Determination of Ideal Mild steel weld properties using the simple Additive weighting (SAW) Method.

Abstract

Weld deformation which directly contributes to failure of welded components, has been a real time challenge in the manufacturing industry. To resolve this challenge, subtle manipulation of input process parameters is recommended by Researchers. This manipulation of input process parameters is done through the application of optimization methods hence this study.
In this study, the Simple Additive Weighting (SAW) method was used. This method was categorized into four groups, which are namely, linear scale transformation-Max method; linear scale transformation-Sum method; Vector normalization method and linear scale transformation-MaxMin method. Each of these SAW methods was used to optimize the output parameters, which were classified as maximum criteria. It was noticed from the analysis, that the higher the values of the mechanical properties, the better the weld quality obtained and from using the linear scale transformation maximum method, weldment 7 was found to possess the best mechanical properties with ultimate tensile strength (UTS) of 395MPa, Impact energy (CVN) of 250J, Bead Height (BH) of 1.98mm and Bead Width (BW) of4.82mm was found to possess the best input and output parameters.

Keywords: weldment, Bead Height (BH), Bead Width (BW), Impact energy(CVN), mild steel,

1. Introduction

Welding is a versatile process of fabrication that involves the joining of two or more materials permanently by applying heat input sufficient enough to bring about the coalescence of the materials being joined (Etin-osa and Achebo, 2017), the material could be metal or thermoplastics. Achebo and Odinikuku (2015) were of the opinion that welding technology is very vital for the industrial development and technological advancement of any country. Therefore, it is imperative that weld quality should not be compromised, as its reliability and integrity contributes greatly to the service life of the entire structure (Etin-Osa D and Etin-Osa C.E., 2019). Achebo, (2011) said that welding is a cheaper fabrication process that joins materials permanently. So as a result of this, lots of researches are put into it, to make the quality of its weldment better, because poor quality weld is the main causes of structural accidents that occur on a regular basis in most West African countries.

Poor weld quality has been attributed to poor welding skills of the welder and also to the wrong selection and application of input process parameters (Etin-Osa *et al*, 2020). This is because, too high a current could cause weld spatter where molten metal reduces drastically in its viscosity, which makes it over flows from the bead into other parts of the weldment. Therefore, the choice of excellent process parameters cannot be over-emphasized as they are achieved by applying the optimization methods for selecting the optimum parameters. Kim et al (2005) were of the opinion that because of the cost and time consumed by trial and error experiments as well as the complex and non-linear nature of welding process parameters, it is required to determine optimum process parameters through simulation.

In this study, the Simple Additive Weighing (SAW) method was used to optimize weld mechanical properties. Afshari et al (2010) wrote that SAW is a simple and most often used multi attribute decision technique, it is also known as weighted linear combination or scoring methods. The authors said that the method is based on the weighted average. An evaluation score is calculated for each alternative by multiplying the scaled value given to the alternative

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of that attribute with the weights of relative importance directly assigned by decision makers followed by summing of the products for all criteria. The advantage of this method is that it is a proportional linear transformation of the raw data which means that the relative order of magnitude of the standardized scores remains equal.

SAW is an integral part of multi-criteria decision making (MCDM) methods, as a result of that, some researchers have applied these methods in their optimization process. Kim et al (2005) who determined the optimal welding conditions used a controlled random search procedure to select the optimum welding processes. Venkadeshwaran et al (2015) were able to optimize process parameters using the Tagnchi method. Achebo and Omoregie (2015) applied TOPSIS in determining optimum welding process parameters and the corresponding weld properties. Omoregie and Achebo (2015) evaluated the performances of different welding process using the weighted aggregate sum product assessment method.

In this study, the optimum process parameters and properties of mild steel weldments was carried out using the Simple Additive Method.

2.Materials and Methods

2.1 Materials

Locally purchased 10mm mild steel plates was subjected to gas metal arc welding (GMAW) operation, after it was cut to dimensions as shown in Figure 1 and 2. Bead height (BH) and Bead width (BW) were measured respectively using a Planimeter. Five welded samples were made using each input process parameter presented in Table 1. The average of the bead height and width values were recorded, this was done for each weld operation using a semi-automatic welding machine with adjustable voltage, current, and gas flow rate input. A 1.6mm consumable wire electrode of AWS classification ER70S-3 with 80% argon and 20% carbon dioxide shielding gas were used.

The specimens were subjected to tensile and impact energy tests using the Tensometer and Charpy impact testing machine.

Tensile test specimens of dimensions shown in Figure1 were machined from the all-weld metal deposits.

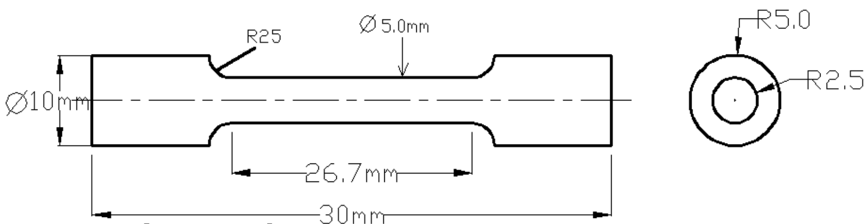

Figure1Tensile Strength Test specimen

Impact test specimens of dimensions shown in Figure 2 were prepared from the all-weld metal deposits;

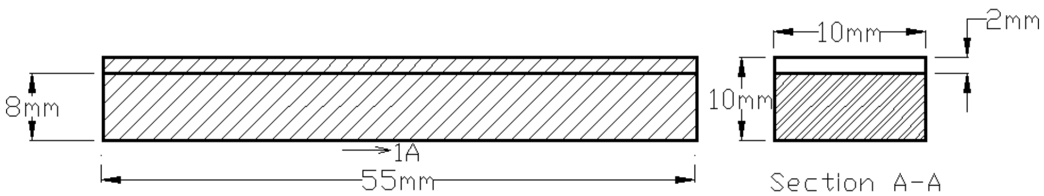

Figure 2: Impact test specimens of dimensions

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2.2 Methods

A novel multi-criteria decision making tool known as Simple Additive Weighting (SAW) method was used to analyze the responses generated for optimum result. Typical normalization methods used in SAW are:

(a) Linear scale transformation (LST), Max Method

$$r_{ij} = \begin{cases} x_{ij} / x_j^{+} \,;\, j \in \Omega_{\max} \\ x_j^{-} / x_{ij} \,;\, j \in \Omega_{\min} \end{cases} \tag{1}$$

(b) Linear Scale Transformation – Sum Method

$$r_{ij} = \begin{cases} x_{ij} \Big/ \sum_{i=1}^{n} x_{ij} & ;\, j \in \Omega_{\max} \\ \left(1/x_{ij}\right) \Big/ \sum_{i=1}^{n} \left(1/x_{ij}\right) & ;\, j \in \Omega_{\min} \end{cases} \tag{2}$$

(c) Vector Normalization

$$r_{ij} = \begin{cases} x_{ij} \Big/ \left[\sum_{i=1}^{n} x_{ij}^{2}\right]^{1/2} & ;\, j \in \Omega_{\max} \\ 1 = \left[x_{ij} \Big/ \left[\sum_{i=1}^{n} x_{ij}^{2}\right]^{1/2} \right] & ;\, j \in \Omega_{\min} \end{cases} \tag{3}$$

(d) Linear Scale Transformation – Max Min Method

$$r_{ij} = \begin{cases} \dfrac{x_{ij} - x_j^{-}}{x_j^{+} - x_j^{-}} & ;\, j \in \Omega_{\max} \\ \dfrac{x_j^{+} - x_{ij}}{x_j^{+} - x_j^{-}} & ;\, j \in \Omega_{\min} \end{cases} \tag{4}$$

Where x_j^{+} is the largest number
x_j^{-} is the smallest number

3. RESULTS AND DISCUSSION

3.1: Presentation of Results

Table 1 shows the categorization of the measured mechanical properties such as ultimate tensile strength (UTS), absorbed impact energy (CVN), Bead height (BH) and Bead width (BW). These properties were categorized as maximum for the UTS and CVN which implies that the higher the values of the weld properties the better the quality of the weldments, whereas, BH and BW were categorized under the lower the/values of the measured weld properties, the better the quality of the weldments.

Table 1, shows the categorization of the measured weld properties

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

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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 normalized decision making matrix using the LST Max method for the UTS, CVN, BH and BW.

Table 2: Normalized decision making matrix using the LST Max method

Weld Ment W	Mechanical Property			
	Maximum		Minimum	
	UTS (MPa)	CVN (J)	BH (mm)	BW (mm)
1	0.8608	0.8400	0.7557	0.9640
2	0.6835	0.7600	0.8082	0.4949
3	0.8354	0.6000	0.6387	0.4662
4	0.9114	0.6600	0.08082	0.6292
5	0.6329	0.5600	0.7071	0.5691
6	0.8658	0.8800	0.9612	0.7508
7	1	1	1	1
8	0.7544	0.1201	0.6387	0.6741

Table 3 shows the Weighted Normalized Decision Matrix Using the LST Max Methodfor the UTS, CVN, BH and BW.

Table 3: Weighted NormalizedDecision Matrix Using the LST Max Method

Weld Ment W	Mechanical Property			
	Maximum		Minimum	
	UTS (MPa)	CVN (J)	BH (mm)	BW (mm)
1	0.1980	0.2352	0.2040	0.2024
2	0.1572	0.2128	0.2182	0.1039
3	0.1921	0.1680	0.1725	0.0979
4	0.2096	0.1848	0.2182	0.1321
5	0.1456	0.1568	0.1909	0.1195
6	0.1991	0.2464	0.2595	0.1577

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7	0.23	0.28	0.27	0.21
8	0.1735	0.2408	0.1725	0.1416

Table 4 shows the Overall Ranking Index Using LST Max Method for the eight (8) weld samples.

Table 4: Overall Ranking Index Using LST Max Method

Weldment W	$Q = \sum_{j=1}^{n} w_j r_{ij}$	Rank
1	0.8396	3
2	0.6921	6
3	0.6305	7
4	0.7447	4
5	0.6128	8
6	0.8627	2
7	0.9900	1
8	0.7284	5

Applying the linear scale transformation-sum method to values in Table 1 resulted in the creation of Table 5.

Table 5: Normalized Decision Matrix Using the Sum Method

Weldment W	Maximum		Minimum			
	UTS (MPa)	CVN (J)	BH $\left(1/x_{ij}\right) / \sum_{i=1}^{n} \left(1/x_{ij}\right)$		BW $\left(1/x_{ij}\right) / \sum_{i=1}^{n} \left(1/x_{ij}\right)$	
1	0.1315	0.1364	0.3817	0.1196	0.2000	0.1737
2	0.1044	0.1234	0.4084	0.1279	0.1027	0.0892
3	0.1277	0.0974	0.3226	0.1011	0.0967	0.0840
4	0.1393	0.1071	0.4082	0.1279	0.1305	0.1134
5	0.0967	0.0909	0.3571	0.1119	0.1181	0.1026
6	0.1323	0.1429	0.3571	0.1521	0.1558	0.1353
7	0.1528	0.1623	0.5051	0.1583	0.2075	0.1802
8	0.1153	0.1396	0.3226	0.1011	0.1399	0.1215

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Total			3.1909		1.1512	

Table 6 shows the weighted normalized decision matrix using the Sum method for the UTS, CVN, BH and BW.

Table 6: weighted normalized decision matrix using the Sum method

Weld ment, W	Maximum		Minimum	
	UTS (MPa)	CVN (J)	BH (mm)	BW (mm)
1	0.0302	0.0382	0.0323	0.0365
2	0.0240	0.0346	0.0345	0.0187
3	0.0294	0.0273	0.0273	0.0176
4	0.0320	0.0300	0.0345	0.0238
5	0.0222	0.0255	0.0302	0.0215
6	0.0304	0.0400	0.0411	0.0284
7	0.0351	0.0454	0.0427	0.0378
8	0.0265	0.0391	0.0273	0.0255

Table 7 shows the Overall Ranking Index Using LST Sum Method for the eight (8) samples.

Table 7: Overall Ranking Index Using LST Sum Method

Weld ment W	$Q = \sum_{j=1}^{n} w_j r_{ij}$	Rank
1	0.1372	3
2	0.1118	6
3	0.1016	7
4	0.1203	4
5	0.0994	8
6	0.1399	2
7	0.01610	1
8	0.1184	5

Table 8 shows the Vector Normalization of Decision Making Matrix

Table 8: Vector Normalization of Decision Making Matrix

Weld	UTS	CVN	BH	BW

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Ment, W	x_{ij}^2	$\frac{x_{ij}}{\left[\sum_{i=1}^{n} x_{ij}^2\right]}$	x_{ij}^2	$\frac{x_{ij}}{\left[\sum_{i=1}^{n} x_{ij}^2\right]}$	x_{ij}^2	$1-\left\{\frac{x_{ij}}{\left[\sum_{i=1}^{n} x_{ij}^2\right]}\right.$	x_{ij}^2	$1-\left\{\frac{x_{ij}}{\left[\sum_{i=1}^{n} x_{ij}^2\right]}\right.$
1	115,600	0.3685	44100	0.3554	6.8644	0.6438	25000	0.7700
2	72,900	0.2926	36100	0.3215	6.0025	0.6669	94.8676	0.5520
3	108,900	0.3577	22,500	0.2538	9.6100	0.5785	06.9156	0.5244
4	129,600	0.3902	27,225	0.2792	6.0025	0.6669	58.6756	0.6477
5	62,500	0.2710	19,600	0.2369	7.8400	0.6193	71.7409	0.6104
6	116,964	0.3707	48400	0.3723	4.2436	0.7199	41.2164	0.7047
7	156,025	0.4281	62500	0.4230	3.9204	0.7307	23.2324	0.7783
8	88,804	0.3230	88804	0.3554	9.6100	0.5785	51.1225	0.6712
Σx_{ij}^2	851,293		349229		54.0934		472.7710	
$(\Sigma x_{ij}^2)^{½}$	922.6554		590.9560		7.3548		21.7433	

Table 9 shows the weighted Vector normalized decision making matrix

Table 9: weighted Vector normalized decision making matrix

weld ment, W	UTS MPa	CVN (J)	BH (mm)	BW (mm)
1	0.0848	0.0995	0.1738	0.1617
2	0.0673	0.0900	0.1801	0.1159
3	0.0823	0.0711	0.1562	0.1101
4	0.0898	0.0782	0.1801	0.1360

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5	0.0623	0.0663	0.1672	0.1282
6	0.0853	0.1042	0.1944	0.1480
7	0.0985	0.1184	0.1973	0.1634
8	0.0743	0.1412	0.1562	0.1410

Table 10 shows the Overall Ranking Index Using Vector Normalization Method

Table 10: Overall Ranking Index Using Vector Normalization Method

Weld ment W	$Q = \sum_{j=1}^{n} w_j r_{ij}$	Rank
1	0.1372	3
2	0.4533	6
3	0.4197	8
4	0.4841	5
5	0.4240	7
6	0.5319	2
7	0.5776	1
8	0.5127	4

Table 11shows the Normalized Decision Making Matrix Using LST, MaxMin. Method

Table 11: Normalized Decision Making Matrix Using LST, MaxMin. Method

Weld Ment, W	Maximum		Minimum	
	UTS $\frac{x_{ij}-250}{395-250}$	CVN $\frac{x_{ij}-140}{250-140}$	BH $\frac{3.10-x_{ij}}{3.10-1.98}$	BW $\frac{10.34-x_{ij}}{10.34-4.82}$

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1	0.6207	0.6364	0.4286	0.9674
2	0.1379	0.4545	0.5804	0.1087
3	0.5517	0.0909	0	0
4	0.7586	0.2273	0.5804	0.4855
5	0	0	0.2679	0.3388
6	0.6345	0.7273	0.9286	0.7101
7	1	1	1	1
8	0.3310	0.6818	0	0.5779

Table 12 shows the Weighted Normalized Decision Making Matrix Using LST, MaxMin Method

Table 12: Weighted Normalized Decision Making Matrix Using LST, MaxMin Method

Weldment W	UTS	CVN	BH	BW
1	0.1428	0.1782	0.1157	0.2032
2	0.0317	0.1273	0.1567	0.0228
3	0.1269	0.0255	0	0
4	0.1745	0.0636	0.1567	0.1020
5	0	0	0.0723	0.0711
6	0.1459	0.2036	0.0411	0.1491
7	0.2300	0.2800	0.2700	0.2100
8	0.0761	0.1909	0	0.1214

Table 13 shows the Overall Ranking Index Using LST Max Min Method

Table 13: Overall Ranking Index Using LST Max Min Method

Weldment W	$Q = \sum_{j=1}^{n} w_j r_{ij}$	Rank
1	0.6399	3
2	0.3385	6

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3	0.1524	7
4	0.4968	4
5	0.1434	8
6	0.7493	2
7	0.9900	1
8	0.3884	5

3.2 Discussion of Results

Table 1 shows the measured weld properties of 10mm mild steel plates. These weld properties consist of ultimate tensile strength (UTS), impact energy (CVN), bead height (BH) and Bead Width (BW) . After the mild steel weld mechanical tests were conducted using the various corresponding process parameters. The mechanical test results shown in Table 1 were given to five (5) Experts comprising of the welders with over 10 years' experience, in mechanical, metallurgical and manufacturing Engineering fields. The test results were evaluated by the experts using the likert scale method and the Expert Scores were converted to weights allocated to each mechanical property.

Table 2 shows the normalized decision making matrix using the linear scale transformation, maximum method. The UTS and CVN are under the higher value of the weld property the better the weldment quality, under this criterion, each of the test results were divided by the highest available test result for the entire process parameters. The BH and BW which are under the criterion that the lower the value of the weld property, the better the weldment quality. In this case, the lowest value is being divided by each of the test results.

Table 3 shows the weighted normalized decision matrix. In this case, the normalized decision matrix, (see Table 2) are multiplied by the corresponding weights. Table 4 shows the overall ranking index which comprises of the summation of the weighted normalized decision matrix values in each row. The summation with the highest value gives the process parameters with the best mechanical properties. From using the linear scale transformation maximum method, weldment 7 was selected to possess the best mechanical properties.

The values of UTS , CVN, BH and BW of weldment 7, which are 395MPa, 250J, 1.98mm and 4.82mm respectively compare well with those in other literature.

Table 5 shows the normalized decision matrix using the linear scale transformation sum method. This process reduces the values of the experimental results into lower proportions. Table 6 shows the weighted normalized decision matrix, the calculated weights, multiplied by the corresponding normalized decision making matrix for each of the weldment properties. Table 7 shows the overall raking index using the scale transformation sum method. From Table 7, it is found that weldment 7 has the best mechanical properties.

Table 8 shows the Vector Normalization of Decision Making Matrix. This process reduces the values of the experimental results into lower proportions. Table 9 shows the weighted Vector normalized decision making matrix, the calculated weights, multiplied by the corresponding normalized decision making matrix for each of the weldment properties. Table 10 shows the Overall Ranking Index using Vector Normalization Method.. From Table 10, it was found that weldment 7 has the best mechanical properties.

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Table 11 shows the normalized decision making matrix using the linear scale transformation, maximum minimum method. This method reduces the experimental result values into small proportions less than 1.0. Table 12 shows the weighted normalized decision making matrix using the linear scale transformation maximum minimum methods. In this case the normalized values in Table 11 are been multiplied by the corresponding weights shown in Table 1. Table 13 shows the overall ranking index indicating that weldment 7 possess the best mechanical properties.
The simple Additive Weighting (SAW) method, contain four different methods of prioritizing the mechanical properties of the weldments according to importance and closeness to accepted standards of these properties when compared to those published in literatures. From these four methods considered, there was a common agreement of judgment that weldment 7 has the best mechanical properties.

4. Conclusion

The SAW methods were applied to the mechanical test and measurement results obtained in this study. The four different methods of the SAW model, collectively selected the seventh weldment as the weldment with the optimized process parameters and best mechanical properties. Of these four methods, the Vector normalization method shows that the third weldment has the least acceptable properties, whereas, the other three methods of SAW collectively show that the fifth weldment has the worst mechanical properties. This contrast demands for further evaluation process.
However, the SAW method has adequately optimized the weld mechanical properties. It acts as a check and balance method where results obtained by using one method can be validated by comparing them with the results obtained by applying the other methods of SAW. The SAW method has also revealed some variations in result interpretation. Therefore the results from the dominant methods are upheld above the other one.

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