International Journal of Applied Science and Engineering Review

ISSN: 2582-6271

Vol.2 No.1; Jan-Feb 2021

APPLICATION OF SWARA – WASPAS INVESTIGATIVE MODEL TO BOOST MILD STEEL WELDMENT

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ABSTRACT

The incessant occurrence of weld failure in both domestic and industrial structures in Nigeria, resulting from poorly welded joints, has caused irredeemable losses to humans and properties. To mitigate against these failures, it is imperative to establish optimum process parameters that can improve mechanical properties of welded joints. The Step-wise Weight Assessment Ratio Analysis (SWARA) method, a multi-criteria decision making tool 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 Weighted Aggregates Sum Product Assessment (WASPAS) method is an exceptional blend of weighted sum model (WSM) and Weighted Product Model (WPM). This method makes use of linear normalization of decision matrix elements to achieve optimality. In this study, the SWARA-WASPAS method was embraced to assess the outcome of process parameters on the quality of mild steel welded joints. From applying the SWARA-WASPAS method, weldments six (6) was selected optimally to possess the best mechanical properties amongst the eight (8) experimental welded joints analysed, with bead penetration (BP) of 6.35mm, ultimate tensile strength (UTS) of 450MPa, heat affected zone (HAZ) width of 0.95mm and weld undercut (UC) of 0.05mm. This method has successfully optimized the mechanical properties of mild steel weldments.

KEYWORDS: Ultimate Tensile Strength (UTS), SWARA, WASPAS, weld undercut (UC), mild steel

1. INTRODUCTION

Failure of metal material has been a major point of discussion globally, for the reason that most of these failures result to accidents that leads to death. Some catastrophic accidents have been reported where heavy duty cranes used for lifting weights failed at welded joint due to poor weld quality. Bridges have disintegrated due to weld decay, this has made it imperative for this study to investigate and apply new methodologies in improving on the quality of weldments in order to prevent future failures of metal material and also increase the service life of these welded joints

One of the most trusted method used for repairing degraded mild steel material is by application of the welding process. Boumerzoug et al (2010) defined welding as the process of joining materials into one piece. Because steel is made up of metal alloy, it has good properties which can work well for building construction, bridge building, tool equipment, weapon production and more (Sacks and Bonhart, 2005) and (Smith and Hashemi, 2006). One major drawback for mild steel is its weakness against material degradation when its exposed to elevated services, especially after long-term exposure, this can be worsen with the presence of poorly finished weld (Malpally, 2014).. The Tungsten Inert Gas (TIG) process is one of the best welding process used by experts. During welding, it generates heat by an electric arc struck between a non-consumable tungsten electrode and the workpiece to fuse the parent metals in the joint area and produce a molten weld pool. The arc area is covered in an inert or reducing gas shield to protect the weld pool and the non-consumable electrode. TIG produces very high quality welds across a wide range of materials with thickness up to 8 or 10mm. it is particularly well suited to sheet material (Al-Qawabah et al, 2012).

There are other researchers that have worked in area of optimization of welding process parameters, such as Achebo and Odinikuku (2015) who optimized Gas Metal Arc Welding (GMAW) process parameters using standard deviation and multi-objective optimization on the basis of ratio analysis. Sarkar et al (2014) optimized welding parameters of submerged arc welding using analytic hierarchy process which is based on Taguchi method. Achebo and Ebhojiaye (2015) selected welding process parameters of gas metal arc welding using the metallographical methods. Optimization methods from these researchers have been used to produce good quality welded joints, but applying a novel method appears to be a welcomed development because researchers globally are developing and applying newer methods to optimize the process parameters that will produce the weldment with the best acceptable mechanical properties that would in turn improve welded joint strength.

In this study, the SWARA-WASPAS method was used to optimize the process parameters that are expected to produce the weldment with the best weld properties.

2. MATERIALS AND METHODS

2.1. Materials

120mm x 60mm x 5.5mm mild steel plates locally purchased, were used for this study. Tungsten inert gas welding machine with 100% Argon gas was used to weld the mild steel plates. Tensile test was conducted on all welded samples, to determine the "Ultimate Strength" or UTS of the material. The bead penetration was obtained by using the Planimeter, heat affected zone and weld undercut were also determined using the digitally calibrated Caliper. The process parameters considered are the current, voltage and gas flow rate.

2.2. Methods

2.2.1. SWARA Method

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To analyze the results obtained from the experimental process, the SWARA-WASPAS method was applied; a step by step approach is as listed herein under

Step 1. The criteria are sorted in descending order based on their expected significances.

Step 2. Starting from the second criterion, the respondent expresses the relative importance of criterion in relation to the previous (j-i) criterion, for each particular criterion. According to Kersuliene et al. (2010), this ratio is called the Comparative importance of average value, sj.

Step 3. Determine the coefficient k as follows

$$k_l = \begin{cases} 1 & j = 1 \\ s_j + 1 & j > 1 \end{cases} \quad (1)$$

Step 4. Determine the recalculated weight *qj* as follows

$$q_l = \begin{cases} 1 & j = 1 \\ \dfrac{k_{j-1} + 1}{k_j} & j > 1 \end{cases} \quad (2)$$

Step 5. The relative weights of the evaluation criteria are determined as follows

$$w_j = \frac{q_j}{\sum_{k=1}^{n} q_k} \quad (3)$$

where w denotes the relative weight of j-th criterion, n denotes number of criteria.

1.1.1. WASPAS Method

Every MCDM problem starts with the following decision/evaluation matrix:

$$x = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (4)$$

where m is the number of candidate alternatives, n is the number of evaluation criteria and X_{jj} is the performance of ith alternative with respect to jth criterion.

The application of WASPAS method, which is a unique combination of two well known MCDM approaches, i.e. weighted sum model (WSM) and weighted product model (WPM) at first requires linear normalization of the decision matrix elements using the following two equations:

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For beneficial criteria,

Where $\bar{x}_{ij}$ is the normalized value;

$$\bar{x}_{ij} = \frac{x_{ij}}{\max_i x_{ij}} \quad (5)$$

For non-beneficial criteria,

$$\bar{x}_{ij} = \frac{\min_i x_{ij}}{x_{ij}} \quad (6)$$

In WASPAS method, a joint criterion of optimality is sought based on two criteria of optimality. The first criterion of optimality, i.e. criterion of a mean weighted success is similar to WSM method. It is a popular and well accepted MCDM approach applied for evaluating a number of alternatives in terms of a number of decision criteria. Based on WSM method (MacCrimon, 1968), the total relative importance of *ith* alternative is calculated as follows:

$$q_i^{(1)} = \sum_{j=1}^{n} \bar{x}_{ij} wj \quad (7)$$

Where wj is weight (relative importance) of significance (weight) of *jth* criterion.

On the other hand, according to WPM method (Triantaphyllou and Mann, 1989), the total relative importance of *ith* alternative is computed using the following expression:

$$Q_i^{(2)} = \prod_{j=1}^{n} \left(\bar{x}_{ij}\right) wj \quad (8)$$

A joint generalized criterion of weighted aggregation of additive and multiplicative methods is then proposed as follows (Zavadskaset at., 2013a, 2013b):

$$Q_i = 0.5_i^{(1)} + (1-\lambda) Q_i^{(2)} = \lambda \sum_{j=1}^{n} \bar{x}_{ij} wj + (1+\lambda) \prod_{j=1}^{n} \left(\bar{x}_{ij}\right) wj \quad (9)$$

$\lambda = 0, 0.1, \ldots, 1$

Now, the candidate alternatives are ranked based on the Q values, i.e the best alternative would be that one having the highest Q value. When the value of λ is 0, WASPAS

Method is transformed to WPM, and when λ is 1, it becomes WSM method. Till date, WASPAS method has very few successful applications, only in location selection problems (Zolfani*etal*., 2013) and civil engineering domain (Dejus and Antucheviciene, 2013).

3. PRESENTATION AND DISCUSSION OF RESULTS

3.1. Presentation of Results

Table 1 shows the weld properties obtained from the mechanical test and measurements carried out for the BP, UTS, HAZ and UC.

Table 1: Weld Properties

Weldment, W	Mechanical properties			
	Maximum		Minimum	
	Bead Penetration BP(mm)	Ultimate tensile strength, UTS (MPa)	Heat Affected Zone HAZ (mm)	Weld undercut, (UC) (mm)
1	4.70	353	1.20	1.65
2	5.40	405	1.80	0.18
3	4.35	275	1.05	1.12
4	6.10	455	1.25	0.16
5	4.82	387	1.70	1.34
6	6.35	450	0.95	0.05
7	5.15	430	0.90	0.09
8	4.95	368	1.46	1.22

Table 2 shows the first expert assessment

Table 2: First Expert Assessment

Weld Ment	BP Likert Scale Score Criterion of 1 to 5		UTS Likert Scale Score Criterion of 1 to 5		HAZ Likert Scale Score Criterion of 1 to 5		UC Likert Scale Score Criterion of 1 to 5	
1	3	Average = 3.75	4	Average = 3.875	4	Average = 3.375	2	Average = 3.625
2	4		4		2		4	
3	3		3		3		3	
4	5		5		3		4	
5	3		3		2		3	
6	5		4		5		5	

7	4		4		5		5	
8	3		4		3		3	

For Criterion of 1 to 5: 1 = very poor, 2 = poor, 3 = good, 4 = very good and 5 = Excellent

Table 3 shows the second expert assessment

Table 3: Second Expert Assessment

Weld ment	BP Likert Scale Score Criterion of 1 to 5		UTS Likert Scale Score Criterion of 1 to 5		HAZ Likert Scale Score Criterion of 1 to 5		UC Likert Scale Score Criterion of 1 to 5	
1	2	Average = 3.250	3	Average = 3.000	3	Average = 3.375	2	Average = 2.875
2	4		2		3		2	
3	2		2		3		2	
4	3		2		4		4	
5	2		3		3		3	
6	5		5		5		4	
7	4		4		3		4	
8	4		3		2		2	

Table 4 shows the third expert assessment

Table 4: Third Expert Assessment

Weld ment	BP Likert Scale Score Criterion of 1 to 5		UTS Likert Scale Score Criterion of 1 to 5		HAZ Likert Scale Score Criterion of 1 to 5		UC Likert Scale Score Criterion of 1 to 5	
1	3	Average = 3.375	4	Average = 2,875	3	Average = 3.250	3	Average = 2.500
2	4		2		2		2	
3	4		2		2		2	
4	3		3		4		2	
5	4		3		4		3	
6	5		4		4		4	
7	3		3		3		2	
8	2		2		4		2	

Table 5 shows the final result of SWARA method in relation to first expert assessment

Table 5: Final Result of SWARA Method in relation to First Expert Assessment

Criterion	Pre-weight	Comparative importance of average value, S_j	Coefficient $K_j = S_j + 1$	Recalculated weight $W_j = \frac{K_{j-i}}{k_j}$	Weight $q_i = \frac{w_i}{\sum w_j}$
UTS	3.875	0	1	1	0.3020
BP	3.750	0.125	1.125	0.8889	0.2685
UC	3.625	0.125	1.125	0.7901	0.2386
HAZ	3.375	0.250	1.250	0.6321	0.1909
Total				3.3111	1.0000

Table 6 shows the final result of SWARA method in relation to second expert assessment

Table 6: Final Result of SWARA method in relation to Second Expert Assessment

Criterion	Pre-weight	Comparative importance of average value, S_j	Coefficient $K_j = S_j + 1$	Recalculated weight $W_j = \frac{K_{j-i}}{k_j}$	Weight $q_i = \frac{w_i}{\sum w_j}$
UTS	3.375	0	1	1	0.3094
BP	3.250	0.125	1.125	0.8889	0.2750
UC	3.000	0. 250	1. 250	0.7111	0.2200
HAZ	2.875	0. 125	1.125	0.6321	0.1956
Total				3.32321	1.0000

Table 7 shows the final result of SWARA method in relation to third expert assessment

Table 7: Final Result of SWARA Method in relation to Third Expert Assessment

Criterion	Pre-weight	Comparative importance of average value, S_j	Coefficient $K_j = S_j + 1$	Recalculated weight $W_j = \frac{K_{j-i}}{k_j}$	Weight $q_i = \frac{w_i}{\sum w_j}$
UTS	3.375	0	1	1	0.3327
BP	3.250	0.125	1.125	0.8889	0.2958
UC	2.875	0. 375	1. 375	0.6465	0.2151
HAZ	2.500	0. 375	1.375	0.4702	0.1564
Total				3.0056	1.0000

Table 8 shows the Geometric mean of weights obtained from the three Experts' Assessments

Table 8: Geometric mean of weights obtained from the three Experts' Assessments

Criterion	weight
BP	0.2921
UTS	0.2457
HAZ	0.2653
UC	0.1969

Table 9 show the WASPAS normalized decision making matrix

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Table 9: WASPAS Normalized Decision Making Matrix

Weld Ment W	maximum		minimum	
	BP	UTS	HAZ	UC
1	0.7402	0.7758	0.7500	0.0303
2	0.8504	0.8901	0.5000	0.2778
3	0.6850	0.6044	0.8571	0.0446
4	0.9606	1.0000	0.7200	0.3125
5	0.7591	0.8505	0.5294	0.0373
6	1.0000	0.9890	0.9474	1.0000
7	0.8110	0.9451	1.0000	0.5556
8	0.7795	0.8088	0.6164	0.0410

Table 10 shows WASPAS weighted normalized decision making matrix for Summarizing Part

Table 10: WASPAS Weighted Normalized Decision Making Matrix for Summarizing Part

Weld Ment W	maximum		minimum	
	BP	UTS	HAZ	UC
1	0.2162	0.1906	0.1990	0.0060
2	0.2484	0.2187	0.1327	0.0547
3	0.2001	0.1485	0.2274	0.0088
4	0.2806	0.2457	0.1910	0.0615
5	0.2217	0.2090	0.1405	0.0073

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6	0.2921	0.2430	0.2513	0.1969
7	0.2369	0.2322	0.2653	0.1094
8	0.2277	0.1987	0.1635	0.0081

Table 11 shows WASPAS weighted normalized decision making matrix for Multiplication Part

Table 11: WASPAS Weighted Normalized Decision Making Matrix for Multiplication Part

Weld Ment W	maximum		minimum	
	BP	UTS	HAZ	UC
1	0.9159	0.9395	0.9265	0.5023
2	0.9538	0.9718	0.8320	0.7771
3	0.8954	0.8836	0.9599	0.5421
4	0.9883	1	0.9165	0.7953
5	0.9226	0.9610	0.8447	0.5233
6	1	0.9973	0.9858	1
7	0.9406	0.9862	1	0.8907
8	0.9298	0.9492	0.8795	0.5332

Table 12 shows WASPAS Result for all the eight (8) responses, with their corresponding ranks.

Table 12: WASPAS Result

Weld Ment W	$0.5\sum_{j=1}^{n}\bar{x}_{ij}$	$0.5\prod_{j=1}^{n}\bar{x}_{ij}$	WPS	Rank
1	0.3059	0.2002	0.5061	5
2	0.3273	0.2996	0.6269	4
3	0.2924	0.2059	0.4983	7
4	0.3894	0.3602	0.7496	3
5	0.2893	0.31960	0.4853	8
6	0.4917	0.4916	0.9833	1
7	0.4219	0.4131	0.8350	2
8	0.2990	0.2069	0.5059	6

3.2. Discussion of Results

Table 1, shows that eight welding operations were done and their weldments were subjected to some mechanical tests and measurements which were clustered into two points, that is, maximum for properties with higher values leading to better weldment quality and minimum for properties with lower values leading to better weldment quality.

Table 2 shows the first expert evaluation of the test and measurement results in Table 1. This first expert evaluation was based on a Likert scale procedure of 1 -5 where scale. 5 represents excellent, 4 represents very good, 3 represents good, 2 represents poor whereas I represent very poor. The expert scores assigned by each expert were eventually converted into weights for each weld quality property (see Table 2 – 4). Tables 5 – 7, show the final results of the SWARA method application to the first, second and third experts. The SWARA method was used to determine the actual weights for each quality property used for determining the optimal process parameters. Table 8 shows the geometric mean of the weights calculated for each of the quality properties as evaluation by the three expert's as contained in Table 5 – 7. Table 9 shows the application process of the WASPAS method where the weldments quality processes were normalized. Table 10 shows WASPAS weighted normalized decision making matrix for Summarizing Part. It shows the product of the multiplication process of each normalized weldments quality property with the corresponding geometric mean of weights as contain in Table 8.

Table 11, shows the WASPAS weighted normalized decision making matric for multiplication part. In this case, the normalized value for each quality property is raised to the power of the corresponding weight. Table 12 contains the WASPAS result which is the combination of the summations of the value in Table 10 multiplied by 0.5 and product of the values in Table 11 multiplied by 0.5. From Table 12, it is found that weldments 6 is ranked first which implies that, it has the best weldments quality properties when compared to the other weldments properties. The weld quality properties of weldments 6 is shown in Table 1, it has a bead penetration 6.35mm, UTS of 450MPa, HAZ of 0.95mm and weld undercut value of 0.05mm. For bead penetration and weld ultimate tensile strength, it is established that the higher values of these properties, the better the quality.

Considering the Eight welding operations or runs made, weldments 6 has highest values of BP and the second to the top value of UTS. For the HAZ and UC, which belong to the criteria that the smaller the values the better the weld quality properties. In this study, for weldments 6, HAZ of 0.95mm is the smallest value when compared with the HAZ of weldments from other welding process. Also, the undercut of 0.05mm is the smallest of all the undercut measurements.

From the above comparative analysis, it is clear that weldments 6 possess the best quality properties.

4. CONCLUSION

This study focuses on selecting Tungsten inert gas welding process parameters optimally using the SWARA – WASPAS method. The SWARA – WASPAS method is a multi-criteria decision making tool used for prioritizing alternative criteria. In this study, the experimental design matrix was developed and weldments were made according to the layout of the matrix design.

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Mechanical test and measurements were done on the weldments and test results were modelled and processed using the SWARA – WASPAS method. From the eight weldments produced, the 6th weldment was optimally selected to have the best mechanical properties. These properties conform to the values obtained in other literature.

In this study, the SWARA – WASPAS method has successfully optimized the welding process parameters.

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