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APPLICATION OF VIKOR BASED TAGUCHI METHOD FOR MULTI-RESPONSE OPTIMIZATION: A CASE STUDY IN SUBMERGED ARC WELDING (SAW)

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ABSTRACT

The term optimization is intensively related to the field of quality engineering. The product quality depends on different quality indices (called attributes) which should reach expected target level in order to meet customer's satisfaction. Deviation from the target results severe quality loss which may not be accepted by the consumers. Therefore, every manufacturing or production unit should have better concern for both quality as well as productivity. High quality can be achieved by optimizing various quality attributes or by selecting an optimal process environment efficient enough to fetch desired requirements of quality. To address this issue several methodologies were recommended in literature but most of the research carried out earlier seeks for optimizing a single objective function. In this context, Taguchi's design of experiment (Orthogonal Array) and Signal-to-Noise (S/N) ratio concept were found to be the most efficient having worldwide application in various fields. This method was proved robust and largely recommended for continuous quality improvement and off-line quality control. However, traditional Taguchi method cannot solve a multi-objective optimization problem. To overcome this shortcoming several hybrid Taguchi techniques were developed. But these methods are based on quality loss of individual attributes from their ideal condition. They fail to consider variations of relative quality loss of multiple attributes. It may so happen that the quality loss associated with some responses is small; but the quality loss associated with rest of the responses is very large, even though the overall average quality loss is small. Such situation may not be accepted by the customers. In consideration of the above, the present study explores application of Taguchi based VIKOR method adapted from Multi-Criteria-Decision Making (MCDM) in order to solve multi-response optimization problem through a case study in SAW. An attempt has been made to evaluate the best process environment (process condition) for achieving desired multi-quality features of the weldment.

Keywords: Taguchi Based Vikor Method, Multi-Criteria-Decision Making (Mcdm), Saw

1. INTRODUCTION

It is well known that several process control parameters influence weld bead geometry, bead quality and joint performance in Submerged Arc Welding. These parameters should be selected in a judicious manner to reach the desired target or objective which is dictated by the area of application of the weldment. This can be achieved by optimization of welding phenomena.

Literature depicts that the common approaches to tackle simulation modeling and optimization problem in welding include multiple regression analysis, Response Surface Methodology (RSM), Artificial Neural Network (ANN) modeling and Taguchi method, [Unal, R. and Dean, Edwin B., (1991), Rowlands, H., *et al.* 2000, Antony, J. and Antony, F., (2001), Maghsoodloo, S. *et al.* (2004)]. In most of the cases the optimization has been performed using single objective function. For a multi-response process, while applying the optimal setting of control factors, it can be observed that, an increase/improvement of one response may cause change in another response, beyond the acceptable limit. Thus for solving multi-criteria optimization problem, it is convenient to convert all the objectives into an equivalent single objective function. This equivalent objective function, which is the representative of all the quality characteristics of the product, is to be optimized (maximized).

Optimization using desirability function (DF) approach is very helpful in this context [Asiabanpour, B. *et al.* (2004), Ful-Chiang, Wu. (2005)]. Similarly Taguchi's philosophy has also been recommended as an efficient tool for the design of high quality manufacturing system. However, traditional Taguchi method cannot solve multi-objective optimization problem Jeyapaul, R. *et al.* (2005). Therefore, Taguchi method coupled with grey relational analysis is the appropriate option. Tarng, Y. S. *et al.* (2002) applied grey-based Taguchi methods for optimization of Submerged Arc Welding process parameters in hardfacing. Apart from desirability function and grey-based Taguchi approach, Genetic Algorithm (GA) and Fuzzy Logic are also found to be useful techniques to solve optimization problem in the field of welding [Al-Aomar, Reid (2002)].

Apart from Genetic Algorithm, fuzzy logic also comes into the scenario of solving optimization problems in material processing technology [Wang, Jen-Ting and Jean, Ming-Der (2006)]. Xue, Y. *et al.* (2005) reported the possibilities of the fuzzy regression method in modeling and optimization of the bead width in the robotic arc-welding process.

Desirability Function (DF) approach coupled with Taguchi method has been used by some researchers to investigate conditions leading to process optimization. In this context, application of other hybrid techniques deserves mention. These techniques are: - (i) Taguchi method coupled with fuzzy logic, (ii) Genetic Algorithm and fuzzy logic, (iii) desirability function approach coupled with fuzzy logic, (iv) Genetic Algorithm in combination with Response Surface Methodology, and (v) Taguchi-Genetic Algorithm [Tsai, Jinn-Tsong (August 2004)]. Tarng, Y. S. *et al.* (July 2000) applied fuzzy logic in the Taguchi method to optimize the submerged arc welding process with multiple performance characteristics. Another approach for optimization is the Controlled Random Search Algorithm (CRS), developed by Price, W. L. (1977).

It has been observed that Taguchi based hybrid methods are based on quality loss of individual quality attributes from their ideal (desired) condition. They fail to consider variations of relative quality loss of multiple attributes. The situation may arise that the quality loss associated with some responses is small; but the quality loss associated with rest of the responses is very large, even though the overall average quality loss is small. Such situation may not be accepted by the consumers.

In order to overcome aforesaid shortcoming, the present study proposes VIKOR method adapted from Multi-Criteria Decision Making (MCDM) hybridized with Taguchi method for solving multi-criteria optimization problem of submerged arc welding. With relevant illustrations, the robustness and application feasibility of the proposed method has been verified through a case study, discussed in the paper.

2. 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:

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

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 [Opricovic, S. and Tzeng, G.-H., 2007]:

Step 1: Representation of normalized decision matrix

The normalized decision matrix can be expressed as follows:

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

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.

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

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

$$A^* = \left\{ \begin{array}{l} (\max f_{ij} \,|\, j \in J)\, or\, (\min f_{jj} \,|\, j \in JK^{/}), \\ i = 1,2,...,m \end{array} \right\} \qquad (3)$$

$$= \left\{ f_1^*, f_2^*, ..., f_n^* \right\}$$

$$A^- = \left\{ \begin{array}{l} (\min f_{ij} \,|\, j \in J)\, or\, (\max f_{jj} \,|\, j \in J^{/}), \\ i = 1,2,...,m \end{array} \right\} \qquad (4)$$

$$= \left\{ f_1^-, f_2^-, ..., f_n^- \right\}$$

Here,

$$J = \left\{ j = 1, 2, ..., n \,|\, f_{ij}, if\ desired\ response\ is\ l\arg e \right\}$$

$$J^{'} = \left\{ j = 1, 2, ..., n \,|\, f_{ij}, if\ desired\ response\ is\ small \right\}$$

Step 3: Calculation of utility measure and regret measure

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

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

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

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.

Step 4: Computation of VIKOR index

The VIKOR index can be expressed as follows:

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

Here, Q_i, represents the ith alternative VIKOR value, $i = 1, 2, \ldots\ldots.., m$; $S^* = \underset{i}{Min}(S_i)$; $S^- = \underset{i}{Max}\,(S_i)$; $R^* = \underset{i}{Min}\;(R_i)$; $R^- = \underset{i}{Max}\;(R_i)$ 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.

3. OPTIMIZATION PROCEDURE ADOPTED

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 lower-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, $i = 1, 2, \ldots\ldots.., m$; $j = 1, 2, \ldots\ldots., n$; $k = 1, 2, \ldots\ldots.., r$.

Step 2: Calculation of normalized quality loss (NQL) for individual responses in each experimental run. The NQL can be obtained as follows:

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

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

Step 3: Evaluation of ideal and negative-ideal solutions.

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

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

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:

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

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.

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. Taguchi 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.

4. CASE STUDY

4.1 Experiments and Data Collection

Bead-on-plate submerged arc welding on mild steel plates (thickness 10 mm) has been carried out as per Taguchi's L_{25} OA design, with 25 combinations of voltage (OCV), wire feed rate, traverse speed and electrode stick-out. Copper coated electrode wire of diameter 3.16 mm (AWS A/S 5.17:EH14) has been used during the experiments. Welding has been performed with flux (AWS A5.17/SFA 5.17) with grain size 0.2 to 1.6 mm with basicity index 1.6 (Al_2O_3+MnO_2 35%, CaO+MgO 25% and SiO_2+TiO_2 20% and CaF_2 15%).

The experiments have been performed on Submerged Arc Welding Machine- INDARC AUTOWELD MAJOR (Maker: IOL Ltd., India). Weld being made, the specimens have been prepared for metallographic test. Features of bead geometry: bead width, penetration depth, reinforcement and %dilution have been observed in Optical Trinocular Metallurgical Microscope (Make: Leica, GERMANY, Model No. DMLM, S6D & DFC320 and Q win Software). The domain of experimentation is shown in Table 1. The design of experiment, based on

Taguchi's L_{25} OA, and the collected experimental data, related to individual quality indicators of bead geometry have been listed in Table 2 and Table 3 respectively.

4.2 Data Analysis

Quality loss estimates for individual responses have been calculated using equations (8 and 9). For penetration depth, %dilution (HB) and for reinforcement and bead width (LB) criterion have been selected. Normalized quality loss estimates have been determined using equation (10). While calculating utility measure of individual responses (criterion) it has been assumed that all responses are equality important. Therefore, 25% weightage has been assigned to each response. Utility and regret measure for each alternative have been calculated next. VIKOR INDEX of each alternative has been evaluated finally. The optimal parametric condition indicates smallest VIKOR INDEX. This has been achieved by optimizing (minimizing) the VIKOR INDEX by Taguchi method.

The S/N ratio of VIKOR INDEX has been calculated using LB (Lower-the-Better) criteria. Optimal parametric setting has been evaluated from Figure 1. The predicted optimal setting becomes: ***V1 F5 S4 N4***. Mean response table for (VIKOR INDEX) indicates that the most significant factor is wire feed, next traverse speed then voltage. Stick-out showed negligible effect. After predicting the optimal setting, it has been verified through conduction of confirmatory test. It showed satisfactory result. Table 4 represents the result of confirmatory test.

5. CONCLUSIONS

In the present work, multi-response optimization problem has been solved by searching an optimal parametric combination, capable of producing desired quality weld. Four bead geometry features: depth of penetration, reinforcement, bead width and dilution has been optimized using VIKOR based Taguchi method. The study demonstrates the effectiveness of VIKOR's multi-attribute decision making technique hybridized with Taguchi method in relation to parametric optimization of SAW process.

Table 1: Domain of experimentation

Parameters	**Units**	**Notation**	**1**	**2**	**3**	**4**	**5**
Voltage (OCV)	Volts	V	32	34	36	39	40
Wire feed	cm/s	F	0.42	0.46	0.51	0.79	1.46
Traverse speed	cm/s	S	0.21	0.23	0.24	0.4	0.71
Stick-out	mm	N	20	21	22	23	24

Table 2: Taguchi's L25 OA design

Sl. No.	**Levels of factors (Factorial combinations)**			
	V	**F**	**S**	**N**
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	1	5	5	5
6	2	1	2	3
7	2	2	3	4
8	2	3	4	5
9	2	4	5	1
10	2	5	1	2
11	3	1	3	5
12	3	2	4	1
13	3	3	5	2
14	3	4	1	3
15	3	5	2	4
16	4	1	4	2
17	4	2	5	3
18	4	3	1	4
19	4	4	2	5
20	4	5	3	1
21	5	1	5	4
22	5	2	1	5
23	5	3	2	1
24	5	4	3	2
25	5	5	4	3

Table 3: Response data (individual quality attributes related to bead geometry)

Sl. No.	**Response data (quality attributes)**			
	Bead width	**Reinforcement**	**Penetration**	**%Dilution**
1	9.7722	2.2773	4.1970	35.3825
2	10.0102	1.6683	3.8740	41.9825
3	9.8975	1.5475	3.8475	43.2125
4	9.6303	1.5493	3.9110	43.0625
5	8.6323	1.9203	4.3080	38.6225
6	10.3875	1.4183	3.4545	41.1875
7	10.3522	1.2705	3.4755	44.1950
8	10.0600	1.2780	3.5285	42.2200
9	8.6742	1.4667	3.3670	47.3125
10	13.3842	2.4087	4.9320	46.7725
11	10.7202	1.2280	3.2985	39.5975
12	10.1157	1.1878	3.2430	46.8300
13	8.6950	1.3325	3.2500	44.8250
14	14.5050	1.9793	4.1605	45.4525
15	12.0157	1.7803	4.3830	46.9700
16	10.3557	1.1163	3.1750	41.5325
17	8.9875	1.2717	3.1925	42.0325
18	15.7650	1.7940	3.8205	43.5350
19	13.4857	1.4048	3.7450	42.7625
20	10.9453	1.8085	4.1795	54.0250
21	10.0042	1.3317	3.3450	34.6525
22	18.9743	1.6557	3.5500	37.7525
23	15.0150	1.5340	3.5285	48.6350
24	13.4223	1.4625	3.6315	47.9050
25	11.4425	1.7582	4.0525	47.0425

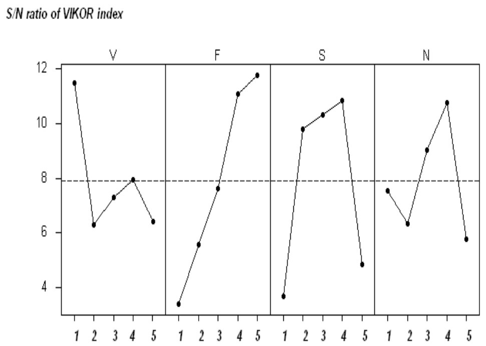

Fig 1. S/N ratio plot for VIKOR INDEX

Table 4: Results of confirmatory test

	Optimal setting	
	Prediction	**Experiment**
Level of factors	***V1 F5 S4 N4***	***V1 F5 S4 N4***
S/N ratio of VIKOR INDEX	**21.2526**	**22.3016**

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