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Selection of Optimal Process Parameters for a Mild Steel Weld using Technique for Order of Preference by Similarity to Ideal Solution

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ABSTRACT: Welding is a major operation in many industries such as production and manufacturing, oil and gas, amongst others. Obtaining an optimal weld with the required properties; tensile strength and hardness is of high importance. The work used the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to select the optimal process parameters for a mild steel weld by employing five (5) standard steps in ranking 30 experimental steps. The result obtained gave an optimal tensile strength and hardness of 496.5MPa and 190.2 respectively for a combined input parameters of 170Amp, 20volts, 22l/min, and 3.2mm. These data is very important as it will provide the necessary information for evaluating the durability and lifespan of the weld product which are factors considered in assessing its quality.

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In the fabrication and manufacturing industry, welding is a key process of joining metals as an excellent alternative method to casting, forging, bolting or riveting of joints. With welding, the joining of metals of even different properties is made possible to have them act as a single piece through the application of thermal energy. Its application ranges from manufacturing of vastly different components such as pressure vessels, ships, offshore structures, or bridges to the repair of most products made of metal (Richards 2014). The choice of the welding input parameters is very critical in minimizing the difficulties encountered during welding and guaranteeing high-strength joint, free from weld defects (Paul Kah *et al.,* 2014), (Bodude and Momohjimoh 2015).

Among the different types of welding processes, the Gas Tungsten Arc Welding (GTAW) process belongs to fusion welding classification. It is an arc welding process of high preference employed for exotic metals and joints of high quality, as a result of its high level of precision and recorded welding flexibility (Sathish *et al.*, 2012).

This accounts for the major reason it is widely used in the high-tech industry, aircraft, food industry, maintenance and a wide range of fabrication works. However, it is has its own limitations such as the need for highly skilled manpower, or the selection/identification of the ideal weld parameters which remain daunting issues which manufacturers have continued to investigate in order to achieve high quality weld joints. In curbing these challenges brought about by the increasing decision-making criteria, manufacturers have now been saddled with the responsibility of developing sound mechanical components through the deployment of acceptable techniques (Sada, 2018). A key methodology and technique which has been widely applied in achieving successful and reliable structures in these industries is the application of Multi-Criteria Decision-Making (MCDM) and artificial intelligence approaches.

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With the use of MCDM approaches, the selection of the best amongst the various available alternatives through ranking can be achieved (Figueira *et al.,* 2005). MCDM approaches are very efficient tools used in evaluating problems with decision making characterized by multiple criteria and finding a compromise solution. (Ishizaka and Nemery, 2013). The MCDM distinguishes three types of problems: choice difficulties, ranking problems, and sorting problems. The goal of choice issues is to assist the decision maker by selecting a subset of the "best" answer or alternative. The objective of ranking problems is to aid decision maker arrange the options in a progressive manner from the best to the worst. The goal of the decision maker (DM) in each type of problem is different and so is the approach (Kaur, 2009). The application of these techniques have become necessary in order to eliminate much of the Welders frequently use "guess work" while determining welding parameters for every particular assignment (Kim *et al.*, 2005) in addition to making sure cost are kept at a minimum. Hence, the objective of this paper is to select an optimal process parameters for a mild steel weld using Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

MATERIALS AND METHOD

With the use of statistical designed tool known as Design Expert, thirty (30) experimental run were constructed through the application of the central composite design CCD. The range of the values of the process parameters were obtained from literature (Babkin and Gladkov, 2016), with each parameter having two levels comprising of high and low as shown in Table 1.

Testing of Mild Steel Weld Specimen: Test specimens were accurately measured before testing; specimens were fitted into the jaws of a tensile test machine and subjected to a continuous increasing tensile force until the specimen fractures. A standard design of the specimen in accordance with ASTM specification E8/E8M-11 is shown in Figure 1. *Hardness Test:* Brinell hardness test is widely used for testing hardness of metals and non-metals of low to medium hardness. This is obtained by pressing a 10-mm diameter hardened steel ball made of cemented carbide into the surface of a specimen using different loads ranging from 500-3000 kg. Brinell hardness number (BHN) has units of kg/mm^2, but the units are usually omitted in expressing the number. The various specimens were tested and recorded.

Table 1: Welding Parameters and their levels

Parameters	Unit	Symbol	Coded Value	Coded Value
			Low (-)	High (+1)
Welding Current	Amp	A	140	200
Arc Voltage	Volts	V	15	25
Gas Flow Rate	Lit/min	F	20	24
Filler Rod	Mm	T	2.4	3.2

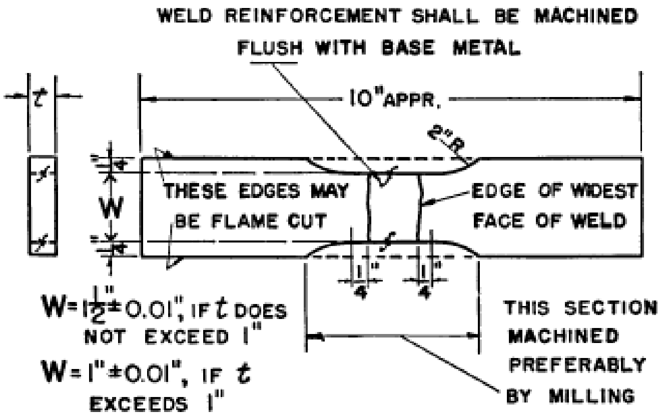

Fig 1 Showing the standard machined for tensile test.

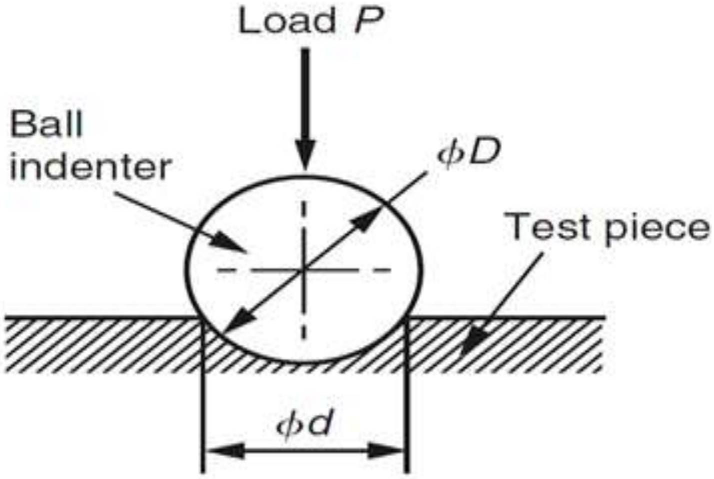

Fig 2: Brinell hardness testing method

Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS): There are three phases to using any numerical analysis of alternatives decision-making technique:

1) Identify the appropriate criteria and options.
2) Assign numerical values to the relative relevance of the criteria and the effects of the alternatives on them.
3) Sort the numerical data to assign a ranking to each option.

The TOPSIS method used for optimizing the process parameters was broken down into steps as presented here and adopted by Hwang and Yoon, (1981). The standard steps are:

(i) The formation of normalized matrix to aid decisions.
(ii) The formation of weighted normalized matrix.
(iii) The determination of positive and negative-ideal solution.
(iv) The calculation of separation measurement.
(v) Analyses of relative closeness to ideal solutions.
(vi) The ranking of preference order.

Formation of normalized decision matrix: This transforms the different attribute/ dimensions into non-dimensional attributes and allows comparison across the attribute. The formula is given as shown in equation 1

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \forall_j \qquad (1)$$

for i = 1,…, m; j = 1, …, n

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

Construction of weighted normalized decision matrix:

$$v_{ij} = r_{ij} * w_j \ \forall_{i,j} \qquad (2)$$

Where w_j is the assigned weight to attribute j.

Table 2: Results of Experimental Test

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
21	140	25	24	2.4	472.3	190.2
22	200	25	24	2.4	488.1	187.6
23	140	15	20	3.2	477.8	178.2
24	200	15	20	3.2	472.9	173.4
25	140	25	20	3.2	485	169.8
26	200	25	20	3.2	475.7	174.9
27	140	15	24	3.2	492.3	187.7
28	200	15	24	3.2	482.1	182.3
29	140	25	24	3.2	486.3	185.4
30	200	25	24	2.4	480.2	190.4

Weight Allocation: According to Ozturk and Batuk (2011), weight derivation is a central step required in eliciting the preferences of the decision-maker. The weight is a value the decision maker assigns to indicate the importance of evaluation criterion relative to other criteria being considered. As the weight's value rises, the criterion's importance in the overall utility rises as well. The weights are normally adjusted so that they add up to one. A set of weights is defined as follows in the case of n criteria: (Malczewski, 1999):

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

According to Malczewski, (1999), rating of weights are calculated according to Equation (4).

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

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.

Determination of ideal (A^+) and negative-ideal (A^-) solutions

$$A^+ = \{(max_j\ v_{ij} | i \in I), (min_j v_{ij} | i \in I'); \forall_j\} = \{v_1^+, v_2^+, \ldots..\} \ (5)$$

$$A^{-} = \{(min_j\, v_{ij} \mid i \in I), (max_j v_{ij} \mid i \in I'); \forall_j\} = \{v_1^-, v_2^-, \ldots..\} \quad (6)$$

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

Calculate of separation measure between the target alternative and ideal solution and the negative-ideal solutions

$$S_i^+ = \sqrt{\sum_{i=1}^{n}(V_{ij} - V_{\mathrm{i}}^{+})^2}\ \forall_j \quad (7)$$

$$S_i^- = \sqrt{\sum_{i=1}^{n}(V_{ij} - V_{\mathrm{i}}^{-})^2}\ \forall_j \quad (8)$$

Calculation of relative closeness to the ideal solution

$$C_j^+ = \frac{s_i^+}{s_i^+ + s_i^-} \quad (9)$$

Ranking of alternatives based on C_i^+ values

RESULTS AND DISCUSSION

The study was performed using the tungsten inert gas welding process, with the consideration of the four input parameters stated above (weld current, arc voltage, filler rod diameter and gas flow rate) and two output parameters (tensile strength and hardness).

From the result of both responses, optimal tensile strength of 496.5MPa and hardness of 190.2 was recorded (Table 1) at combined input parameters of the following values 170Amp, 20volts, 22l/min, and 3.2mm respectively using the TOPSIS technique.

Table 3: Normalized Decision Matrix

Table 4a			Table 4b: Normalized 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
21	223067.29	36176.04	0.177957755	0.188459922
22	238241.61	35193.76	0.183911032	0.185883709
23	228292.84	31755.24	0.180030099	0.176569706
24	223634.41	30067.56	0.178183829	0.17181362
25	235225	28832.04	0.182742984	0.168246555
26	226290.49	30590.01	0.17923884	0.173299897
27	242359.29	35231.29	0.185493549	0.185982794
28	232420.41	33233.29	0.181650294	0.180632197
29	236536.3225	34373.16	0.18325165	0.183703836
30	230592.04	36252.16	0.180934394	0.188658093
$\sum x_{ij}^2$	7043719.488	1018551.54		
$\sqrt{\sum x_{ij}^2}$	2654.000657	1009.233145		

Table 4: 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
21	0.111223597	0.070672471		0.111224	0.070672
22	0.114944395	0.069706391		0.114944	0.069706
23	0.112518812	0.06621364		0.112519	0.066214
24	0.111364893	0.064430108		0.111365	0.064430
25	0.114214365	0.063092458		0.114214	0.063092
26	0.112024275	0.064987461		0.112024	0.064987
27	0.115933468	0.069743548		0.115933	0.069744
28	0.113531434	0.067737074		0.113531	0.067737
29	0.114532281	0.068888938		0.114532	0.068889
30	0.113083996	0.070746785		0.113084	0.070747
	3.422439337	2.052622837			

Table 5: 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

Table 6 (Step 4): Calculation of separation measure

	values of Euclidian distance		**Performance score**	
	S- =∑ (rij-S+)^2	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
21	0.0000339	0.000065442	0.65878	0.811649
22	0.0000072	0.000086604	0.92278	0.960613
23	0.0000475	0.000026726	0.36021	0.600176
24	0.0000810	0.000010594	0.11567	0.340096
25	0.0000776	0.000033834	0.30358	0.550976
26	0.0000665	0.000016743	0.20116	0.448508
27	0.0000040	0.000101025	0.96151	0.980564
28	0.0000258	0.000047928	0.65015	0.806320
29	0.0000126	0.000071233	0.84940	0.921631
30	0.0000158	0.000080550	0.83619	0.914432

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

TOPSIS was successfully employed to identify the best set of inputs from our run of experiment that gave us the optimum outputs of tensile strength and hardness 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 3.2. The decision matrix is presented in Table 4.

Step 2 and 3: This is then followed by the formation of a weighted normalized decision matrix using equations 3.3, 3.4 and 3.5. The determination of ideal (A^+) and negative-ideal (A^-) solutions are also carried out using equations 3.6 and 3.7. The results of these two steps are shown in the Table 5 and Table 6.

Step4: The separation measure, the variance between the target alternative to the ideal and the negative-ideal solutions are calculated using equations 3.8 and 3.9

Table 7: 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
21	0.65878	0.811649	18
22	0.92278	0.960613	11
23	0.36021	0.600176	23
24	0.11567	0.340096	29
25	0.30358	0.550976	25
26	0.20116	0.448508	27
27	0.96151	0.980564	9
28	0.65015	0.806320	19
29	0.84940	0.921631	16
30	0.83619	0.914432	17

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

Conclusion: Having identified the need to have a scientific approach to obtaining optimal output values, the selection of input parameters for optimal values of the tensile strength and hardness of a 6mm mild steel tungsten inert gas weld was successfully carried out using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) with weld current, arc voltage, filler rod diameter and gas flow rate as process parameters.

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