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MULTIPLE OBJECTIVE OPTIMIZATION OF WELD GEOMETRY OF DISSIMILAR METALS

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ABSTRACT

The parameters affecting on bead geometry of the dissimilar welding between stainless steel (AISI-304) and Low carbon steel (ASTM A516 Grade 70) using (Gas Metal Arc Welding-GMAW) technique were studied in this paper. A multi-response optimization approach to determine the optimal process parameters in (GMAW) was used. Three process parameters were used in the experiments: welding current, welding speed and wire diameter, in three levels for obtaining the responses on bead width, reinforcement and penetration of the weldments. Taguchi (L_9) orthogonal array was used to gather information regarding the welding process with less number of the experimental runs. A multi criteria decision making method (TOPSIS) passive was applied in the present study to approve a significant Taguchi approach in solving multi response optimization problem. In order to consider experimental uncertainty, the responses are expressed in linguistic terms rather than crisp values. In additional the (ANOVA) test was passive also applied to identify most the significant factors. The results of (ANOVA) showed that optimum bead geometry can be reached by a control on the parameters mentioned above. Also it was found that the welding current factor contributed the highest percentage (88.14%) to the factor effects, followed by (wire diameter) which equal (8.92%) and (welding speed) which equal (2.94%). Confirmation experiments showed that developed models are accurate.

KEY WORDS: TOPSIS, Taguchi Concepts, Multi-response, GMAW, ANOVA.

تحديد العوامل المثلى المتعددة الاستجابة للشكل الهندسي لوصلة لحام المعادن المختلفة

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الخلاصة :-

يتضمن هذا البحث دراسة تاثيرالعوامل على الشكل الهندسي لدرز لحام المعادن المختلفة المكونة من الفولاذ المقاوم للصدا نوع (AISI-304) والفولاذ منخفض الكاربون نوع (ASTM A516 Grade 70) باستخدام طريقة لحام القوس (GMAW). تم استخدام اسلوب الامثلية متعددة الاستجابة لتحديد العوامل المثلى لطريقة (GMAW) حيث استخدمت ثلاث عوامل تجريبية (تيار اللحام، سرعة اللحام، وقطر سلك اللحام) بثلاث مستويات للحصول على استجابة لكل من عرض الدرز، التقوية، والاختراق في الوصلات الملحومة. استخدمت مصفوفة (Taguchi) نوع (L_9) لتجميع بيانات عملية اللحام عند اقل عدد ممكن من التجارب ، بالاضافة الى ذلك استخدمت طريقة صنع القرار المتعدد المعيار (TOPSIS)في هذه الدراسة لغرض تطبيق طريقة (Taguchi) لحل الامثلية المتعددة الاستجابة. لغرض تلافي الغموض التجريبي فقد تم التعبير عن الاستجابة من خلال المصطلحات النصية بدلاً من القيم العددية . أضافة الى ذلك تم تطبيق طريقة تحليل التباين (ANOVA) لتحديد العوامل الاكثر تاثير على الاستجابة المتعددة. واظهرت نتائج تحليل (ANOVA)ان الشكل الهندسي الامثل لدرز اللحام يمكن الحصول عليه من خلال السيطرة على العوامل اعلاه ، ووفقاً لنتائج (ANOVA) فان تيار اللحام كان له التأثير الأكبر على الاستجابة وبنسبة (88.14%) يليه قطر السلك بنسبة (8.92%) وثم سرعة اللحام بنسبة (2.94%)، واخيرا اضهرت نتائج تجارب الاثبات دقة الأنموذج الرياضي المعتمد.

كلمات رئيسية : القرار المتعدد المعيار ، مفاهيم مصفوفة تاكوجي ، متعددة الأستجابة ، لحام القوس ، طريقة تحليل التباين

INTRODUCTION :-

Engineers always seeking for joining dissimilar materials because of the continuous need in different structures. Also joining dissimilar materials sometime can provide suitable properties for special engineering products. Structures may need some mechanical properties (i.e. toughness, wear resistance…etc.) in one area combined with high strength in another one. While joining dissimilar materials and one of its difficulties, more problems will appear, than joining the same materials or alloys with minor differences in compositions. However, many dissimilar materials can be joined successfully with the appropriate joining process and specialized procedures [Kamble A. G, et al, 2011]. Joining dissimilar materials reduces the cost of engineering products and their weight. Presently, the method of joining dissimilar materials include: (GMAW, GTAW and SAW-fusion welding). The (GMAW) process allows welding of several materials that are extremely difficult to weld continuously [Kamble A. G, et al, 2011]. Welding process parameters play a significant role in making good quality joints. To produce a good quality joint, it is important to set up proper welding process parameters. This can be done by employing optimization techniques. [D.T. Thao and I.S. Kim, 2009]. T.W.Nelson, et al [T. W. NELSON, et al, 2000] studied the dissimilar welding for the different kinds of the stainless steel with (70Ni-30Cu) filler type. They found that there were an effect on the microstructure while welding dissimilar metals in (HAZ) new phases were obtained and are different from the base dissimilar metals and filler. Barnhous and Lippold were studied the changing in the microstructure and corrosion resistance of the dissimilar welding among stainless steel, plain carbon steel with filler metal (ER2209) and (Ni- based Alloy 625) by using the (GTAW). They found the effects on mechanical properties and microstructure around (HAZ) by using these fillers, [E. J. Barnhouse and J. C. Lippold, 1998]. Welding quality was strongly characterized by the weld bead geometry shown in Figure (1). The weld bead geometry plays an important role in determining the mechanical properties of the welding joints, [Nilesh T. Mohite and Jaydeep S. Bagi, 2014]. Therefore, it is very important to select the welding process parameters for obtaining optimal weld bead geometry [P. Thamilarasi, et al, 2014]. Welding parameters (Gas Metal Arc Welding-GMAW) are the most important factors affecting the quality, productivity and cost of welding [A.Khorram, et al, 2010]. This reseach presents the influence of welding parameters like: welding current, welding speed and wire diameter on penetration, bead width and reinforcement of dissimilar welding process between stainless steel (AISI-304) and Low carbon steel (ASTM A516 Grade 70). In this research, a new approach (i.e. Multi objective optimization Approach) was considered by representing the experimental results in the terms of linguistic variables, since experiment results involved some sort of fuzziness. Also, expressing the responses in the linguistic terms enables the decision maker to account for fuzziness embedded in the experimental data. An attempt was made to apply (TOPSIS - Techniques for order preferences by similarity to ideal solution) method for converting multiple responses in to an equivalent single response. The optimal process parameters were then established using Taguchi approach. Finally, a confirmatory test was carried out to verify the obtained optimal setting.

METHODOLOGY :-

The algorithms of (TOPSIS) based on two criteria values, the basic concept of the (TOPSIS) method was selected alternative which had the shortest distance from the ideal solution. As well the longest distance from the (negative –ideal) solution in the geometrical sense. The method evaluates the decision matrix, which refers to (*n*) alternatives that were evaluated in the terms of (*m*) criteria. The number (*ij*) denotes the performance measure of the (*j*th) alternative in terms of the (*i*th) criterion. The classical (TOPSIS) use vector normalization [Edmundas, et al, 2006].

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{j=1}^{n} a_{ij}^2}} \quad (1)$$

Where:
r_{ij}: is the normalized value when i= 1, 2……, m, j= 1, 2… n.
a_{ij}: measured value for experimental results.
The weighted normalized value (v_{ij}) is calculated as below:

$$v_{ij} = q_i r_{ij} \qquad \text{When } i = 1, 2\ldots m,\ \ j = 1, 2\ldots n \quad (2)$$

Where:
q_i: is the weight of (*i*th) criterion.
The (ideal) and the (negative - ideal) and (solution) denoted respectively as ($A^*$and A^-), they are defined as follows:

$$A^* = \{v_{1^*}, v_{2^*}, \ldots, v_{m^*}\} \text{ when } i = 1, 2\ldots m. \quad (3)$$

$$A^- = \{v_{1^-}, v_{2^-}, \ldots, v_{m^-}\} \text{ when } i = 1, 2\ldots m. \quad (4)$$

Where:
$v_{i^*} = max_j\, v_{ij},\ \ v_{i^-} = min_j v_{ij},\ \ i = 1, 2, \ldots, m\ ;\ \ j = 1, 2, \ldots, n$, when the (*i*th) criterion represents a cost.
The Euclidean distance method is then applied to measure the distances of each alternative from the ideal solution (S_{j^*}) and (negative-ideal) solution(S_{j^-}) :

$$S_{j^*} = \sqrt{\sum_{i=1}^{m} (v_{ij} - v_{i^*})^2} \text{ when } j = 1, 2, \ldots, n. \quad (5)$$

$$S_{j^-} = \sqrt{\sum_{i=1}^{m} (v_{ij} - v_{i^-})^2} \text{ when } j = 1, 2, \ldots, n. \quad (6)$$

The relative closeness of an alternative (A_j) to the ideal solution (A^*) is defined as below:

$$C_{j^*} = \frac{S_{j^-}}{S_{j^*} + S_{j^-}} \quad (7)$$

Where:
$1 \geq C_{j^*} \geq 0$ when j = 1, 2…n. The best alternative can be found according to the preference order of (C_{j^*}) [Edmundas, et al, 2006].

The procedural steps for the in present research are listed as below:

Step I: First the experimental responses are normalized as all the response considered for (GMAW) to avoid the different units and dimensions. Data is normalized by using the following criteria:

a) Lower – the – Better (LB)

$$X_i(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)} \tag{8}$$

b) Higher – the – Better (HB)

$$X_i(k) = \frac{y_i(k) - min\, y_i(k)}{\max y_i(k) - \min y_i(k)} \tag{9}$$

Where:

yi(k): represents (*i*th) value for the response (*k*).
minyi(k): represents minimum of the response values for (*k*th) response.
max yi(k): represents maximum of the response values for (*k*th) response.
Xi(k): is the normalized data of the (*i*th) experimental of (*k*th) response.
Xi(k): lies between (0 - 1).

Step II: The normalized responses are expressed in linguistic variables to account for the uncertainties involved in it using a (5 points) scale: very low, low, medium, high and very high, as shown in figure (2).

Step III: Using the triangular fuzzy numbers as presented in Table (1), the linguistic variables were converted into crisp score. Chen and Hwang's fuzzy ranking method was used to converted fuzzy numbers into crisp scores.

Chen and Hwang (1992) also proposed a fuzzy scoring method to convert fuzzy numbers to corresponding crisp (Numerical) scores and defined (*max*) a fuzzy and (*min*) as:

$$\mu_{max}(x) = \begin{Bmatrix} x, 0 \le x \le 1, \\ 0, otherwise \end{Bmatrix} \tag{10}$$

$$\mu_{min}(x) = \begin{Bmatrix} 1 - x, 0 \le x \le 1, \\ 0, otherwise \end{Bmatrix} \tag{11}$$

The left and right utility scores of each fuzzy number (M_i) are defined as:

$$\mu_L(i) = \sup_x [\mu_{min}(x) \wedge \mu_{Mi}(x)] \tag{12}$$

$$\mu_R(i) = \sup_x [\mu_{max}(x) \wedge \mu_{Mi}(x)] \tag{13}$$

In equation (12), the left utility score ($\mu_L(i)$) can be interpreted as the maximum membership value of the intersection of fuzzy number (M_i) and the fuzzy (*min*). Similarly, the right utility score ($\mu_R(i)$) is maximum membership value of the intersection of fuzzy number (M_i) and the fuzzy (*max*). These definitions are illustrated in figure (3).

EXPERIMENTAL PROCEDURE :-

In this research, the (GMAW) process of dissimilar metals was done using the welding machine shown in figure (4).Metals were used were plates of stainless steel (AISI-304) and low carbon steel (ASTM A516 Grade 70), having dimension of (60x150x6 mm). Steel wire (GFW304L) was used in welding. Then the specimen was subjected to cutting in to nine specimens. The chemical composition of base metals is shown in Table (2). Experiments were conducted for various welding process parameters like: welding current, welding speed and wire diameter. To obtain (bead - on - plate) welding by (GMAW) process three values are taken for each parameter, shown in Table (3). To evaluate the effect of welding process parameter on the performance characteristic of welding like: bead width, reinforcement and penetration, a special designed experimental procedure was required Multi objective optimization Approach. In this research, Taguchi (L_9) orthogonal array was used to gather maximum information regarding the process with less number of experimental run. The experiments were conducted for each combination of factors the (rows) as per selected orthogonal array. (Higher-the-Better) approach was employed in order to maximize the objective functions. The (S/N) ratio was calculated as follows:

$$SN_i = -10log\left(\frac{1}{N_i}\sum_{k=1}^{N_i}\frac{1}{y_k^2}\right) \quad (14)$$

Where:

(i , k , N_i) stand for experiment number, trial number and number of trials for experiment (i), respectively.

The results obtained from the Taguchi Method validated by the confirmation tests. The validation process is performed by conducting the experiments with a specific combination of the factors and levels [Hartaj Singh, 2012]. Weld geometry measurements were performed from transverse cross sections that were polished and etched using (3%) nital before eximination. The weld geometry measurement was done using physical measurment on plates. This done on plates using adigital caliper shown in figure (5).Table (4) shows the experimental results corresponding to orthogonal array. Then the experimental results were normalized by using equation (1) for bead width, reinforcement and equation (2) for depth of the penetration. Normalized responses were converted into linguistic variables as listed in Table (5). Figure (6) Shows the welded specimens of the dissimilar materials corresponded to (L_9) orthogonal array.

RESULTS AND DISCUSSION :-

The probability plot use to evaluate the fit of distribution of experimental data, which include plots each value vs the percentage of values in sample that are less than or equal to it along a fitted distribution line (middle line). For figures (7) because the data points roughly follow the straight - line the p- value is over 0.05, it can conclude that the data are from a normally distribution population. The linguistic variables shown in Table (1) were described by using the triangle fuzzy numbers, by using Chen and Hwang's fuzzy ranking method [N. Parandin and M. A. Fariborzi Araghi, 2008].The crisp values of fuzzy numbers were computed. The values of the responses were normalized in order to determine the relative normalized weight of each criterion of (GMAW). The assigned weight should be satisfy the following condition [Edmundas, et al, 2006]:

$$\sum_{i=1}^{k} W_i = 1 \quad (15)$$

Where:

(W_i) is the weight assigned to the performance characteristic (i) and the sum of the weights for all performance characteristic is equal to 1. The weights are assigned as:

$W_{\text{Bead Width}} = 0.3$, $W_{\text{Reinforcement}} = 0.3$ and $W_{\text{Penetration}} = 0.4$.

The values in the normalized matrix were multiplied to obtain the weighted normalized matrix. The ideal and negative ideal solutions were calculated by using equations (3, 4) respectively, as listed in Table (6). The separation measures of each criterion from the ideal and negative ideal solutions were computed as shown in Table (7) via using equation (5, 6). The relative closeness coefficient (CCi) value for each combination of the parameters of (GMAW) was calculated by using equation (7) as shown in Table (8)**.**The average of the (S/N) ratio of the responses bead width, reinforcement and penetration for each level of each factor is shown in Table (9).Regardless of the performance characteristics category, a greater (S/N) value corresponds to a better performance. Therefore, the optimal level of the welding parameters is the level with the greatest (S/N) value. From Table (8), the optimal (GMAW) parameter levels are (I_1 S_3 d_2).The optimal (GMAW) parameter obtained from response graph is shown in figure (8). The optimal input parameter setting is welding current at (level 1), welding speed at (level 3) and wire diameter at (level 2), for maximizing depth of penetration and minimizing Bead width and reinforcement. Analysis of variance (ANOVA) method has been applied to fine out the significance of main factors [Hartaj Singh, 2012]. Also, (ANOVA) is performed to see statistically significant process parameter and percent contribution of these parameters on the characteristic properties. The results of (ANOVA) were shown in Table (10). The review of percentage contribution (%) column in Table (9), Shaw that (welding current - I) factor contributed the highest percentage (88.14%) to the factor effects, followed by (wire diameter - d) which equal (8.92%) and (welding speed - S) which equal (2.94%). Thus, the welding speed had little significance compared to the other factors.

Effects of process variables

Contour plots use to explore the potential relationship between three variables. Contour plots display the three dimensional relationship in two dimensions, with (x- and y- factors predictors) plotted on (x- and y- scales and responses values repented by contours). A contour plot is like topographical map in which (x, y and z - values) are plotted instead of longitudes latitude and elevation. As shown in figure (9), the welding speed and welding current affect significantly the closeness coefficient (CCi). Also, as shown in figure (10), the wire diameter and welding speed were demonstrated the most influence on the closeness coefficient (CCi). The width of yellow zone is decreased with increasing the speed of welding and wire diameter. In addition, the wire diameter and welding current significantly affects the value of closeness coefficient (CCi) as shown in figure (11). The increase of Welding current results a decrease in yellow zone width. On the contrary, yellow zone width increases with increasing the wire diameter.

Conformation Experiment

Improvement of performance characteristic at optimum level is verified by conducting the confirmation experiment. The (S/N) ratio at the optimum level has been determined by the following formula:

$$\eta_{opt} = \eta_m + \sum_{i=1}^{P}(\eta_i - \eta_m) \tag{16}$$

Where:

η_m: is the mean value of the (S/N) ratio in all experimental runs.
η_i: is the value of the (S/N) ratio corresponding to optimum level.
p: is the number of factors [Hartaj Singh, 2012].
Table (11) shows the results of confirmation experiment using optimal (GMAW) parameters. In Table (11), (S/N) ratio for (CCi) becomes (- 7.50304) where as in confirmatory experiment it is obtained a value of (- 6.3713). So quality has improved using the optimal setting of levels for welding parameters.

CONCLUSIONS :-

This paper outlines that the application of TOPSIS Approach and fuzzy inference system coupled with Taguchi method to optimize quality of bead geometry of the dissimilar welding between stainless steel (AISI-304) and Low carbon steel (ASTM A516 Grade 70). The optimization of (GMAW) process parameters is carried out with minimum number of test conditions by using orthogonal array. Fuzzyfication technique helps to avoid the vagueness in the results. Based on experimental results, the following conclusions are:

1. The experimental results for optimal settings showed that there was a considerable improvement in the performance characteristics viz., bead width, reinforcement and penetration of the weldments.
2. The order of influenced parameters found from Fuzzy-Taguchi analysis coupled with TOPSIS method and ANOVA is as follows:
   - welding current (most influential, 88.14%);
   - Wire diameter (moderately influential, 8.92%);
   - welding speed (least influential, 2.94%).
3. The following factor settings have been identified as to yield the best combination of process variables: (I1 = 100 Amp, S3 = 300 mm/s and d2 = 1 mm) i.e. there is improvement of closeness coefficient (CCi) from initial combination (I1 S1 d1) to optimal combination (I1 S3 d2).
4. The Taguchi method with fuzzy logic technique using TOPSIS approch converts the multiple performance characteristics into single performance characteristics and, therefore, simplifies the optimization procedure.
5. Confirmation test has been conducted and results are satisfactory.

Table 1: Conversion of linguistic terms into crisp scores.

Linguistic variables	Triangular fuzzy numbers	Crisp score
Extremely Low (EL)	(0.0,0.0,0.1)	0.045
Very Low (VL)	(0.0,0.1,0.3)	0.160
Low (L)	(0.1,0.3,0.5)	0.330
Medium (M)	(0.3,0.5,0.7)	0.510
High (H)	(0.5,0.7,0.9)	0.670
Very High (VH)	(0.7,0.9,1.0)	0.830
Extremely H (EH)	(0.9,1.0,1.0)	0.955

Table 2: Chemical composition of stainless steel and lower carbon steel.

Stainless steel (AISI – 304)					
Chemical	C %	Cr %	Ni %	-	-
Nominal	0.08	18-20	8-12		
Actual	0.034	18.93	9.64		
Lower carbon steel (A516G.70)					
Chemical	C %	Mn %	P %	S %	Si %
Nominal	0.27	0.85-1.2	0.035	0.033	0.13-0.45
Actual	0.22	1.37	-	-	0.37

Table 3: Process parameters and their levels.

No	Parameter	Unit	Level 1	Level 2	Level 3
1	Welding current (I)	Amps	100	125	150
2	Welding speed (S)	mm/s	200	250	300
3	Wire diameter (d)	mm	0.7	1.0	1.3

Table 4: Experimental results.

Bead width (mm)	Reinforcement (mm)	Penetration (mm)
10.31	2.20	1.50
9.11	2.12	1.10
5.30	1.33	1.40
10.7	1.25	1.30
8.50	1.37	0.81
7.30	2.10	0.91
8.20	2.36	1.50
6.30	2.40	1.60
5.50	1.52	1.80

Table 5: Experimental data in terms of linguistics using (L_9) orthogonal Array.

Exp.No.	I	S	d	Bead width (mm)	Reinforcement (mm)	Penetration (mm)
1	1	1	1	EL	VL	H
2	1	2	2	L	L	L
3	1	3	3	EH	EH	H
4	2	1	2	EL	EH	M
5	2	2	3	M	VH	EL
6	2	3	1	H	L	VL
7	3	1	3	M	EL	H
8	3	2	1	VH	EL	VH
9	3	3	2	EH	VH	EL

Table 6: Ideal and Negative Ideal value for Responses.

Response	A^*	A^-
Bead Width	0	0.107522
Reinforcement	0	0.108270
Penetration	0.220044	0

Table 7: Separation measures.

Exp. No.	S_{j^*}	S_{j^-}
1	0.113203	0.184093
2	0.201481	0.142736
3	0.201196	0.120278
4	0.198304	0.092197
5	0.222053	0.119991
6	0.222053	0.119991
7	0.115477	0.173974
8	0.107165	0.180724
9	0.118155	0.224709

Table 8: Closeness coefficient values (CCi).

Exp.No	I	S	d	CCi	(S/N) ratio
1	100	200	0.7	0.619225	-4.16303
2	100	250	1.0	0.414669	-7.64598
3	100	300	1.3	0.374146	-8.53919
4	125	200	1.0	0.317373	-9.96861
5	125	250	1.3	0.350805	-9.09868
6	125	300	0.7	0.350805	-9.09868
7	150	200	1.3	0.601004	-4.42245
8	150	250	0.7	0.627757	-4.04417
9	150	300	1.0	0.655388	-3.67003

Table 9: Response table for signal to noise ratios (larger is better) .

Level	I	S	d
1	- 6.783	- 6.185	- 5.769
2	- 9.389	- 6.930	- 7.095
3	- 4.046	- 7.103	- 7.353
Delta	5.343	0.918	1.585
Rank	1	3	2

Table 10: The results of (ANOVA).

ANOVA – Table						
Factor	DOF	SS	MS	F	P-value	Contribution (%)
Welding	2	42.832	21.416	7.49	0.118	88.14
Welding Speed	2	1.4270	0.7135	0.25	0.8	2.940
Wire Diameter	2	4.3370	2.1685	0.76	0.569	8.920
Error	2	5.7160	2.8580			
Total	8	54.313				

Table 11: Results of confirmation experiments .

	Initial	Optimum welding parameters	
	Welding Parameters	Prediction	Experiment
Setting Level	$I_1S_1d_1$	$I_1S_3d_2$	$I_1S_3d_2$
(S/N) ratio	-4.163026715	-7.50304	-6.3712

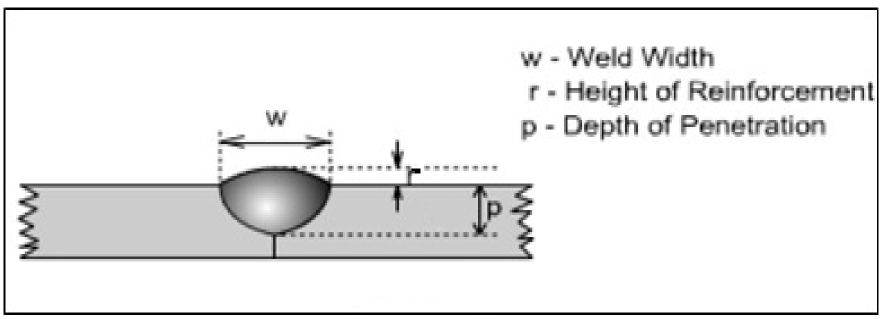


Fig.1: Weld bead geometry [Deepak Kumar Choudhary, et al, 2011].

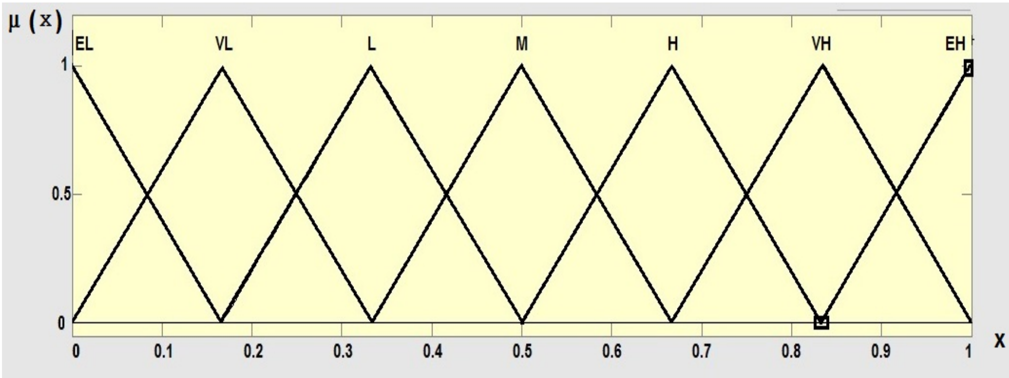


Fig.2: Membership functions of linguistic values for criteria rating [Edmundas, et al, 2006].

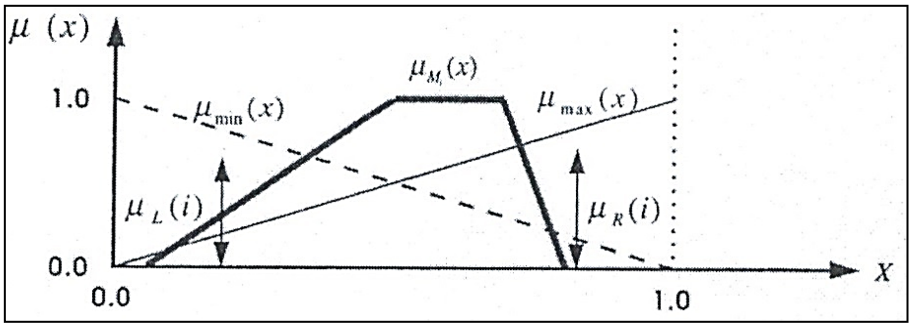


Fig.3: Chen and Hwang's Fuzzy scoring Method [N. Parandin and M. A. Fariborzi, 2008].

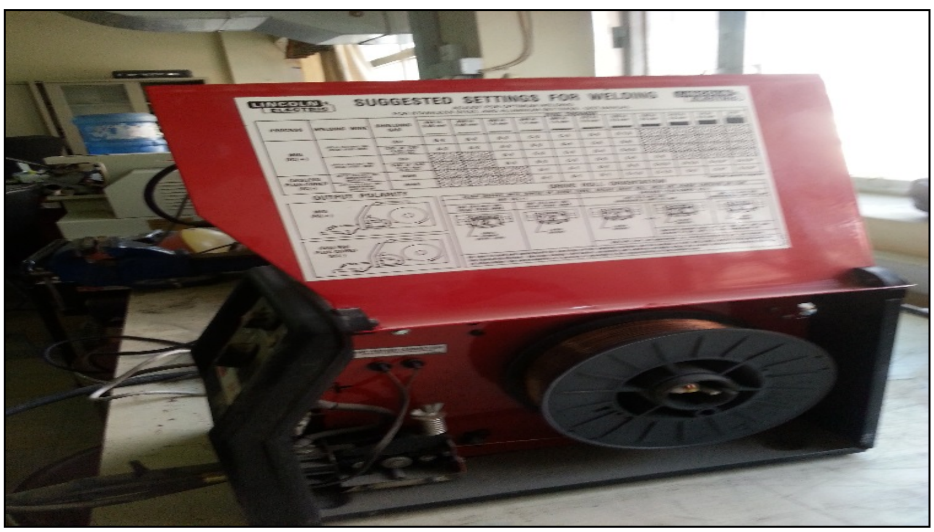


Fig.4: GMAW Machine.

Fig.5: Digital caliper.

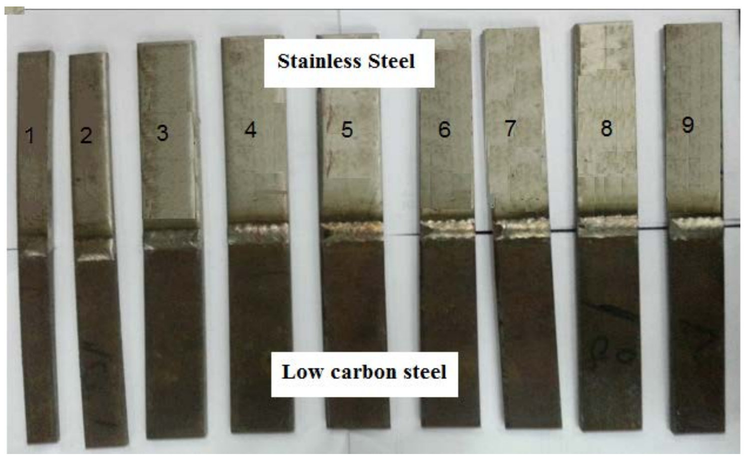
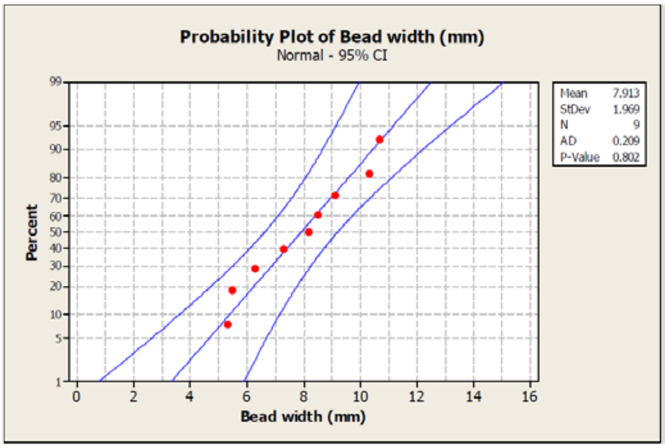
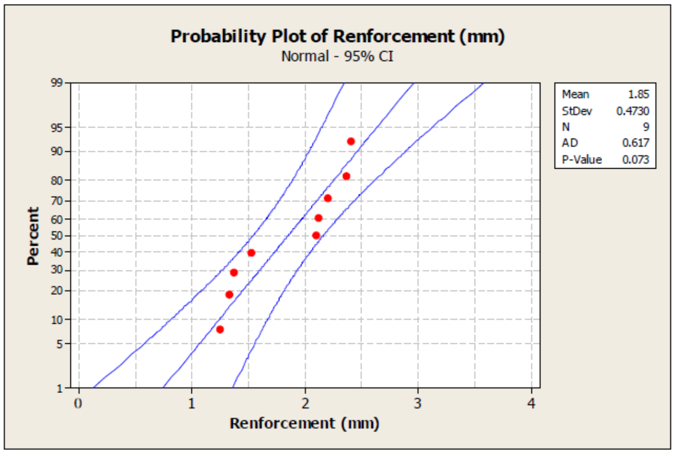


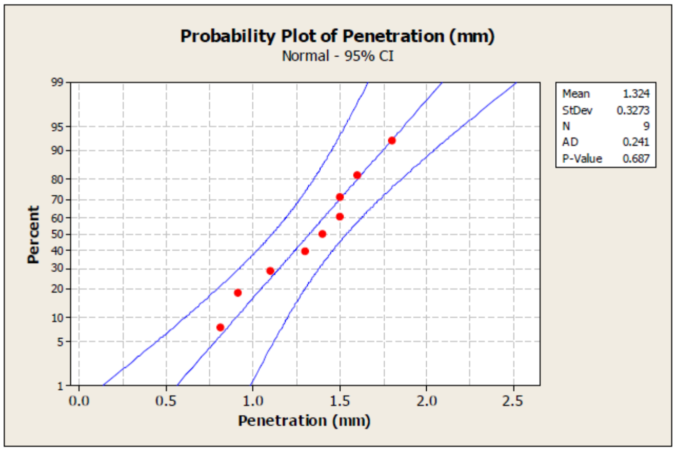
Fig.6: The welded specimens.



(a): Bead width.



(b): Reinforcement.



(c): Penetration.

Fig.7: Probability plot (a, b and c).

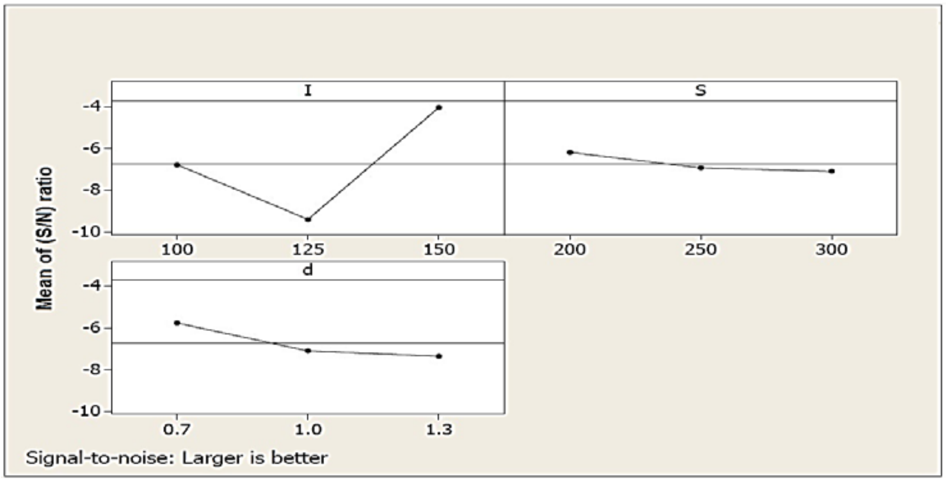


Fig.8: Response plot for the closeness coefficient.

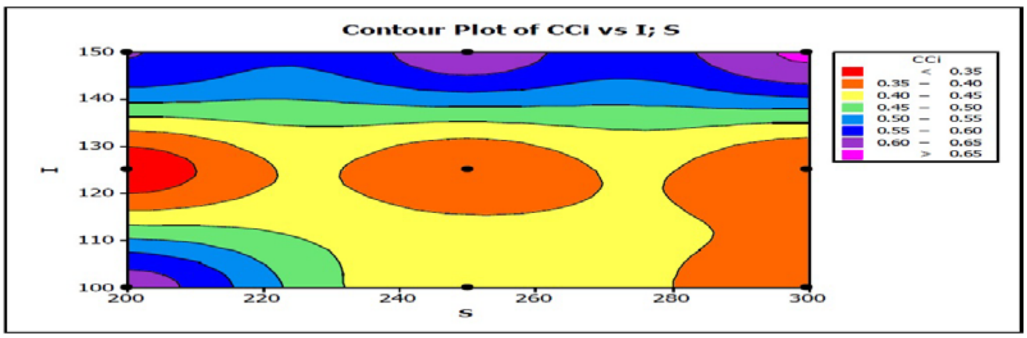


Fig.9: The effects of welding current and welding speed on the relative closeness coefficient (CCi) value.

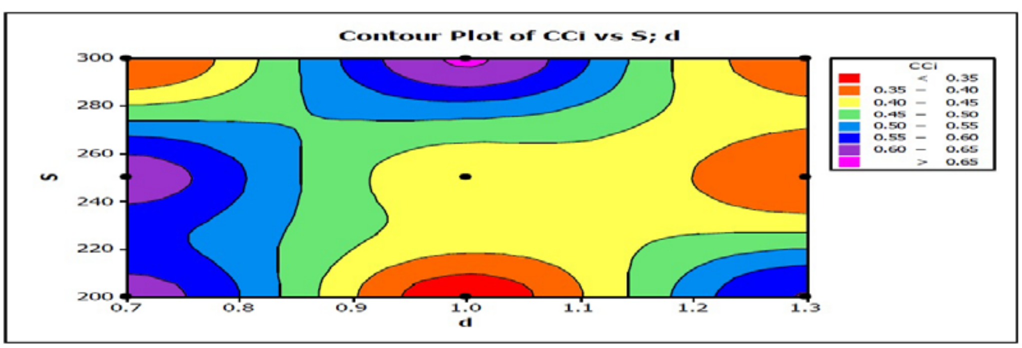


Fig.10: The effects of welding speed and wire diameter on the relative closeness coefficient (CCi) value.

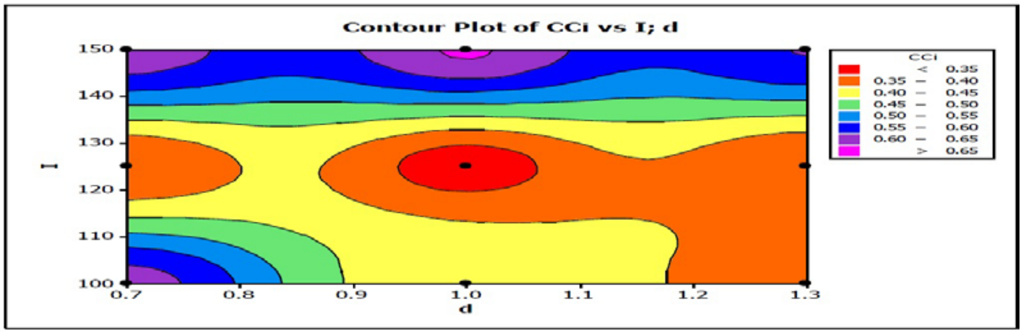


Fig.11: The effects of welding current and wire diameter on the relative closeness coefficient (CCi) value.

3. REFERENCES

A.Khorram, M.R.SoleymaniYazdi, M.Ghoreishi and M.Moradi , "Using ANN Approach to Investigate the Weld Geometry of Ti 6Al 4V Titanium Alloy", IACSIT International Journal of Engineering and Technology, Vol.2, No.5, October 2010.

D.T. Thao, I.S. Kim, "Interaction model for predicting bead geometry for Lab Joint in GMA welding process", International Scientific Journal published quarterly by the Association of Computational Materials Science and Surface Engineering, Vol.1, Issue 4, 2009, PP: 237-244.

E. J. Barnhouse and J. C. Lippold, "Microstructure/Property Relationships in Dissimilar Welds between Duplex Stainless Steels and Carbon Steels", Welding Journal, Vol.77, Issue: 12, December 1998.

Edmundas kazimieras zavadskas, algimantas zakarevicius, Jurgita antucheviciene, "Evaluation of Ranking Accuracy in Multi-Criteria Decisions", INFORMATICA, Vol. 17, No. 4, 2006, PP: 601–618.

Hartaj Singh, " Taguchi Optimization of Process Parameters: A review and case study ", International Journal of Advanced Engineering Research and Studies (IJAERS), E-ISSN2249 – 8974, Vol. I, Issue III, April-June 2012, PP: 39-41.

Kamble A. G., R. V. Rao & Kale A.V., "Development Of Mathematical Models For Prediction Of Weld Bead Geometry For AISI 430 Grade Of Steel For GMAW Welding Process", International Journal Of Manufacturing Technology And Industrial Engineering (IJMTIE),Vol.1, No.1, January-June 2011, PP: 1-6 .

N. Parandin, M. A. Fariborzi Araghi, "Ranking of Fuzzy Numbers by Distance Method", Journal of Applied Mathematics, Islamic Azad University of Lahijan, Vol.5, No.19, winter 2008 .

Nilesh T. Mohite, Jaydeep S. Bagi, "Optimization of Geometrical Parameters of Resistance Spot Welding Process for Strength of Welded Joints", International Journal of Emerging Engineering Research and Technology Vol.2, Issue 5, August2014, PP: 60-66.

P. Thamilarasi, S. Ragunathan and E. Mohankumar, "Modeling and Analysis of the Weld Bead Geometry in Robotic Gas Metal Arc welding by using Taguchi Techniques", International Journal of Research in Mechanical Engineering, © IASTER 2014, Vol.2, Issue-2, March-April 2014, PP:88-93.

T. W. Nelson, J. C. Lippold and M. J. Mills, “Nature and Evolution of the Fusion Boundary in Ferritic-Austenitic Dissimilar Metal Welds - Part 2: On-Cooling Transformations”, supplement to the welding journal, October 2000, PP: 267s-277s.