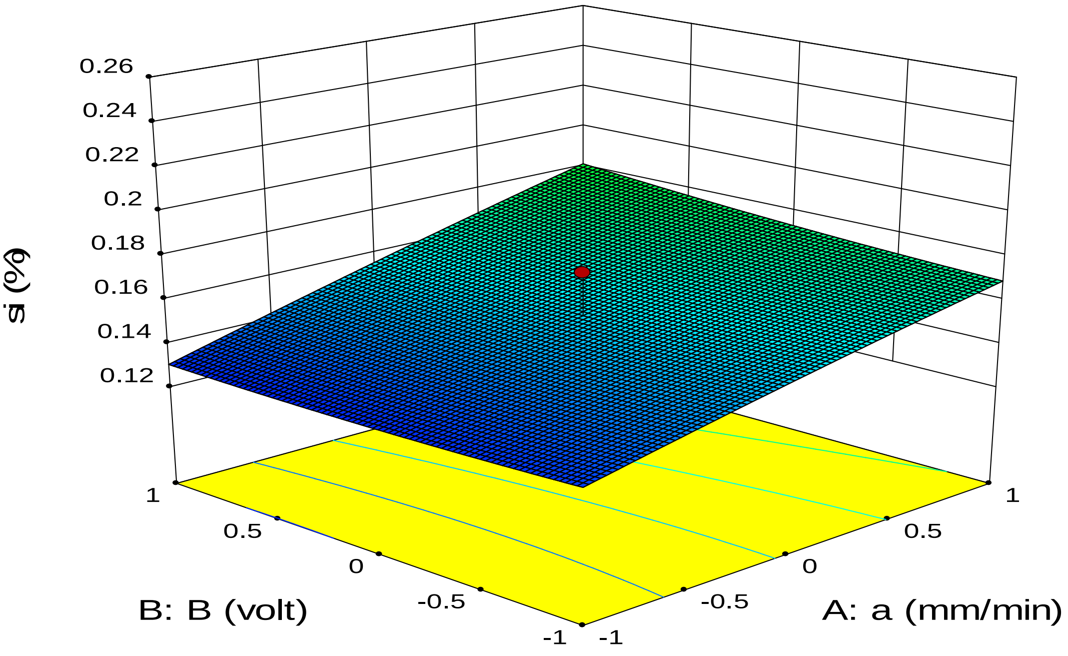

Figure 3 Variation in silicon percentage with voltage and wire feed rate

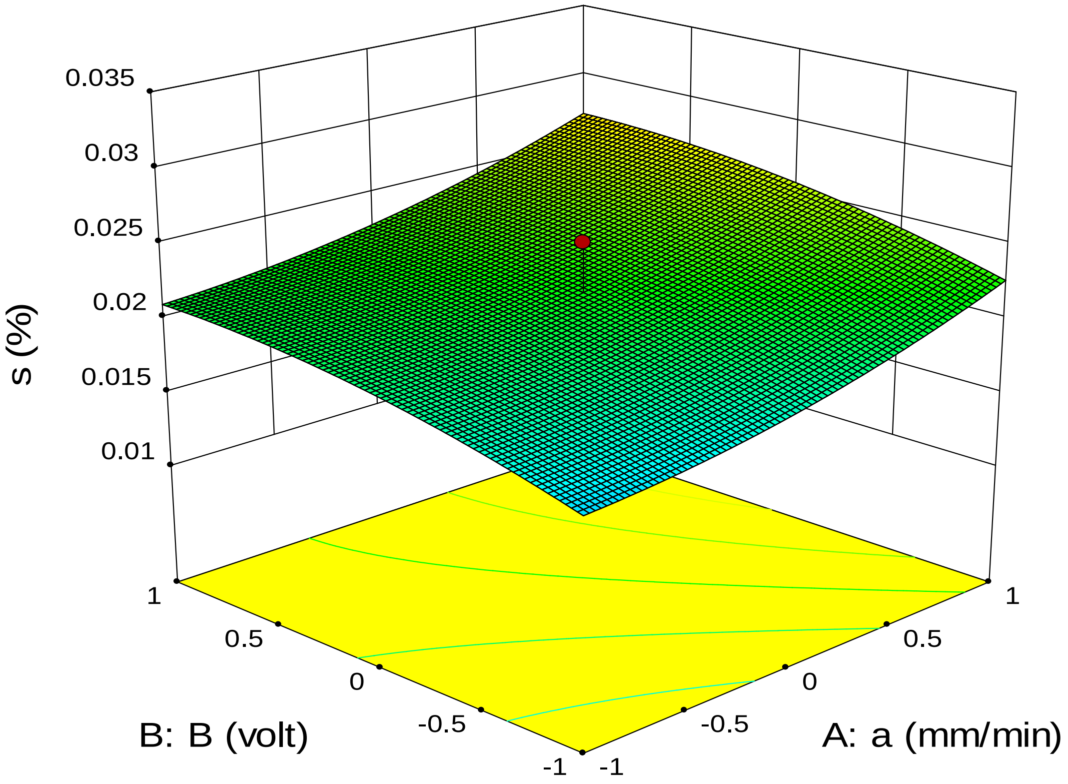

Figure 4 Variation in sulphur percentage with voltage and wire feed rate

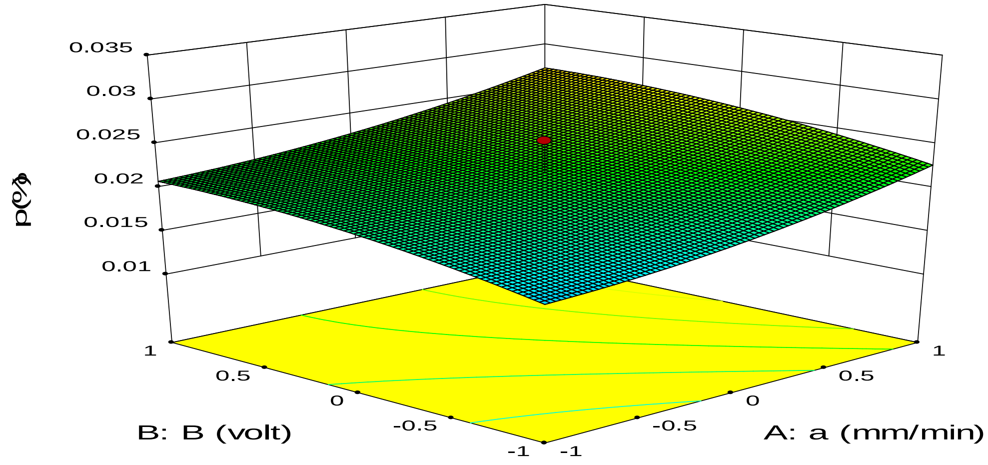

Figure 5 Variation in phasphorous with the volt amd mm/min

## VI. CONCLUSIONS

Following conclusions were drawn from the research work

*A.* Element transfer can be predicted within controllable working parameters by implementing five factorial technique for developing mathematical models.
*B.* RSM can be efficiently used in investigating the cause and effect of process variables on response parameters. RSM shows the interaction effect of different input parameter through contour graphs for various output responses.
*C.* Maximum value of responses, i.e C, Mn, Si, S, and P are found to be 0.07%, 0.826%, 0.18%, 0.027%, and 0.027%, respectively.

## VII. ACKNOWLEDGEMENT

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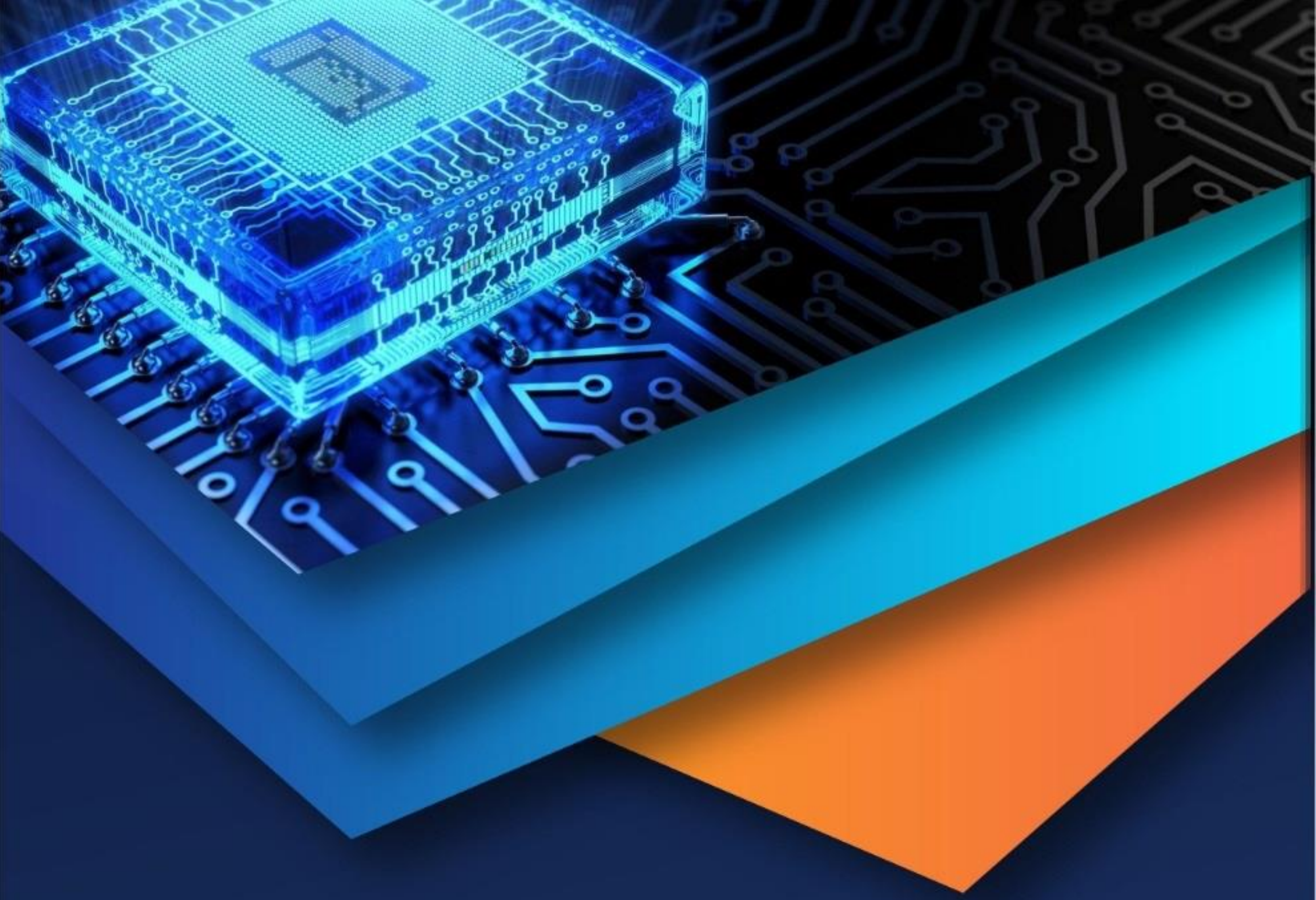

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