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RESEARCH ARTICLE OPEN ACCESS

Enrichment of Mild Steel Weld Joint Quality Characteristics Using the SWARA – ARAS Method

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ABSTRACT
Optimization of process parameters to enrich welded joint quality has been a focus of global research. Some optimization methods have produced welds of low strength and quality, however, other methods have produced demonstrably high quality welded joints. The Step-wise Weight Assessment Ratio Analysis (SWARA) method was used to determine the geometric mean of weights for each of the output parameters which include the mechanical test and weld sample measurement values taken. The Additive Ratio Assessment (ARAS) method was applied to optimize these parameters by utilizing the weights generated using SWARA method. In this study, the SWARA-ARAS method was adopted to assess the effect of process parameters on the quality of welded mild steel joints. From applying the SWARA-ARAS method, weldment number seven (7) of the eight (8) weldments evaluated, having an ultimate tensile strength (UTS) of 395 MPa, Impact energy (CVN) of 250J, Bead Height (BH) of 1.98mm and Bead Width (BW) of 4.82mm, was found to possess the best input and output parameters.

KEYWORDS: Gas flow rate (GFR), SWARA, ARAS, mild steel, weldment

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I. INTRODUCTION

Experts have generally observed that metal materials and parts which fail when loads are applied on them, are found to be caused by the retrogressive quality of their welded joints. This failure is linked to shortcomings in the application of the various input process parameters such as the welding current, welding voltage, gas flow rate, welding speed etc. Hence, to obtain the required optimum weld joint quality, what is required is a careful selection of the most appropriate welding parameters. Optimality can only be obtained in welded joints when their mechanical properties have been enriched by improving on the ductile nature and strength architecture of the joints. An optimum welded joint of the best quality, in most cases, possesses enough strength to carry or sustain the designed load over time, and with a significantly reduced chance of failure. This optimality can be attained by choosing the appropriate process parameters along each step of the design journey. This can be possible only when the right model or method is used for the optimization process.

Weld mechanical properties can be evaluated not only by experimental investigations but also by the knowledge based skill set of experts in the area of research study. Expert investigations may require physical examination of the weld specimen, thereafter scoring or rating the performance of the welding process based on the quality of the eventual welded joint specimen. This could be achieved by using the Likert Scale Preference Method. This scoring and the consequent data generated are entirely subject to the judgements of selected respondents/ experts.

In this study, expert evaluation of mild steel weldment was used to optimize the performances of its mechanical properties by applying SWARA-ARAS method. For steel welding, the experts evaluating the quality of the weldment should be drawn from trainees and practitioners in the field/area of Mechanical/Manufacturing Engineering and/or welding technology/sciences. These experts in the course of their training are accustomed to mechanical tests and measurements of weldments' assessment criteria. The results there from are expected to reveal the presumed status of the weldments.

The obtained results are optimized using any of the various multi criteria decision making models or methods. So many researchers have done some work in this area such as Yan et al (2017) who worked on the multi objective optimization of arc welding parameters based on fitness sharing Genetic Algorithm (FSGA). FSGA was proposed for energy

reduction and thermal energy improvement. The optimization method and results are analysed with the actual data and Generic Algorithm. Kumar et al (2016) combined Taguchi method with grey relational analysis to optimize the process parameters of gas metal arc welding of AISI 1020 carbon steels for multiple quality characteristics. Khatter et al (2014) proposed a method to decide near optimal settings of the welding process parameters in TIG welding. The Taguchi method was used to optimize the process parameters whereas the analysis of variance was applied to determine the extent of the contribution of each parameter to the improvement of the quality of the bead geometry. Mvola (2016) adopted adaptive gas metal arc welding procedure and optimized the output welding parameters that influence welded joints.
In this study, a step by step approach of the SWARA-ARAS method was clearly elucidated.

II. MATERIALS AND METHODS

2.1 Materials

Locally purchased Mild steel plate of thickness 10mm was subjected to gas metal arc welding (GMAW) operation, after it was cut to dimension of 50mm by 100mm. Five welded samples were made using each input process parameters. These weldments were itched and polished with a 0.5mm emery paper. The weld bead height and bead width were measured using the Planimeter. The average of the bead height and bead width values was recorded; this was done for each weld operation. The welding machine used was semi-automatic with adjustable voltage, current, and gas flow rate input. A 1.6mm wire electrode with 80% argon and 20% carbon dioxide shielding gas were used. Monsanto Tensometer was used for determining the ultimate tensile strength. The charpy V-notch impact tester consists of a swinging pendulum or hammer with an energy of 0 – 300 J and a swinging speed of 5 – 7 m/s was used to determine the impact energy.

2.2 Methods

The SWARA method used for this study has the ability to estimate experts' opinion about the allocation of weights to each output parameters. The Expert investigations require physical and technical examination of the welded specimen leading to the scoring or rating of these welded specimens using the Likert Scale Preference Method.
Step by step process in the application of the SWARA method is outlined hereinunder;

1. Comparative importance of average value, Sj

2. Coefficient, $K_j = \begin{cases} 1 \,;\, j = 1 \\ S_{j+}1; j > 1 \end{cases}$ (1)

3. Recalculated weight, q_j

$$K_j = \begin{Bmatrix} 1;\ j = 1 \\ \frac{K_{j-1}}{K_j};\ j > 1 \end{Bmatrix} \quad (2)$$

4. Relative weight, W_j for each criterion

Step by step approach in the application of the ARAS method is outlined herein under;

1. Optimal performance ratings, X_{oj} are calculated as X_{oj} = Max X_{ij}

2. Normalized performance ratings. r_{ij}

$$r_{ij} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}} \quad (3)$$

3. Weighted normalized performance ratings V_{ij}

$$V_{ij} = w_j \,.r_{ij} \quad (4)$$

4. Overall performance, index, S_i for each alternative

$$Si = \sum_{j=1}^{m} V_{ij} \quad (5)$$

5. Degree of utility for each alternative

$$Q_i = \frac{S_1}{S_0} \quad (6)$$

S_0 is the overall performance index of optimal alternative, and it is usually 1

6. Rank alternatives and or select the most efficient one. That is the alternative with the greater value of Q_i is expected to have a higher priority, i.e best placed (rank)

III. RESULTS AND DISCUSSION

3.1 Presentation of Results

Table 1 shows the measured mechanical properties/responses comprises of ultimate tensile strength (UTS), absorbed impact energy (CVN), Bead height (BH) and Bead width (BW). These properties are categorized, for the UTS and CVN the higher the amount/values the better the quality of the weldments, whereas, for BH and BW the lower the amount/values the better the quality of the weldments.

Table 1: Measured Mechanical Properties

Input Parameters				Mechanical properties			
Weldment Number	Current, I	Voltage, V	Gas Flow Rate, GFR (l/min)	Maximum		Minimum	
				UTS (MPa)	CVN (J)	BH (mm)	BW (mm)
1	140	18	13	340	210	2.62	5.00
2	140	18	18	270	190	2.45	9.74
3	180	23	13	330	150	3.10	10.34
4	180	23	18	360	165	2.45	7.66
5	140	23	13	250	140	2.80	8.47
6	140	23	18	342	220	2.06	6.42
7	180	18	13	395	250	1.98	4.82
8	180	18	18	298	215	3.10	7.15

Table 2 shows the assessment of First Expert evaluation process. Table 3 shows the assessment of second Expert evaluation process

Table 2: First Expert Evaluation

Weld ment	Weld Mechanical Properties			
	Maximum		Minimum	
	UTS	CVN	BH	BW
1	4	4	3	3
2	3	3	5	3
3	5	4	3	4
4	3	4	4	4
5	4	3	3	3
6	3	3	4	4
7	4	5	3	4
8	4	3	2	3

Table 3: Second Expert Evaluation

Weld ment	Weld Mechanical Properties			
	Maximum		Minimum	
	UTS	CVN	BH	BW
1	5	4	3	4
2	2	3	3	4
3	3	3	2	4
4	5	3	4	3
5	4	3	3	4
6	3	4	4	5
7	3	5	3	4
8	5	3	3	4

Table 4 shows the assessment of third Expert evaluation process and Table 5 shows the assessment of the fourth Expert evaluation process.

Table 4: Third Expert Evaluation

Weld ment	Weld Mechanical Properties			
	Maximum		Minimum	
	UTS	CVN	BH	BW
1	4	2	5	4
2	4	3	4	5
3	2	4	2	3
4	4	2	3	4
5	3	4	2	4
6	2	5	4	3
7	4	4	5	4
8	3	3	3	4

Table 5: Fourth Expert Evaluation

Weld ment	Weld Mechanical Properties			
	Maximum		Minimum	
	UTS	CVN	BH	BW
1	3	4	5	4
2	4	3	2	3
3	4	3	4	3
4	4	3	2	3
5	4	4	3	4
6	5	5	4	4
7	5	4	3	3
8	4	4	3	3

Table 6 shows the assessment of the fifth Expert evaluation process

Table 6: Fifth Expert Evaluation

Weld ment	Weld Mechanical Properties			
	Maximum		Minimum	
	UTS	CVN	BH	BW
1	3	3	3	4
2	3	4	3	3
3	3	4	2	5
4	3	2	4	3
5	4	2	4	3
6	4	3	2	3
7	3	3	2	3
8	3	3	4	5

After the different evaluation of the weldments by the Experts, the next step was to determine the comparative importance of average value, S_j for each of the evaluation criteria using the method adopted by stanujkic et al (2015). In determining S_j, the first step was to determine the relative weights of responses (see Table 2) obtained from the first Expert as contained in Table 7.

Table 7: Determination of Relative Weights from the First Expert Evaluation

	Weld Mechanical Properties				
	UTS	CVN	BH	BW	Overall Score
Total	30	29	27	28	115
Relative weight W_j	0.26	0.25	0.23	0.24	

The relative weights as contained in Table 7 are rearranged in the descending order and arrangement as shown in Table 8

Table 8: Determination of Comparative Importance of Average Value, S_j from the Responses of the First Expert

Relative weight W_j	W_{j-1}	$\frac{w_j - w_{j-1}}{w_j} = S_j$
0.23	0.23	0
0.24	0.22	0.08
0.25	0.21	0.16
0.26	0.20	0.23

Table 9 shows the final results of SWARA method in weighting assessment indicator for the First Expert evaluation.

Table 9: Final results of SWARA method in weighting of First Expert Responses

Criterion or mechanical properties	Comparative importance of average value, S_j	Coefficient $K_j = S_j + 1$	Recalculated weight $W_j = \frac{W_{j+1}}{K_j}$	Weight $q = \frac{W_j}{\sum w_j}$
BH	0	1	1	0.30
BW	0.08	1.08	0.93	0.27
CVN	0.16	1.16	0.80	0.24
UTS	0.23	1.23	0.65	0.19
Total			3.38	1.00

We repeat same procedure for second, third and fourth weighted assessment expert response. Table 10 shows the final results of SWARA method in weighting assessment indicator for the second Expert Evaluation.

Table 10: Final Results of SWARA Method in Weighting of Second Expert Responses

Criterion or mechanical properties	Comparative importance of average value, S_j	Coefficient $K_j = S_j + 1$	Recalculated weight $W_j = \frac{w_{j+1}}{K_j}$	Weight $q = \frac{W_j}{\sum w_j}$
BH	0	1	1	0.34
CVN	0.17	1.17	0.86	0.29
UTS	0.31	1.31	0.65	0.22
BW	0.43	1.43	0.46	0.15
Total			2.97	1.00

Table 11 shows the final results of SWARA method in weighting assessment indicator for the Third Expert Evaluation.

Table 11: Final Results of SWARA Method in Weighting of Third Expert Responses

Criterion or mechanical properties	Comparative importance of average value, S_j	Coefficient $K_j = S_j + 1$	Recalculated weight $W_j = \frac{w_{j+1}}{K_j}$	Weight $q = \frac{W_j}{\sum w_j}$
UTS	0	1	1	0.30
CVN	0.08	1.08	0.93	0.28
BH	0.16	1.16	0.80	0.24
BW	0.36	1.36	0.59	0.18
Total			3.32	1.00

Table 12 shows the final results of SWARA method in weighting assessment indicator for the Fourth Expert Evaluation.

Table 12: Final Results of SWARA Method in Weighting Assessment of Fourth Expert

Criterion or mechanical properties	Comparative importance of average value, S_j	Coefficient $K_j = S_j + 1$	Recalculated weight $W_j = \frac{w_{j+1}}{K_j}$	Weight $q = \frac{W_j}{\sum w_j}$
BH	0	1	1	0.34
BW	0.17	1.17	0.86	0.29
CVN	0.31	1.31	0.65	0.22
UTS	0.43	1.43	0.46	0.15
Total			2.97	1.00

Table 13 shows the final results of SWARA method in weighing assessment indicator for the firth expert evaluation

Table 13: Final Results of SWARA method in weighting of Fifth Expert

Criterion or mechanical properties	Comparative importance of average value, S_j	Coefficient $K_j = S_j + 1$	Recalculated weight $W_j = \frac{w_{j+1}}{K_j}$	Weight $q = \frac{W_j}{\sum w_j}$
CVN	0	1	1	0.35
UTS	0.17	1.17	0.86	0.30
BW	0.39	1.39	0.62	0.22
BH	0.60	1.60	0.39	0.13
Total			2.87	1.00

Table 14 shows the geometric mean of weight obtained from the entire First to Fifth experts' evaluation processes, making it a total number of five (5) Experts' Evaluations.

Table 14: The geometric mean of weight

Criterion	Geometric mean of weights
UTS	0.23
CVN	0.28
BH	0.27
BW	0.22

Application of Additive Ratio Assessment (ARAS) method

Table 15 shows the average ratings of expert's responses considering Tables 2, 3, 4, 5, and 6

Table 15: Average ratings of Experts' Responses

Weldment	Weld Mechanical Properties			
W	UTS	CVN	BH	BW
W_1	3.8	3.4	3.8	3.8
W_2	3.2	3.2	3.4	3.6
W_3	3.4	3.6	2.6	3.8
W_4	3.8	2.8	3.4	3.4
W_5	3.8	3.2	2.6	3.4
W_6	3.4	4.0	3.6	3.8
W_7	3.8	4.2	3.2	3.6
W_8	3.8	3.8	3.0	4.2
Maximum Value =W_0 of W	3.8	4.2	3.8	4.2
Total, W_T =	32.8	32.4	29.4	33.8

Table 16 shows the normalized decision making matrix, drawn from Table 15

Table 16 Normalized Decision Making Matrix

Weldment	Weld Mechanical Properties			
W	UTS	CVN	BH	BW
1	0.116	0.105	0.129	0.112
2	0.098	0.099	0.116	0.107
3	0.104	0.111	0.088	0.112
4	0.116	0.086	0.116	0.101
5	0.116	0.099	0.088	0.101
6	0.104	0.123	0.122	0.112
7	0.116	0.130	0.109	0.107
8	0.116	0.117	0.102	0.124
0	0.116	0.130	0.129	0.124

Table 17 shows the normalized decision making matrix and weights.

Table 17: Normalized Decision Making Matrix and Weights

Weldment, W_{0-8}	Weld Mechanical Properties			
	UTS	CVN	BH	BW
Weight from Table 14	0.23	0.28	0.27	0.22
0	0.116	0.130	0.129	0.124
1	0.116	0.105	0.129	0.112
2	0.098	0.099	0.116	0.107
3	0.104	0.111	0.088	0.112
4	0.116	0.186	0.116	0.101
5	0.116	0.099	0.088	0.101
6	0.104	0.123	0.122	0.112
7	0.116	0.130	0.109	0.107
8	0.116	0.117	0.102	0.124

Table 18 shows the weighted normalized performance rating

Table 18: Weighted Normalized Performance Rating

Weldment W	Mechanical Properties			
	Maximum		Minimum	
	UTS (MPa)	CVN (J)	BH (mm)	BW (mm)
0	0.0270	0.0360	0.0350	0.0260
1	0.0267	0.0294	0.035	0.0235
2	0.0225	0.0277	0.0313	0.0225
3	0.0239	0.0311	0.0238	0.0255
4	0.0267	0.0241	0.0313	0.0212
5	0.0267	0.0277	0.0238	0.0212
6	0.0239	0.0344	0.0329	0.0255
7	0.027	0.0364	0.0294	0.0225
8	0.027	0.0328	0.0275	0.0260

Table 19 shows the overall performance index of the Experts' responses and Degree of Utility.

Table 19: Overall Performance Index and Degree of Utility

Weldment Wi Where i=0,1,2,…n	$Si = \sum_{j=1}^{m} V_{ij}$	$Q_i = \frac{S_i}{S_0}$ Where $S_0 = W_0$	Rank
0	0.1240		
1	0.1144	0.9226	3
2	0.1040	0.8387	5
3	0.1023	0.8250	7
4	0.1033	0.8331	6
5	0.0994	0.8016	8
6	0.1147	0.9250	2
7	0.1130	0.9274	1
8	0.1130	0.9113	4

IV. DISCUSSION OF RESULTS

Table 1 shows the eight experimental welding runs made using the corresponding input parameters to produce the weldments whose mechanical properties constitute the output parameters. The output parameters comprise of ultimate tensile strength (UTS), absorbed impact energy (CVN), Bead height (BH) and Bead width (BW).

The mechanical test results of the weldments as obtained in Table 1 were given to five (5) Experts in the area of Manufacturing Engineering/welding technology with above 2 years working experience to rate/score the weldments according to the level of their quality using the Likert scale preference method. The average of scores made as a result of the Experts' evaluation process was recorded. The recorded average ratings/scores for each mechanical property are shown in Tables 2-6.

Tables 7 to 13 describe the various steps taken by applying the SWARA method in arriving at the average weight of each of the determined mechanical properties as contained in Table 1. This average weight is also known as the geometric mean of weight, as shown in Table 14. These weights were the actual weights used for the optimum selection process.

The optimum selection process was carried out by applying the additive ratio assessment (ARAS) method. By applying the ARAS method, it requires that average ratings of the expert's responses be obtained as shown in Table 15. Table 16 shows the normalized values of the average ratings. Table 17 and 18 express and contain the product of the normalized values of each of the weld properties and their corresponding weights. Table 19 contains the overall performance index of the Experts responses and the degree of utility. This performance index indicates that weldment 7 of the 8 weldments contained in this study, possesses the best weld properties, having a UTS of 395 MPa, Impact energy (CVN) of 250J, BH of 1.98mm and BW of 4.82. From the quality criterion which reveals that the higher the UTS and CVN, the better the weld quality and the smaller the BH and BW, the better the weld quality, perfectly fits the expression of the results obtained for each of the weld properties. Other Researcher who did their study in this area, the results obtained were compared with the ones obtained for this study. Ampaiboon et al. (2015) determined the UTS of a Mild steel (ST37- 2) weldment of 6 mm thickness and obtained a UTS of 57-551MPa. Gejendhiran et al (2019) determined the mechanical properties of 10mm Thick mild Steel and the Impact energy was obtained to be in the range of 170 J-180 J and UTS was found to be in the range of 375-392 MPa. Pondi et al (2018) in their study that produced a 10mm thick mild steel weldment, UTS determined were found to be in the range of 358-381 MPa. Yadav and Paswan (2019) took the measurements of weldments produced from ASTM A36 steel bead geometry of 9mm thickness and obtained BH in the range of 0.67mm – 6.67mm, and BW in the range of 1.68mm – 8.47mm. Comparing the output results in the study to the results from other Researchers, it is found that the results of this study falls within the range of values of results obtained from the study conducted by other Researchers.

V. CONCLUSIONS

In this study, the SWARA-ARAS method was used to select the appropriate and optimized process parameters that showed some promise in improving the quality of the welded joint. The SWARA-ARAS method appears to be novel in its application to the welding optimization process. This method has successfully optimized the welding parameters and its potency has been proven.

Weldment 7, which is found to possess the optimum welding parameters, has comparatively the highest ultimate tensile strength and impact strength and the least bead height and bead width. This weldment status confirms with the criteria that the larger the ultimate tensile strength and impact strength, the better the weld quality and the lower the bead height and width, the better the weld quality.

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