Characterization of Stainless Steel 410 L weld bead for Plasma Transferred Arc Hardfaced Valve Seat Rings

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Abstract. Wear brings about drastic fallout in metallic components during their application. It is established that hardfacing process has substantially matured over the recent times. To start with, Stainless steel 410 L is hardfaced over the face of low carbon steel IS-2062 valve seat rings by plasma transferred arc hardfaced process. The main and interaction effects of Plasma Transferred Arc hardfaced variables for stainless steel were obtained. These investigations were based on a design matrix of five factors, five level factorial method. The Regression analysis was tested for scrutinizing the adequacy. The percentage dilution was optimized. The conformity test was conducted and the optimized results were verified, with the percentage of error being calculated. The impact factors on the dry sliding wear resistance of Stainless Steel 410 L alloy was investigated under conditions leading to an obdurate metallic wear condition of the hard facing alloy. Mathematical model was developed relating the wear and the main factors, such as, normal load, Disc Speed, track radius. The Optimized wear model was obtained for minimizing the wear rate. Mathematical models relating wear testing parameters to wear and coefficient of friction were developed. The developed mathematical model can be used to assess the wear and the wear was found to increase.

Keywords- Plasma Transferred Arc Hard facing, Friction, Wear

1. Introduction
Fabrication or repeated rebuilding of composite wall section in materials by Plasma transferred arc hardfacing has significant advantages [11]. Substantial advancements are made in the hardfacing steam valve seat rings [11,8]. The Plasma transferred arc hardfacing process ensures a high degree of consistency permitting precise control of weld parameters [7]. Low dilution with crack free overlay necessitates the study of mathematical model, and the main and interaction effects of the various process parameters affecting the weld-bead dimensions, were factorial technique [2] was involved to reduce the cost and time. Automatic PTA hard facing was carried out by depositing stainless steel SS410L onto a carbon steel (ASTM A105) ring having inner diameter 76 millimeters, outer diameter 92 millimeters, thickness 15 millimeters and the observed data was used to develop the model. Weld-bead geometry of valve seat rings [9] were clad for prediction and thereby optimising dilution.
This research article discusses about the mathematical models used for predicting effects of Plasma transferred arc hardfaced variables on dilution and bead geometry from the experimental data obtained. The conformity tests were compared with the results of Artificial Neural Network by back propagation. Also, the wear behaviour of stainless steel 410 L alloy deposited on carbon steel IS-2062 ring are analysed. Sliding wear test using a pin on disc machine was conducted. Mathematical models relating to wear was developed using. The effect of wear testing parameters was analysed.

2. Methodology

2.1. Identification of process variables

The process variables identified for affecting the quality: Area denoted by A, travel speed denoted by S, powder feed rate denoted by F, oscillation frequency denoted by H and torch standoff denoted by N. The experiments were conducted by forming a single layer with DC electrode negative. Industrially pure argon was used at a constant flow rate for shielding at 12 Lmin\(^{-1}\), for plasma at 3.5 Lmin\(^{-1}\) and for powder feeding at 3 Lmin\(^{-1}\).

By altering one of the parameters, trial experiments were conducted by keeping rest constant. Trial runs were conducted after examining the weld-bead for an even exterior when flaws. The coded factors for upper limit was taken +2, and the lower limit was taken as -2. The in-between range was calculated using Equation (I). The response function in lieu with the dimensions are expressed \[3\] as \( y = f (A, S, F, H, N) \) where \( y \) is the yield. The 2nd order polynomial regression equation for the 5 factors is articulated.

\[
X_i = 2[2x-(X_{max} - X_{min})]/ (X_{max} – X_{min}) \quad (I)
\]

Where, the required coded value of a variable is \( X_i \) extending from \( X_{max} \) to \( X_{min} \); with \( X_{max} \) taken as the superior level and \( X_{min} \) taken as the lower level of the variable.

2.2. Design matrix and Conducting experiments

A central composite rotatable factorial design matrix \[5\] consists of thirty-two sets of coded conditions and encompassing a half duplication of 24 with16 factorial design plus 6 centre points and 10 star points. An automatic Plasma Transferred Arc hardfacing system, designed and fabricated by M/s Omplas Systems, Coimbatore, India was used for experimentation. The surfacing system ranges for a table rotational speed of 10mms\(^{-1}\) and 750mm diameter with 0.05mm resolution. The design matrix experiments were conducted at random and thereby avoided errors in random. The deposition of Stainless steel SS410 L was completed over the un-preheated carbon steel IS-2062 valve seat ring.

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2.4. Responses Recorded

In order to achieve a typical test specimen which is 10 mm wide, the hardfaced valve seat rings was cross-sectioned radially at their mid points. The bead geometry specimens were prepared by etching using 2% nital for the bead geometry measurements. An optical profile projector was used to trace the profiles of the weld-bead and the bead dimensions; viz, penetration P, reinforcement R and width W were measured. A digital planimeter was used to measure the weld metal forming and reinforcement thereby to calculate percentage dilution.

2.5. Assessing Adequacy of models

The Analysis of variance technique $[5, 3, 10]$ was used to test the adequacies of models. For this, to assess the adequacy of models, it was checked if the calculated value of F-ratio of did not surpass the standard tabularized value for the preferred level of confidence (95%) and the same for R-squared value. The final mathematical models that predicted the effects of the altered parameters for the weld-bead dimensions are found to be adequate and are given in Table 1. The Confirmatory test experiments directed to determine the accuracy of the mathematical model using the same investigational research setup.

Table 1. Final Mathematical Models

| S. No. | Mathematical Model |
|--------|-------------------|
| 1.     | Penetration, $P=1.204+0.394A-0.135S-0.110F+0.218N+0.150A2+0.094H2-0.268AS+0.132AN+0.137SF-0.336SN$ |
| 2.     | Reinforcement, $R=4.179-0.202A+0.046S+0.289F-0.049H+0.083N-0.150S2-0.107N2+0.160AF-0.238AH-0.213AN+0.255SF+0.319SN-0.228HN$ |
| 3.     | Dilution, $D=5.990+1.215A-0.902S-0.569F-0.191H+0.189N+0.312F2+0.326H2+0.444AN+1.077AN-640SN+0.418HN$ |
| 4.     | Width, $W=10.160+0.403A-0.086S+0.100F-0.173H+0.176N-0.318H2-0.414AF+0.444AH-0.765AN+0.239SF-0.245SH+0.261FH-0.363FN+0.650HN$ |
| 5.     | Total Area, $TA=37.586+0.767A-0.556S+1.159F-0.309H-0.916N-1.374S2-1.23N2+2.387AS-1.032AH-3.009AN+2.281SF+1.748SN$ |

3. Artificial Neural Network

In Artificial Neural Network, the output or the yield layer receives signals from the hidden layer and does calculations to give the yield signal, which represents the neural network response for the specific input vector $[4, 13]$. For predicting the weld-bead geometry of valve seat rings, efforts were done and the output layer was taken as the hidden layer $[12, 16]$. If the initial weights are too small the net input to the hidden or output unit would be close to zero, which also causes extremely slow learning $[6]$. Neural network inputs typically range from 0 to 1 (inclusive) and usually the output ranges from 0 to 1 continuously $[1]$. The Comparison of experimental and predicted output was calculated for the predicted dimensions of bead parameters using the test data from neural network.

4. Results and Discussion

For investigating the range of parameters and in order to predict the weld-bead geometry and dilution, the respective values were taken in the coded form and were substituted utilizing the mathematical model equations. The effects of process parameters on the bead geometry were plotted and computed using these models. The values of the control parameters were obtained by substituting the coded form values of the desired bead geometry. Figure 1 shows that the welding current A increases with an increase in penetration P and with a decrease in reinforcement R. With an increase in A, the total area TA increases. With an increase in A the Dilution D increases. Figure 2 shows that with an increase in travel speed S; the values of R, D, W and TA decreases. With any further increase
in S, the value of P decreases with increase in S to an optimum value and then increases. Figure 3 shows that with an increase in F, the powder feed rate F increases with increase in the values of P, R, W and TA. And thus, Dilution D decreases. Figure 4 shows that while Oscillation frequency H increases with an increase in D and W and it has a very less effect on P and R. Figure 5 shows with an increase in torch standoff N, the total area TA increases and width W increases slightly while P and R have less significant effect on P and R. Dilution D decreases upto an optimum value and then increases with further increase in N. The mathematical model for the weld-bead by artificial neural network is predicted accurately. The Comparison of experimental and predicted data for dilution by artificial neural network is shown in figure 6.

Figure 1. Direct effect of welding current on bead dimensions. Figure 2. Direct effect of travel speed on bead dimensions.

Figure 3. Direct effect of powder-feed-rate on bead dimensions. Figure 4. Direct effect of oscillation frequency on bead dimensions.

4.1 Wear Analysis
Wear testing pin specimens of size 10 x 10 x 10 mm³ were prepared from the stainless hard facing deposited at optimum dilution condition by machining. Dry sliding wear test was conducted at room temperature (30°C) with a Pin-on Disk type machine. A circular disk made up of C45 steel with a diameter of 200 mm and heat - treated to a hardness of HRC 60 prior to wear test was installed in the machine chuck to slide against the mating pin mounted in the holder. The disk was slid against a #1000 grade abrasive paper for 1 min to provide a sound surface contact between pin and disk. Lesser importance effects were found from sliding speed and effects of load on the wear behavior and on wear studies [15]. For conducting the experiments, Model TR 20, a computer controlled wear and friction monitor was employed.
The wear and friction coefficient are recorded by the software. In order to avoid errors skulking, the experiments were conducted as per the design matrix. Coefficients of wear models were tested for their significance and the final mathematical models were constructed using the significant coefficients. The final models are given in Table 2.

**Figure 5.** Direct Effect of Stand-Off Distance on Bead Dimensions

**Figure 6.** Comparison of experimental and predicted data for dilution

**Table 2.** Final Mathematical Model of wear analysis

| S. No. | Mathematical Model |
|--------|--------------------|
| 1.     | Wear = 37.55 – 1.64 NL - 1.64 TR + 1.86 DS + 4.82 NL 2 + 0.82 TR 2 + 3.12 DS 2 – 3.00 NL TR + 3.00 TR DS + 1.00 NL DS |
| 2.     | Coefficient of friction = 0.37 + 0.04 NL - 0.11 TR + 0.05 DS + 0.04 NL2 + 0.05 TR2 – 0.03NL TR + 0.04 DS TR + 0.01 NL DS |

Using QA Six Sigma DOE package, the values of the coefficients were calculated by using linear regression analysis for finding out the responses. The Analysis of variance for testing adequacy of models, square multiple R-values and standard error of estimates are adequate. From the interaction effect of track radius and normal load on wear, it is found that normal load the wear increases gradually and reaches maximum as shown in Figure 7. At higher normal loads, the wear increases as the track radius increases. From the interaction effect of track radius and normal load on co-efficient of friction, it is evident that with the increase in track radius provided for hard facing, the coefficient of friction increases gradually. At higher normal loads, the coefficient of friction increases as the track radius T increases. From the interaction effect of disc speed and normal load on wear, shown in Figure 8, it is obvious that with the increase in normal load provided, the wear increases gradually and reaches a maximum. The increase in disc speed has a commendable impact on wear.
Figure 7. Response surface showing interaction effect of track radius and normal load on wear

Figure 8. Response surface showing interaction effect of disc speed and normal load on wear

5. Conclusion
   a) For developing mathematical models of desired quality for automated robotic surfacing, and a five level factorial technique program can be easily engaged. The dilution increases steadily, with an increase in welding current.

   b) It can be observed from the scatter diagram for dilution in Figure 9, the neural network was more precise in predicting bead dimensions. Figure 10 shows the comparison of experimental and neural network predicted data of bead dimensions, indicating a very close proximity to each other.

   c) For minimum number of experiments, the experimental model and predicted output of bead parameters from the neural network were compared. By performing the Conformity test, a small estimation error of 1.49% found out to for dilution reveals that dilution could be predicted accurately using the artificial neural network.

   d) The QA Six Sigma DOE IV PC software package can be effectually employed for the predictions of wear behavior and finding the corresponding optimum process variables. The wear and coefficient of friction increased when the normal load and disc speed increased.

   e) It was found that the average error for most of the models was less than 1%, thereby validating the model. On comparison of experimental and predicted output of wear. Also, it was found that the average error for the wear model was 1.148%

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