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The optimization of welding hardfacing on wear resistance of FC-25 grey cast iron steel substrate by response surface methodology (RSM)

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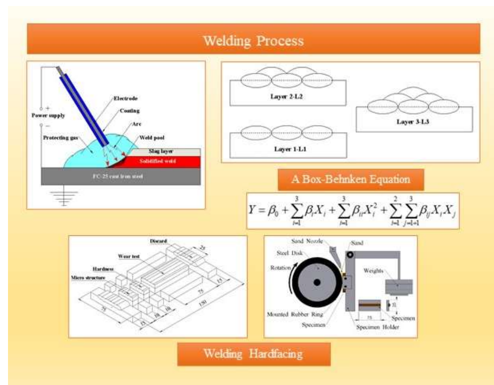
Abstract



This paper aimed to identify the optimal conditions for welding hardfacing by applying the Response Surface Methodology (RSM). The welding heat input, electrode type, and hardfacing layer on wear resistance of welding hardfacing were all optimized using the Box-Behnken experimental design. The findings revealed that these three variables had an impact on the volume loss of welding hardfacing. Because of the high coefficient of determination, the experimental data obtained were to a quadratic equation (96.90%). The ideal condition was determined using a 3D response surface plot and a contour map produced from mathematical models. The following were the ideal welding conditions: With a welding heat input of 1.58 J, a filler metal type of DFA2-600-B, and a third layer of hardfacing, the lower volume loss of the weld was 1.29 mm^3.

Keywords: Response surface; Welding hardfacing; FC-25 grey cast iron

1. Introduction

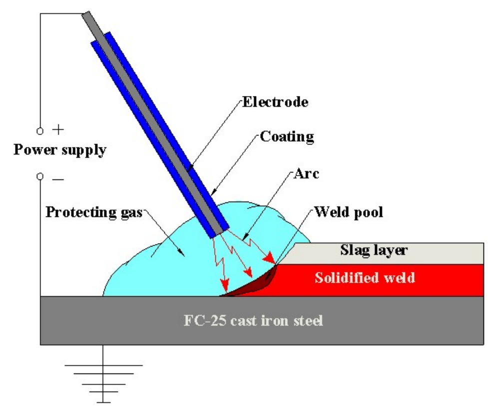
Maintenance is a critical activity in many industrial plants since the various machinery employed in the manufacturing process have varying service lives based on the nature of the operation. Mechanical components will wear out or break regardless of how well components are maintained [1]. Particularly moving parts During the operation of equipment such as shafts, gears, and crushing, for example [2], there is rotation, friction, or receiving friction. When these parts wear out or break, it's time to replace them. An engineer or person in charge can undertake maintenance work by determining where replacement or repair is necessary. By considering the damaged pieces' behavior, shape, and substance. It was preferable to employ a point repair welding procedure with Shielded Metal Arc Welding: SMAW, which has a high welding wire addition, to repair these sections [3]. As a result, it's a good choice for welding metal parts that require more reinforcement, such as hard face welding of wear parts. Before reshaping the area to the parts' original shape and size. After a failure, the quickest and most efficient approach to repair it is to replace the parts with new ones. However, in the case of machines built in Thailand, difficulties with after-sales service or parts with exorbitant prices are common, while in the case of machines imported from overseas, problems with after-sales service or parts with extreme prices, are common as well. The welding procedure has grown popular for post-defective repair of parts as a result of the aforementioned issues. Small and medium businesses employ this technique, in particular, where the majority of the machines are made in the United States. A welding process is used to "hardface" the wear sections in the repair of parts by brazing. Shield metal arc welding is extensively utilized in the hardfacing process in maintenance work. It is suitable for large structural welding procedures because it has great welding flexibility and is easy to weld [4].

Welding repair of wear parts necessitates welds with mechanical qualities that differ from standard welding, especially hardness qualities, and wear resistance that will emerge after being put to use, even though, suitable welding electrodes, appropriate for the nature of the welding work are used in maintenance work. However, it has been discovered, that as wrong quantities of various elements were identified, the metallurgy could be altered at the weld line and produce a decline in repair performance. Welding electrodes, current, welding speed, and the temperature of the test pieces before welding are all elements that can affect the mechanical qualities of the welds. As a result, the response surface methodology (RSM) was utilized to analyze the hardness of the FC-25 grey cast iron welding hardfacing, to find the best parameters in the production process and [5]. because it is a widely used substance in the sugar business. To evaluate the welding parameter, research of the shielded metal arc welding process was conducted. The RSM approach is intended to be able to create an effective hardfacing process, making it valuable for manufacturers and others who want to learn more about the welding hardfacing process.

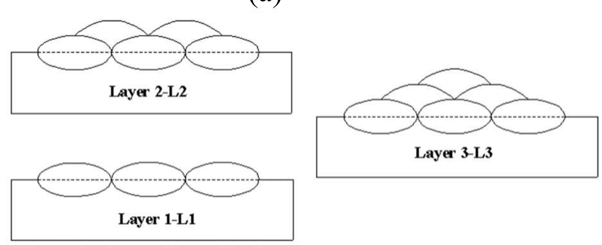
2. Materials and Methods

Materials and welding processes

Figure 1(a) depicts welding. The experimental technique used shield metal arc welding (SMAW) to compare welding heat input, electrode type, and hardfacing layers. Table 1 lists the welding parameters. FC-25 grey cast iron steel, 75 × 150 × 10 mm, materials for an experiment Table 2 shows the chemical composition of the filler metal and the base metal. Before welding, the electrodes are annealed at 100 degrees Celsius, the workpiece is preheated to 400 ºC, and each inter welding layer is heated to 200 ºC. Figure 1 depicts the pattern of hardfacing interlayers (b). Manual welding was used in the trials, which were carried out with a welder that had been qualified for national skill levels. Hardfacing welding rods with a diameter of 4 mm are known as filler metal. The welding electrodes used in the experiment are low hydrogen type electrodes for surfacing worm machine parts that have been subjected to a lot of attrition from metal to metal sliding or rolling.



(a)



(b)

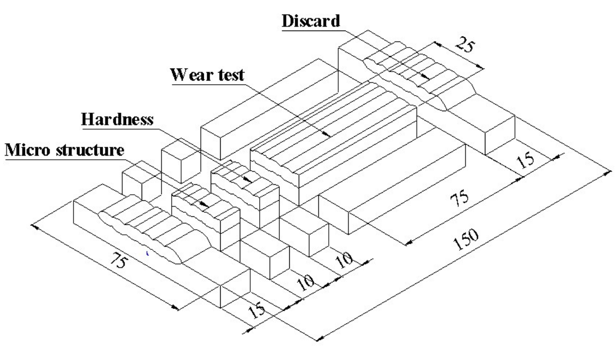
Fig. 1 welding process (a) Shield metal arc welding (SMAW) (b) Hardfacing layers produced [6].

Table 1 Variations in the study of welding hardfacing.

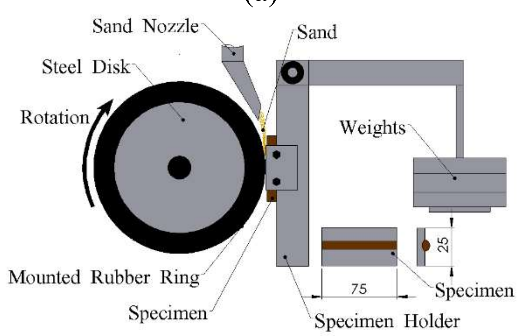
Experimental factors	Experimental level		
Welding heat input: J (X1)	1.50	1.84	2.17
Filler metal: F (X2)	DFA2-350-R	DFA2-450-R	DFA2-600-B
Hardfacing layers: L (X3)	1	2	3

Estimate of wear rate

Welding hardfacing wear tests are conducted in accordance with ASTM-G65/Procedure (A) [7]. Rectangular specimen with a friction surface of 75 × 25 mm, fine sandblasting, a sand flow rate of 300 g min^{1}, a test time of 30 minutes, and a test weight of 130 N. Preparation of welding hardfacing test pieces and wear tests are shown in Fig. 2(a – b).



(a)



(b)

Fig. 2 Investigation of welding hardfacing (a) Preparation of welding hardfacing test pieces (b) Wear test according to ASTM-G65 [8].

Experimental design

A Box-Behnken experiment with three elements: heat input: J(X1), filler metal: F(X2), and hardfacing layers: L was used to identify the factors impacting the amount of volume loss (X3). By establishing the degree to which relevant research aspects are considered, as well as the experimental tools' limits. Table 3 shows the three levels of factors in the experiment: low (–1), medium (0), and high (1), as well as the order of the tests. Model validation, coefficient of determination (R-Square), and analysis of variance are statistical tools used to analyze the findings of the experiment (ANOVA). Using the values of the components obtained from the coefficient analysis of the weld wear regression analysis as Eq. (1) [9], we built an equation for forecasting the amount of volume loss. In terms of generating the volume loss of the response surface produced from the experiment. Heat input, filler metal, and hardfacing layers were all compared as experimental parameters. In addition to determining the optimum factor and composite desirability: D, where the response satisfaction ranged from 0 – 1, and if D was one (1), the response was entirely satisfied [10]. where Y is predicted value, β_0, β_i are the estimated parameters, X^2 is a quadratic model. X_i, X_j represent the independent variables.

$$Y = \beta_0 + \sum_{i=1}^{3} \beta_i X_i + \sum_{i=1}^{3} \beta_{ii} X_i^2 + \sum_{i=1}^{2} \sum_{j=1+1}^{3} \beta_{ij} X_i X_j \quad (1)$$

Table 2 The chemical composition of the electrode and base metal (%wt.).

Material	Element				
	C	Si	Mn	Cr	Mo
Fc-25 grey cast iron steel	3.20	2.30	0.55	0.40	–
DFA2-350-R (X2 : –1)	0.16	0.43	1.32	1.55	–
DFA2-450-R (X2: 0)	0.25	–	0.75	3.05	0.54
DFA2-600-B (X2: 1)	0.45	0.50	1.15	4.51	0.60

Table 3 Factors and levels of each factor of the experiment.

Factor	Level		
	– 1	0	1
Welding heat input: J (X1)	1.50	1.84	2.17
Filer metal: F (X2)	350	450	600
Hardfacing layers: L (X3)	1	2	3

Table 4 Experiments and results of volume loss.

Run	Factor of Experimental			Volume loss (mm^3)
	X_1	X_2	X_3	
1	1.50(– 1)	350(– 1)	2(0)	4.17
2	2.17(1)	350(– 1)	2(0)	4.12
3	1.50(– 1)	600(1)	2(0)	1.82
4	2.17(1)	600(1)	2(0)	2.65
5	1.50(– 1)	450(0)	1(– 1)	3.26
6	2.17(1)	450(0)	1(– 1)	3.41
7	1.50(– 1)	450(0)	3(1)	2.58
8	2.17(1)	450(0)	3(1)	3.64
9	1.84(0)	350(– 1)	1(– 1)	4.07
10	1.84(0)	600(1)	1(– 1)	2.12
11	1.84(0)	350(– 1)	3(1)	4.24
12	1.84(0)	600(1)	3(1)	1.44
13	1.84(0)	450(0)	2(0)	2.42
14	1.84(0)	450(0)	2(0)	2.58
15	1.84(0)	450(0)	2(0)	2.50
16	1.84(0)	450(0)	2(0)	2.50
17	1.84(0)	450(0)	2(0)	2.65

3. Results and Discussion

The goal of the experiment was to use response surface methodology to discover the best circumstances. The Box-Behnken experimental design was used to determine the level of welding heat input, electrode, and hardfacing layers that had the least influence on welding hardfacing wear resistance. Table 4 illustrates the findings of the welding hardfacing wear experiment, which revealed that the volume loss ranged from 1.44 to 4.24 mm^3. The quadratic replication was deemed to be adequate based on the p-value (p0.05), lack of fit (p0.05), and the decision coefficient (R-Square: R-Sq) being high in the correlation analysis of the response factor using a regression model at the significance level = 0.05. The regression analysis in Table 5 shows that the R-Sq value is 96.90 percent, indicating that the independent variables (welding heat input, electrode, and hardfacing layers) can explain the variations or changes in the variables, indicating that the model can be used to create suitable equations for predicting the solution.

Table 6 investigates the model's variability using analysis of variance. The p-value of the interaction term was 0.00, and the square term was 0.00, which is less than the value, according to the analysis of the variation of the volume loss of welding hardfacing at a statistically significant level of 0.05. An arc appears at the response surface, based on the statistical significance. A quadratic model equation can be utilized to forecast volume loss from wear examination, it can be asserted. Eq. (2) was used to forecast the amount of welding hardfacing wear using a factor analysis of the coefficients of the equation tray pitching loss of the weld, as indicated in Table 6. When evaluating the equation's appropriateness (Lack-of-Fit) The Lack-of-Fit p-value in Table 6 was 0.06, which is close to and greater than 0.05, indicating that this model is adequate for the variables in the equation. As a result, the equation can be used to forecast welding hardfacing volume loss.

The volume loss of welding hardfacing was established on the response surface. The response surface map is constructed once the equation for estimating welding volume loss is calculated, as illustrated in Fig.3. The level of the welding heat input with the electrode type can be determined from the reaction surface plot depicting the volume loss of welding hardfacing. It was discovered that as the welding heat input level rises, so does the likelihood of volume loss. The volume loss is decreased when the Electrode type is changed to DFA2-600-B. The dilution quantity is reduced

Table 5 Response surface of regression analysis.

Term	Coeff	SE Coeff	T-Value	P-Value
Constant	2.53	0.07	37.18	0.00
Welding heat input : J	0.25	0.05	4.64	0.00
Filler metal : F	– 1.07	0.05	– 19.91	0.00
hardfacing layers: L	– 0.12	0.05	– 2.24	0.06
Welding heat input : J*Welding heat input : J	0.46	0.07	6.14	0.00
Filler metal : F*Filler metal : F	0.20	0.07	2.75	0.03
hardfacing layers: L*hardfacing layers: L	0.23	0.07	3.16	0.02
S = 0.15, R-sq = 96.90%, R-sq (adj) = 81.89%				

$$\textit{Volume loss} = 2.53 + 0.25X_1 - 1.07X_2 - 0.12X_3 + 0.46X_2^2 + 0.20X_3^2 + 0.23X_1X_2 \quad (2)$$

Table 6 Analysis of variation, volume loss of welding hardfacing.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	11.78	1.31	56.52	0.00
Linear	3	9.79	3.26	140.98	0.00
Square	3	1.40	0.47	20.18	0.00
Interaction	3	0.58	0.19	8.39	0.01
Error	7	0.16	0.02		
Lack-of-Fit	3	0.13	0.04	5.91	0.06
Pure Error	4	0.03	0.01		
Total	16	11.94			

due to the low welding heat input, resulting in high weld hardness, and the weld has high hardness after cooling when utilizing DFA2-600-B Electrode type as a high alloy filler metal. Then, when the response surface plot is given, a contour plot is shown to observe the relationship between welding heat input and Electrode type as shown in Fig. 3(a) to see the relationship between welding heat input and volume loss. It was discovered to be a nonlinear effect, as illustrated in Fig. 3(b), with the top curve indicating a volume loss of less than 2 mm^3, and the lower curve indicating a volume loss rate of 2, 2.50, 3, and 3.50 mm^3, respectively.

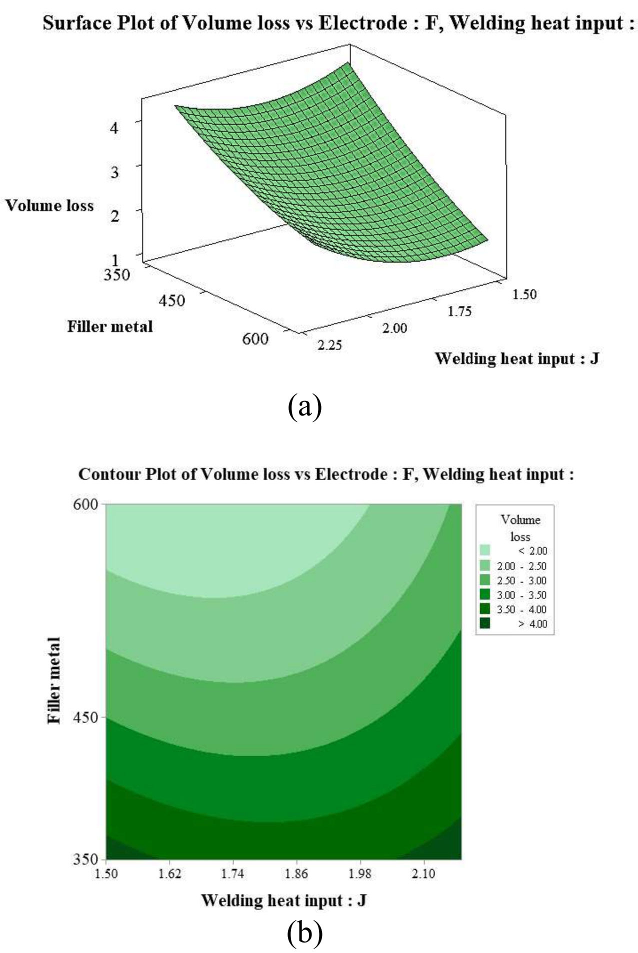


Fig. 3 show volume loss of welding hardfacing (a) surface plot and (b) contour plot, between the electrode type and the welding heat input

The volume loss of the reaction surface between the welding heat input and the hardfacing layer is shown in Fig. 4. The amount of volume loss was found to be the smallest at the middle welding heat input, but as the welding heat input was reduced or raised, the amount of volume loss increased. In contrast to the hardfacing layer, the quantity of volume loss was reduced when a hardfacing layer was added, as illustrated in Fig. 4(a). The combined effects of welding heat input and the hardfacing layer is then shown in a contour plot to understand how the interaction between welding heat input and the hardfacing layer affects the amount of volume loss, as shown in Fig. 4(b). The next curve reflects the rise in volume loss amount: 2.50, 2.75, 3, and 3.25 mm^3, respectively, while the middle curve represents the minimal weld loss amount of 2.50 mm^3.

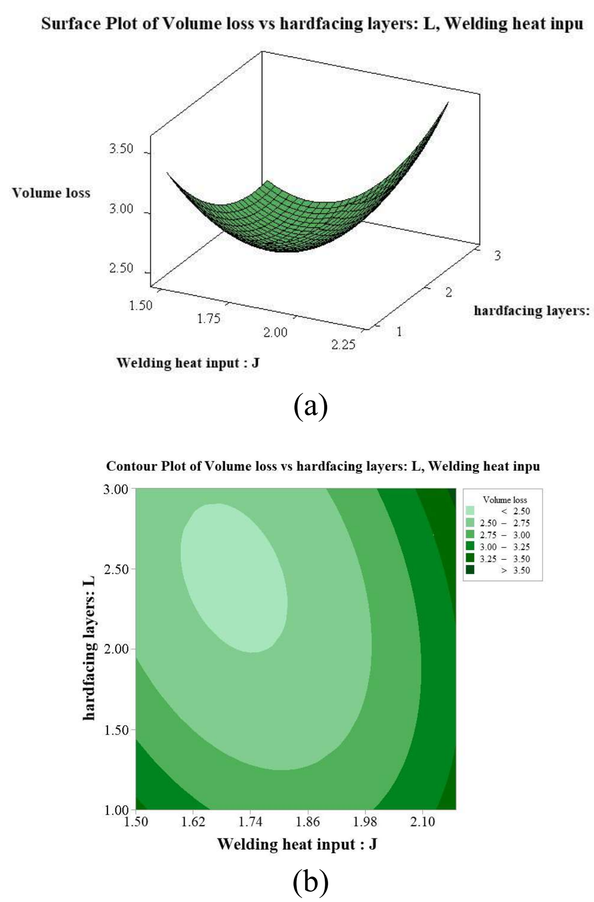
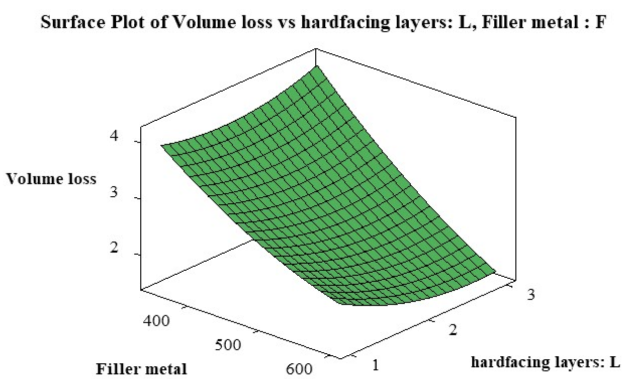
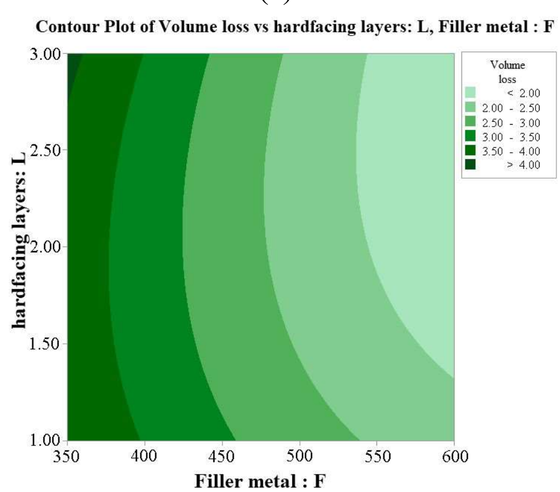


Fig. 4 show volume loss of welding hardfacing (a) surface plot and (b) contour plot, between the welding heat input and the hardfacing layer.

Then, as illustrated in Fig. 5, compare the relationship between filler metal and the hardfacing layer in welding that effect the volume loss of weld hardfacing. The electrode type DFA2-600-B reduced the volume loss of the weld, while the hardfacing layer had no effect on the volume loss of the weld change in Fig. 5(a). Fig.5 depicts a contour graph of the response surface plot of the influence between the Filler metal and the hardfacing layer Fig. 5(b). The hardfacing layer and the filler metal were discovered to have a nonlinear impact. The following curve illustrates the increase in the amount of weld loss to 2, 2.50, 3, and 3.50 mm^3, respectively, while the right-hand curve reflects the amount of volume loss less than 2 mm^3.



(a)



(b)

Fig. 5 show volume loss of welding hardfacing (a) surface plot and (b) contour plot, between the Filler metal and the hardfacing layer.

Using the response optimizer function to determine the best factor for achieving the lowest volume loss of weld, it was discovered that the ideal condition of wear resistance was welding heat input 1.58 J, electrode type DFA2-600-B, and third hardfacing layer supplied volume. As indicated in Fig.6, the lowest mean loss of weld was 1.29 mm^3 with a composite attractiveness of 1.

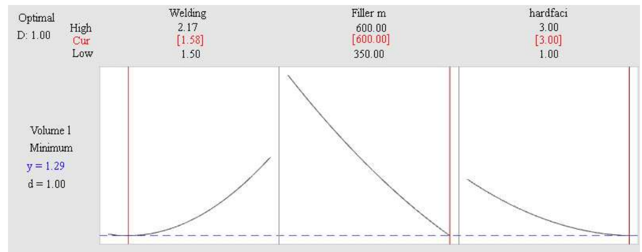


Fig. 6 Analysis of the optimal factors for the volume loss of welding hardfacing.

4. Conclusion

Using the Box-Behnken design, estimate the ideal value of welding factors and volume loss of welding hardfacing using response surface methods. The volume loss of welding is affected by all three elements, namely welding heat input (X1), filler metal (X2), and hardfacing layer (X3). A volume loss of welding prediction equation can be used to express this. Volume loss $= 2.53 + 0.25X_1 - 1.07X_2 - 0.12X_3 + 0.46X_2^2 + 0.20X_3^2 + 0.23X_1X_2$. When the optimal factor was computed using the response optimizer function, the coefficient of determination was 96.90 percent. Welding heat input 1.58 J, electrode type DFA2-600-B, and third hardfacing layer provided volume, were found to be the best determining parameters for volume loss. With a composite desire of 1, the lowest mean loss of weld was 1.29 mm^3.

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