Modelling and predicting the Effects of Process Parameters on Weldment Characteristics in Shielded Metal Arc Welding

By

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Abstract

Weldment characteristics like penetration, bead geometry and depth of HAZ are extremely important characteristics for structural integrity. SMAW welding process is used throughout the world for its simplicity and versality. Electrode diameter, current, voltage, arc travel speed, electrode feed rate, arc length and arc spread are influential factors in deciding the weldment characteristics. In this present works the effects of these process parameters on weldment characteristics in case of SMAW process was studied. Bead-on-plate experiments was conducted using a preset feed based SMAW machine. Weldment characteristics like depth of penetration, depth of HAZ and number of undercuts, were examined. An artificial neural network based modeling of the experiments was sucessfully done to predict the patterns of results obtained from the experiments.

INTRODUCTION

The weldment characteristics include bead geometry, depth of penetration, depth of heat affected zone, undercutting and thermal cracks. The parameters like arc length, arc spread, current, electrode diameter and rate of energy input influence the weldment characteristics. As the length of arc increases, the bead width also increases. Depth of penetration on the other hand decreases with either too long or too short an arc length. A long arc length may also cause oxidation and embitterment of the bead and heat affected zone. The electrode diameter has also considerable effect on the weldment characteristics. With the increase in electrode diameter the area of arc increases, thus the energy density decreases. The depth of penetration decreases with the increase in electrode diamemter. The contour of the weldment geometry gets affected by the electrode feed rate and the arc travel rate (table speed). With the increase in arc travel rate the bead width decreases with consequent possibility of occurence of defects like undercutting. With higher arc travel rate, the depth of penetration decreases to reach a steady level.

It is very important to consider all the welding parameters while studying the weldment characteristics. With different welding conditions the resulting characteristics of weldment differ significantly. It is generally difficult and time consuming to model the process numerically. Artificial neural networks based approaches can be utilized to model and predict the patterns obtained from the experiments. In this work ANN with supervised learning has been utilized sucessfully for predicting bead geometry, depth of penetration, depth of heat affected zone and undercuts for different welding conditions. The result obtained from the experiments and ANN closely matched thus proving the suitability of using ANN for predicting the weldment characteristics.

EXPERIMENTAL PROCEDURE

To investigate the weldment characteriistics, beads were deposited on mild steel flat plates using mild steel electrodes. A semi automatic preset feed based welding machine was used to deposit beads on plates. The machine has the capability to vary the table speed (arc travel rate) and electrode feed rate. The electrode feed rates used for experiments were 178 and 218 mm/min. The table speeds used were 126 and 152 mm/min. Since the weldment characteristics also depend on the electrode diameter. it was varied and three values namely 3.15 mm, 4 mm and 5 mm were used.

To study the bead geometry, each bead was sectioned transversely at the two points - one near the start (leaving 2 cm from the start) and the other near the end (leaving 2 cm from the end). To get the microstructure, these sectioned beads were then polished with 0,2,3 grade emery paper and then etched with 2% nital solution. To measure the bead height and bead width each sample was placed uner toolmaker's microscope having least count of 0.001 mm. The average values of bead height and bead width of each pair of samples were noted. Figure.1. shows the two beads prepared for measuring the characteristics.Bead height, bead width, depth of penetration, depth of HAZ and number of undercuts were measured. the experimental results are shown in Table.1. The values obtained were used further for training a network based on back propagation algorithm.

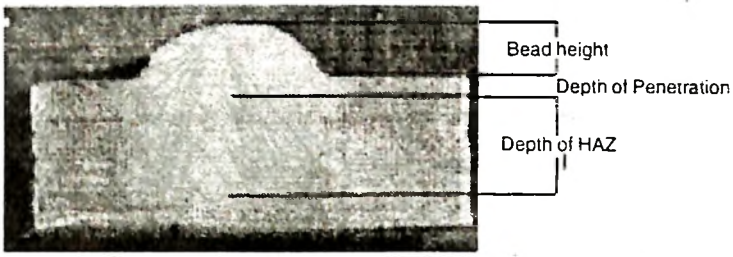

Figure 1 (a)

Figure 1 (b)

NEURAL NETWORK MARKETING

Welding process might result into such characteristics which may not be indicating a trend as observed in the present work. in this situation the conventional forecasting techniques like regression analysis may be useful to show the current trend but future prediction is difficult and less accurate. Neural networks are generally used for pattern recognition. A neural network is an adaptable system that can learn relationships through repeated presentation of data and is capable

Sl.No	Current in amp	Table speed in mm/min	Electrode feed rate in mm/min	Electrode diameter in mm	Electrode length before welding	Electrode length after welding	Voltage in volts	Arc length in mm	Arc spread in mm	Bead length in mm	Bead height in mm	Bead width in mm	Depth of penetration in mm	Depth of of HAZ in mm	No. of undercuts
61a	160	152	218	5	440	307	35	9.33	10.63	107	2.414	13.746	3.048	4.421	0
61b	160	152	218	5	440	307	35	9.33	10.63	107	2.385	13.706	3.09	4.021	0
62a	180	152	218	5	450	295	28	6.6	8.2	111	1.691	14.04	3.232	4.072	1
62b	180	152	218	5	450	295	28	6.6	8.2	111	1.6	14.021	3.268	4.62	1
63a	100	152	218	3.15	450	280	39	6	7.33	122	2.195	8.685	3.785	3.212	0
63b	100	152	218	3.15	450	280	39	6	7.33	122	2.18	8.678	3.609	3.105	0
64a	115	152	218	3.15	450	270	42	8.82	9.2	129	1.802	10.327	2.005	4.16	1
64b	115	152	218	3.15	450	270	42	8.82	9.2	129	1.813	10.318	2.016	4.175	1
65a	85	152	218	3.15	450	270	37	5.35	8.33	126	2.558	10.078	2.618	2.935	0
65b	85	152	218	3.15	450	270	37	5.35	8.33	126	2.508	10.167	2.63	2.987	0
66a	130	152	218	3.15	450	278	44	5.3	8.12	122	1.602	9.652	2.241	4.454	1
66b	130	152	218	3.15	450	278	44	5.3	8.12	122	1.619	9.611	2.312	4.46	2
67a	190	152	218	5	450	296	40	6.1	7.38	109	1.92	15.132	1.786	5.925	0
67b	190	152	218	5	450	296	40	6.1	7.38	109	1.911	14.987	1.777	5.92	0
68a	200	152	218	5	450	304	43	7.4	10.1	110	1.016	15.473	3.893	4.782	1
68b	200	152	218	5	450	304	43	7.4	10.1	110	1.218	15.438	3.78	4.777	2
69a	210	152	218	5	450	303	38	8.2	9.7	100	1 535	17.041	3.455	4.763	1
69b	210	152	218	5	450	303	38	8.2	9.7	100	1.528	17.095	3.456	4.604	1
70a	230	152	218	5	450	295	29	9.3	10.2	104	1.184	22.256	4.008	4.26	1
70b	230	152	218	5	450	295	29	9.3	10.2	104	1.165	22.886	4.62	4.57	1

Table 1 : Experimental Data

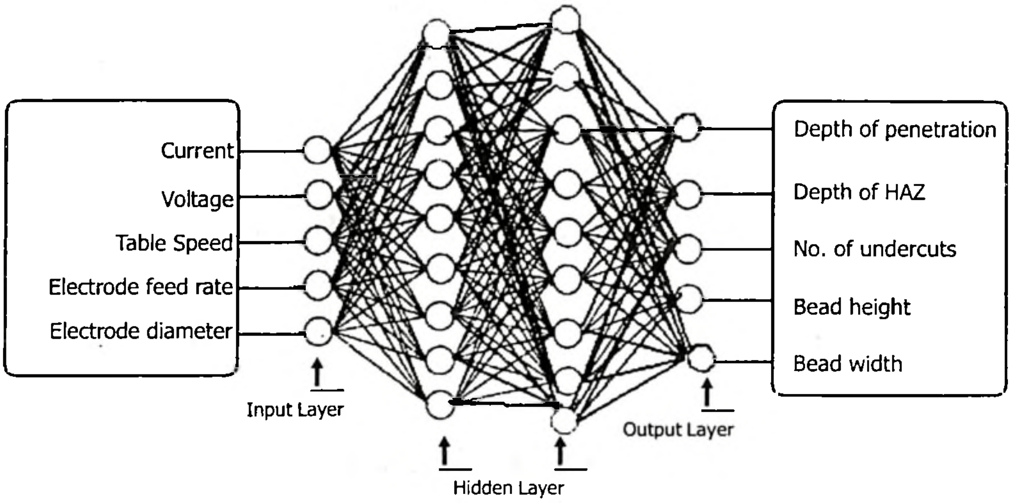

Figure.2. Neural Network Diagram Indicating Input Process parameters and Outputs

pf generalizing to new, previously unseen data. a supervised learning system can be used to suitably train a network based on input process parameters and outputs to form a basis for further prediction. A typical back propagation network based on supervised learning system is shown in figure.2. Neurons are arranged in a distinct layered topology. the input layer is not really the neural at all.

The input units simply serve to introduce the values of the input variables. the input variiables used lin the present investigation are : current, voltage, electrode diameter, electrode travel speed & electrode feed rate. The output layer forming the variables which are to be predicted consist of bead width, depth of penetration, depth of HAZ and number of undercuts. The hidden and output layer neurons are each connected to all of the units in the preceeding layer. When the network is executed (used), the input variable values are placed in the input, and then the hidden and output layer units are progressively executed. Each of them calculates their activation value by taking the layer,

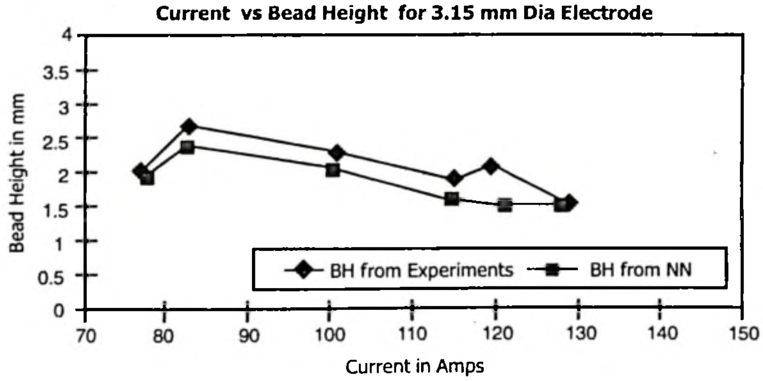

Figure 3 : Current vs Bead Height for 3.15 mm Diameter Electrode

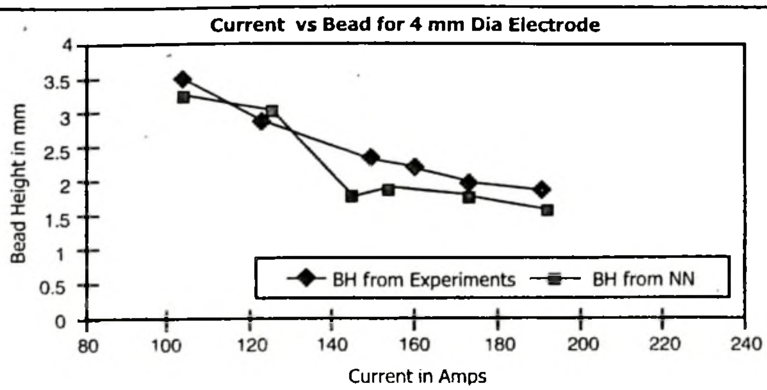

Figure 4 : Current vs Bead Height for 4 mm Diameter Electrode

and substracting the threshold. The activation value is passed through the activation function to produce the output of the neuron. When the entire network has been executed the outputs of the output layer act as the outputs of the entire network. The experimental data used to train the proposed neural network is shown in Table.1.

RESULTS AND DISCUSSIONS

The performance of the neural network depends on the number of hidden layers and number of neurons in the hidden layers. Therefore many trials may be needed in choosing the optimal structure for the neural network by changing the number of hidden layers as well as the number of neurons in each of the hidden layers. The appropriate neural network structure for predicting bead height, bead width, depth of HAZ and penetration was chosen by trial and error method [8, 9]. In this work back propagating algorithm based neural networks architecture was used. In this study the structure of neural network was 5-9-9-5 (5 neuron in the input later, 9 neuron in the 1st hidden layer, 9 neurons in the second hidden layer and 5 in output layer). The experimental data to get the trained output of the neural network is shown in Table.1. The network was trained for 110 samples and trained outputs were obtained. The network was trained for 9000 iterations. Further training did not improve the modelling performance of the network. A schematic diagram of the neural network in the present work is shown in figure.2.

The results of the investigation conducted on the weldment characteristics of mild steel work pieces welded with mild steel electrodes for are shown in figures 3 to 14. it was stated by Datta [24] that arc spread increases almost linearly with the arc length and the area of the arc is more with larger diameter of the electrodes. From the figure.3. it can be observed that with 3.15mm electrode diameter as the current increases the bead height initially increases then decreases. In case of

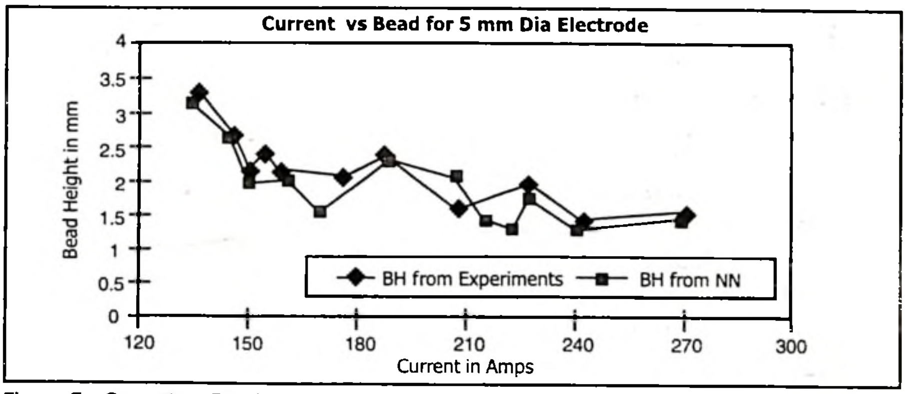

Figure 5 : Current vs Bead Width for 5 mm Diameter Electrode

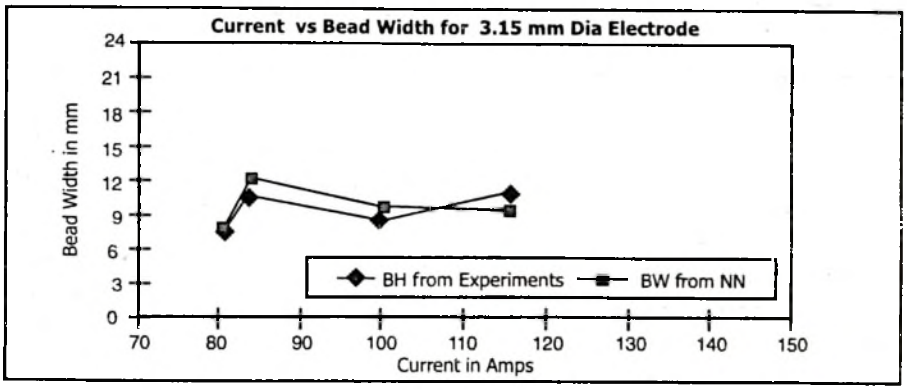

Figure 6 : Current vs Bead Width for 3.15 mm Diameter Electrode

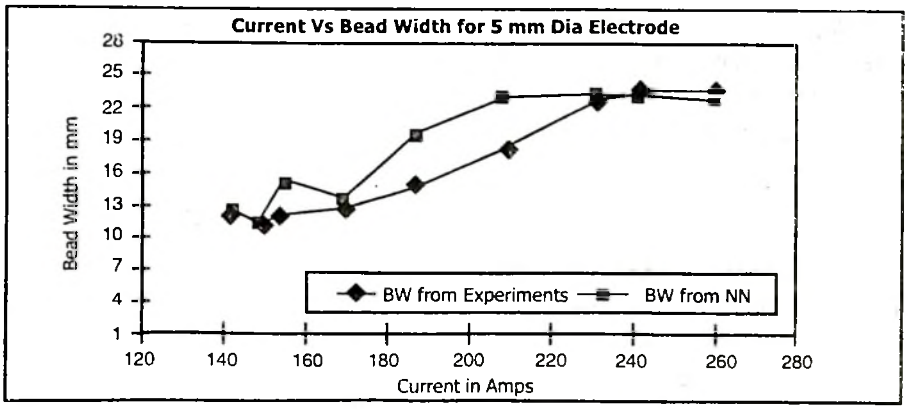

Figure 7 : Current vs Bead Width for 5 mm Diameter Electrode.

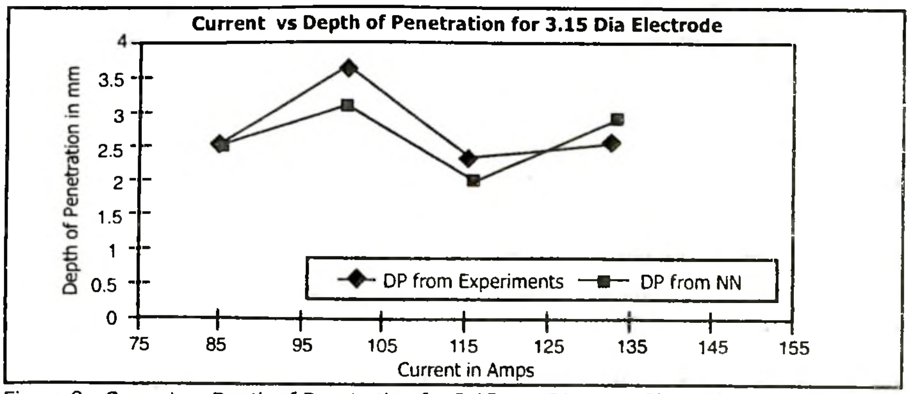

Figure 8 : Current vs Depth of Penetration for 3.15 mm Diameter Electrode.

4 and 5 mm electrode diameter the bead height decreases with the increase in the current as shown in the figures 4 and 5.

Values of bead heights obtained from experiments and neural net works are given in the Table.2. It can be observed that maximum error percentage is 6.25 in case of 4 mm diameter electrodes. The minimum percentage error of 0 was obtained for 4 and 5 mm diameters electrodes. As observed in figures 3,4 and 5 the neural network modeling closely matched with that of experimental results.

As stated by Datta [24] with the increase in radius of tne ar: spread, the width of the weld beao increases and the depth of penetration decreases. It can be observed from figure.6. that in case of 3.15 diameter electrode initially the bead width increases as the current increases then attains almost a constant value for a current range of 85 to 120 amps. Beyond this current range welding is not possible with the said electrode diameter for 8 mm plate thickness. From figure.7, it can be observed that in case of 5 mm electrode diameter the bead width rapidly increases for a current range of 140 to 240 amps then it remains constant for a current in range of 240 to 270 amps. Beyond this current range weld bead will not form because of excessive spatter. The neural network prediction of bead widths also closely indicated the same trend. As it can be observed from Table.3. that the maximum percentage error obtained for bead width is 4.3 for 5 mm diameter electrodes.

In case of 3.15 mm diameter electrode, as the current increases

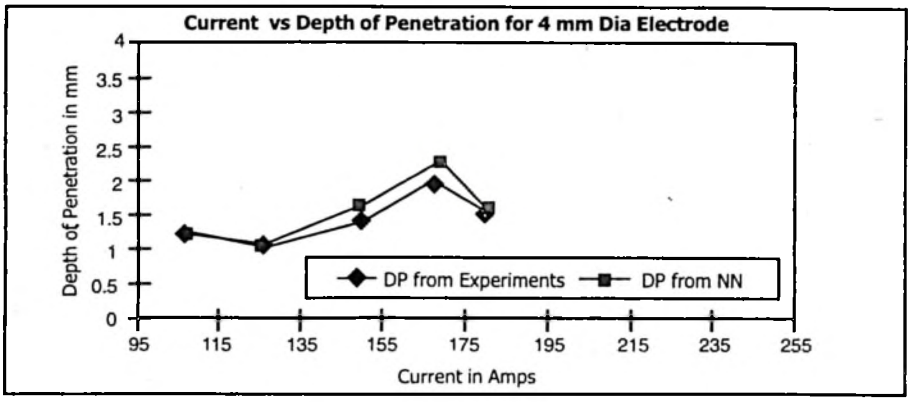

Figure 9 : Current vs Depth of Penetration for 4mm Diameter Electrode

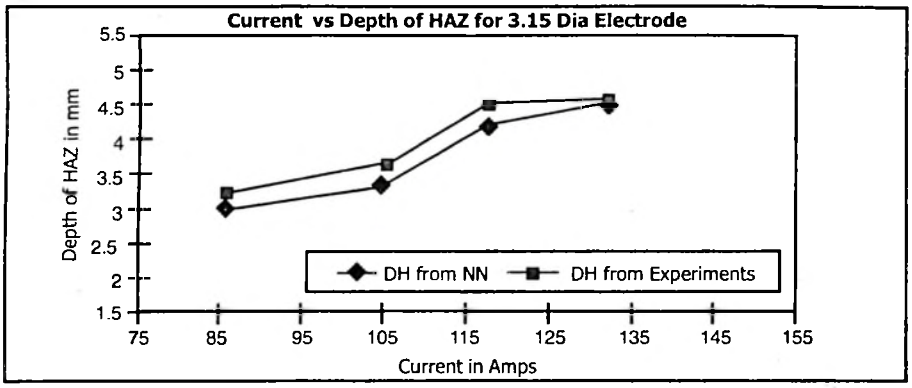

Figure 10 : Current vs depth of HAZ for 3.15 mm Diameter Electrode

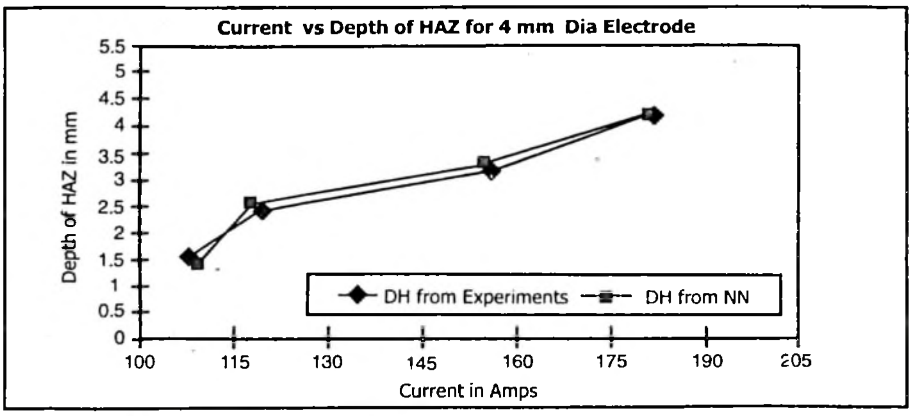

Figure 11 : Current vs Depth of HAZ for 4 mm Diameter Electrode

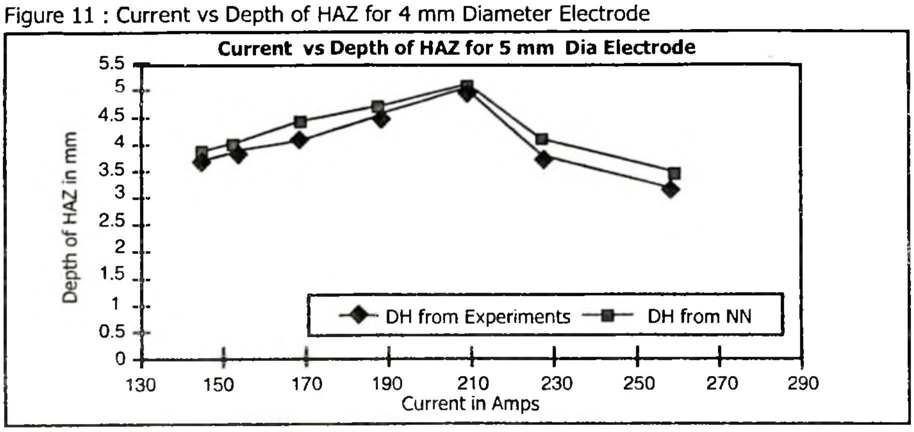

Figure 12 : Current vs Depth of HAZ for 5 mm Diameter Electrode

the depth of penetration increases initially then decreases. This trend can be observed from the figure.8. From figure.9 the same trend is obtained for 4mm diameter electrode.

Table.4. shows the values obtained for depth of penetration from neural networks and experiments. In this case it has been observed that the maximum error is 16.8 for 3.15 electrode diameter. The values of depth of penetration obtained from experiments and modelling are 2.01 and 1.7 mm. The values in other cases matched closely.

It has been seen from the literature that the penetration and HAZ are controlled by the rate of heat input, which is a function of current, arc length, arc travel rate and polarity. The depth of HAZ varies for different current ranges and electrode diameters.As it can be observed from figures 10 and 11 that for 3.15 and 4 mm electrode diameters as the current increases the depth of HAZ increases and attains a constant value at higher range of current till the bead is feasible. But in case of 5 mm diameter electrode, with the increase in current the depth of heat affected zone initially increases and obtains a maximum value. If the current is further increased then the depth of HAZ decreases. This can be substantiated from figure.12.

From figures 8 to 12 it can be seen that in the current range where the depth of penetration is minimum, the depth of HAZ is higher. The bead width and depth of HAZ reach their maximum values in the same range of current. From this we can safely conclude that when the energy density is low then the depth of penetration and bead height decreases and bead width and depth

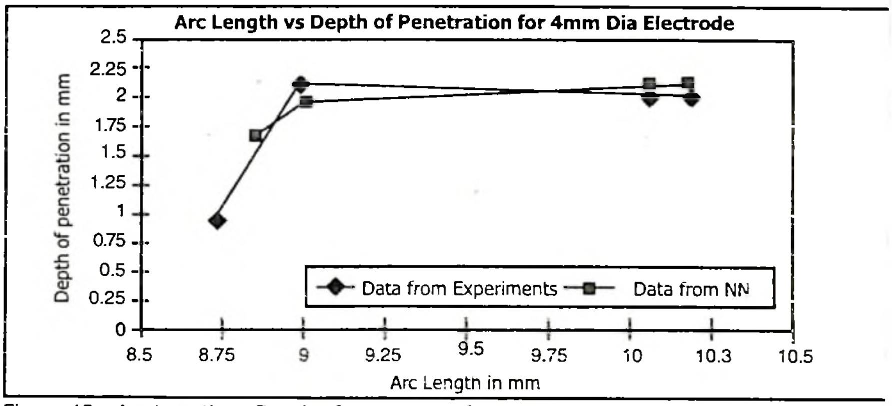

Figure 13 : Arc Length vs Depth of Penetration for 4 mm Diameter Electrode.

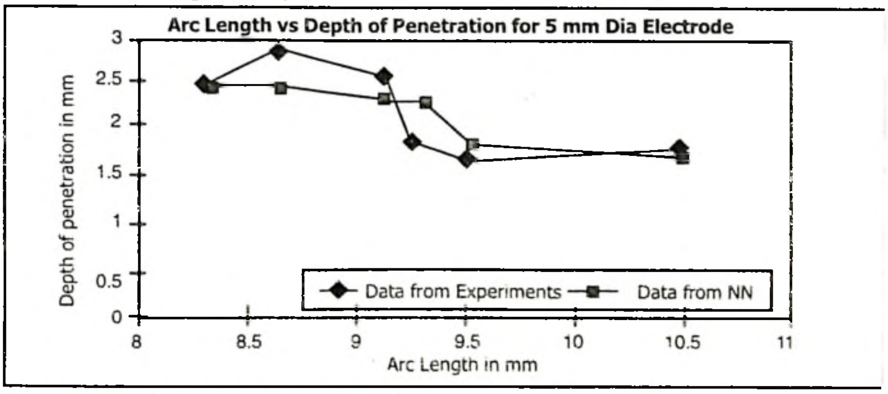

Figure 14 : Arc Length vs Depth of Penetration for 5 mm Diameter Electrode.

Sample No	Electrode Dia. in mm	Bead height from Experiments in mm	Bead height from NN in mm	Percentage Error (%)
1	3.15	1.936	1.86	3.92562
2	3.15	2.508	2.4	4.30622
3	3.15	2.195	2.1	4.328018
4	3.15	1.602	1.56	2.621723
11	4	3.498	3.31	5.3745
12	4	2.79	2.81	-0.71685
13	**4**	**2.125**	**1.992**	**6.258824**
21	5	2.185	2.2	-0.6865
22	5	2.185	2.2	-0.6865
23	5	2.19	2.22	-1.36986
24	5	1.535	1.5	2.28013
25	5	1.528	1.55	-1.43979

Table 2 : Comparison of Bead Height Values Obtained From Experiments and Neural networks.

of heat affected zone increases. The neural network based prediction also indicated this trend as shown in Table.5. It can be observed from Table.5, that the maximu percentage of error (0) is obtained f 4mm and 5 mm diameter electrode

: is further observed from figures 13 nd 14 that for 4 mm and 5 mm iameter electrodes the depth of enetration increases rapidly as the rc length increases. Then it ecreases to attain a constant value. rom figures 13 and 14 it is seen that ɔr arc lengths of 7 mm to 9 mm ıe depth of penetration is the ıaximum. Beyond this the depth of enetration decreases. This is ecause the arc spread increases lmost linearly with the arc length 24]. So with the increase in arc ɔread bead width increases thus ecreasing the depth of penetration. he predicted values using neural etwork is closely match the kperimental values.

Sample No	Electrode Dia. in mm	Bead height from Experiments in mm	Bead width from NN in mm	Percentage Error (%)
31	3.15	7.614	7.3	4.123982
32	3.15	10.078	10.21	-1.30978
33	3.15	10.167	10.305	-1.35733
27	5	12.175	12.7	-4.31211
28	5	23.322	24.03	-3.03576
29	5	25	25.006	-0.024
30	5	25	24.8	0.8

ble 3 : Comparison of Bead Width Values Obtained From Experiments and Neural tworks.

Sample No	Electrode Dia. in mm	Depth of penetration from Experiments in mm	Bead width from NN in mm	Percentage Error (%)
5	3.15	2.63	2.575242	2.082035
7	3.15	2.016	1.676568	16.83691
8	3.15	2.241	2.479953	2.621723
15	4	1.158	1.176	-1.5544
16	4	1.029	1.041	-1.16618
17	4	1.486	1.624	-9.28668
18	4	2.01	2.116	-5.27363
19	4	1.473	1.501	-1.90088

ble 4 : Comparison of Depth of Penetration values Obtained from Experiments 1 Neural Networks.

CONCLUSIONS

Based on the experimental work and the neural network modeling work done the following conclusions can be drawn :

(1) With increase in the current the bead height decreases in case of 3.15, 4 and 5 mm diameter electrodes. This trend can be observed from figures 3,4 and 5.

(2) Penetration increases initially with the increase in current then decreases. The rate of decrease of penetration with increasing current is more in case of 3.15 mm diameter electrode. This trend can be observed in figures 8 and 9.

(3) As indicated by experiments and neural networks, it can be concluded that for 3.15 and 4 mm diameter electrodes the depth of HAZ increases as the current increases up to stable arc length as shown in figures 10 and 11. But in case of 5mm diameter electrode depth of HAZ increases upto 210 amps then decreases.

(4) From figures 13 and 14 it can be concluded that for 3.15 and 5 mm diameter electrodes the arc lengths of more than 9 mm results in less penetration because of greater spread of arc.

(5) It also can be observed that the output trends for bead height, bead width, depth of penetration and depth of HAZ may not be predicted accurately by linear curve fitting.

(6) Figures 3,4 and 5 show that for 3.15, 4 and 5 mm diameter electrodes the trends obtained for bead height are similar but the trends obtained for bead width are significantly different as observed from figures 6 and 7 for 3.15 and 5 mm diameter electrodes. Similar type of trends for depth of penetration and HAZ showing significant differences for different diameters of electrodes are observed as shown in figures 8 to 12. It is concluded that results of this type may not be easily predicted by conventional forecasting techniques.

(7) Artificial neural networks based approaches can be used successfully for predicting the output parameters like bead width, bead height, depth of

penetration and depth of HAZ as shown in Tables 2,3,4 and 5. however the error is rather high as some cases like prediction of depth of penetration as observed in the Table.4. Increasing the number of hidden layers and iterations can minimize this error.

Sample No	Electrode Dia. in mm	Depth of HAZ from Experiments in mm	Bead width from NN in mm	Percentage Error (%)
40	3.15	2.935	3.104	-5.75809
41	3.15	3.212	3.514	-9.40224
42	3.15	4.175	4.372	-4.71856
43	3.15	4.454	4.5	-1.03278
35	4	1.786	1.608	9.966405
36	4	2.31	2.403	-4.02597
37	4	3.102	3.233	-4.22308
38	4	4.371	4.351	0.457561
42	5	3.828	3.941	-2.95193
43	5	3.982	4.015	-0.82873
44	5	3.987	4.371	-9.6313
45	5	4.623	4.759	-2.94181
46	5	4.983	5.1	-2.34798
47	5	3.826	4.101	-7.18766

Table 5 : Comparison of Depth of HAZ Values Obtained from Experiments and Neural Networks.

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