ISSN: 0974-5823 Vol. 7 No. 5 May, 2022

International Journal of Mechanical Engineering

Welding parameters optimization of AISI 904L thin steel sheets using pulsed current Micro plasma arc welding by PROMETHEE–II

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ABSTRACT

AISI 904L steel which is also designated as UNS N08904 is a non-stabilized super austenitic stainless steel and contains low carbon with high alloy content. Micro Plasma Arc Welding (MPAW) is a precocious method of welding that can be easily mechanized and utilized for accurate welding of minuscule components. Welding with MPAW, the arc is sustained at a current as low as 0.1 Ampere and sheets of thickness 100 microns are welded. The ongoing work articulates joining of AISI 904L sheets having dimensions of (100 x 200 x 0.4) mm^3 with MPAW by varying four factors such as Pulse Width, Base Current, Pulse Rate and Peak Current at five various levels. By calculating Ultimate tensile strength (UTS), Grain size and Micro hardness, AISI 904L weld joint standard is explored. Central composite rotatable design (CCD) matrix of Response surface methodology method (Design of Experiments) is chosen to organize the experiments and an attempt is made to maximize hardness, minimize grain size and maximize ultimate tensile strength. For optimization, PROMETHEE-II (Preference Ranking Organization Method for Enrichment of Evaluations) which is Multi attribute decision making (MADM) method is endorsed for taking decisions for giving ranks or choosing between alternatives. In the present study of research, MPAW process input parameters are optimized by PROMETHEE-II method.

Key words: Micro plasma arc welding, Response surface methodology, CCD, AISI 904L steel, MADM, PROMETHEE-II.

1. INTRODUCTION

For moderate to high corrosion resistance, AISI 904L stainless steel is used widely in process environments. Good corrosion resistance is obtained by the combination of Nickel and Chromium content in addition with molybdenum and copper. To endure dilute sulfuric acid contained environments, Alloy 904L is developed. Hot phosphoric acid which is an inorganic acid and many organic acids are also resisted by AISI 904L steel [1]. Alloy 904L is easily welded by standard shop fabrication processes and largely used in chemical, paper, oil refinery industries etc. [2]. In MPAW, plasma gas is heated to an exceedingly high temperature and also ionized so that it turns into electrically conductive. Electric arc is transferred to a work piece in MPAW by utilizing this plasma similar to TIG welding. The metal to be welded by this intense heat of the arc, melts and fuses together [3].

Majid Behzadian et al. [4] designed a classification scheme and a comprehensive literature survey in order to classify and interpret research on PROMETHEE methodologies and applications. Liao Huchang et al. [7] researched one of the outranking based methods, PROMETHEE for multi-criteria decision making and elongated it into intuitionistic fuzzy circumstance. D.P.Pandya et al. [8] utilized A-TIG welding process on mild steel of 10 mm thickness plate and accomplished experiments to find the effect of different input welding parameters on weld bead width and weld penetration. Taguchi method with L9 (9) orthogonal array is employed to find out the relationship between various responses (weld bead width and weld penetration) and welding input parameters (fluxes, welding current and welding speed,). For optimization PROMETHEE method is adopted. A.P.Aravind et al. [9] made an effort to examine the cold metal transfer (CMT) welding of Al 5083 sheets having a thickness of 3 mm implied on the L9 Taguchi orthogonal array with welding frequency (Hz) , welding current (A) and welding speed (mm/min) as input parameters. The optimized parameters were obtained by the VIKOR multi-objective optimization method.

Ravipudi Venkata Rao et al. [10] enhanced PROMETHEE in the present work by combining analytic hierarchy process (AHP) and fuzzy logic. The method demonstrated in this paper is very effective for decision making in various real-life situations of the manufacturing environment. Four examples are taken into consideration to illustrate the method. MahdiNasrollahi et al. [11] tried to resolve the problem on the selection of robot using Fuzzy Best-Worst Method and PROMETHEE two most suitable multi-criteria decision-making (MCDM) methods for weighting criteria and ranking of decision alternatives respectively. Saeed Kazem et al. [12] applied PROMETHEE method to select the best radial basic function that efficiently solved 2D heat transfer equation depending on Hermite interpolation. P.Sathiya et al. [13] optimized the weld bead characteristics of 904L through grey-based Taguchi method. Juan M. Sanchez-Lozano et al.[14] conveyed that how combining the multi-criteria decision making (MCDM) process with fuzzy logic can be very efficient to resolve decision problems in which there are criteria of different natures. Joseph Achebo et al. [15] adapted TOPSIS method and inspected that weldment 9 has good 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%.

2. EXPERIMENTATION

For experimentation 0.4 mm thick 100 x 200mm^2 steel sheets of AISI 904L were used as a base metal. These sheets were present in rolls form from which the required sizes of 100 mm x 200 mm were sheared using shearing machine and the pieces were made clean applying ultrasonic cleaner before welding to remove any strains of oil and grease. PLASMA FIX 50E equipment was operated for welding shown in Fig 1. Total 31 pairs of the sheets were cut to make 31 welded joints.

Figure-1: Equipment PLASMAFIX 50E

Experiments were conducted based on Response Surface Methodology (RSM) related central composite rotatable design(CCD) method with 4 input parameters namely pulse width, pulse rate, base current and peak current at various 5 levels shown in Table 1. Grain size was measured using Metallurgical Microscope as shown in Fig 2, Ultimate Tensile strength was measured using Universal Testing Machine as shown in Fig 3 and Hardness was measured using Vickers Hardness Testing Machine as shown in Fig 4.

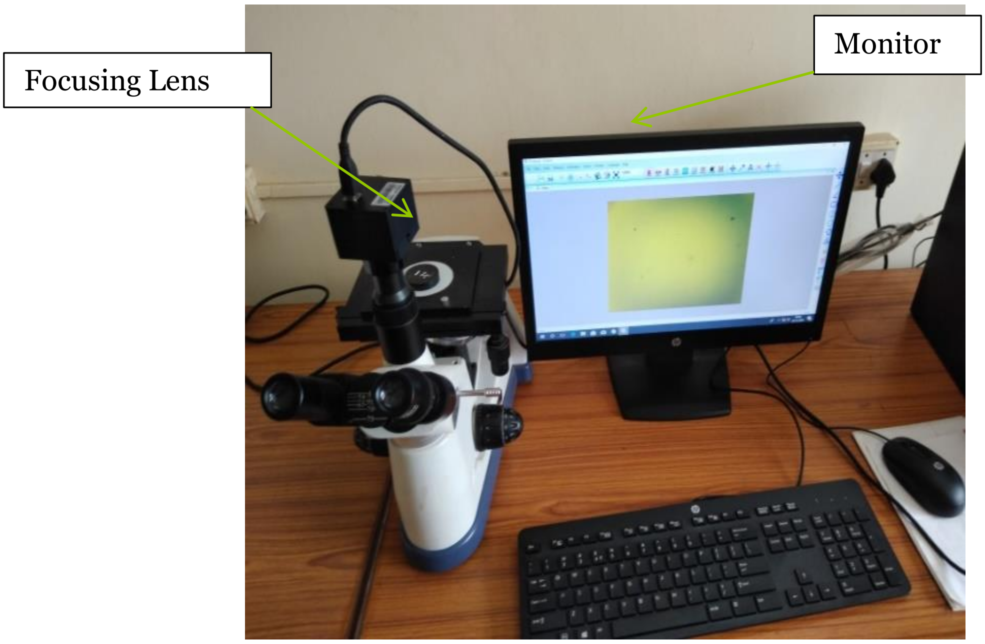

Figure-2: Equipment Metallurgical Microscope

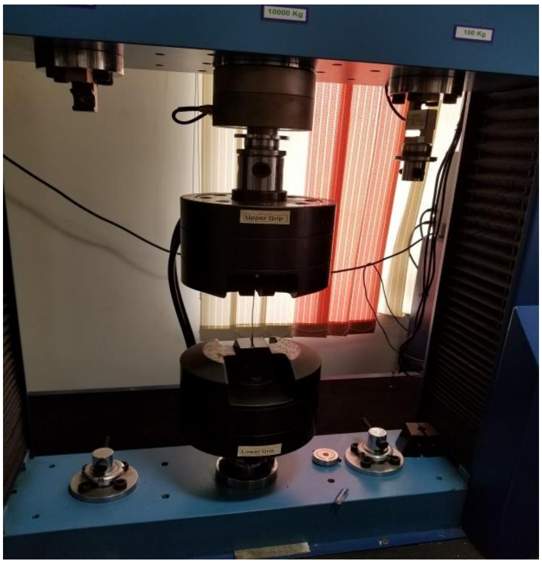

Figure-3: Equipment UTM **Figure-4: Vickers Hardness Testing Machine**

RSM was more frequently used in analyzing the relationships and the influences of input parameters on the output responses. The results of response parameters were shown in Table 4. The mechanical properties and chemical composition of AISI 904L were presented in Table 2 and Table 3.

Recently Multi-Criteria Decision Making (MCDM) problems such as PROMETHEE II (Preference Ranking Organization Method for Enrichment of Evaluations) has emerged as one of the most effective and fruitfully applied outranking method. PROMETHEE II (complete ranking) was designed by Jean Pierre. Brans and showed for the first time in 1982[5]. This method was relied on a comparison pair per pair of possible decisions along each criterion. Possible decisions were evaluated in accordance with different criteria, which have to be increased or decreased. PROMETHEE II method requires 2 types of information for each criterion: the weight and the preference function. The preference function specifies the divergence for a criterion between the evaluations obtained by 2 possible decisions into a preferable degree ranging from 0 to 1.

PROMETHEE can handle qualitative and quantitative criteria concurrently [6]. PROMETHEE II was applied for the problems implying priority setting, resource allocation, selection and planning among alternatives. So PROMETHEE II was a general methodology for treating multi criteria problems and a decision-making tool. Basically, it can provide complete ranking and ordering of alternatives when decision makers need to choose the most appropriate options.

Table 1: Input parameters for welding and levels

S.No	**Input Parameters of welding**	**Units**	**Input Levels**				
			-2	-1	0	+1	+2
1	Peak Current	Amperes(A)	16	18	20	22	24
2	Base Current	Amperes(A)	8	9	10	11	12
3	Pulse rate	Pulses /Second	30	40	50	60	70
4	Pulse width	Percentage (%)	40	50	60	70	80

Table 2: Chemical composition of AISI 904L (weight %)

Cu	Ni	Mo	Cr	Fe
1.43	24.75	4.33	19.92	49.57

Table 3: Mechanical properties of AISI 904L

Yield Strength(MPa)	Tensile Strength (MPa)	Hardness(VHN)	Elongation (%)
220	573	242	36

Table 4: Results of response parameters after the completion of the experiments

	INPUT VALUES OF PARAMETERS				**OUTPUT RESPONSES (VALUES FROM EXPERIMENTS)**		
Serial No	**Peak Current**	**Base Current**	**Pulse Rate**	**Pulse Width**	**Grain size (Microns)**	**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. METHODOLOGY

The decision making process by the PROMETHEE II method was composed of seven steps that are detailed below and the results obtained after applying PROMETHEE-II were given below stepwise. Here in this the equal weights considered are 0.3333, 0.3333 and 0.3333.

Step [1]: The decision matrix normalization

Normalize the decision matrix as shown in Table 5 for the criteria depending on beneficial using Eq -1and for the non-beneficial criteria using Eq -2:

$T_{ij} = [s_{ij} - \min(s_{ij})] / [\max(s_{ij}) - \min(s_{ij})]$................ (1)

$i=1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$

$T_{ij} = [\max(s_{ij}) - s_{ij}] / [\max(s_{ij}) - \min(s_{ij})]$………... (2)

Table 5: Normalized decision matrix

EXP	Grain size	Hardness	Tensile
1	0.625	0.313	0.500
2	0.688	0.594	1.000
3	0.484	0.625	0.667
4	0.633	0.938	0.833
5	0.438	0.25	0.500
6	0.195	0.5	0.708
7	0.547	0.688	0.375
8	0.438	1	0.750
9	0.016	0.25	0.250
10	0.625	0.375	0.458
11	0.234	0.25	0.417
12	0.781	0.906	0.833
13	0	0	0.333
14	0.594	0.063	0.708
15	0.484	0.188	0.542
16	1	0.813	0.833
17	0.047	0	0.000
18	0.75	0.469	0.854
19	0.297	0.125	0.250
20	0.75	0.938	0.750
21	0.609	0.563	0.708
22	0.438	0.438	0.583
23	0.531	0.75	0.875
24	0.413	0.25	0.438
25	0.453	0.563	0.688
26	0.516	0.625	0.646
27	0.453	0.563	0.688
28	0.594	0.625	0.646
29	0.531	0.563	0.688
30	0.594	0.625	0.646
31	0.484	0.688	0.708

Step [2]: Evaluative differences calculation from one alternative with other alternatives

The difference in criterion value (hj) as shown in Table 6 between different alternatives pair-wise is calculated using Eq (3)

$h_j(a, b) = f_j(a) - f_j(b)$………………… (3)

For all remaining 30 experiments we have to find the difference criterion value (h_j) between different alternatives pair-wise.

Table 6: Calculating the differences

EXP	GS	VHN	UTS
A1	-0.06	-0.28	-0.5
A2	0.141	-0.31	-0.17
A3	-0.01	-0.63	-0.33
A4	0.187	0.063	0
A5	0.43	-0.19	-0.21
A6	0.078	-0.38	0.125
A7	0.187	-0.69	-0.25
A8	0.609	0.063	0.25
A9	0	-0.06	0.042
A10	0.391	0.063	0.083
A11	-0.16	-0.59	-0.33
A12	0.625	0.313	0.167
A13	0.031	0.25	-0.21
A14	0.141	0.125	-0.04
A15	-0.38	-0.5	-0.33
A16	0.578	0.313	0.5
A17	-0.13	-0.16	-0.35
A18	0.328	0.188	0.25
A19	-0.13	-0.63	-0.25
A20	0.016	-0.25	-0.21
A21	0.187	-0.13	-0.08
A22	0.094	-0.44	-0.38
A23	0.213	0.063	0.063
A24	0.172	-0.25	-0.19
A25	0.109	-0.31	-0.15
A26	0.172	-0.25	-0.19
A27	0.031	-0.31	-0.15
A28	0.094	-0.25	-0.19
A29	0.031	-0.31	-0.15
A30	0.141	-0.38	-0.21

Step [3]: Preferences calculation E_j (a, b) as shown in Table 7

Six types of preference functions are there, such as V-form criteria, ordinary criteria, U-shape criteria, etc. but most are common criteria using the following formula:

$E_j (a, b) = 0 \; if \; T_{aj} \leq T_{bj}$ …………………………….. (4)

$E_j (a, b) = (T_{aj} - T_{bj}) \; if \; T_{aj} > T_{bj}$ …………………….(5)

Table 7: Calculating Preferences

EXP	GS	VHN	UTS
A1	0	0	0
A2	0.1406	0	0
A3	0	0	0
A4	0.1875	0.0625	0
A5	0.4297	0	0
A6	0.0781	0	0.125
A7	0.1875	0	0
A8	0.6094	0.0625	0.25
A9	0	0	0.042
A10	0.3906	0.0625	0.083
A11	0	0	0
A12	0.625	0.3125	0.167
A13	0.0313	0.25	0
A14	0.1406	0.125	0
A15	0	0	0
A16	0.5781	0.3125	0.5
A17	0	0	0
A18	0.3281	0.1875	0.25
A19	0	0	0
A20	0.0156	0	0
A21	0.1875	0	0
A22	0.0938	0	0
A23	0.2125	0.0625	0.063
A24	0.1719	0	0
A25	0.1094	0	0
A26	0.1719	0	0
A27	0.0313	0	0
A28	0.0938	0	0
A29	0.0313	0	0
A30	0.1406	0	0

Step [4]: Aggregated Preferences Index calculation and summation

Calculate the preference index by considering the weighted value criterion as shown in Table 8 with the following equation

$\Pi_k(a, b) = [\sum_{j=1}^{n} W_j E_j (a, b)] / [\sum_{j=1}^{n} W_j]$……….(6)

Where W_j is the weight of the j criterion and do summation of values of three properties for every experiment.

Table 8: Aggregated Preferences Index

EXP	GS*w	VHN*w	UTS*w	SUM
A1	0	0	0	0
A2	0.0469	0	0	0.0469
A3	0	0	0	0
A4	0.0625	0.0208	0	0.0833
A5	0.1432	0	0	0.1432
A6	0.026	0	0.0417	0.0677
A7	0.0625	0	0	0.0625
A8	0.2031	0.0208	0.0833	0.3073
A9	0	0	0.0139	0.0139
A10	0.1302	0.0208	0.0278	0.1788
A11	0	0	0	0
A12	0.2083	0.1042	0.0556	0.368
A13	0.0104	0.0833	0	0.0937
A14	0.0469	0.0417	0	0.0885
A15	0	0	0	0
A16	0.1927	0.1042	0.1667	0.4635
A17	0	0	0	0
A18	0.1094	0.0625	0.0833	0.2552
A19	0	0	0	0
A20	0.0052	0	0	0.0052
A21	0.0625	0	0	0.0625
A22	0.0312	0	0	0.0312
A23	0.0708	0.0208	0.0208	0.1125
A24	0.0573	0	0	0.0573
A25	0.0365	0	0	0.0365
A26	0.0573	0	0	0.0573
A27	0.0104	0	0	0.0104
A28	0.0312	0	0	0.0312
A29	0.0104	0	0	0.0104
A30	0.0469	0	0	0.0469

Step [5]: Leaving Flow and Entering Outranking Flow determination

Leaving Flow and Entering Outranking Flow will be obtained using the equations (7), (8)

Leaving (Positive) Flow (LF)

$\varphi_k{}^{+}(a) = 1/\,(m_1-1)\sum_{y=1}^{m} \Pi_k(a, y)$ ………………….(7)

Entering (Outranking) Flow (EF)

$\varphi_k{}^{-}(a) = 1\,/(m_1-1)\sum_{y=1}^{m} \Pi_k(y, a)$ ………………….(8)

Step [6]: The net outranking flow (LF-EF) calculation

$\varphi_k(a) = \varphi_k{}^{+}(a) - \varphi_k{}^{-}(a)$ ………………………………. (9)

Step [7]: Find the Rank of all experiments

Calculate the RANK as shown in Table 9. The better of alternative is the higher value. In this work using this PROMETHEE-II method 16th experiment is the optimal experiment from all 31 experiments.

Table 9: RANK calculation table

EXP	LF	EF	LF-EF	RANK
1	0.088	0.151	-0.063	22
2	0.263	0.029	0.234	5
3	0.156	0.066	0.090	13
4	0.288	0.012	0.276	3
5	0.047	0.189	-0.143	25
6	0.097	0.159	-0.062	21
7	0.123	0.120	0.003	18
8	0.249	0.047	0.202	6
9	0.013	0.387	-0.374	29
10	0.091	0.140	-0.049	20
11	0.027	0.268	-0.241	27
12	0.323	0.007	0.317	2
13	0.033	0.442	-0.410	30
14	0.095	0.177	-0.082	23
15	0.054	0.188	-0.134	24
16	0.368	0.038	**0.330**	**1**
17	0.001	0.536	-0.535	31
18	0.213	0.051	0.162	8
19	0.017	0.337	-0.320	28
20	0.300	0.039	0.261	4
21	0.146	0.050	0.096	9
22	0.077	0.127	-0.049	19
23	0.223	0.032	0.191	7
24	0.040	0.212	-0.173	26
25	0.113	0.078	0.035	16
26	0.128	0.064	0.064	14
27	0.113	0.078	0.035	16
28	0.144	0.053	0.091	11
29	0.125	0.063	0.062	15
30	0.144	0.053	0.091	11
31	0.150	0.054	0.096	10

4. CONCLUSIONS

In this work 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 out according to RSM method CCD with four factors and five levels to optimize grain size, hardness and tensile strength. PROMETHEE II method was explored to solve the problem of determining the best experiment and generate high effective decisions and 16th experiment is the optimized experiment from 31 experiments. The optimal performance for grain size, hardness and UTS are obtained for the following combination of input parameters: Peak Current 22 Amps, Base Current 11 Amps, Pulse Rate 60 pulses/sec, Pulse Width 70 %.

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