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Application of VIKOR method for optimizing welding parameters of pulsed current micro plasma arc welded thin sheets of AISI 904L steel

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ABSTRACT

Welding is a fundamental manufacturing method utilized in connecting pipelines and ducts which are used in aerospace, petroleum, automotive and marine industries. For attaining leak proof joints of thin walled pipelines, ducts and also extreme quality welded joints of thin sheets, joining is very essential as they need legitimate welding techniques. This research work is aimed to weld AISI 904L Super Austenitic Stainless steel sheets of thickness 0.4mm using Micro Plasma Arc Welding (MPAW) of pulsed current mode by considering base current, pulse width, peak current and pulse rate as independent parameters and ultimate tensile strength, grain size and micro hardness of the welded joints as output dependent variables. Using Design of Experiments (DOE), 31 experiments are conducted in accordance with Central Composite rotatable Design (CCD) method of Response Surface Methodology (RSM) method by considering 4 factors and 5 levels. Then experimental values are attained for hardness, tensile and grain size by measuring with different equipments. Multi attribute decision making (MADM) methods are designed at identifying the utmost satisfactory of several comparative alternatives. This work is concentrated on application of MADM method such as VIKOR (VIseKriterijumska Optimizacija Kompromisno Resenje) so as to validate the results which are used for maximizing hardness and ultimate tensile strength and minimizing grain size to find the optimal combination of weld input parameters. The same weightages for the output responses are applied in the VIKOR method.

Keywords: *RSM, MADM, VIKOR, MPAW, AISI 904L steel.*

1. INTRODUCTION

It is not possible to attain metal fabrication with modern technological methods without welding. However, it is crucial to comprehend the differences between all the subsisting welding techniques for the sake of making an educated decision when it comes to choosing the correct welding method for the job. For attaining better control to the arc in lower current range, plasma arc welding technique is inaugurated in the welding industry. Plasma arc welding method strikes a plasma arc between the electrode and base material and applies it for welding. AISI 904L Super Austenitic Stainless steel is one of the growing stainless steel grades which has unique applications in marine, defense and nuclear industries [15]. Several different processes have been adopted for the optimization of weld quality of AISI 904L joints with the ultimate aim of upgrading the service life of the resulting weld joints.

AISI 904L steel is a high alloy, non-stabilized, non-magnetic and low carbon super austenitic stainless steel. Micro Plasma Arc Welding (MPAW) is operated for precision welding of tiny components. With MPAW, arc is maintained at a current as low as 0.1 Ampere and sheets are welded as thin as 100 microns [16]. To identify the effect of input welding parameters on the quality of MPAW welded joints, a preferably suitable method should be selected and the factors which effect the responses should be analyzed. As the present research work is coupled to thin sheets of 0.4mm thickness, MPAW has been selected and the schematic diagram is exhibited in Fig 1, where we apply less current.

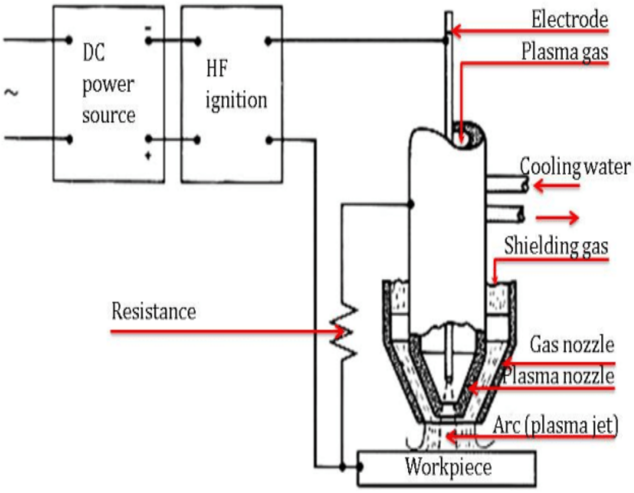

Figure 1: Schematic Diagram of MPAW

P. Manavalan et al.[1] resolved optimum parameters for multi performance characteristics in pulsed gas metal arc welding of AISI 904L stainless steel of thickness 5mm with 5 factors using Grey Relational Analysis(GRA). P. Sathiya et al. [2] optimized the weld pool geometry in laser welding of AISI 904L stainless steel of thickness 5mm by outlining the experiments according to Taguchi process of RSM and using multi-input/multi-output grey relational analysis(GRA).Y.F. Hslao et al. [3] designed the optimal welding parameters of PAW by the Taguchi process with GRA by taking torch stand-off, plasma gas flow rate, welding speed and welding current. Saadat Ali Rizvi et al. [4] studied the effect of gas metal arc (GMA) welding parameters wire feed speed, gas flow rate and arc voltage on the weld bead geometry of IS2062 structural steel of A grade by connecting Taguchi technique with grey relational analysis to resolve the multi-response optimization problem. V.Elango et al.[5] focused on the GTAW parameters optimization of AISI 904L joints employing TOPSIS method depending on Taguchi L9 orthogonal array with input process parameters shielding gas flow rate, current, travel speed and voltage and discovered that TOPSIS process to be the encouraging technique to get the optimum conditions for such studies.

Joseph Achebo et al. [6] implemented TOPSIS method on Mild Steel and spotted that weldment 9 has the best weld mechanical properties with a BHN of 216, Ultimate tensile strength (UTS) of 600MPa, Charpy V-notch (CVN) impact energy of 90J, and a percentage elongation of 23%. Also scrutinized the relationship between the input parameters and the output parameters and decided that TOPSIS has fruitfully optimized the input process parameters which have produced the most desired mechanical properties. L. Srinivasan et al. [7] made an attempt to optimize the welding parameters of GTAW of 15CDV6 plates with thickness 3.7 mm steel by conveying Taguchi’s L9 orthogonal array with input variables such as travel speed, voltage and current. They applied GRA and TOPSIS methods for pointing out the optimized input parameters. Nidhi Sharma et al.[8] considered the effect of combination of different friction stir welding process parameters such as Shoulder diameter (A), Pin offset (B), Welding speed (C), and Rotational speed (D) on ultimate tensile strength and micro-hardness of the joints during joining of Al-6101 and pure copper by using Taguchi L18 orthogonal array .Taguchi technique is applied for single response optimization, whereas Taguchi-based TOPSIS method is employed for multi-response optimization.

A.P.Aravind et al. [9] attempted to examine the cold metal transfer (CMT) welding of Al 5083 sheets having a thickness of 3mm depending on the L9 Taguchi orthogonal array. The optimized parameters were established by the VIKOR multi-objective optimization method. Aakash Singh Bhadauria et al.[10] secured the optimal parametric combination for combined multi-response quality characteristics for MIG welding process parameters for AISI 1008 low carbon steel using VIKOR method by taking into consideration 4 input variables and 3 output responses, bending, hardness and tensile. Shivani parmar [11] focused on the optimization of the Metal Arc Welding using VIKOR method by considering 4 input welding variables Wire Feed Rate, Voltage, Gas Flow Rate and Current and 3 output welding responses bending, hardness and tensile on the weldments by outlining the experiments as per Taguchi‘s L9. OA. S. Ajay Biswas et al**.** [12] explored application of Taguchi based VIKOR process adapted from Multi-Criteria-Decision Making (MCDM) in order to resolve multi-response optimization problem through a case study in SAW. An attempt has been made to decide the best process environment (process condition) for acquiring desired multi-quality features of the weldment. D.P.Pandya et al. [13] applied A-TIG method on mild steel of 10 mm thick plate and conducted experiments to observe the effect of various input parameters on weld bead width and weld penetration. Taguchi with L9 (9) orthogonal array is applied for searching the relationship between various output responses (weld penetration and weld bead width) and welding input parameters (welding current ,welding speed and fluxes). For optimization PROMETHEE method is adopted. MahdiNasrollahi et al. [14] tried to solve the robot selection problem using Fuzzy Best-Worst Method and PROMETHEE as the two most appropriate multi-criteria decision-making (MCDM) methods for weighting criteria and ranking of decision alternatives, respectively. From the above literature review, it is understood that no works are reported related to optimization of welding process parameters by using VIKOR optimization method. So as attempt has been made to weld AISI 904L steel by MPAW and optimize the output factors using VIKOR method.

2. EXPERIMENTAL PROCEDURE

Thickness of 0.4mm steel sheets of AISI 904L grade were used for experimentation as a base metal. In the form of rolls, these sheets were available from which, using shearing machine the required sizes of (100 mm x 200 mm) were sheared. To avoid any strains of oil and grease, the pieces were cleaned using ultrasonic cleaner before welding. PLASMA FIX 50E was used for the welding as shown in Fig 2. Table 1 denotes specifications of PLASMAFIX 50E MPAW welding equipment.

To prepare 31 welded joints, total 31 pairs of the sheets were cut based on Response Surface Methodology (RSM) CCD with 4 input parameters namely pulse width, peak current, , pulse rate and base current at 5 different levels and experiments were conducted as shown in Table 2. The results of response parameters grain size, hardness and tensile strength are shown in Table 3 which were obtained after doing experimentation.

Chemical composition of AISI 904L is Cr 19.92%, Ni 24.75%, Mo 4.33%, Cu 1.43% and Fe 49.57% and the mechanical properties are Elongation 36% ,Yield Strength 220 MPa ,Tensile Strength 573 MPa, Hardness 242 VHN.

Figure 2: PLASMAFIX 50E MPAW welding equipment

Table 1: Specifications of MPAW equipment named PLASMAFIX 50E

S.No	Feature	Specification
1	Model	PLASMAFIX 50E
2	Make	Secheron, USA
3	Serial No	MB/MP-50A/01
4	Input Supply	220 VAC/50-60Hz/ 1 – Ø
5	Welding current range	0.08- 50 A
6	Pulse frequency range	0.1HZ-10k HZ
7	Input KVA	2.2
8	Input KW	1.9

Table 2: Process parameters and their limits

S.No	INPUT WELDING PARAMETERS	Levels				
		-2	-1	0	+1	+2
1	Peak Current (Amps)	16	18	20	22	24
2	Base Current (Amps)	8	9	10	11	12
3	Pulse Rate (Pulses/sec)	30	40	50	60	70
4	Pulse Width (percentage)	40	50	60	70	80

Table 3: Experimental Results of output responses

	INPUT WELDING PARAMETERS				OUTPUT WELDING PARAMETERS (EXPERIMENTAL VALUES)		
S. No	Peak Current(A)	Base Current (A)	Pulse Rate (Pulses/sec)	Pulse Width (%)	Grain size (Microns)	Micro Hardness (VHN)	UTS (MPa)
1	18	9	40	50	68.4	257	530
2	22	9	40	50	67.6	266	554
3	18	11	40	50	70.2	267	538
4	22	11	40	50	68.3	277	546
5	18	9	60	50	70.8	255	530
6	22	9	60	50	73.9	263	540
7	18	11	60	50	69.4	269	524
8	22	11	60	50	70.8	279	542
9	18	9	40	70	76.2	255	518
10	22	9	40	70	68.4	259	528
11	18	11	40	70	73.4	255	526
12	22	11	40	70	66.4	276	546
13	18	9	60	70	76.4	247	522
14	22	9	60	70	68.8	249	540
15	18	11	60	70	70.2	253	532
16	22	11	60	70	63.6	273	546
17	16	10	50	60	75.8	247	506
18	24	10	50	60	66.8	262	547
19	20	8	50	60	72.6	251	518
20	20	12	50	60	66.8	277	542
21	20	10	30	60	68.6	265	540
22	20	10	70	60	70.8	261	534
23	20	10	50	40	69.6	271	548
24	20	10	50	80	71.12	255	527
25	20	10	50	60	70.6	265	539
26	20	10	50	60	69.8	267	537
27	20	10	50	60	70.6	265	539
28	20	10	50	60	68.8	267	537
29	20	10	50	60	69.6	265	539
30	20	10	50	60	68.8	267	537
31	20	10	50	60	70.2	269	540

3. RESULTS AND DISCUSSION

Using RSM Central composite design experiments were planned and 31 experiments were conducted with four factors and five levels. Then optimization technique was applied to find out optimal welding parameters where minimum grain size, maximum hardness and maximum ultimate tensile strength should be obtained. The optimization method is VIKOR, and same weightages were considered and the value was 0.3333 as shown in Table 4.

Table 4: Weights of output responses

Criteria	Grain Size	Hardness	Ultimate Tensile Strength
WEIGHT	0.3333	0.3333	0.3333

3.1 VIKOR OPTIMIZATION METHOD

The VIKOR (VIseKriterijumska Optimizacija Kompromisno Resenje) method is developed for multi-criteria optimization of complex problems. It finds the compromise ranking list and the compromise solution gained with the initial (given) weights. This method targets on ranking and choosing from a group of alternatives in view of conflicting criteria [9]. It introduces the multi-criteria ranking index based on the particular measure of “closeness” to the “ideal” solution.

Step-(1): Determine the best and worst values according to beneficiary and non beneficiary output responses as shown in Table 5 ($X_i^{+,}$ X_i^-).

Table 5: Best and Worst values

Criteria	Grain Size(GS) (Microns)	Hardness (VHN)	Ultimate Tensile Strength (UTS) (MPa)
X_i^+	63.6	279	554
X_i^-	76.4	247	506

Step-(2): Find S_j (Utility measure) as shown in Table 6 by Equation (1) and R_j (Regret measure) as shown in Table 7 for output responses by Equation (2).

j= 1,2,3,…..J and i = 1,2,3,…..n.

The weights (W_i) considered are equal and taken as 0.3333, 0.3333, 0.3333.

S_j=SUM[$W_{i*}(X_i^+ - X_{ij})/ (X_i^+ - X_i^-)$] ………..(1)

R_j=MAX[$W_{i*}(X_i^+ - X_{ij})/ (X_i^+ - X_i^-)$]………..(2)

where W_i are the weights of criteria

Table 6: Utility measure values

EXP	GS	VHN	UTS	S
1	0.1250	0.2291	0.1667	0.521
2	0.1042	0.1354	0.0000	0.240
3	0.1719	0.1250	0.1111	0.408
4	0.1224	0.0208	0.0556	0.199
5	0.1875	0.2500	0.1667	0.604
6	0.2682	0.1667	0.0972	0.532
7	0.1510	0.1042	0.2083	0.463
8	0.1875	0.0000	0.0833	0.271
9	0.3281	0.2500	0.2500	0.828
10	0.1250	0.2083	0.1805	0.514
11	0.2552	0.2500	0.1944	0.700
12	0.0729	0.0312	0.0556	0.160

13	0.3333	0.3333	0.2222	0.889
14	0.1354	0.3125	0.0972	0.545
15	0.1719	0.2708	0.1528	0.595
16	0.0000	0.0625	0.0556	0.118
17	0.3177	0.3333	0.3333	0.984
18	0.0833	0.1771	0.0486	0.309
19	0.2344	0.2916	0.2500	0.776
20	0.0833	0.0208	0.0833	0.187
21	0.1302	0.1458	0.0972	0.373
22	0.1875	0.1875	0.1389	0.514
23	0.1562	0.0833	0.0417	0.281
24	0.1958	0.2500	0.1875	0.633
25	0.1823	0.1458	0.1042	0.432
26	0.1614	0.1250	0.1180	0.404
27	0.1823	0.1458	0.1042	0.432
28	0.1354	0.1250	0.1180	0.378
29	0.1562	0.1458	0.1042	0.406
30	0.1354	0.1250	0.1180	0.378
31	0.1719	0.1042	0.0972	0.373

Table 7: Regret measure values

EXP	GS	VHN	UTS	R
1	0.1250	0.2291	0.1667	0.229
2	0.1042	0.1354	0.0000	0.135
3	0.1719	0.1250	0.1111	0.172
4	0.1224	0.0208	0.0556	0.122
5	0.1875	0.2500	0.1667	0.250
6	0.2682	0.1667	0.0972	0.268
7	0.1510	0.1042	0.2083	0.208
8	0.1875	0.0000	0.0833	0.187
9	0.3281	0.2500	0.2500	0.328
10	0.1250	0.2083	0.1805	0.208
11	0.2552	0.2500	0.1944	0.255
12	0.0729	0.0312	0.0556	0.073
13	0.3333	0.3333	0.2222	0.333
14	0.1354	0.3125	0.0972	0.312
15	0.1719	0.2708	0.1528	0.271
16	0.0000	0.0625	0.0556	0.062
17	0.3177	0.3333	0.3333	0.333
18	0.0833	0.1771	0.0486	0.177
19	0.2344	0.2916	0.2500	0.292
20	0.0833	0.0208	0.0833	0.083

21	0.1302	0.1458	0.0972	0.146
22	0.1875	0.1875	0.1389	0.187
23	0.1562	0.0833	0.0417	0.156
24	0.1958	0.2500	0.1875	0.250
25	0.1823	0.1458	0.1042	0.182
26	0.1614	0.1250	0.1180	0.161
27	0.1823	0.1458	0.1042	0.182
28	0.1354	0.1250	0.1180	0.135
29	0.1562	0.1458	0.1042	0.156
30	0.1354	0.1250	0.1180	0.135
31	0.1719	0.1042	0.0972	0.172

Step-(3): VIKOR index (Q) calculation

VIKOR index (Q) is calculated according to Equation (3)

$Q_i = \{T^*[(S_j – S^*)/(S^- - S^*)]\} + \{(1-T)^*[(R_j - R^*)/(R^- - R^*)]\}$………(3)

Where $S^* = \min (S_j)$ (j=1,..., J) $S^- = \max (S_j)$ (j=1,..., J)

$R^* = \min (R_j)$ (j=1,..., J) $R^- = \max (R_j)$ (j=1,..., J).

Step-(4): Find out the Rank

Highest rank is given to least VIKOR index value as shown in Table 8.

Table 8: VIKOR RANKS

Exp	Utility measure(S)	Regret measure(R)	Q	Rank(R)
1	0.521	0.229	0.540	21
2	0.240	0.135	0.205	5
3	0.408	0.172	0.369	15
4	0.199	0.122	0.157	4
5	0.604	0.250	0.627	23
6	0.532	0.268	0.619	22
7	0.463	0.208	0.469	19
8	0.271	0.187	0.319	10
9	0.828	0.328	0.900	29
10	0.514	0.208	0.498	20
11	0.700	0.255	0.691	26
12	0.160	0.073	0.043	2
13	0.889	0.333	0.945	30
14	0.545	0.312	0.708	27
15	0.595	0.271	0.660	25
16	**0.118**	**0.062**	**0.000**	**1**
17	0.984	0.333	1.000	31
18	0.309	0.177	0.322	11
19	0.776	0.292	0.803	28
20	0.187	0.083	0.079	3

21	0.373	0.146	0.301	9
22	0.514	0.187	0.459	18
23	0.281	0.156	0.267	6
24	0.633	0.250	0.644	24
25	0.432	0.182	0.403	16
26	0.404	0.161	0.348	13
27	0.432	0.182	0.403	17
28	0.378	0.135	0.285	7
29	0.406	0.156	0.339	12
30	0.378	0.135	0.285	8
31	0.373	0.172	0.349	14

From the Table 8, it was observed that in all, 16^{th} experiment was the optimal experiment but slightly deferred in ranking positions of other experiments. Although TOPSIS, VIKOR and PROMETHEE II methods delivered the first rank for the same experiment, the Kendall's coefficient of concordance was also computed to verify the degree of similarity between rankings of all the experiments. The similarity of ranks produced from the three MADM methods was measured by using Kendall's coefficient of concordance value (W) and it was computed by using the following equation.

$$W = \frac{\sum\left(S_i - \frac{\sum_{i=1}^{n} s_i}{n}\right)^2}{\frac{K^2 n(n^2-1)}{12}}$$

Where K= Number of judgments (methods) which are considered

s_i = Sum of ranks that are assigned to a decision option i across all K methods

n = Number of attributes (Experiments) under priority rank evaluation

Table 9: COMPARISION OF RANKS of TOPSIS, VIKOR and PROMETHEE-II

EXP	TOPSIS	VIKOR	PROMETHEE-II
1	18	21	22
2	5	5	5
3	16	15	13
4	4	4	3
5	24	23	25
6	25	22	21
7	13	19	18
8	7	10	6
9	29	29	29
10	17	20	20
11	27	26	27
12	2	2	2
13	30	30	30
14	19	27	23
15	23	25	24
16	**1**	**1**	**1**
17	31	31	31
18	6	11	8

19	28	28	28
20	3	3	4
21	9	9	9
22	22	18	19
23	8	6	7
24	26	24	26
25	20	16	16
26	14	13	14
27	20	17	16
28	10	7	11
29	15	12	15
30	10	8	11
31	12	14	10

The range of values of W was from 0 to 1, where $W = 0$ shows that there was a lack of agreement and $W = 1$ shows that there was a perfect match among the methods on contributing ranking order. In the present research work, the value of W was calculated as 0.98, which indicates that there was an almost perfect agreement between the considered MADM methods.

4. CONCLUSIONS

The following conclusions were drawn based on the experiments performed.

In the present investigation, Pulsed current micro plasma arc welding was used to weld AISI 904L super austenitic stainless steel sheets of thickness 0.4mm. Total 31 experiments were carried in accordance with RSM method of Central composite design with 4 factors such as pulse width, pulse rate, base current and peak current and 5 levels to optimize grain size, hardness and tensile strength. To find out the optimal experiment, VIKOR Multi attribute decision making(MADM) method was used and compared with other two MADM methods such as TOPSIS and PROMETHEE II and 16^{th} experiment was the optimized experiment which was obtained from 31 experiments in all methods and Kendall's coefficient value 0.98 was obtained which was acceptable.

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