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Evaluating the Mechanical Properties of Tensile Strength and Hardness after Optimization during a Mild Steel Metal Plate Welding Operation

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ABSTRACT: The choice of choosing between alternatives is a prerequisite for a chain of different engineering selection problems, such as process selection, machine selection, tools selection, material handling equipment selection, supplier selection. Hence, the objective of this paper was to evaluate the mechanical properties of tensile strength and hardness after optimization using the application of Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) during a steel metal welding process. The result obtained reveals that the weld current 170amp, weld voltage 20v, filler rod diameter 22mm and gas flow rate 3.3lit/min gave the optimal tensile strength of 496.5N/mm2 and Hardness of 190.2.

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Decision making is as it relates to dealing with conflicts, is not limited to any sector of the world, as it can be witness with policy makers, economist, technology developers, and down to manufacturers. The choice of choosing between alternatives is a prerequisite for a chain of different engineering selection problems, such as process selection, machine selection, tools selection, material handling equipment selection, supplier selection (Abbasi *et al.*, 2012). The welding industry, which is saddled with aiding manufacturers in the production of modern mechanical equipments through quality joints has been overwhelmed with the challenge of choosing the right welding parameters (Ghazvinloo *et al.*, 2010). The choice of the welding parameters plays a critical role in minimizing the difficulties encountered during welding and guarantees the strength of the weld (Bodude and Momohjimoh 2015). Deciding rightly on these factors or parameters, is crucial, as this can result in the optimal performance of the joint (Deng *et al.*, 2014). A key technique which has been widely applied in achieving successful and reliable structures in these industries is the application of MCDM. MCDM approaches are powerful tools used in evaluating problems with the process of making decisions characterized with multiple criteria for finding a compromise solution (Shukla, and Shukla 2019). These methods have a strong decision support focus and interact with other disciplines such as intelligent systems dealing with uncertainty (Kumar *et al.*, 2017). With the use of a Multi-Criteria Decision-Making approach, a technique widely used in decision-making problems, the selection of the best decision among the various alternatives through

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ranking can be achieved (Varatharajulu *et al.,* 2022). These techniques have become necessary in order to eliminate "guess work" often employed by welders in specifying weld parameters in addition to keep cost at a minimum (Sada, 2018). Among the numerous MCDM methods developed to solve real world decision problems, Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) continues to work satisfactorily across different application areas. Nikolic *et al.* (2012) used the TOPSIS approach to find the best electric arc welding process for the aluminum alloy AlMgSi. The TOPSIS methodology was applied by Park and Lee (2005) in laser welding operations with digital manufacturing technologies. For multiple attribute decision making situations, Li (2009) assessed the efficiency of two relative ratio approaches, VIKOR and TOPSIS.

In TOPSIS the optimum solution is the one having the smallest Euclidian distance from the ideal solution and largest from the negative ideal solution. It has high consistency, less computation effort and provides a more realistic form of modelling. Therefore, the objective of this paper is to evaluate the mechanical properties of tensile strength and hardness after optimization using the application of Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) during a steel metal welding process.

MATERIAL AND METHOD

In order to produce weld specimens, a 6mm thick mild steel plate was obtained for the experiment and cut to dimensions of 50mm x 100mm with the aid of a power hack saw and grinded at the edges to smoothen the surfaces to be welded. The welding process was performed at the mechanical workshop of the Petroleum Training Institute, Effurun, Delta State, with the grinding and cleaning of the edges of the specimens. With the specimens prepared and the weld equipment setup, the pieces of steel cut (coupons) were paired and aligned on a table with the use of an angular Iron, after which the welding circuit was initiated. With heat input taken into consideration, the following inputs current, voltage, gas flow rate was chosen for this experiment.

Optimization: The application of Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) was used during a steel metal welding process as adopted from Wei *et al.*, (2015) with the normalization matrices presented in equations 1 to 7. Construction of normalized decision matrix, to transform the various attribute dimensions into non-dimensional attributes, which allows comparison across the attributes is given as shown in equation 1..

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \forall_j \; for \; i = 1, \dots, m; \; j = 1, \dots, n \qquad (1)$$

Where r_{ij} and x_{ij} are the elements of normalized and original decision matrix respectively.

Construction of weighted normalized decision matrix i.e.,

$$vij = rij * wj \, \forall_{i,j} \qquad (2)$$

$$= \begin{pmatrix} v_{11} & v_{12} & \cdots & v_{1j} & \dots & v_{1n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ v_{i1} & v_{i2} & \vdots & v_{ij} & \vdots & v_{in} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ v_{m1} & v_{m2} & \dots & v_{mj} & \dots & v_{mn} \end{pmatrix} = \begin{pmatrix} w_1 r_{11} & w_2 r_{12} & \cdots & w_j r_{1j} & \dots & w_n r_{1n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ w_1 r_{i1} & w_2 r_{i2} & \vdots & w_j r_{ij} & \vdots & w_n r_{in} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ w_1 r_{m1} & w_2 r_{m2} & \dots & w_j r_{mj} & \dots & w_n r_{mn} \end{pmatrix}$$

Where w_j is the assigned weight to attribute j.

Weight Allocation: Ozturk and Batuk (2011) said that the derivation of weights is a central step in eliciting the decision-maker's preferences. A weight can be defined as a value assigned to an evaluation criterion that indicates its importance relative to other criteria under consideration. As the value of the weight increases, the criterion's importance in the overall utility also increases.

The weights are usually normalized to sum to 1. In the case of *n* criteria, a set of weights is defined as in equation 3:

$$W_{ij} = (W_1, W_2, ---, W_j, --, W_n), \qquad \sum w_{ij} = 1 \qquad (3)$$

The simplest method to assess the importance of weights is to arrange them in ranked order. Every criterion under consideration is ranked in the order of the decision-maker's preference.

Once the ranking is established for a set of criteria, several procedures are available to generate numerical weights from rank order information (Malczewski, 1999).

In the rating method, the decision-maker estimates weights based on a predetermined scale; for example, a scale of 0 to 100 can be used (Malczewski, 1999). Rating weights were calculated according to Equation (2).

$$W_{ij} = \frac{w}{\sum_{j-1}^{i=0} w} \qquad (4)$$

Kaur *et al* (2009) said that the weights of bands are also normalized by summing up the total and then dividing the individual weight of the band by this total.

Wu and Olson (2006) said that in decision analysis, these weights reflect relative criterion importance (as long as scale differences are eliminated through standardization).

Here, they are interested in the relative value of each attribute in explaining the outcome of each case. These *m* weights *wi* will be between 0 and 1 and will have a sum of 1 as presented in Equations 5, 6, and 7.

Determination of ideal (A^+) and negative-ideal (A^-) solutions i.e.,

$$A^+ = \{(max_j\, v_{ij} | i \in I), (min_j v_{ij} | i \in I'); \forall_j\} = \{v_1^+,$$

$$A^- = \{(min_j\, v_{ij} | i \in I), (max_j v_{ij} | i \in I'); \forall_j\} = \{v_1^-,$$

Where I and I' are associated with benefit and cost attributes respectively.

Calculate of separation measure i.e.,

$$S_i^+ = \sqrt{\sum_{i=1}^{n} (V_{ij} - V_i{}^+)^2}\ \forall_j \qquad (5)$$

$$S_i^- = \sqrt{\sum_{i=1}^{n} (V_{ij} - V_i{}^-)^2}\ \forall_j \qquad (6)$$

Calculation of relative closeness to the ideal solution i.e,

$$C_j^+ = \frac{s_i^+}{s_i^+ + s_i^-} \qquad (7)$$

Ranking of alternatives based on C_i^+ values

RESULTS AND DISCUSSION

The result obtained from the experiment, is recorded and tabulated as shown in Table 1.

Optimization of Experimental Results using TOPSIS: The TOPSIS technique is applied to the results obtained from the experiment to determine the best parameters to choose for optimum tensile strength and hardness. To achieve this aim,

Step 1: The first step in the TOPSIS analysis is the formation of the decision matrix using equation 2. The decision matrix is presented in Table 2.

Table 1: Experimental Result for the Mild steel welded plate

Exp No	Current (Amp)	Voltage (Volt)	Gas flow Rate (L/min)	Filler Rod (mm)	Tensile Strength (MPa)	Hardness BHN
1	170	20	22	3.2	496.5	190.2
2	170	20	22	3.2	496.3	189.4
3	170	20	22	3.2	496.4	189.6
4	170	20	22	3.2	495.9	189.3
5	170	20	22	3.2	496.3	189.6
6	170	20	22	3.2	496.2	189.2
7	110	20	22	3.2	496.8	173.4
8	230	20	22	3.2	489.9	186.5
9	170	10	22	3.2	485.9	179.2
10	170	30	22	3.2	483.4	189.4
11	170	20	18	3.2	462.3	171.3
12	170	20	26	3.2	490.2	191.2
13	170	20	22	2.4	480.35	192.3
14	170	20	22	2.4	478.2	174.5
15	140	15	20	2.4	468.7	182.4
16	200	15	20	2.4	469.6	184.2
17	140	25	20	2.4	460.3	181.3
18	200	25	20	2.4	486.35	185.4
19	140	15	24	2.4	494.6	190.5
20	200	15	24	2.4	496.1	185.4

The table 1, shows results for each of the (20) twenty experimental run for the responses; tensile strength and hardness of the welded plate.

Step 2 and 3: This is then followed by the formation of a weighted normalized decision matrix using equations 3, 4 and 5. The determination of ideal (A^+) and negative-ideal (A^-) solutions are also carried. The results of these two steps are shown in the Table 3 and Table 4.

Step 4: The separation measure, the variance between the target alternative to the ideal and the negative-ideal solutions are calculated.

The ranking of the results shows that the optimal parameter corresponds with the 1st experimental run.

Table 2: Nnormalized Decision Matrix

Table 1a			Table 1b: Normalised Value	
Samples	Tensile	Hardness	R_{ij} (Tensile)	R_{ij} (Hardness)
1	246512.25	36176.04	0.187076065	0.188459922
2	246313.69	35872.36	0.187000707	0.187667241
3	246412.96	35948.16	0.187038386	0.187865412
4	245916.81	35834.49	0.186849991	0.187568156
5	246313.69	35948.16	0.187000707	0.187865412
6	246214.44	35796.64	0.186963028	0.187469071
7	246810.24	30067.56	0.187189102	0.17181362
8	240002.01	34782.25	0.184589253	0.184793772
9	236098.81	32112.64	0.183082095	0.177560558
10	233675.56	35872.36	0.182140121	0.187667241
11	213721.29	29343.69	0.174189859	0.169732832
12	240296.04	36557.44	0.18470229	0.189450774
13	230736.1225	36979.29	0.180990912	0.19054071
14	228675.24	30450.25	0.180180814	0.172903556
15	219679.69	33269.76	0.176601313	0.180731282
16	220524.16	33929.64	0.176940423	0.182514814
17	211876.09	32869.69	0.17343628	0.179641345
18	236536.3225	34373.16	0.18325165	0.183703836
19	244629.16	36290.25	0.186360165	0.188757178
20	246115.21	34373.16	0.186925349	0.183703836
$\sum x_{ij}^2$	7043719.488	1018551.54		
$\sqrt{\sum x_{ij}^2}$	2654.000657	1009.233145		

Table 3: Results of weighted normalized decision matrix

Determination of Weight Value			Total	Ideal best (K+) and the ideal worst (K-) values	
Weight	0.625	0.375	1	By Sort Max-Min	
Samples	Tensile	Hardness		Tensile	Hardness
1	0.116922541	0.070672471		0.116923	0.070672
2	0.116875442	0.070375215		0.116875	0.070375
3	0.116898991	0.070449529		0.116899	0.070450
4	0.116781245	0.070338059		0.116781	0.070338
5	0.116875442	0.070449529		0.116875	0.070450
6	0.116851893	0.070300902		0.116852	0.070301
7	0.116993189	0.064430108		0.116993	0.064430
8	0.115368283	0.069297665		0.115368	0.069298
9	0.114426309	0.066585209		0.114426	0.066585
10	0.113837575	0.070375215		0.113838	0.070375
11	0.108868662	0.063649812		0.108869	0.063650
12	0.115438931	0.07104404		0.115439	0.071044
13	0.11311932	0.071452766		0.113119	0.071453
14	0.112613009	0.064838834		0.112613	0.064839
15	0.11037582	0.067774231		0.110376	0.067774
16	0.110587765	0.068443055		0.110588	0.068443
17	0.108397675	0.067365505		0.108398	0.067366
18	0.114532281	0.068888938		0.114532	0.068889
19	0.116475103	0.070783942		0.116475	0.070784
20	0.116828343	0.068888938		0.116828	0.068889
	3.422439337	2.052622837			

Table 4: Ideal (A^+) and negative-ideal (A^-) solutions

BY SORT MAX-MIN, Ideal best (K+) and the ideal worst (K-) values		
	Tensile	Hardness
MAX	0.1169932	0.0714528
MIN	0.1083977	0.0630925

The optimal welding experimental result corresponding to the assigned weight of each attribute and obtained reveals that the weld current 170amp, weld voltage 20v, filler rod diameter 22mm and gas flow rate 3.3lit/min gave the optimal tensile strength of 496.5N/mm2 and Hardness of 190.2.

Tables 5 and Table 6 presents the Calculation of separation measure as in step 4 and Ranking of Results as in Step 5: Ranking of alternatives based on C_i^+ values respectively

Table 5 (Step 4): Calculation of separation measure

	values of Euclidian distance		**Performance score**	
	S- =∑ (rij-S+)^2	Xi=√(s-/(s- - s+))		
	S+	S-	s-/(s- - s+)	Xi=√(s-/(s- - s+))
1	0.0000006	0.000130130	0.99530	0.997649
2	0.0000012	0.000124911	0.99068	0.995329
3	0.0000010	0.000126399	0.99203	0.996007
4	0.0000013	0.000122783	0.98962	0.994797
5	0.0000010	0.000125999	0.99197	0.995975
6	0.0000013	0.000123435	0.98921	0.994588
7	0.0000493	0.000075672	0.60543	0.778091
8	0.0000073	0.000087094	0.92281	0.960631
9	0.0000303	0.000048544	0.61584	0.784752
10	0.0000111	0.000082631	0.88140	0.938827
11	0.0001269	0.000000532	0.00418	0.064642
12	0.0000026	0.000112807	0.97762	0.988745
13	0.0000150	0.000092189	0.86000	0.927364
14	0.0000629	0.000020819	0.24859	0.498584
15	0.0000573	0.000025832	0.31066	0.557365
16	0.0000501	0.000033425	0.40024	0.632645
17	0.0000906	0.000018259	0.16775	0.409570
18	0.0000126	0.000071233	0.84940	0.921631
19	0.0000007	0.000124404	0.99428	0.997135
20	0.0000066	0.000104675	0.94068	0.969888

Step 5: Ranking of alternatives based on C_i^+ values

Table 6: Ranking of Results

	Performance score		Ranking
	s-/(s- - s+)	Xi=√(s-/(s- - s+))	
1	0.99530	0.997649	1
2	0.99068	0.995329	5
3	0.99203	0.996007	3
4	0.98962	0.994797	6
5	0.99197	0.995975	4
6	0.98921	0.994588	7
7	0.60543	0.778091	21
8	0.92281	0.960631	12
9	0.61584	0.784752	20
10	0.88140	0.938827	13
11	0.00418	0.064642	30
12	0.97762	0.988745	8
13	0.86000	0.927364	14
14	0.24859	0.498584	26
15	0.31066	0.557365	24
16	0.40024	0.632645	22
17	0.16775	0.409570	28
18	0.84940	0.921631	15
19	0.99428	0.997135	2
20	0.94068	0.969888	10

Conclusions: The application of TOPSIS method has been successfully applied in analysing the data obtained from the welding experiment performed to determine the optimal welding parameters. The following input parameters weld current, arc voltage, and gas flow rate were considered, and the response parameter considered are tensile strength, and hardness. With the application of TOPSIS, the optimal results corresponding a combination of input parameters were 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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