Predicting the effects of Process Parameters on Weld Bead Geometry in Mig Welding using ANN

[1]Subrata Saha, [2]Naseem Ahmed, [3]Md. Abdur Rafiq, [4]Tarapada Bhowmick

[1] Mechanical Technology, Kushtia Polytechnic Institute, Kushtia, Bangladesh. E-mail: subrata2011new@gmail.com

[2] Professor, Department of Mechanical Engineering, Khulna University of Engineering and Technology, Khulna, Bangladesh

[3] Professor, Department of Electrical and Electronic Engineering, Khulna University of Engineering and Technology, Khulna, Bangladesh.

[4] Professor, Department of Mechanical Engineering, Khulna University of Engineering and Technology, Khulna, Bangladesh.

ABSTRACT

Bead-on-plate experiments were conducted using a semi-automatic MIG welding machine to determine the effects of process parameters like wire diameter, wire feed rate, welding current, welding speed etc. on weld bead geometry like bead height, bead width, depth of penetration etc. An artificial neural network based modeling had successfully been done to correlate the effects of process parameters on weld bead geometry.

INTRODUCTION

The weld bead geometry includes bead width, bead height and depth of penetration. The process parameters like welding current, electrode wire diameter, electrode wire feed rate influence the weld bead geometry. As the current increases the bead width and depth of penetration also increases. Electrode wire diameter has also a great effect on weld bead geometry. With the increase in electrode wire diameter, the molten metal volume will increase and the bead width will increase. With increasing electrode wires feed rate the bead height increases. With the increase in arc travel rate the bead width, bead height and the depth of penetration decreases [1-5, 8].

It is very important to consider all the important welding process parameters while studying the weld bead geometry. With different welding conditions the resulting characteristics of weld bead geometry differ significantly. It is generally difficult and time consuming to model the process numerically. Artificial neural network based approach can be utilized to model and predict the patterns obtained from the experiments. In this work ANN with supervised learning had been utilized successfully for predicting bead geometry for different welding conditions. The result obtained from the experiments and ANN closely matched, thus proving the suitability of using ANN for predicting the weld bead geometry [3, 4, and 6].

EXPERIMENTAL PROCEDURE

To investigate the bead geometry, beads were made on 12 mm thick mild steel flat plates using mild steel electrode wire. A semi-automatic preset feed and current based MIG welding machine was used to deposit beads on plates. The machine had the capability to vary the current and electrode wires feed rate. The electrode wires feed rates used in the experiments were 4600 & 5600 mm/min. The welding speed and arc length were almost steady at 140 mm/min and around 3 mm respectively. The weld bead geometry also depends on the electrode wire diameter and current, so, these were varied and the values were 0.8 & 1.0 mm and 20 steps from 194 amps to 340 amps respectively. To study the bead geometry each bead was sectioned transversely at the middle of the bead length, shown in **Fig. 1**.

Fig. 1 : Sectioned Views of Bead Geometry

To get the macro dimension, these sectioned beads were polished with 0, 2, 3 & 4 grade emery paper and then etched with 5% nital solution. To measure the bead height, bead width and depth of penetration each sample was measured with digital slide caliper. The experimental values were shown in **Table 1**. The values obtained had been used further for training through an artificial neural network based on real-time recurrent learning algorithm. Almost same procedures had been used by Mahapatra et al [1].

ARTIFICIAL NEURAL NETWORKS

An artificial neural network is an adaptable system that can learn relationships through repeated presentation of data and is capable of generalizing to new, which are previously unseen data. Since, experimental results can't indicate a trend which can guess about future, as observed in this work; so, to forecasting about future prediction is difficult and less accurate. Therefore, artificial neural network technique among many others is generally used for prediction of pattern

Table 1: Experimental Results

Sample Serial No.	Process Parameters			Weldment Charateristics		
	Electrode Wires diameter (mm)	Electrode wires feed rate (mm/min)	Welding Current (Amp)	Bead Width (mm)	Bead Height (mm)	Depth of Penetration (mm)
1	0.8	4600	194	7.00	3.50	1.50
5	0.8	4600	202	7.00	3.50	1.50
8	0.8	4600	209	7.50	3.50	2.00
12	0.8	4600	217	7.50	3.50	2.00
15	0.8	4600	225	8.00	3.50	2.00
47	0.8	4600	232	8.50	3.50	2.50
50	0.8	4600	240	9.00	3.50	2.50
53	0.8	4600	248	9.50	3.00	2.50
56	0.8	4600	255	10.00	3.00	2.50
59	0.8	4600	263	10.00	3.00	2.50
32	0.8	5600	271	11.00	3.50	2.50
34	0.8	5600	278	11.00	3.50	2.50
38	0.8	5600	286	11.00	3.50	2.50
42	0.8	5600	294	11.50	3.00	3.00
44	0.8	5600	302	11.50	3.00	3.00
18	0.8	5600	309	12.00	3.00	3.00
21	0.8	5600	317	12.50	3.00	3.00
22	0.8	5600	325	12.50	3.00	3.50
25	0.8	5600	332	13.00	3.00	3.50
29	0.8	5600	340	13.00	3.00	3.00
62	1.0	4600	194	8.00	4.00	2.00
64	1.0	4600	202	8.00	4.00	2.00
69	1.0	4600	209	10.00	4.00	2.50
71	1.0	4600	217	10.00	4.00	2.50
74	1.0	4600	225	11.00	4.00	3.00
77	1.0	4600	232	12.50	4.50	3.00
81	1.0	4600	240	12.50	4.50	3.00
83	1.0	4600	248	12.50	4.00	3.50
86	1.0	4600	255	13.50	3.50	3.50
89	1.0	4600	263	13.50	3.50	3.50
93	1.0	5600	271	14.00	4.00	2.50
96	1.0	5600	278	14.50	4.00	2.50
97	1.0	5600	286	15.00	4.00	3.50
101	1.0	5600	294	15.00	3.00	3.00
103	1.0	5600	302	15.00	3.50	3.00
108	1.0	5600	309	15.50	3.00	3.00
111	1.0	5600	317	15.50	3.00	3.50
113	1.0	5600	325	16.00	3.00	2.50
115	1.0	5600	332	16.00	3.00	3.00
119	1.0	5600	340	16.00	2.50	3.00

recognition. A supervised real-time recurrent learning (RTRL) algorithm can be used to suitably train a network based for further prediction. RTRL system is shown in **Fig. 2** [9].

The input units simply serve to introduce the values of the input variables. The input variables used in the present investigation were: electrode wire diameter, electrode wire feed rate, welding current and arc length. The outputs forming the variables which were to be predicted consist of bead width, bead height, depth of penetration, depth of heat affected zone and hardness. Each of the output neurons were connected to each of the input neurons. When the network was executed, the input variable values were placed in the input and the output units were progressively executed by passing the values through activation function to produce the output of the neuron.

When the entire network had been executed the outputs of the output neuron acted as the outputs of the entire network. In this work the results had been extracted from the above mentioned outputs, shown in **Table 2**.

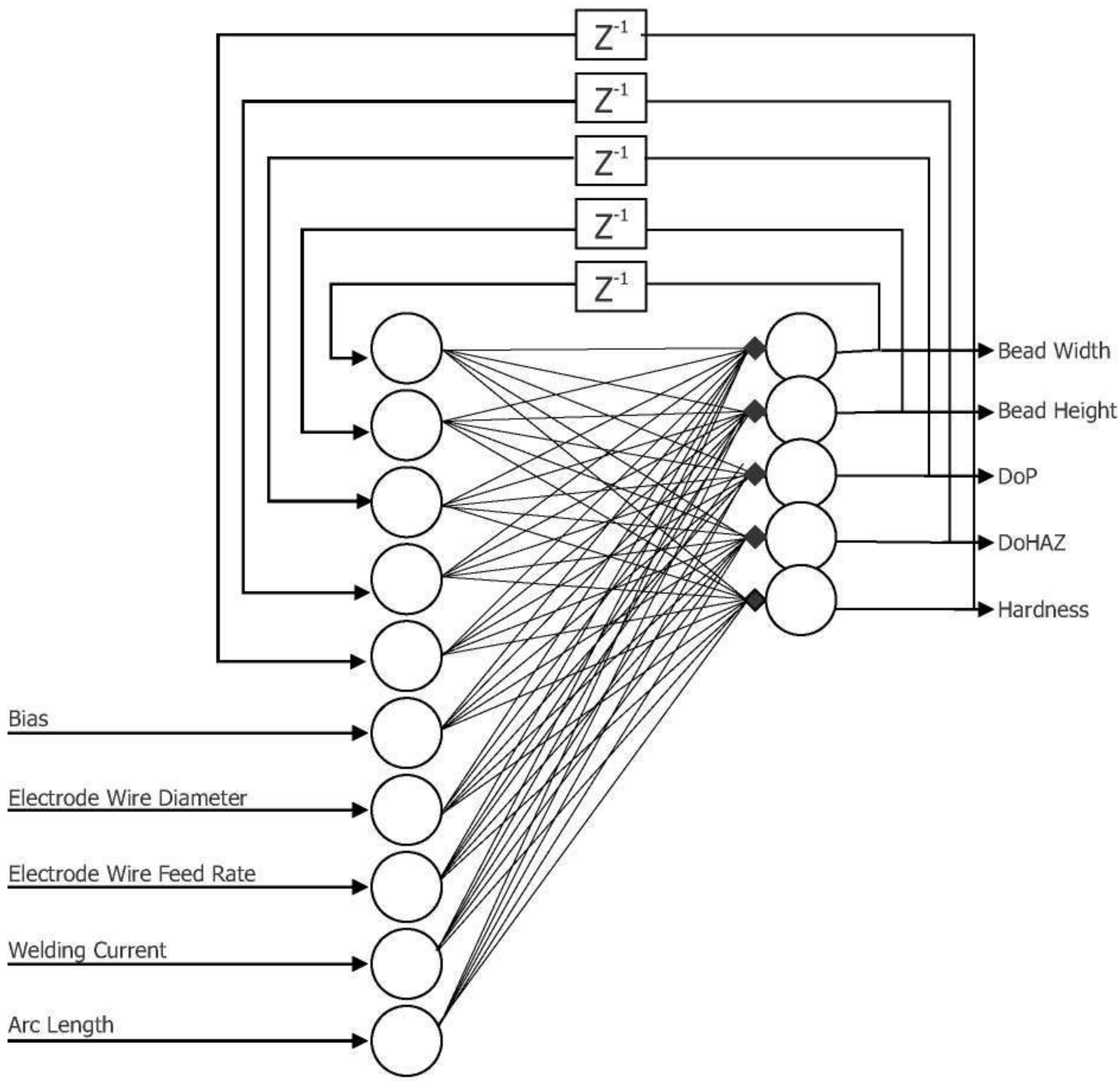

Fig. 2: RTRL Diagram indicating Input process parameters and Outputs

Table 2: Predicted Results by ANN

Sample Serial No.	Process Parameters			Weldment Charateristics		
	Electrode Wires diameter (mm)	Electrode wires feed rate (mm/min)	Welding Current (Amp)	Bead Width (mm)	Bead Height (mm)	Depth of Penetration (mm)
1	0.8	4600	194	7.0251	3.5782	1.5156
5	0.8	4600	202	7.0369	3.5693	1.5149
8	0.8	4600	209	7.5288	3.5328	2.0243
12	0.8	4600	217	7.5327	3.5125	2.0251
15	0.8	4600	225	8.0423	3.5122	2.0235
47	0.8	4600	232	8.5478	3.5113	2.5109
50	0.8	4600	240	9.0492	3.5087	2.5207
53	0.8	4600	248	9.5287	3.0763	2.5225
56	0.8	4600	255	10.0639	3.0385	2.5233
59	0.8	4600	263	10.0471	3.0238	2.5247
32	0.8	5600	271	11.0729	3.5293	2.5332
34	0.8	5600	278	11.0467	3.5182	2.5126
38	0.8	5600	286	11.0821	3.4751	2.5189
42	0.8	5600	294	11.5934	3.0187	2.9813
44	0.8	5600	302	11.5626	3.0152	2.9887
18	0.8	5600	309	12.0345	3.0129	2.9912
21	0.8	5600	317	12.5573	3.0151	3.0412
22	0.8	5600	325	12.5828	2.9864	3.4896
25	0.8	5600	332	13.0652	2.9752	3.4537
29	0.8	5600	340	13.0981	2.9678	3.4695
62	1.0	4600	194	8.0326	4.0127	2.0167
64	1.0	4600	202	8.0434	4.0495	2.0249
69	1.0	4600	209	9.9424	3.9765	2.4876
71	1.0	4600	217	9.9365	3.9537	2.4917
74	1.0	4600	225	10.9572	3.9821	2.8873
77	1.0	4600	232	12.4358	4.4983	2.9185
81	1.0	4600	240	12.4208	4.4897	2.9367
83	1.0	4600	248	12.4455	3.9873	3.4873
86	1.0	4600	255	13.4217	3.4827	3.4913
89	1.0	4600	263	13.3854	3.4801	3.4987
93	1.0	5600	271	13.9257	3.9835	2.5378
96	1.0	5600	278	14.4308	3.9723	2.5286
97	1.0	5600	286	14.9165	3.9687	3.4827
101	1.0	5600	294	14.9202	3.0185	2.9138
103	1.0	5600	302	14.8705	3.5297	2.9562
108	1.0	5600	309	15.4726	3.0141	2.9593
111	1.0	5600	317	15.3872	3.0178	3.4897
113	1.0	5600	325	15.9217	2.9873	2.5134
115	1.0	5600	332	15.9183	2.9756	3.0183
119	1.0	5600	340	15.8924	2.5274	3.0127

RESULTS AND DISCUSSIONS

The performance of the neural network depends on the number of neurons in the input and output layer. More number of neurons in the input layer, more precise output may be obtained. In this work RTRL algorithm based neural networks architecture had been used. In this study the structure of neural network is 5-5 (at beginning) and 10-5 (later on). A schematic diagram of the neural network of the present work shown in **Fig. 2**, the experimental data shown in **Table 1** was used as input variables to get the predicted results (output) of the neural network shown in **Table 2**. The network had been trained for 40 samples and trained outputs were obtained. The network had been trained for so many iterations, that further training had not much more improvement in the modeling performance of the network. The results of the investigation had been plotted in **Fig. 3** to **Figs. 14**.

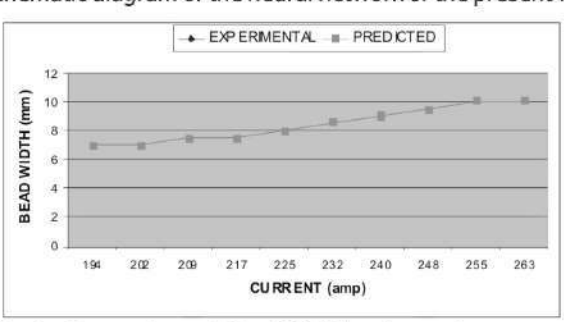

Fig. 3: Comparison of Bead Width values using current range from 194 – 263 amps, electrode wire diameter and feed rate respectively 0.8 mm and 4600 mm/min.

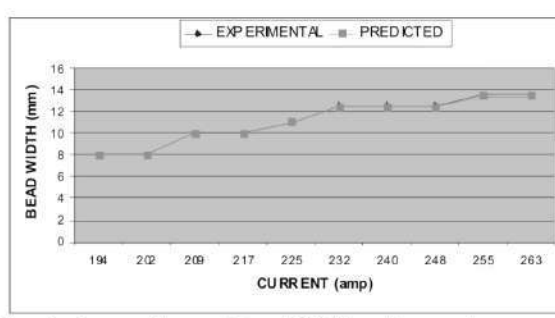

Fig. 4 : Comparison of Bead Width values using current range from 194 - 263 amps, electrode wire diameter and feed rate respectively 1.0 mm and 4600 mm/min.

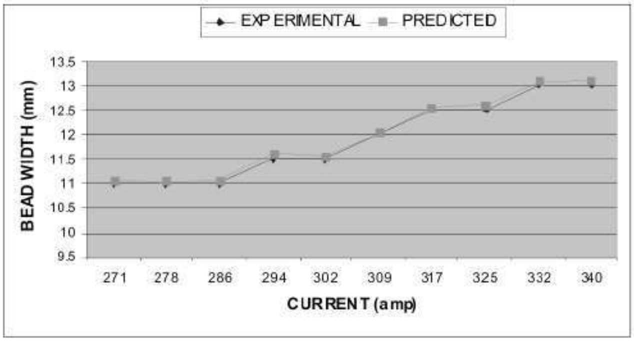

Fig. 5 : Comparison of Bead Width values using current range from 271- 340 amps, electrode wire diameter and feed rate respectively 0.8 mm and 5600 mm/min.

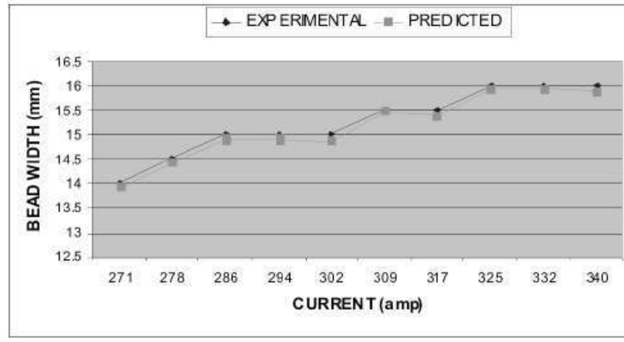

Fig. 6 : Comparison of Bead Width values using current range from 271- 340 amps, electrode wire diameter and feed rate respectively 1.0 mm and 5600 mm/min.

Table 3: Experimental and Predicted values with Percentage of error

Sample Serial No.	Process Parameters			Bead Width (mm)		Percentage of Error
	Electrode Wires diameter (mm)	Electrode wires feed rate (mm/min)	Welding Current (Amp)	Experimental Values	Predicted Values	
1	0.8	4600	194	7.00	7.0251	-0.3586
5	0.8	4600	202	7.00	7.0369	-0.5271
8	0.8	4600	209	7.50	7.5288	-0.3840
12	0.8	4600	217	7.50	7.5327	-0.4360
15	0.8	4600	225	8.00	8.0423	-0.5288
47	0.8	4600	232	8.50	8.5478	-0.5624
50	0.8	4600	240	9.00	9.0492	-0.5467
53	0.8	4600	248	9.50	9.5287	-0.3021
56	0.8	4600	255	10.00	10.0639	-0.6390
59	0.8	4600	263	10.00	10.0471	-0.7410
32	0.8	5600	271	11.00	11.0729	-0.6627
34	0.8	5600	278	11.00	11.0467	-0.4245
38	0.8	5600	286	11.00	11.0821	-0.7464
42	0.8	5600	294	11.50	11.5934	-0.8122
44	0.8	5600	302	11.50	11.5626	-0.5443
18	0.8	5600	309	12.00	12.0345	-0.2875
21	0.8	5600	317	12.50	12.5573	-0.4584
22	0.8	5600	325	12.50	12.5828	-0.6624
25	0.8	5600	332	13.00	13.0652	-0.5015
29	0.8	5600	340	13.00	13.0981	-0.7546
62	1.0	4600	194	8.00	8.0326	-0.4075
64	1.0	4600	202	8.00	8.0434	-0.5425
69	1.0	4600	209	10.00	9.9424	0.5760
71	1.0	4600	217	10.00	9.9365	0.6350
74	1.0	4600	225	11.00	10.9572	0.3891
77	1.0	4600	232	12.50	12.4358	0.5136
81	1.0	4600	240	12.50	12.4208	0.6336
83	1.0	4600	248	12.50	12.4455	0.4360
86	1.0	4600	255	13.50	13.4217	0.5800
89	1.0	4600	263	13.50	13.3854	0.8489
93	1.0	5600	271	14.00	13.9257	0.5307
96	1.0	5600	278	14.50	14.4308	0.4772
97	1.0	5600	286	15.00	14.9165	0.5567
101	1.0	5600	294	15.00	14.9202	0.5320
103	1.0	5600	302	15.00	14.8705	0.8633
108	1.0	5600	309	15.50	15.4726	0.1768
111	1.0	5600	317	15.50	15.3872	0.7277
113	1.0	5600	325	16.00	15.9217	0.4894
115	1.0	5600	332	16.00	15.9183	0.5106
119	1.0	5600	340	16.00	15.8924	0.6725

From **Figs. 3** to **Fig. 6**, it had been observed that in case of all increasing values of process parameters, the bead width increased gradually. At lower current, electrode wire diameter and electrode wire feed rate the bead width was lower; on the other hand at higher values of those the bead width was higher; because the melting rate of electrode wire increased at higher current. Percentage of error was shown in **Table 3**, which was closely matched.

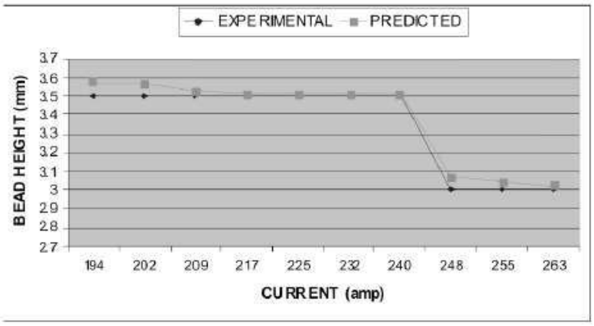

Fig. 7 : Comparison of Bead Height values using current range from 194 - 263 amps, electrode wire diameter and feed rate respectively 0.8 mm and 4600 mm/min.

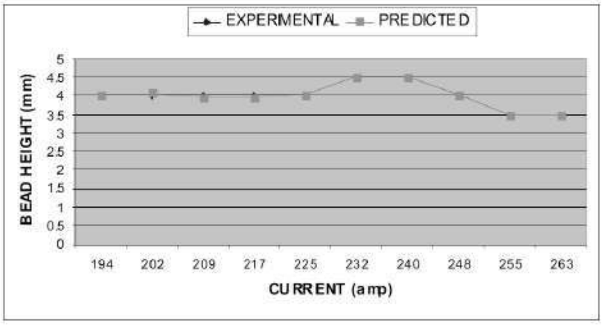

Fig. 8 : Comparison of Bead Height values using current range from 194 - 263 amps, electrode wire diameter and feed rate respectively 1.0 mm and 4600 mm/min.

Table 4: Experimental and Predicted values with Percentage of error

Sample Serial No.	Process Parameters			Bead Height (mm)		Percentage of error
	Electrode Wires diameter (mm)	Electrode wires feed rate (mm/min)	Welding Current (Amp)	Experimental Values	Predicted Values	
1	0.8	4600	194	3.50	3.5782	-2.2343
5	0.8	4600	202	3.50	3.5693	-1.9800
8	0.8	4600	209	3.50	3.5328	-0.9371
12	0.8	4600	217	3.50	3.5125	-0.3571
15	0.8	4600	225	3.50	3.5122	-0.3486
47	0.8	4600	232	3.50	3.5113	-0.3229
50	0.8	4600	240	3.50	3.5087	-0.2486
53	0.8	4600	248	3.00	3.0763	-2.5433
56	0.8	4600	255	3.00	3.0385	-1.2833
59	0.8	4600	263	3.00	3.0238	-0.7933
32	0.8	5600	271	3.50	3.5293	-0.8337
34	0.8	5600	278	3.50	3.5182	-0.5200
38	0.8	5600	286	3.50	3.4751	0.7114
42	0.8	5600	294	3.00	3.0187	-0.6233
44	0.8	5600	302	3.00	3.0152	-0.5067
18	0.8	5600	309	3.00	3.0129	-0.4300
21	0.8	5600	317	3.00	3.0151	-0.5033
22	0.8	5600	325	3.00	2.9864	0.4533
25	0.8	5600	332	3.00	2.9752	0.8267
29	0.8	5600	340	3.00	2.9678	1.0733

Sample Serial No.	Process Parameters			Bead Height (mm)		Percentage of error
	Electrode Wires diameter (mm)	Electrode wires feed rate (mm/min)	Welding Current (Amp)	Experimental Values	Predicted Values	
62	1.0	4600	194	4.00	4.0127	-0.3175
64	1.0	4600	202	4.00	4.0495	-1.2375
69	1.0	4600	209	4.00	3.9765	0.5775
71	1.0	4600	217	4.00	3.9537	1.1575
74	1.0	4600	225	4.00	3.9821	0.4475
77	1.0	4600	232	4.50	4.4983	0.0378
81	1.0	4600	240	4.50	4.4897	0.2289
83	1.0	4600	248	4.00	3.9873	0.3175
86	1.0	4600	255	3.50	3.4827	0.4943
89	1.0	4600	263	3.50	3.4801	0.5686
93	1.0	5600	271	4.00	3.9835	0.4125
96	1.0	5600	278	4.00	3.9723	0.6925
97	1.0	5600	286	4.00	3.9687	0.7825
101	1.0	5600	294	3.00	3.0185	-0.6167
103	1.0	5600	302	3.50	3.5297	-0.8486
108	1.0	5600	309	3.00	3.0141	-0.4700
111	1.0	5600	317	3.00	3.0178	-0.5933
113	1.0	5600	325	3.00	2.9873	0.4233
115	1.0	5600	332	3.00	2.9756	0.8133
119	1.0	5600	340	2.50	2.5274	0.9880

From **Fig. 7** to **Fig. 10**, it had been observed that at greater current range there was a tendency to lower the bead height in case of both type of electrode wire. It can be said that the bead height decreased more at higher current than that at lower current. Again from the above figures, it had also been observed that at the same current range the bead height was lower at lower size of electrode wire; because at higher current the more molten electrode wire generally minimized by the bead width, not by the bead height. Percentage of error was shown in **Table 4**, which was closely matched.

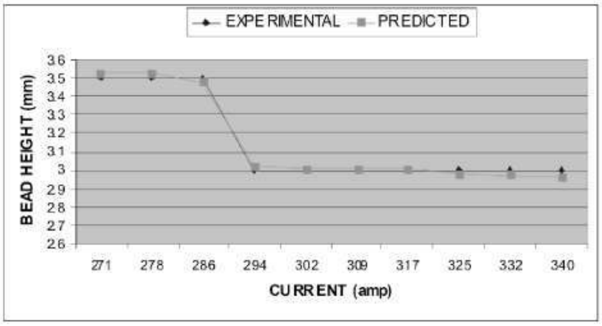

Fig. 9 : Comparison of Bead Height values using current range from 271 - 340 amps, electrode wire diameter and feed rate respectively 0.8 mm and 5600 mm/min.

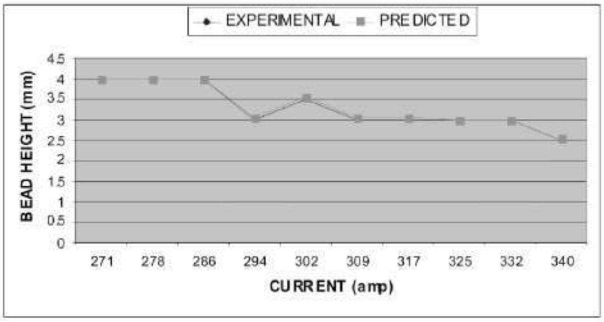

Fig. 10 : Comparison of Bead Height values using current range from 271 - 340 amps, electrode wire diameter and feed rate respectively 1.0 mm and 5600 mm/min.

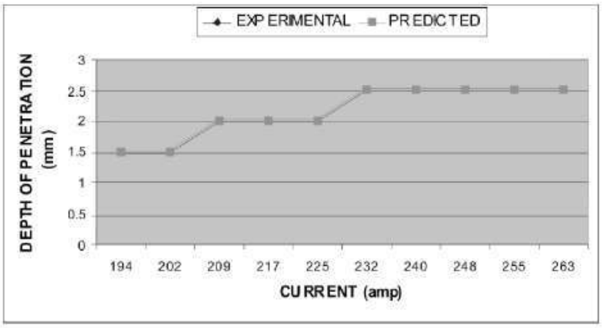

Fig. 11 : Comparison of Depth of Penetration values using current range from 194 - 263 amps, electrode wire diameter and feed rate respectively 0.8 mm and 4600 mm/min.

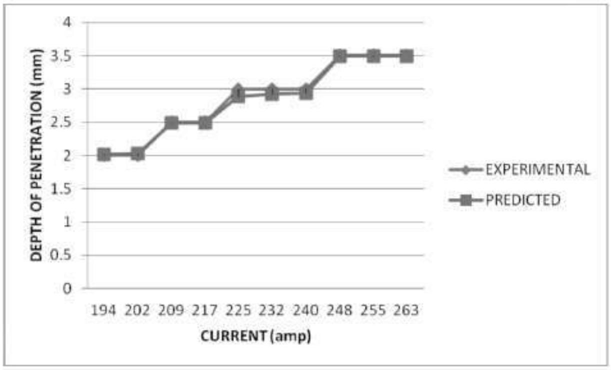

Fig. 12 : Comparison of Depth of Penetration values using current range from 194 - 263 amps, electrode wire diameter and feed rate respectively 1.0 mm and 4600 mm/min.

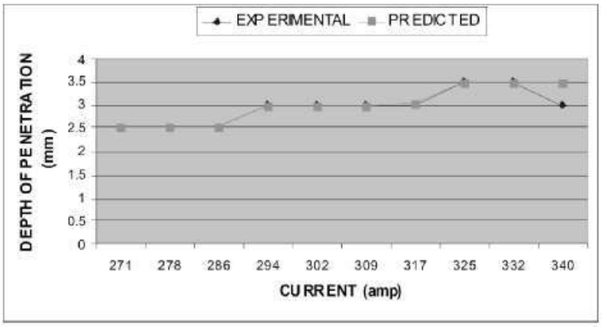

Fig. 13 : Comparison of Depth of Penetration values using current range from 271 - 340 amps, electrode wire diameter and feed rate respectively 0.8 mm and 5600 mm/min.

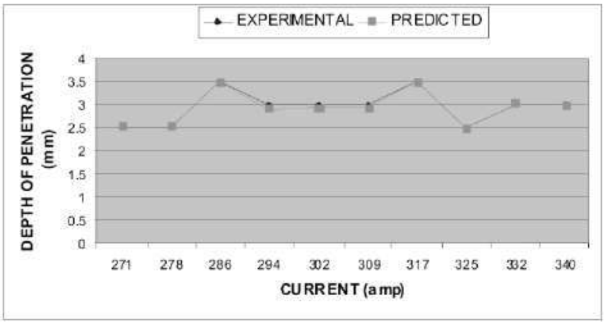

Fig. 14: Comparison of Depth of Penetration values using current range from 271 - 340 amps, electrode wire diameter and feed rate respectively 1.0 mm and 5600 mm/min.

Table 5: Experimental and Predicted values with Percentage of error

Sample Serial No.	Process Parameters			Depth of Penetration (mm)		Percentage of error
	Electrode Wires diameter (mm)	Electrode wires feed rate (mm/min)	Welding Current (Amp)	Experimental Values	Predicted Values	
1	0.8	4600	194	1.50	1.5156	-1.0400
5	0.8	4600	202	1.50	1.5149	-0.9933
8	0.8	4600	209	2.00	2.0243	-1.2150
12	0.8	4600	217	2.00	2.0251	-1.2550
15	0.8	4600	225	2.00	2.0235	-1.1750
47	0.8	4600	232	2.50	2.5109	-0.4360
50	0.8	4600	240	2.50	2.5207	-0.8280
53	0.8	4600	248	2.50	2.5225	-0.9000
56	0.8	4600	255	2.50	2.5233	-0.9320
59	0.8	4600	263	2.50	2.5247	-0.9880
32	0.8	5600	271	2.50	2.5332	-1.0400
34	0.8	5600	278	2.50	2.5126	-0.9933
38	0.8	5600	286	2.50	2.5189	-1.2150
42	0.8	5600	294	3.00	2.9813	1.2550
44	0.8	5600	302	3.00	2.9887	1.1750
18	0.8	5600	309	3.00	2.9912	0.4360
21	0.8	5600	317	3.00	3.0412	-0.8280
22	0.8	5600	325	3.50	3.4896	0.9000
25	0.8	5600	332	3.50	3.4537	0.9320
29	0.8	5600	340	3.00	3.4695	-0.9880
62	1.0	4600	194	2.00	2.0167	-0.8350
64	1.0	4600	202	2.00	2.0249	-1.2450
69	1.0	4600	209	2.50	2.4876	0.4960
71	1.0	4600	217	2.50	2.4917	0.3320
74	1.0	4600	225	3.00	2.8873	3.7567
77	1.0	4600	232	3.00	2.9185	2.7167
81	1.0	4600	240	3.00	2.9367	2.1100
83	1.0	4600	248	3.50	3.4873	0.3629
86	1.0	4600	255	3.50	3.4913	0.2486
89	1.0	4600	263	3.50	3.4987	0.0371
93	1.0	5600	271	2.50	2.5378	-1.5120
96	1.0	5600	278	2.50	2.5286	-1.1440
97	1.0	5600	286	3.50	3.4827	0.4943
101	1.0	5600	294	3.00	2.9138	2.8733
103	1.0	5600	302	3.00	2.9562	1.4600
108	1.0	5600	309	3.00	2.9593	1.3567
111	1.0	5600	317	3.50	3.4897	0.2943
113	1.0	5600	325	2.50	2.5134	-0.5360
115	1.0	5600	332	3.00	3.0183	-0.6100
119	1.0	5600	340	3.00	3.0127	-0.4233

From **Fig. 11** to **Fig. 14**, it had been observed that for same electrode feed rate the depth of penetration values increased within lower current range for increased electrode wire diameter. But at higher current range and at same electrode wire feed rate the depth of penetration did not increase with increasing electrode wire diameter. Again it had been observed that for same electrode wire diameter the depth of penetration values increased with increase in electrode wire feed rate and welding current simultaneously. Percentage of error was shown in **Table 5**, which was closely matched. The effect had been widely studied by other researchers and almost the same results were observed [1-7].

CONCLUSIONS

Depending on the experimental and predicted results through ANN modeling the following conclusions could be drawn:

1. With increase in the current and electrode wire diameter the bead width increased.
2. With increase in electrode wire diameter at lower current range the bead height increased; but at higher current range the bead height decreased.
3. With increase in electrode wire diameter at lower current range the depth of penetration increased; but later on the depth of penetration did not increase significantly.
4. Artificial neural networks based approach could be used effectively for predicting the effects of process parameters on weld bead geometry.

REFERENCES

1. Mahapatra, M. M., Sadat, Ali M., Datta, G. L. and Pradhan, B., (2005); Modeling and Predicting the effects of process parameters on weldment characteristics in shielded metal arc welding, IWJ, 38(2), pp.22-29.

2. Nagesh, D. S. and Datta, G. L., (2002); Prediction of weld bead geometry and penetration in shielded metal arc welding using artificial neural networks, Journal of Material Processing Technology, 123(2), pp.303-312.

3. Faruk, A. A., Hasib, M. N., Ahmed, M. N., and Das, U. K., (2008); Prediction of Weld Bead Geometry and Penetration in Electric Arc Welding using Artificial Neural Networks, International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS, 10(4), pp.23-28.

4. Dey, V., Pratihar, D. K. and Datta, G. L., (2008); Prediction of Weld Bead Profile Using Neural Networks, Proceedings of the 1ST International Conference, ICETET'08 on Emerging Trends in Engineering and Technology, held on16 – 18 July, at Nagpur, Maharashtra, India, pp.581-586.

5. Srihari, T. and Parmar, R. S., (1995), Weld bead geometry prediction, Journal of The Institution of Engineers (India), Mechanical Engineering Division, 76, pp.39-43.

6. Nagesh, D. S. and Datta, G. L., (2010); Genetic algorithm for optimization of welding variables for height to width ratio and application of ANN for prediction of bead geometry for TIG welding process, Journal of Applied Soft Computing, 10(3), pp.897-907.

7. Erdal Karadeniza, Ugur Ozsaracb and Ceyhan Yildizc, (2007); The effect of process parameters on penetration in gas metal arc welding processes, Journal of Materials and Design, 28(2), pp.649-656.

8. Khanna, O. P., (2003), A text book of Welding Technology, Dhanpat Rai Publications (P) Ltd., New Delhi, pp.1-8 and 80-87.

9. Simon Haykin, (2001); Neural Networks, A Comprehensive Foundation, 2nd edition, pp.1-63 and 756-761.