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Application of VIKOR Approach for Multi Response optimization of MIG Welding Process Parameters

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Abstract: The Low Carbon steel is widely used material in various industries like automobile industry, construction Industry as well as in shipping Industry. This study focuses on the optimisation process parameters of Metal Inert Gas (MIG) welding on low carbon steel by using VIKOR approach. For this study input parameters considered are welding current, voltage, gas flow rate and wire feed rate and analysing their effect on three quality characteristics tensile strength, bending strength and hardness of the weldments. Taguchi L_9 Orthogonal array has been used for design of experiments (DOE). Three specimens are fabricated (for tensile, bending, and hardness) for each experimental run are fabricated for the measurement of respective strength and hardness. All the reponses are normalized according to higher-is-better. The experiment investigation is done and VIKOR index is found. Finally, the analysis of VIKOR index using S/N ratio is carried out to find out the most significant factors and predicted the optimal parametric combination for higher tensile, bending strength and hardness. Confirmation test is done to verify the improvement in quality characteristics. It is found that determined optimal parametric combination gives lowest VIKOR INDEX, which indicates the multi response of MIG welding is improved greatly through this study.

Keywords: Metal Inert Gas (MIG) Welding, Low carbon steel, VIKOR method, S-N ratio.

I. INTRODUCTION

Metal inert gas (MIG) welding or Gas metal arc welding (GMAW) is one of the widely used welding processes in manufacturing industries to the ferrous metals such as low carbon steel, stainless steel and non ferrous metals such as aluminium, magnesium, nickel and its alloys due to its high weld quality, good penetration and comparatively low investment. Metal inert gas welding is a type of arc welding process in which consumable electrode is melted, then dripping and, solidifying to form weld on the parent materials to be welded. MIG welding is basically a semi automatic process, in which feeding of wire and length of consumable electrode is automatically controlled. All the major commercial metals can be welded by MIG(CO_2) process.. The quality of weld generally depends upon the selection of input parameters during the welding process. Unfortunately the common problems that have been faced by manufacturers are to control the input process parameters to obtain a good quality weld. In order to overcome this problem, various optimization methods can be applied by researchers that define the desired output variables through developing mathematic models to specify the relationship between the input output parameters. Some of them investigation of this field are given- Murugan and Parmar [1] devoped a mathematical equation used a four factor, 5 level factorial techniques to predict the geometry of the welded bead. Developed model have been checked for their adequacy and significance by used the F-test and T-test respectively. Tay and Butler [2] used experimental design and neural network technique foe modelling and optimizing a MIG welding process parameters. Kim and Basu [3] developed an unsteady two dimensional axisymmetric model for investigated the heat and fluid flows in weld pools and also determine the weld bead geometry, and velocity and temperature profiles for the MIG welding. Suban and Tusek [4] described a study on melting efficiency of the filler material (solid and cored wires) in various shielding gases and welding flux. Ganjigati et al. [5] established a relation between input output parameters by regression analysis carried out both globally as well as cluster-wise. And found that cluster-wise regression analysis is to perform better than global approach. Karadeniz et al. [6] were described the effect of various input welding parameters on welding penetration. Considered input parameters are welding current; arc voltage and welding speed were chosen. Shahi and Pandey [7] studied the effects of metal arc welding (GMAW) and universal gas metal arc welding process parameters on dilution in single layer stainless steel cladding of low carbon structural steel plate. Malviya and pratihar [8] used particle swarm optimization(PSO) technique for tuning of neural networks for carried out both forward and reverse mapping of MIG welding process. In the Taguchi approach, it is supposed that all quality characteristics are independent but in actual case the assumption may deviate. To overcome this problem some researchers have applied Grey Taguchi method, Principal Component Analysis, Genetic Algorithm, Particle swarm optimisation (PSO). The present work investigates the effect of welding current, voltage, gas flow rate and wire feed rate on the multi quality characteristics tensile strength, bending strength and hardness of the weldments in MIG welding of AISI1008 low Carbon steels and estimate the optimal combination of the welding parameters for the maximisation of the tensile, bending strength and hardness of the weldments by application of the VIKOR approach coupled with signal to noise ratio methodology.

II. METHODOLOGY

A. VIKOR Method

The MCDM method is very popular technique widely applied for determining the best solution among several alternatives having multiple attributes or alternatives. A MCDM problem can be represented by a decision matrix as follows [9]:

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ . \\ . \\ . \\ . \\ A_m \end{array} \begin{bmatrix} Cx_1 & Cx_2 & . & . & . & . & Cx_n \\ x_{11} & x_{12} & . & . & . & . & x_{1n} \\ x_{21} & x_{22} & . & . & . & . & x_{2n} \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ x_{m1} & x_{m2} & . & . & . & . & x_{mn} \end{bmatrix} \quad (1)$$

Here, A_i represents ith alternative, $i = 1, 2, ..., m$; Cx_j represents the jth criterion, $j = 1, 2, ..., n$; and x_{ij} is the individual performance of an alternative. The procedures for evaluating the best solution to an MCDM problem include computing the utilities of alternatives and ranking these alternatives. The alternative solution with the highest utility is considered to be the optimal solution.

The following steps are involved in VIKOR method:

1) *Step 1:* Representation of normalized decision matrix

The normalized decision matrix can be expressed as follows:

$$F = \left[f_{ij} \right]_{m \times n} \quad (2)$$

Here, $f_{ij} = \dfrac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$, $i = 1, 2, ..., m;$ and x_{ij} is the performance of alternative A_i with respect to the jth criterion.

2) *Step 2:* Determination of ideal and negative-ideal solutions

The ideal solution A^* and the negative ideal solution A^- are determined as follows:

$$A^* = \left\{ (\max f_{ij} \mid j \in J) \; or \; (\min f_{ij} \mid j \in J'), i = 1, 2, ..., m \right\} = \left\{ f_1^*, f_2^*, ... f_j^*, ... f_n^* \right\} \quad (3)$$

$$A^- = \left\{ (\min f_{ij} \mid j \in J) \; or \; (\max f_{ij} \mid j \in J'), i = 1, 2, ..., m \right\} = \left\{ f_1^-, f_2^-, ... f_j^-, ... f_n^- \right\} \quad (4)$$

where, $J = \{ j = 1,2, \ldots\ldots, n \mid f_{ij}, if \; desired \; response \; is \; large \}$

$J' = \{ j = 1,2, \ldots\ldots, n \mid f_{ij}, if \; desired \; response \; is \; small \}$

3) *Step 3:* Calculation of utility measure and regret measure

The utility measure and the regret measure for each alternative are given as

$$S_i = \sum_{j=1}^{n} w_j \frac{\left(f_j^* - f_{ij} \right)}{\left(f_j^* - f_j^- \right)} \quad (5)$$

$$R_i = \underset{j}{Max} \left[w_j \frac{\left(f_j^* - f_{ij} \right)}{\left(f_j^* - f_j^- \right)} \right] \quad (6)$$

where, S_i and R_i, represent the utility measure and the regret measure, respectively, and w_j is the weight of the jth criterion.

4) *Step 4:* Computation of VIKOR index

The VIKOR index can be expressed as follows:

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$$Q_i = \upsilon\left[\frac{S_i - S^*}{S^- - S^*}\right] + (1-\upsilon)\left[\frac{R_i - R^*}{R^- - R^*}\right] \tag{7}$$

where, Q_i , represents the ith alternative VIKOR value, $i = 1, 2, ..., m$; $S^* = \underset{i}{Min}(S_i)$; $S^- = \underset{i}{Max}(S_i)$; $R^* = \underset{i}{Min}(R_i)$; $R^- = \underset{i}{Max}(R_i)$ and υ is the weight of the maximum group utility (usually it is to be set to 0.5). The alternative having smallest VIKOR value is determined to be the best solution.

B. *Procedure Adopted For Optimization*

1) Step 1: Estimation of quality loss

Taguchi defined quality loss estimates for responses using Lower-the-better (LB) and Higher-the-better (HB) criterion are given bellow.

(a) For a lower-the-better (LB) response

$$L_{ij} = k_1 \times \frac{1}{r}\sum_{k=1}^{r} y_{ijk}^2 \tag{8}$$

(b) For a higher-the-better (LB) response

$$L_{ij} = k_2 \times \frac{1}{r}\sum_{k=1}^{r} \frac{1}{y_{ijk}^2} \tag{9}$$

Here, L_{ij} is the quality loss associated with the jth response in the ith experimental run; y_{ijk} is the observed kth repetition datum for the jth response in the ith experimental run; r is the number of repetitions for each experimental run. k_1 , k_2 are quality loss coefficients, $i = 1, 2, ..., m$; $j = 1, 2, ..., n$; $k = 1, 2, ..., r$.**Step 2**: Calculation of normalized quality loss (NQL) for individual responses in each experimental run. The NQL can be obtained as follows:

$$f_{ij} = \frac{L_{ij}}{\sqrt{\sum_{i=1}^{m} L_{ij}^2}}, \quad i = 1, 2, \ldots\ldots, m;\ j = 1, 2, \ldots\ldots, n. \tag{10}$$

Here f_{ij} represents the NQL of the jth response in the ith experimental run.

2) *Step 3:* Evaluation of ideal and negative-ideal solutions.

A smaller NQL is preferred, so the ideal and negative-ideal solutions which represent the minimum and maximum NQL of all experimental runs are as follows:

$$A^* = \left\{\min f_{ij} \middle| i = 1, 2, ..., m\right\} = \left\{f_1^*, f_2^*, ..., f_j^*, ..., f_n^*\right\} \tag{11}$$

$$A^- = \left\{\max f_{ij} \middle| i = 1, 2, ..., m\right\} = \left\{f_1^-, f_2^-, ..., f_j^-, ..., f_n^-\right\} \tag{12}$$

3) *Step 4:* Calculation of the utility and regret measures for each response in each experimental run using equation (5) and (6) respectively.

4) *Step 5:* Calculation of VIKOR index of the ith experimental run. Substituting S_i and R_i into equation (7) yields the VIKOR index of the ith experimental run as follows. A smaller VIKOR index produces better multi-response performance.

5) *Step 6:* Determination of optimal parametric combination

The multi-response quality scores for each experimental run can be determined from the VIKOR index obtained in step 5, and the effects of the factors can be estimated from the calculated VIKOR values. The optimal combination of factor-level called optimal parametric combination is finally determined, in view of the fact that a smaller VIKOR value indicates a better quality. Signal to method is to be applied finally to evaluate this optimal setting by minimizing the VIKOR index. Optimal result is to be verified through confirmatory tests.

C. *Signal To Noise Ratio Calculation*

S/N characteristics formulated for three different categories as Larger is best characteristic, Nominal and smaller is best characteristic Data sequence for tensile and flexural strength, which are higher-the-better performance characteristic are pre-processed as Eq. (13)

$$S/N = -10 \log\left(1/n \sum_{i=1}^{t} \frac{1}{y^2}\right) \quad (13)$$

_where y^2 is average of observed data y, and n is the number of observation

III. EXPERIMENTAL SETUP AND DATA COLLECTION

The experiment were conducted using a MIG welding setup (manufactured by "TECHNOLOGY Promoters (I) Pvt. Ltd. MIG 400") shown in figure. 1. Consumable electrode wire of 1.2 mm copper coated Mn-Si double deoxidized is used for depositing the weld beads on the AISI 1008 low carbon steel . Chemical composition of base and filler metal is shown in table 1. Co_2 gas used as a shielding gas during the experiment. Test pieces of size 150mm x 30mm x 6mm were cut from low carbon steel plates. Double V-shaped grove butt weld joint is prepared. To evaluate the quality of the MIG welds four control factors welding current, voltage, gas flow rate and wire feed rate with three levels are considered for study their effect on three responses tensile strength, bending Strength and Hardness. The value of control factors with their level is shown in table 2. The experimental run is carried out as per Taguchi L9 Orthogonal array Universal testing machine(UTM) of capacity 60,000kgf and Rockwell hardness tester (manufactured by Fuel instrument & engineers PVT. LTD.) used for tensile test and hardness test respectively. Bending strength is also recorded by UTM. Table 3 shows the value of values of measured responses. The specimens after testing is shown in figure 2

Table 1 Chemical composition

Designation	C%	Si%	Mn%	P%	S%	Cu%
Base metal	0.065	0.095	0.204	0.018	0.017	0.007
Filler metal	0.090	0.800	1.560	0.025	0.025	0.500

Table 2 Control factors with their level

Parameters	Unit	Notation	Level 1	Level 2	Level 3
Current	Amp.	A	80	100	120
Voltage	Volt.	V	22	26	30
Gas flow rate	Lit./min	Gf	10	13	16
Wire feed	m/min	Wf	8	10	12

Figure 1: MIG Welding Setup

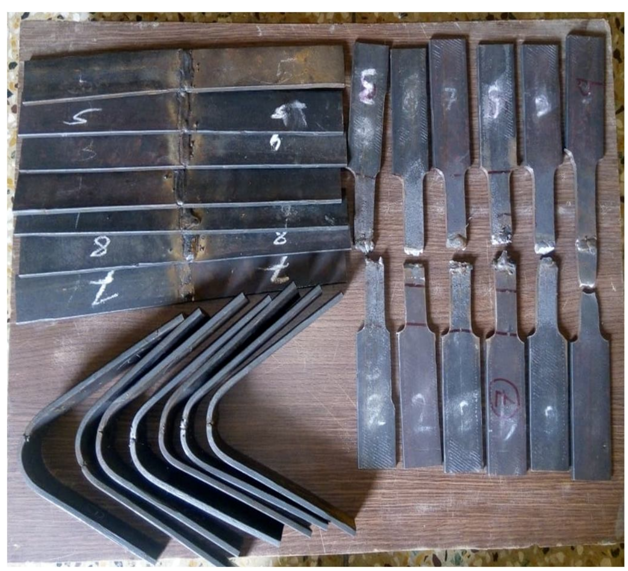
Figure 2: Specimen after testing

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Table 3: Response data as per Taguchi L_9 Orthogonal array design

S. No.	L_9 OA				Response value related to weld quality					
	A	V	Gf	Wf	Ultimate Tensile Strength (MPa)	Bending Strength (KN)	Hardness (HRB)			
							Test 1	Test 2	Test 3	Average
1	1	1	1	1	428	5.821	72.1	75.4	78.3	75.2
2	1	2	2	2	370	4.220	73.9	70.4	76.8	73.7
3	1	3	3	3	375	5.810	74.5	70.3	80.1	74.9
4	2	1	2	3	330	5.420	75.6	69.4	74.3	73.1
5	2	2	3	1	320	5.810	70.2	74.5	71.7	72.1
6	2	3	1	2	350	5.771	75.3	78.6	64.5	72.8
7	3	1	3	2	390	4.680	80.5	70.3	75.2	75.3
8	3	2	1	3	405	4.321	70.8	72.5	70.6	71.3
9	3	3	2	1	425	5.310	79.6	75.4	70.8	75.2

IV. OBSERVED DATA COLLECTIONS AND RESULTS

A. Multi-Criteria Decision Making In MIG Welding Using VIKOR Approach

Quality loss estimates for the responses have been calculated using eq (8) and furnished in table 4. For all the responses higher the better criteria is selected. Normalized quality loss estimates have been calculated using eq (10) and furnished in table 5. Utility measure of individual response is shown in table 6. It has been assumed that all responses are equally important. Therefore, 33.33% weightage has been assigned to each response. Utility and regret measure for each alternative have been shown in Table 7. VIKOR index of each alternative have been presented in Table 8. Analysis of VIKOR index has been done using signal to noise ratio (S/N ratio) and predicted optimal parameter setting found.

Table 4: Calculated Quality loss estimates

S. No.	Quality Loss Estimates		
	Tensile Strength	Bending Strength	Hardness
1	0.00000546	0.029512	0.000177
2	0.00000730	0.056153	0.000184
3	0.00000711	0.029624	0.000178
4	0.00000918	0.034041	0.000187
5	0.00000976	0.029624	0.000192
6	0.00000816	0.030026	0.000189
7	0.00000657	0.045657	0.000176
8	0.00000609	0.053559	0.000197
9	0.00000553	0.035466	0.000177

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Table 5: Normalised Quality loss estimates

S. No.	Normalised Quality Loss Estimates		
	Tensile Strength	Bending Strength	Hardness
1	0.246336	0.248975	0.319862
2	0.329618	0.473725	0.333015
3	0.320887	0.249919	0.32243
4	0.414369	0.287179	0.338504
5	0.440672	0.249919	0.347959
6	0.368365	0.253308	0.3413
7	0.296678	0.385177	0.319013
8	0.275109	0.451838	0.355811
9	0.249826	0.299201	0.319862

The ideal and negative ideal solution which represents the minimum and maximum NQL of all experimental runs are calculated by using Eq. (3) and Eq. (4) are as follows:

$A^* = \{\min f_{ij} \,|i = 1,2,\} = \{f_1^*, f_2^*\} = \{0.24636, 0.248975, 0.319013\}$

$A^- = \{\max f_{ij} \,|i = 1,2,\} = \{f_1^-, f_2^-\} = \{0.440672, 0.473725, 0.355811\}$

Table 6: Utility measure of individual response

S. No.	Utility measure of each criteria (w=0.33)		
	Tensile Strength	Bending Strength	Hardness
1	0	0	0.007613
2	0.141397	0.333333	0.125568
3	0.126569	0.001386	0.030643
4	0.285329	0.056094	0.174792
5	0.333333	0.001386	0.259584
6	0.207201	0.006362	0.199867
7	0.085455	0.199985	0
8	0.048824	0.297863	0.333333
9	0.005886	0.073746	0.007613

Table 7: Utility measure and regret measure of individual alternatives

S. No.	Utility measure(Si) and regret measure (Ri) of individual alternatives	
	Si	Ri
1	0.007613	0.007613
2	0.600298	0.333333
3	0.158598	0.126569
4	0.516215	0.285329
5	0.594303	0.333333
6	0.41343	0.207201
7	0.28544	0.199985
8	0.68002	0.333333
9	0.087245	0.073746

Table 8: VIKOR index of individual alternatives and S/N ratio for different VIKOR index

S. No.	VIKOR Index	S/N Ratio
1	0	-
2	0.9608	0.3473
3	0.3187	9.9323
4	0.8208	1.7152
5	0.9579	0.3735
6	0.6097	4.2976
7	0.5320	5.4817
8	1	0.0000
9	0.1751	15.1342

V. INTERPRETATION OF RESULTS

The optimum condition represents the combination of control factor levels that is expected to produce the best quality performance. The average S/N for each factor level indicate the relative effects of the various factors of MIG welding on quality characteristics tensile strength, bending strength and hardness of the weldments of low carbon steel. Taguchi analysis observes the higher value of mean S/N ratio is better quality characteristics. Therefore, based on the average S/N ratio for each factor level as illustrated in based on Fig.3 the optimum performance for combined tensile, bending strength and hardness was obtained at level 3 current (0.178 mm), level 3 for voltage (15˚), level 2 for gas flow rate (60˚), level 2 for wire feed (0.004mm). The optimum parametric combination for both tensile and flexural strength is A3V3Gf2Wf2. Table 9 is the response table for S/N ratio, which shows the most significant factor for tensile, bending strength and hardness. Voltage having rank 1, which is the most significant factor and gas flow rate having rank 4, which is the less significant factor.

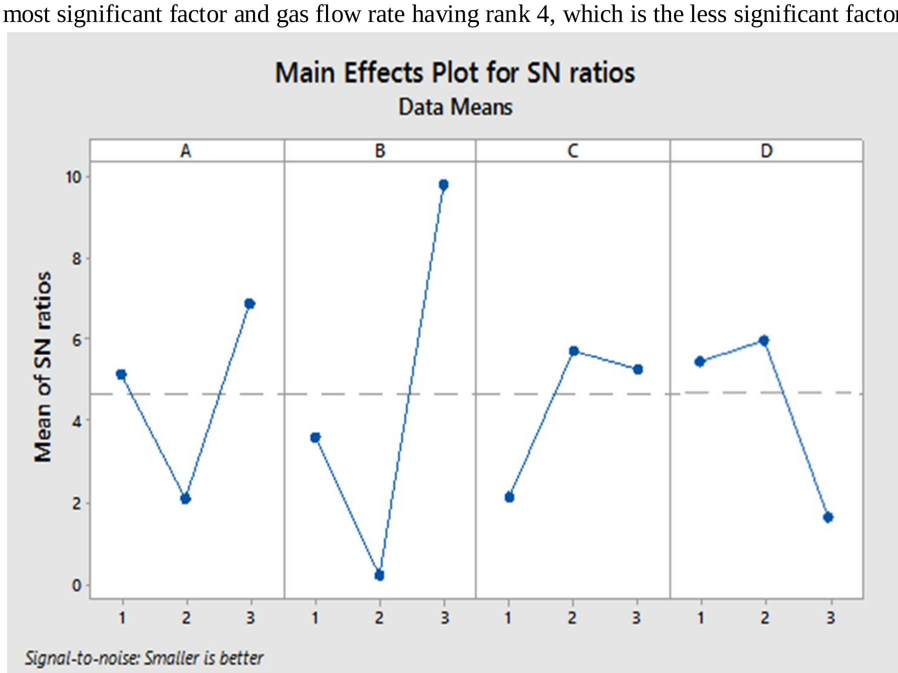

Figure 3: Average S/N ratio by control factor for VIKOR index

Table 9: Average S/N ratio by control factor for VIKOR index

Level	A	V	Gf	Wf
1	5.1398	3.5985	2.1488	5.3756
2	2.1288	0.2403	5.7323	6.0783
3	6.8720	9.7881	5.2626	1.9825
Delta	4.7432	9.5478	3.5835	4.0958
Rank	2	1	4	3

VI. CONCLUSION

In this study, the effects of process parameters setting of Metal Inert Gas (MIG) welding for AISI 1008 low carbon steel material have been investigated. Four process parameters welding current, voltage, gas flow rate and wire feed rate at three levels are selected for experimental runs, and experiment is carried out according to L_9 orthogonal array. Tensile, Bending strength and hardness are selected as a quality target, using VIKOR method the responses have been normalized and VIKOR index found. Signal to noise ratio is calculated by MINITAB-17 software and predicted optimal parameter setting found to be A3B3C2D2 and factor V (Voltage) is found most significant parameter. According to the predicted optimal parameter settings conformation test has been done and VIKOR INDEX 0.0001 is found as per methodology. VIKOR INDEX should be minimum so the successful implementation of VIKOR approach has been done.

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