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Performance Evaluation of Analytic Hierarchy Process Method in the Optimization of Welding Parameters

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ABSTRACT: Obtaining an optimal weld with the required properties is important, as it impacts directly on the durability and lifespan of the product which are factors considered in accessing its quality. This study focuses on the evaluation of the performance of Analytic Hierarchy Process (AHP) method in the optimization of welding parameters. Three input parameters; weld current, arc voltage, and gas flow rate were selected for this study, together with the following responses; tensile strength, hardness, and yield strength. From the results of the analysis using AHP, the following were obtained; arc voltage 25volts, weld current 190 amp, and gas flow rate of 15lt/min, has the highest weight of 0.463 equivalent to 43%.

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Welding provides an excellent alternative method for joining or fabrication of reliable components or equipments for the manufacturing industry through its application which cuts across critical structures from boilers and pressure vessels, offshore usage to water turbines and repairs of steel products (Sada and Achebo, 2022). Its advantages clearly outweigh the use of bolts, riveting, and other mechanical joining methods. However, challenges such as environmental conditions, skilled workers, and the selection of the ideal parameters remain a critical for manufacturers and users. According to (Sinebe and Enyi, 2024), and (Sada *et al.*, 2024), the challenges mentioned above, can be addressed if the right choice of welding parameters is made, as these serves as a prerequisite for achieving optimal results or performance. Based on these challenges, manufacturers are now saddled with developing sound mechanical components through the derivation of acceptable techniques. Studies shows that the application Multi-Criteria Decision-Making (MCDM), has been widely applied in achieving successful and reliable solution in solving decision related problems (Ravisankar *et al.*, 2006; Datta *et al.*, 2008; Sahu *et al.*, 2017)). With the use of a Multi-Criteria Decision-Making approach, the selection of the best decision among the various alternatives through ranking has been achieved (Sada, 2018; Sada *et al.*, 2021).

MCDM approaches are powerful tools used in evaluating problems with the process of making decisions characterized with multiple criteria for finding a compromise solution. The selection of the most suitable alternatives from the obtained (or considered) ones can be faced as a MCDM problem, in which each alternative is assessed according to a set of criteria (Majumder, 2017). Among the numerous MCDM method developed to solve real

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world decision problems, Analytic Hierarchy Process (AHP) Method has been identified as effective and capable of resolving weld parameter decisions (Majumder *et al.*, 2022). Hence, this study evaluates the performance of the analytic hierarchy process (AHP) method in the optimization of welding parameters.

MATERIALS AND METHOD

Mild steel plate of 10 mm thickness was cut into a dimension of 120x30 mm (length x width) each as shown. Sand paper was used to smoothen each of the two specimen to eliminate all possible coatings, corrosion or rust that may have accumulated on the material. The two steel plates were chamfered at 30 degrees each with 2mm depth, after which, fusion welding was used to weld the chamfered section together. The milling of the angle was done using a vertical milling machine. The welding was carried out with the plates properly clamped to avoid misalignment during welding process. To perform the welding experiment, an experimental design with 6 experimental runs, was developed to carry out the experiment in an organise order, with variable voltages ranging from 15-25V, variable currents ranging from 90-180A and variable gas flow rates ranging from 12-18 L/min as presented in Table 1.

Table 1: Welding Input Variables

Weld Runs	Current (amp)	Voltage (V)	Gas Flow Rate (L/min)
1	90	15	12
2	100	15	15
3	110	15	18
4	120	20	12
5	130	20	15
6	140	20	18

Prior to welding, surface of the samples to be welded were cleaned using acetone in order to eliminate surface contamination, and welding was applied to fuse the two flat plates together.

Materials: This section presents the description of the various types of materials required for the analysis and determination of the responses. Materials needed to achieve the aim and objectives highlighted in this study are listed as follows; 10 mm AISI 1020 mild steel plate, Tungsten inert gas welding machine, Argon shielding gas, Tensometer, Vertical milling machine for milling the angles, G-clamp for clamping the work pieces, Welding electrode.

Analytic Hierarchy Process (AHP) Method: AHP belongs to those method with a cardinal level of information on criteria preferences based on a pairwise comparison (Saha and Mondal 2017). AHP consists of the decomposition of complex MCDM problems into partial components, which create the hierarchical structure of the problem. The Analytic Hierarchy Process (AHP) Method begins with the following steps (Maghsoodloo *et., al.* 2004; Arunachalam 2020);

1. *Develop hierarchical framework* : The three-level hierarchical framework was defined (Figure 1).

2. *Construct pairwise comparison matrix:* Preferences between individual criteria are shown in the so-called pairwise comparison matrix (Saaty's matrix) as shown in Table 3.5. Saaty's matrix $S = (s_{ij})$ is a matrix that contains elements $s_{ij}.S_{ij}$ expresses the intensity of the preference between the objects k_i and k_j. It holds that if the object k_i (the object in the row) is more important than k_j (the object in the column), then s_{ij} ∈ {1, 2, 3, 4, 5, 6, 7, 8, 9}, on the other hand $s_{ij} = \frac{1}{s_{ji}}$. The following formula is used to construct Saaty's matrix (Saaty 2008).

$$\begin{matrix} s_i \\ s_j \end{matrix} \begin{pmatrix} 1 & s_{ij} \\ 1/s_{ji} & 1 \end{pmatrix} \qquad (2)$$

Where: k_i; k_j are criteria or alternatives; s_{ij}; $1/s_{ji}$ expresses the intensity of the preference between the objects $k_{i,\text{ and}}$ k_j.

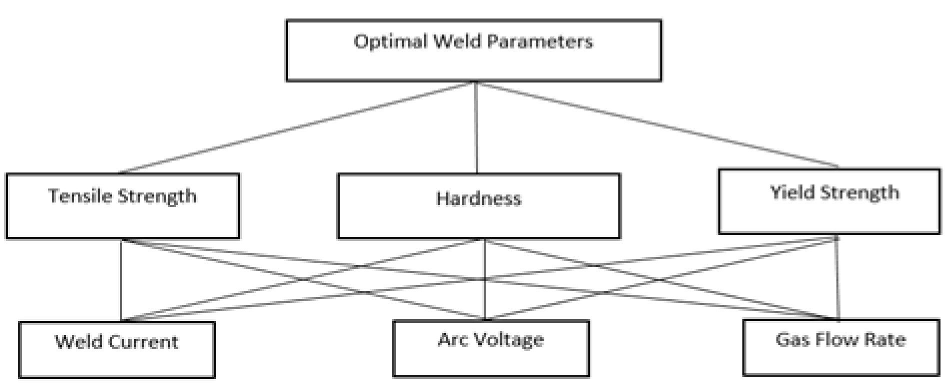

Fig. 1: Hierarchical framework

3. Perform judgement for pairwise comparison: The result of this step determines the weights of individual criteria (if criteria are compared) or the utility of the individual alternatives with respect to a given criterion (if alternatives are compared). Saaty defined a procedure which is based on the calculation of the eigenvector of a matrix according to the following formula.

$$s.v = \lambda_{max}.v \quad (3)$$

Where: S Saaty's matrix; v eigenvector of Saaty's matrix; λ_{max} the largest eigenvalue of Saaty's matrix. The values of the eigenvector must be standardized. This method of calculation is the most complex of all. Precisely because of its complexity, it is used only in specialized decision support programs. The geometric mean method is considered to be a simpler method that produces almost identical results, and for which specialized programs are not needed.

$$G_i = \sqrt[n]{\Pi_{j=1}^{n} s_{ij}} \quad (4)$$

Where: G_i geometric mean expresses the weights of individual criteria or determines the utility of individual alternatives; s elements of Saaty's matrix; n number of criteria or alternatives.

4. Check for consistency: Consistency was described within the definition of the three stages of the AHP method. The consistency ratio expresses the level of consistency (Saaty 2000).

$$CR = \frac{CI}{RI} \quad (5)$$

$$CR = \frac{\lambda_{max} - n}{n - 1} \quad (6)$$

Where: CR the consistency ratio; CI the consistency index; RI the random index; λ_{max} the largest eigenvalue of Saaty's matrix; n the number of objects - criteria/alternatives

The random index was obtained by generating a large number of reciprocal random matrices (matrix elements came from a cardinal scale) and then averaging the eigenvalues of the matrices. A value of 1.56 was set for the number of 13 objects (the number of criteria). A value of 1.40 was set for the number of 8 objects (the number of alternatives – potential business partners) (Saaty 2000). Steps 3 – 6 are performed for all levels of the hierarchy. By multiplying the utility of the individual alternatives with respect to the given criteria by the weights of these criteria, the total utility of the given alternative is determined. The final step is the selection of the optimal alternative based on the value of total utility.

RESULTS AND DISCUSSION

The result from the experiment is tabulated as presented in Table 3, for further analysis using the Analytic Hierarchy Process (AHP) Method.

Table 2: Experimental Results of the Weld Responses

Weld Runs	Current (amp)	Voltage (V)	Gas Flow Rate (L/min)	Tensile Strength (MPa)	Hardness BHN	Yield Strength (MPa)
1	90	15	12	496.5	190.2	223.9
2	110	15	15	496.3	180.4	250.3
3	130	20	18	496.4	181.6	202.3
4	150	20	12	495.9	189.3	202.3
5	170	25	15	496.3	179.6	241.1
6	190	25	18	496.2	189.2	230.7

AHP: For optimizing the MIG condition: This section presents the determination of the optimal welding parameters using the Analytic Hierarchy Process (AHP) Method. From Table 1, the six alternative conditions to be considered for optimization and their experimental observations are obtained.

Determining the Comparison Matrix, and the Priority Vector (Eigen): With the hierarchy established as shown in Fig. 2, the criteria must be evaluated in pairs so as to determine the relative importance between them and their relative weight to the global goal. Table 3 shows the relative weight data between the criteria that have been determined.

Table 3: Condition selection criteria

Criteria No.	Criteria
C1	Tensile Strength
C2	Hardness
C3	Yield Strength

This begins with the determination of the relative weight of the responses which forms the main criteria. On the basis of the three criterias adopted for the study, the AHP is constructed, and the pair-wise comparison matrix for criteria for this problem of selection of optimum parametric condition is given in Table 4. With the comparison matrix for the response criteria obtained, normalization is performed to enable each criterion to be interpreted and given relative weights. Table 5, shows the normalized results obtained by dividing each table value by the total the total column value.

Table 4: Comparison Matrix for the Response Criteria

Criteria.	**Tensile Strength**	**Hardness**	**Yield Strength**
Tensile Strength	1	1/3	1/3
Hardness	3	1	1/3
Yield Strength	3	3	1

The contribution of each criterion to the organizational goal is determined by calculations made using the priority vector (or Eigenvector). The Eigenvector shows that the relative weights between each criterion is obtained in an approximate manner by calculating the arithmetic average of all criteria. It can be observed that all values from the vector sums to one (1). The exact calculation of the Eigenvector is determined only on specific cases.

Table 5: Comparison Matrix for ACME's Group of Criteria after Normalization

Criteria.	**Tensile Strength**	**Hardness**	**Yield Strength**
Tensile Strength	1	1/3	1/7
Hardness	3	1	1/5
Yield Strength	7	5	1
Total sum	11	6.33	1.343
Tensile Strength	1/11=0.091	0.33/6.33=0.05	0.143/1.343=0.107
Hardness	3/11=0.273	1/6.33=0.158	0.2/1.343=0.149
Yield Strength	7/11=0.636	5/6.33=0.790	1/1.343=0.745

This approximation is applied most of the times in order to simplify the calculation process, since the difference between the exact value and the approximate value is less than 10% (Singaravel and Selvaraj, 2017).

Table 6: Eigenvector Calculation (Response Criteria)

Criteria.	**Eigenvector Calculation**	**Eigenvector**
Tensile Strength	[0.091+0.05+0.107]/3	0.0826=8.26%
Hardness	[0.273+0.158+0.149]/3	0.193=19.3%
Yield Strength	[0.636+0.7904+0.745]/3	0.724=72.4%

The Eigenvector values obtained determine for each criterion their participation or weight to the total result of the goal. For example, the yield strength has a weight of 72.4% (exact calculation of the Eigenvector) relative to the total goal. A positive evaluation on this factor contributes approximately 7 (seven) times more than a positive evaluation on the (weight 8.6%). The next step is to look for any data inconsistencies. The objective is to capture enough information to determine whether the decision makers have been consistent in their choices (Tasrif *et al.*, 2006). For example, if the decision makers affirm that the tensile strength criteria are more important than the hardness criteria and that the hardness criteria are more important than the yield strength criteria, it would be inconsistent to affirm that the yield strength criteria are more important than the tensile strength criteria (if A>B and B>C it would be inconsistent to say that A<C). The inconsistency index is based on Maximum Eigenvalue, which is calculated by summing the product of each element in the Eigenvector (Table 6) by the respective column total of the original comparison matrix (Table 5). Table 7, demonstrates the calculation of Maximum Eigenvalue (λMax).

Table 7: Calculation of Maximum Eigenvalue

Criteria.	**Tensile Strength**	**Hardness**	**Yield Strength**
Eigenvector	0.083	0.193	0.724
Total Sum	11	6.33	1.343
Max Eigenvalue (λ_{Max})	[0.086x11] + [0.287 x 4.33] + [0.669 x 1.476] = 3.107		

For consistency index CI = $\frac{\lambda_{max}-n}{n-1} = \frac{3.107-3}{3-1} = \frac{0.107}{2} = 0.054 =$

Where CI is the Consistency Index and n is the number of evaluated criteria.

To verify the adequacy of the Consistency Index (CI), Saaty (2008) suggests what has been called Consistency Rate (CR), which is determined by the ratio between the Consistency Index and the Random Consistency Index (RI). The random index is a fixed value obtained based on the number of criterias evaluated. For 3 criterias, the RI is 0.58 according to SAATY Table. The matrix will be considered consistent if the resulting ratio is less than 10%. The calculation of the Consistency Rate (Saaty, 2008) is given by the following formula

$$CR = \frac{CI}{RI} < 0.1 \sim 10\%$$

$$CR = \frac{0.0535}{0.58} = 0.0922 \sim 9.22\%$$

For the response criteria, with the Consistency Rate 0.0922 = 9.22% which is less than 10%, the matrix is considered to be consistent. And from the result of the Comparison Matrix, the contribution of each criterion to the goal shows that the yield strength criteria contributes the highest with a score of 72.4% to the goal.

Pairwise Comparison for Sub-Criteria: To demonstrate the priority results for the sub-criteria for each one of the criteria groups, and their respective inconsistency indices. The pairwise comparison is performed accordingly for each of the criterias as shown in Tables 8 – 10. From the analysis, the alternative labeled E6 with the following corresponding parameters of arc voltage 25volts, weld current 190 amp, and gas flow rate of 15lt/min, has the highest weight of 0.463 equivalent to 43%.

Table 8: Pair-wise comparison for the Tensile Strength

Tensile Strength							
Weld Runs	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**Weight**
E1	1	1/1	1/1	1/3	1/7	1/9	0.043799
E2	1	1	1/3	1/1	1/5	1/9	0.051093
E3	1	3	1	1/5	1/5	1/9	0.060309
E4	3	1	5	1	1/3	1/5	0.115196
E5	7	5	5	3	1	1/3	0.245169
E6	9	9	9	5	3	1	0.484433
	CI=22	20		λ_{Max}=10.			

Table 9: Pair-wise comparison for the Hardness

Hardness							
Weld Runs	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**Weight**
E1	1	1	1/5	1/3	1/5	1/9	0.037769
E2	1	1	1/3	0.2	1/7	1/9	0.035388
E3	5	3	1	1/3	1/3	1/5	0.101017
E4	3	5	3	1	1/3	1/5	0.137806
E5	5	7	3	3	1	1/3	0.231842
E6	9	9	5	5	3	1	0.456178
	CI=22	20		λ_{Max}=10.			

Table 10: Pair-wise comparison for the Yield Strength

Yield Strength							
Weld Runs	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**Weight**
E1	1	0.2	0.33333	0.33333	0.14286	0.11111	0.031092
E2	5	1	1	1	0.2	0.2	0.091238
E3	3	1	1	0.33333	0.2	0.14286	0.064124
E4	3	1	3	1	0.33333	0.2	0.103121
E5	7	5	5	3	1	0.33333	0.261885
E6	9	5	7	5	3	1	0.44854
	CI=22	20		λ_{Max}=10.			

Table 11: Pair-Wise Comparison Matrices for the Criteria and Alternatives

Weld Runs	**Local Weigh**			**Global Weight**
	Tensile Strength (MPa)	**Hardness BHN**	**Yield Strength (MPa)**	
	0.083	0.193	0.724	
E1	0.0437993	0.0377686	0.0310923	0.037553
E2	0.05109261	0.0353883	0.0912377	0.05924
E3	0.06030939	0.1010169	0.0641239	0.07515
E4	0.11519626	0.1378056	0.103121	0.118708
E5	0.24516942	0.2318424	0.2618849	0.246299
E6	0.48443302	0.4561783	0.4485403	0.463051

Conclusion: The evaluation of Analytic Hierarchy Process (AHP) method in determining the optimal weld parameters shows that for mild steel weld, arc voltage 25volts, weld current 190 amp, and gas flow rate of 15lt/min, has the highest weight of 0.463 equivalent to 43%. This is in conformity with the results observed from the experiments. This findings shows that the determination of the right sets of parameters for a good weld joint by arc welding or any other processes having large number of parameters can be obtained.

Declaration of Conflict of Interest: The authors declare no conflict of interest (if none).

Data Availability Statement: Data are available upon request from the first author or corresponding author or any of the other authors.

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