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Application of MOORA method for multi optimization of GMAW process parameters in stainless steel cladding

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A B S T R A C T

Gas Metal Arc Welding (GMAW) is widely used to perform cladding so as to enhance corrosion resistance and several other properties of substrate material. However, the success of cladding using GMAW depends on the optimal selection of its critical parameters. Therefore, in this study, the cladding of stainless steel over mild steel substrate using GMAW process is investigated with an aim to optimize the GMAW process parameters. Three GMAW process parameters i.e. current, voltage, and torch angle were selected and their effect on the time required to complete the cladding and arc power was investigated and optimized. Multiple objective optimization based on ratio analysis (MOORA) method was employed to evaluate and optimize the effect of the selected process parameters. It was found that the current and voltage have significant effect in reducing the time and power required for the cladding process.

1. Introduction

Metal cladding is a process used to protect base material via deposition of a thin layer of second material on the surface of the base material. This process plays a significant role as it provides corrosion protection, wear protection to the base material and at the same time it is also cost effective (Akramifard et al., 2014; Dhib et al., 2016; Cao et al., 2015). There are different cladding processes which are essentially used to reduce the cost and improve the properties of engineering components. GMAW is one of the processes which is highly suitable for cladding because of its high efficiency, reliability, high deposition rate, low cost, user-friendliness, suitability for both nonferrous and ferrous metals (Zhang et al., 2014; Scotti et al., 2014). The cladding of stainless steel includes depositing a layer of stainless steel over the mild steel substrate through GMAW process. The cladding of stainless steel provides

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resistance to the oxidation, abrasion and corrosion of the mild steel. In addition, the cladding of stainless material also contributes to increase in the strength of substrate and improves the thermal conductivity of the composite (Luo et al., 2016). Further, cladding of stainless steel is also expected to offer economic advantages. However, cladding is considered to be a complicated welding process due to involvement of many input process parameters and multiple response variables. Thus, it is necessary to control as accurately as possible the cladding process parameters to obtain the desired quality of the deposited material (Palani & Murugan, 2007). Statistical design of experiment methods has been used to study different welding processes by several researchers for determining the effect of process parameters and they verified that these methods can be efficiently employed to obtain the desired results with reasonable accuracy (Bidi et al., 2017; Balasubramanian, 2016; Martinez-Conesa et al., 2017). Therefore, in this study, Taguchi L_{27} orthogonal array was used to perform the experiments to investigate the effect of different GMAW process parameters i.e. voltage, current, torch angle on two response variables i.e. time required to complete the bead and the arc power.

MOORA method (multiple objective optimization based on ratio analysis) is a well-known multi-criterion or multi attribute optimization method which can be employed to solve various types of complex decision-making problems in the manufacturing environment (Shihab & Chanda, 2015; Patel & Maniya, 2015; Gadakh et al., 2013). In addition, it is an easy method which can be used to determine the optimum values of a process involving multi responses. Therefore, in this study, MOORA method is used in order to determine the optimum parameters during cladding process.

2. Materials and methods

The substrate material was mild steel (IS 2062) plates with dimensions of 300×200×20 mm. The surfaces of substrate material were ground before cladding to remove dirt and to smooth finish. A filler wire of stainless steel - Grade 308L was used. The chemical composition of the filler wire and substrate material is presented in Table 1. GMAW machine (make: ESAB AUTO K400, India) was used for cladding. Current (A), Voltage (B), torch angle (C) were selected as input process parameters. Table 2 reveals the levels of process parameters that were used in the present study. Argon was used as shielding gas as it is relatively cleaner than other gases and its flow was kept constant i.e. 10 l/min. Time (T) required to complete the bead was recorded with the help of a stop watch and its unit is second. Power was obtained by multiplying voltage and current whose values were displayed by the GMAW machine. Its unit is Watt (W). Fig.1 illustrates the typical cladded plates.

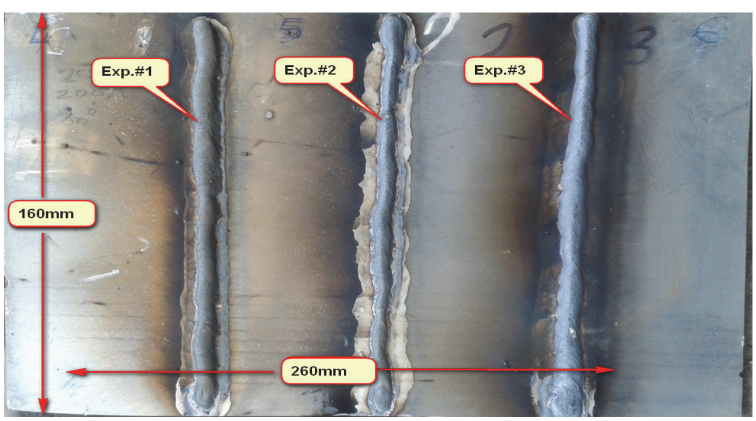

Fig. 1. A typical cladded plate

Table 1
Chemical composition of based Metal and Filler wire in % weights

Elements	C	Si	Mn	S	P	Cr	Mo	Ni	Cu	Fe
IS 2062	0.161	0.091	0.910	0.008	0.015	0.017	0.002	0.008	0.018	Rest
W30813	0.04	1	1.32	0.03	0.04	19.9	0.75	9.5	0.75	Rest

Table 2
Levels of input welding parameters levels

Factors	Process Variable	Units	Levels		
A	Current	A	20	25	30
B	Voltage	V	200	230	260
C	Torch Angle	°	30	45	60

2.1 SDV-MOORA Method

Selecting and evaluating multiple responses of the manufacturing processes is Multi-Criteria Decision Making (MCDM) problem. The importance of weights in solving Multi-Criteria Decision Making (MCDM) problems cannot be over emphasized. The standard deviation (SDV) method suits the problem of allocating weights in MCDM. MOORA method is a multi-objective optimization on the basis of ratio analysis that can be efficiently used to solve various kinds of complex decision problems of manufacturing environment (Gadakh et al., 2013, Brauers et al., 2008). Therefore, in this study, SDV was used to allocate weights to the two response variables. The approach thus used in the present study is called SDV-MOORA which can be applied when no preference among the criteria is considered. Lower-the-better criterion was used for both the response variables i.e. time required to complete the bead and the arc power. The normalization of the response variables was done using Eq. (1) in order to convert different units among different criteria into measurable units to facilitate weights calculation (Achebo & Odinikuku, 2015).

$$X'_{ij} = \frac{X_{ij} - \min\limits_{1<j<n} X_{ij}}{\max\limits_{1<j<n} X_{ij} - \min\limits_{1<j<n} X_{ij}}, \tag{1}$$

where, min and max are the maximum and minimum values of the criterion (j) respectively. The standard deviation (SDV) is computed for every criterion using Eq. (2) (Achebo & Odinikuku, 2015)

$$\mathrm{SDV'}_j = \sqrt{\frac{1}{m}\sum_{i=1}^{m}(X' - \overline{X'}_j)^2}\ , \tag{2}$$

where $\overline{X'_j}$ is the mean of the values of the *jth* criterion after normalization and j = 1,2,….., n . After calculating the SDV for all criterions, the weights (W_j) were calculated by Eq. (3) (Achebo & Odinikuku, 2015).

$$W_j = \frac{\mathrm{SDV'}_j}{\sum_{j=1}^{n}\mathrm{SDV'}_j} \tag{3}$$

The decision matrix being used in the MOORA method can be obtained by Eq. (4) (Chakraborty, 2010).

$$X = \begin{bmatrix} X_{11} & X_{12} & \cdots & \cdots & \cdots & \cdots & X_{1n} \\ X_{21} & X_{22} & \cdots & \cdots & \cdots & \cdots & X_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ X_{m1} & X_{m2} & \cdots & \cdots & \cdots & \cdots & X_{mn} \end{bmatrix} \tag{4}$$

where m represents the number of alternatives, n indicates number of attributes., and Xij is the representation measure of ith alternative on jth attribute, The normalized decision matrix is calculated by Eq. (5) (Chakraborty, 2010)

$$X'_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^{2}}} \tag{5}$$

Then optimization problem can be defined by Eq. (6):

$$y_i = \sum_{j=1}^{b} X'_{ij} - \sum_{j=b+1}^{n} X'_{ij} \tag{6}$$

$\sum_{j=1}^{b} X'_{ij}$ and $\sum_{j=b+1}^{n} X'_{ij}$ are the interest and non-interest criteria respectively. If there are different attributes more significant than the others, the combined score is obtained using W_j where W_j is the weight of jth criterion. Ranking of yi in descending order gives the final priority.

3. Results and discussions

Taguchi's orthogonal array of L_{27} was used as a design of experiment. The design of experiment with the results of Time required to complete the bead (T) and the arc power (P) are tabulated in Table 3.

Table 3
DOE Matrix with experimental results of time and arc power

Exp. Run	A	B	C	T (sec)	P (W)	Exp. Run	A	B	C	T (sec)	P (W)
1	20	200	30	26	4000	**15**	30	230	30	23	6900
2	25	200	45	16	5000	**16**	20	260	45	18	5200
3	30	200	60	20	6000	**17**	25	260	60	24	6500
4	20	230	30	24	4600	**18**	30	260	30	19	7800
5	25	230	45	16	5750	**19**	20	200	60	20	4000
6	30	230	60	21	6900	**20**	25	200	30	25	5000
7	20	260	30	20	5200	**21**	30	200	45	25	6000
8	25	260	45	23	6500	**22**	20	230	60	25	4600
9	30	260	60	22	7800	**23**	25	230	30	16	5750
10	20	200	45	23	4000	**24**	30	230	45	13	6900
11	25	200	60	16	5000	**25**	20	260	60	15	5200
12	30	200	30	22	6000	**26**	25	260	30	24	6500
13	20	230	45	22	4600	**27**	30	260	45	23	7800
14	25	230	60	15	5750						

Table 4 shows the value of standard deviation that has been calculated using Eq. (2). In addition, the weights were calculated using Eq. (3) and the results are tabulated in Table 5.

Table 2
Summary of standardized decision matrix

Exp. Run #	Time	Power	Exp. Run #	Time	Power	Exp. Run #	Time	Power
1	1	0	**10**	0.769231	0	**19**	0.538462	0
2	0.230769	0.263158	**11**	0.230769	0.263158	**20**	0.923077	0.263158
3	0.538462	0.526316	**12**	0.692308	0.526316	**21**	0.923077	0.526316
4	0.846154	0.157895	**13**	0.692308	0.157895	**22**	0.923077	0.157895
5	0.230769	0.460526	**14**	0.153846	0.460526	**23**	0.230769	0.460526
6	0.615385	0.763158	**15**	0.769231	0.763158	**24**	0	0.763158
7	0.538462	0.315789	**16**	0.384615	0.315789	**25**	0.153846	0.315789
8	0.769231	0.657895	**17**	0.846154	0.657895	**26**	0.846154	0.657895
9	0.692308	1	**18**	0.461538	1	**27**	0.769231	1

Table 5
Weights assigned to criteria

Property	SDV'_j	W_j
Time	0.2888	0.217208
Power	0.301816	0.226987

Then, MOORA method was applied on the obtained data using Eq. (4) and Eq. (5), respectively to obtain the normalized decision matrix as shown in Table 6.

Table 6
Normalized decision matrix

Exp. Run	Time	Power	Exp. Run	Time	Power
1	0.239187	0.131385	15	0.211589	0.226639
2	0.147192	0.164232	16	0.165591	0.170801
3	0.18399	0.197078	17	0.220788	0.213501
4	0.220788	0.151093	18	0.174791	0.256201
5	0.147192	0.188866	19	0.18399	0.131385
6	0.19319	0.226639	20	0.229988	0.164232
7	0.18399	0.170801	21	0.229988	0.197078
8	0.211589	0.213501	22	0.229988	0.151093
9	0.202389	0.256201	23	0.147192	0.188866
10	0.211589	0.131385	24	0.119594	0.226639
11	0.147192	0.164232	25	0.137993	0.170801
12	0.202389	0.197078	26	0.220788	0.213501
13	0.202389	0.151093	27	0.211589	0.256201
14	0.137993	0.188866	**Weight, W_j**	**0.217208**	**0.226987**

Table 7
Results of multi objective analysis

Exp. Run	T (Sec.)	Power	$\sum max - \sum min$	Rank	Exp. Run	T (Sec.)	Power	$\sum max - \sum min$	Rank
1	0.051953	0.029823	0.081776	15	15	0.045959	0.051444	0.097403	3
2	0.031971	0.037278	0.06925	26	16	0.035968	0.03877	0.074737	22
3	0.039964	0.044734	0.084698	12	17	0.047957	0.048462	0.096419	5
4	0.047957	0.034296	0.082253	14	18	0.037966	0.058154	0.09612	6
5	0.031971	0.04287	0.074842	20	19	0.039964	0.029823	0.069787	24
6	0.041962	0.051444	0.093407	9	20	0.049955	0.037278	0.087234	11
7	0.039964	0.03877	0.078734	16	21	0.049955	0.044734	0.094689	7
8	0.045959	0.048462	0.094421	8	22	0.049955	0.034296	0.084251	13
9	0.043961	0.058154	0.102115	2	23	0.031971	0.04287	0.074842	21
10	0.045959	0.029823	0.075782	19	24	0.025977	0.051444	0.077421	18
11	0.031971	0.037278	0.06925	25	25	0.029973	0.03877	0.068743	27
12	0.043961	0.044734	0.088695	10	26	0.047957	0.048462	0.096419	4
13	0.043961	0.034296	0.078257	17	*27*	***0.045959***	***0.058154***	***0.104113***	***1 best***
14	0.029973	0.04287	0.072843	23					

The y_i values were obtained using Eq. (6) and based on its value ranks were decided as shown in Table 7. It can be observed from Table 7 that the rank of experiment number 27 is 1. Thus, the optimum combination of parameters is $A_3B_3C_2$ i.e current 30A, voltage 260V and torch angle 45^o. Thus, it can be concluded that the higher values of the current and voltage have the most significant effect on the time required to complete the bead and the arc power. Voltage is an electromotive force which is highly responsible for the impingement of metal droplet to the substrate. Higher voltage leads to reduction in time and the power required for the welding. Torch angle is only responsible for impingement direction and does not have any electrical interaction during weld cladding.

4. Conclusions

The effect of GMAW process parameters (current, voltage and torch angle) on the time to complete the bead and the arc power during cladding stainless steel on mild steel was studied. A statistical design (Taguchi L_{27}) was used as an experimental technique to conduct the experimental work. The MOORA method was used to choose the multi optimum welding process parameters that generate lower time and power required. Further, standard deviation (SDV) method was employed to allocate the weights to the response variables. It has been noticed that the MOORA method has effectively optimized the GMAW parameters considered in the present study. From the obtained results of this study, following conclusions are made:

- The optimum combination of GMAW process parameters used for cladding is $A_3B_3C_2$ i.e. the current 30A, voltage 260V and the torch angle 45^o.

- Maximum value of current, within the selected range of the levels, reduces the time and power required for the cladding process.
- Maximum value of voltage, within the selected range of the levels, reduces the time and power required for the cladding process.
- Value of torch angle, within the selected range of the levels, has no significant effect on the time and power required for the cladding process.

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