Analysis of Depth of Penetration and Impact Strength during Shielded Metal Arc Welding under Magnetic Field using Artificial Neural Networks

Dr. Rudra Pratap Singh
Associate Professor
Department of Mechanical Engineering
GLA University, Mathura

Abstract

Purpose of this work is to find out the optimal welding input process parameters for depth of penetration and impact strength for mild steel plates using shielded metal arc welding process. For this variety of welding experiments were carried out. Parameters such as welding current, welding speed, welding voltage and external magnetic field were chosen as input process parameters, while depth of penetration and impact strength as output parameters. Applications of magnetic field in welding processes have drawn much attention of researchers. However, effect of external magnetic field on quality of weld is still a matter of investigation. In this paper, effect of a longitudinal external magnetic field generated by bar magnets on the weld was experimentally investigated. Based on the results from welding experiments, optimal welding conditions were chosen after analyzing correlation between input and output welding parameters. For this a back propagated feed forward artificial neural network model was trained to predict the output parameters, if four input process parameters were fed to the trained model it would provide the required output variables having values very close to the experimental values. In shielded metal arc welding, non-equilibrium heating and cooling of the weld pool can produce micro structural changes affecting mechanical properties of weld metal. Present work is therefore aimed at characterization of a mild steel weld produced by SMAW technique in terms of its mechanical properties and associated microstructures. Variation in the microstructures of the heat affected zone and weld metal are very critical for life of welded components. Better weld design and optimum combinations of welding parameters are essential for producing high quality weld joints having desired strength, hardness and toughness. Understanding correlation between the process parameters and mechanical properties is a precondition for better productivity and reliability of the welded joints. Although mild steel is widely used in the industry for several applications needed for better strength, hardness and toughness but much information is not available in the open literature regarding variation in tensile strength, hardness and impact properties for change in heat input or other input process parameters. Purpose of present work is to determine effect of input process parameters on the properties of tensile strength and depth of penetration of mild steel using SMAW process. Back propagation artificial neural network having one input layer, one output layer and two hidden layers was used to predict the properties of weld. Initially network was trained with the help of 18 sets of data having input process parameters (current, voltage, speed of welding and external magnetic field) and output properties (tensile strength and depth of penetration) of the weld, obtained by different tests. After this the trained artificial neural network program could be used for predicting the properties of weld for a given set of input process parameters. Similarly desired properties of the weld could be obtained by applying required input welding parameters.

Keywords- Artificial Neural Network, Back Propagation, External Magnetic Field, Shielded Metal Arc Welding, Tensile Properties

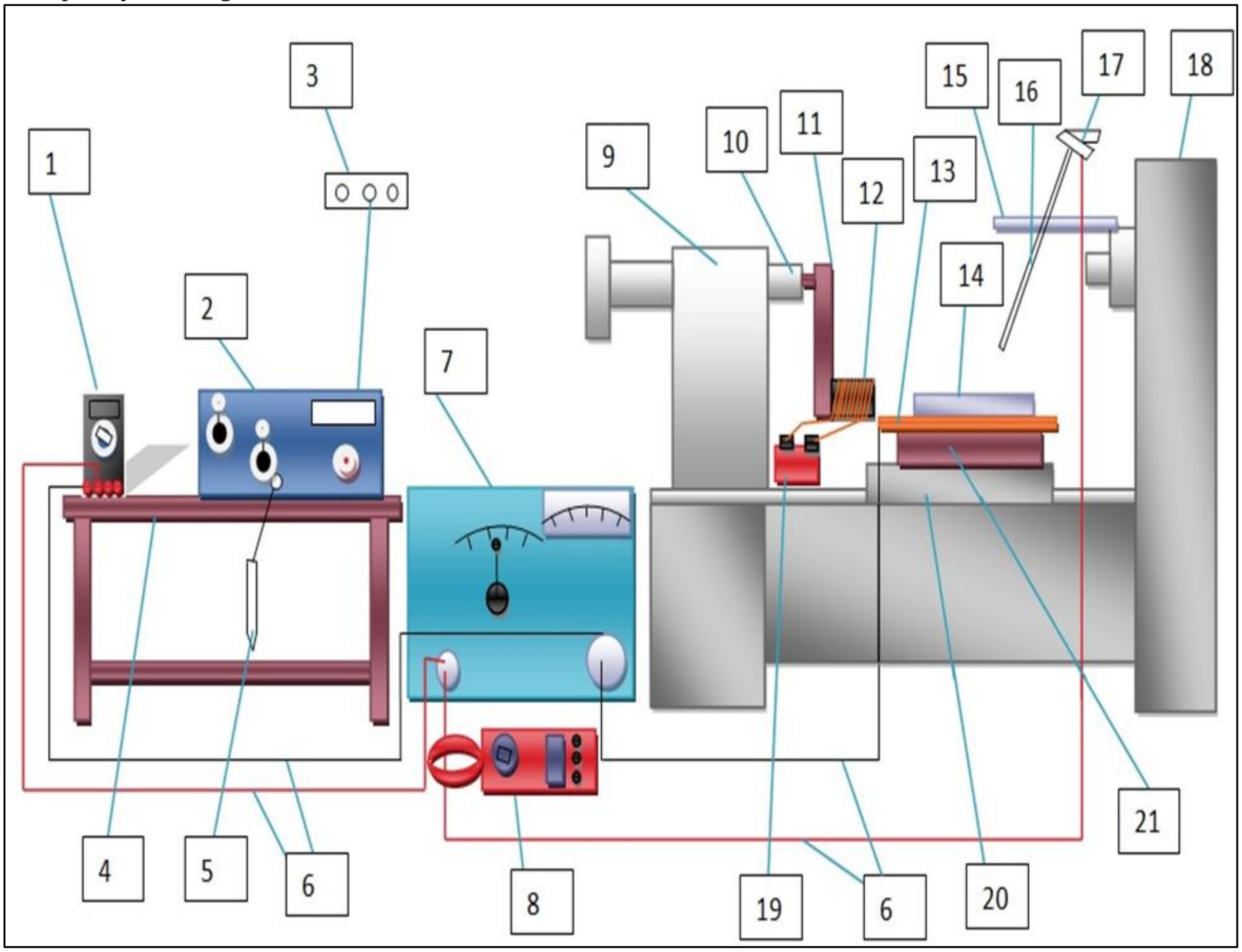
I. INTRODUCTION

Welding is the most important and versatile means of fabrication used in industries. It is used to join millions of different commercial alloys in many different required shapes and sizes. In actual practice, many products could not even be made without the use of welding, for example, guided missiles, nuclear power plants, jet aircraft, pressure vessels, chemical processing equipment, transportation vehicle etc. Many of the problems which are inherent to welding can be avoided by proper consideration of the particular characteristics and requirements of the process. Correct design of the joint is critical. Selection of the particular process requires an understanding of the large number of available options, the variety of possible joint configurations, and the numerous variables that must be specified for each operation. If the potential benefits of welding are to be achieved and harmful side effects are to be avoided, proper consideration should be given to the selection of the process and the design of the joint. The quality of a weld joint is strongly influenced by different process parameters during the welding process. In order to achieve high quality welds a good selection of the process variables should be utilized, which in turn results in optimizing the bead geometry [1 and 2]. In this study an attempt is made to investigate the effect of welding parameters on tensile strength and depth of penetration of the welded joint. These two properties are very important and can predict the structure and properties of the weld in all respects, and the rest properties like hardness, impact strength, ductility etc. can be assumed according to these two properties. With this objective, several test specimens were welded with varying welding speed, current, voltage and external magnetic field [3]. Shielded metal arc welding (SMAW) is a metal joining technique in which the joint is produced by heating the work piece with an electric arc set up between a flux coated electrode and the work piece. The advantages of this method are that it is the simplest of the all arc welding processes. The equipment is often small in size and can be easily shifted from one place to the other [4]. Cost of the equipment is also low. This process is used for numerous applications because of the availability of a wide variety of electrodes which makes it possible to weld a number of metals and their alloys. The welding of the joints may be carried out in flat, horizontal, vertical or overhead in all positions with highest weld quality by this process. Both alternating and direct current power sources could be used effectively. Power sources for this type of welding could be plugged into domestic single phase electric supply, which makes it popular with fabrications of smaller sizes. However, non-equilibrium heating and cooling of the weld pool can produce micro structural changes which may greatly affect mechanical properties of weld metal [5]. Mild steel is perhaps the most popular steel used in the fabrication industry for constructing several daily used items due to its good strength, hardness and moderate to low temperature notch toughness characteristics. In these applications, it is important to form strong joints that allow efficient load transfer between the different components and welding is, generally, the preferred joining method [6]. Good weld design and selection of appropriate and optimum combinations of welding parameters are imperative for producing high quality weld joints with the desired tensile strength. Understanding the correlation between the process parameters and mechanical properties is a precondition for obtaining high productivity and reliability of the welded joints. Depth of penetration is the depth to which the base metal and filler material have melted and mixed during welding process.

Although mild steel is widely used in the industry for many applications requiring good strength, hardness and toughness, there is not much information in the open literature about variations in its tensile, hardness and impact properties with changing heat input or other performance-altering welding parameters. The purpose of this work was to determine the effect of travel speed, welding voltage, current and external magnetic field on the tensile strength and depth of penetration of mild steel welded joints prepared using the SMAW process. This study will improve the current understanding of the effect of heat input, speed of welding and external magnetic field on the tensile strength and depth of penetration of this versatile structural steel [7]. Some weldment characteristics like depth of penetration are extremely important characteristics for structural integrity in case of welded joints. Several variables affecting the weld quality are unknown; also they may not be easily quantified. All these create difficulties for designing reliable welds and equipment's used to produce them. In these circumstances the experience and knowledge of the human welder provides the last steps towards a reliable weld and the artificial neural network is very much helpful for this. Back propagation artificial neural network having one input layer, one output layer and two hidden layers was used to predict the tensile strength and depth of penetration of weld. At first this network was trained with the help of 18 sets of data having input welding parameters (current, voltage, speed of weld and external magnetic field) and output properties (tensile strength and depth of penetration) of the weld, which were obtained with the help of corresponding welding and different tests. After this the trained artificial neural network could be used to predict the tensile strength and depth of penetration of weld for given sets of input welding parameters [8]. In this way the desired properties of the weld could be obtained by applying needed input welding parameters.

II. EXPERIMENTATION

To investigate the weldment characteristics weld beads were obtained by welding two mild steel flat plates of 150 mm x 50 mm x 5 mm dimensions in butt position using AWS E 6013 rutile electrodes of 3.15 mm diameter. A manual welding machine was used to weld the plates. A lathe machine was used to provide uniform speed of welding to support electrode holder and bar magnet. The work piece was kept on cross slide with some arrangement. Work-piece moved with cross slide. Bar magnet was connected with tailstock with a wooden structure Since the weldment characteristics depend on welding current, welding voltage, speed of welding and magnetic field, we select different set of values of these inputs [9]. Welding currents were chosen as 90, 95,100, 105, and 110 A, arc voltages were chosen as 20, 21, 22,23, and 24V, the welding speeds were chosen as 40, 60, and 80 mm/min and external magnetic field strengths were used as 0, 20,40, 60, and 80 Gauss for the experiments. Current was measured with a clamp meter, voltage was measured with a multi meter and magnetic field was measured with a Gauss meter. To study the bead geometry, each bead was sectioned transversely at 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 ground with emery belt grinder having 0, 2, and 3 grade emery papers then polished with a double disk polishing machine. Etching was done with a mixture of 2% nitric acid and 98% ethyl alcohol solution. To measure the depth of penetration a digital slide caliper was used. The average value of depth of penetration was measured. The un-notched smooth tensile specimens were prepared to evaluate transverse tensile properties of the joints such as yield strength and tensile strength. The gripping of tensile specimens on universal testing machine was made easy by welding the both ends of specimens with circular rods. Tensile test was conducted with a 40 ton electro-mechanical controlled universal testing machine. Since the plate thickness was small, sub-size specimens were prepared. Eighteen sets of values out of twenty five such sets obtained were used for training a network based on back propagation algorithm. Remaining seven sets of the values were used for prediction. These data sets are shown in table I. A program of back propagation neural network in C++ was used for training and prediction. In this program one input layer having four neurons, two hidden layers, both having five neurons and one output layer having two neurons, were used.



1. Multimeter 2.Gaussmeter 3.Switch Board 4.Table 5.Probe 6.Connecting Wires 7.Transformer 8.Clampmeter 9.Tailstock 10.Sleeve 11.Wooden Structure 12.Magnetic Coil 13.Copper Plate 14.Work Piece 15.Hand Holder 16.Electrode Rod 17.Electrode Holder 18.Headstock 19.Battery 20.Cross Slide 21.Wooden Block

Fig. 1: Experimental Set-up on Lathe Machine

Table 1: Data for Training and Prediction

	Serial Number	*Current (A)*	*Voltage (V)*	*Welding Speed (mm/min)*	*Magnetic Field (Gauss)*	*Tensile Strength (MPa)*	*Depth of Penetration (mm)*
Data for Training	1	90	24	40	0	266	0.79
	2	90	24	40	20	266	0.79
	3	90	24	40	40	266	0.80
	4	90	24	40	60	268	0.77
	5	90	24	40	80	272	0.76
	6	95	20	60	60	284	0.78
	7	95	21	60	60	282	0.76
	8	95	22	60	60	280	0.75
	9	95	23	60	60	278	0.74
	10	95	24	60	60	276	0.72
	11	100	22	40	40	254	0.83
	12	100	22	60	40	258	0.79
	13	100	22	80	40	262	0.76
	14	90	20	80	20	282	0.70
	15	95	20	80	20	280	0.71
	16	100	20	80	20	278	0.74
	17	105	20	80	20	274	0.77
	18	110	20	80	20	272	0.75

Data for Prediction	*1*	*90*	*23*	*40*	*0*	*268*	*0.76*
	2	*95*	*22*	*60*	*40*	*278*	*0.72*
	3	*95*	*21*	*80*	*60*	*284*	*0.66*
	4	*100*	*24*	*40*	*40*	*252*	*0.78*
	5	*105*	*21*	*60*	*40*	*272*	*0.77*
	6	*105*	*22*	*60*	*20*	*270*	*073*
	7	*110*	*21*	*60*	*20*	*270*	*0.75*

Table 2: Measured and Predicted Values with percentage Error

S.N.	*Current (A)*	*Voltage (V)*	*Welding Speed (mm/min)*	*Magnetic Field (Gauss)*	*Tensile Strength (MPa) Measured*	*Tensile Strength (MPa) Predicted*	*Error in Tensile Strength % age*	*Depth of Penetration (mm) Measured*	*Depth of Penetration(mm) Predicted*	*Error in Depth of Penetration % age*
1	*90*	*23*	*40*	*0*	*268*	*274.5*	*2.43*	*0.76*	*0.74*	*-2.63*
2	*95*	*22*	*60*	*40*	*278*	*275.2*	*-1.01*	*0.72*	*0.71*	*-1.39*
3	*95*	*21*	*80*	*60*	*284*	*276.1*	*-2.78*	*0.66*	*0.70*	*+6.06*
4	*100*	*24*	*40*	*40*	*252*	*273.3*	*8.45*	*0.78*	*0.73*	*-6.41*
5	*105*	*21*	*60*	*40*	*272*	*274.1*	*0.77*	*0.77*	*0.74*	*-3.90*
6	*105*	*22*	*60*	*20*	*270*	*273.3*	*1.22*	*0.73*	*0.72*	*-1.37*
7	*110*	*21*	*60*	*20*	*270*	*273.6*	*1.33*	*0.75*	*0.74*	*-1.33*

III. METHODOLOGY OF ARTIFICIAL NEURAL NETWORK MODELING

Generally the industrial processes are non-linear and complex in which several input variables are involved. The mathematical models are unable to describe the behavior of the processes. ANNs are easy to understand, cost effective and have the capability to learn from examples and can be applied in many industries. ANN model has been developed for general application following some steps like Database collection, pre-processing of input/output data, design and training of neural network, testing of trained network, post processing and use trained network for prediction [10]. The arrangement of neurons into layer and the connection pattern within and between the layers are called as network architecture. The ANN architecture is consisted of input layer, hidden layers and output layers. The input layer receives the welding parameters, hidden layers are considered as black boxes and output layer provides the predicted result. The performance of the neural networks depends upon, the number of hidden layers, number of neurons in the hidden layers and the number of iterations used. Hence, optimum structure is obtained by changing number of hidden layers and number of neurons in hidden layers by making many attempts. The appropriate neural networks structure was chosen by the trial and error method [11]. Feed forward artificial neural network structure was established using C++ by keeping four neurons in the input layer, two hidden layers having five neurons in each and two neurons in output layer. It was trained with help of back propagation (BP) algorithm. In training, it is essential to balance the importance of each parameter; hence the data must be normalized. Since, neural networks works better in the range of 0 to 1 [10], the input and output vector values are converted in the range of 0 to 1. Proposed feed forward neural network architecture is shown in figure-3. Non-linearity and input-output mapping are the useful complement in neural networks. Hence, it has been adapted to model the input-output relation of non-linearity and interconnected system.

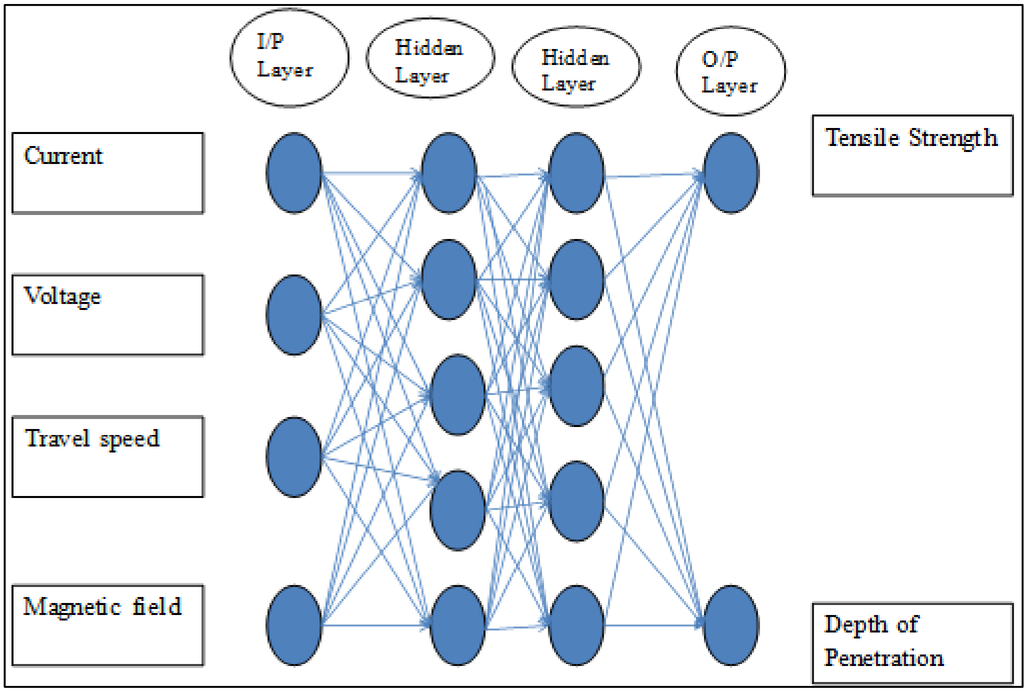


Fig. 2: 4-5-5-2 ANN Diagram

IV. RESULTS

Table-2, depicts the depth of penetration and tensile strength from the experiment and predicts the same output values using artificial neural feed forward network. The measured and predicted output values are close to each other. This strongly recommends the possibility of the use of neural networks to predict the depth of penetration and tensile strength of the weld.

A. Tensile Properties

Transverse tensile property of the joints was evaluated. The specimens were tested, and the results were presented in table 1. The yield strength and tensile strength of unwelded base metal were measured as 359 and 524 M Pa, respectively. But the yield strength and tensile strength of mild steel (fabricated using E-6013, rutile electrode filler metal) joints were reduced by about 50% in both the cases. The tensile strength of the welded joints was unaffected if the magnetic field was changed from 0 to 20 gauss or from 20 to 40 gauss. If the field was increased from 40 gauss to 60 gauss, the tensile strength increased from 266 M Pa to 268 M Pa. and if it was increased from 60 gauss to 80 gauss, the tensile strength increased from 268 M Pa to 272 M Pa. If the speed of welding was increased from 40 mm/min to 60 mm/ min, the tensile strength increased from 254 M Pa to 258 M Pa and if it was increased from 60 mm/min to 80 mm/min, the tensile strength of the weld increased from 258 M Pa to 262 M Pa. The effect of voltage was adverse for tensile strength i.e. if voltage was increased from 20 V to 24 V, the tensile strength decreased continuously from 284 M Pa to 276 M Pa. The increment in current also decreased the tensile strength for all the investigated values. If the current was increased from 90 A to 110 A the tensile strength decreased from 282 M Pa to 272 M Pa. The variation of tensile properties with magnetic field, voltage, welding speed and current were shown in figures 3, 4, 5 and 6 respectively.

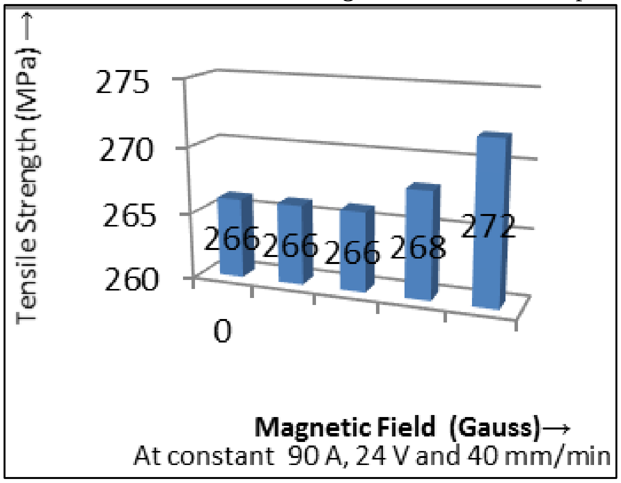


Fig. 3: Tensile Strength Vs Magnetic Field

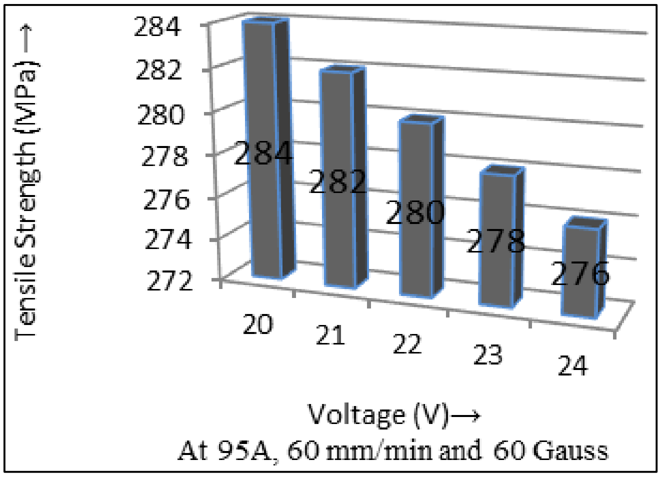


Fig. 4: Tensile Strength Vs Voltage

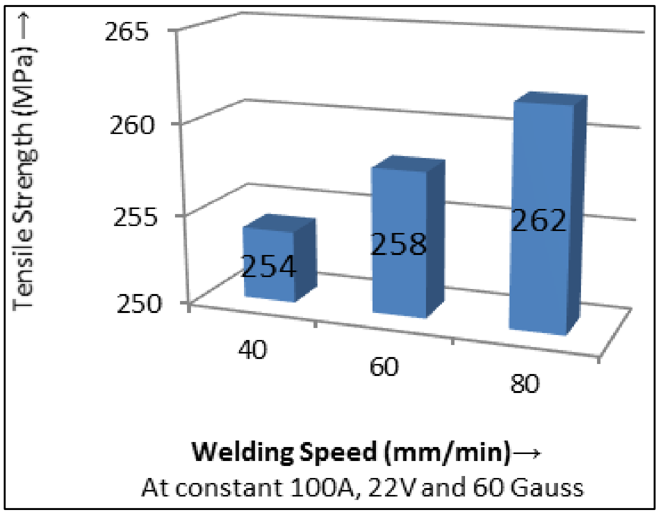


Fig. 5: Tensile Strength Vs Welding Speed

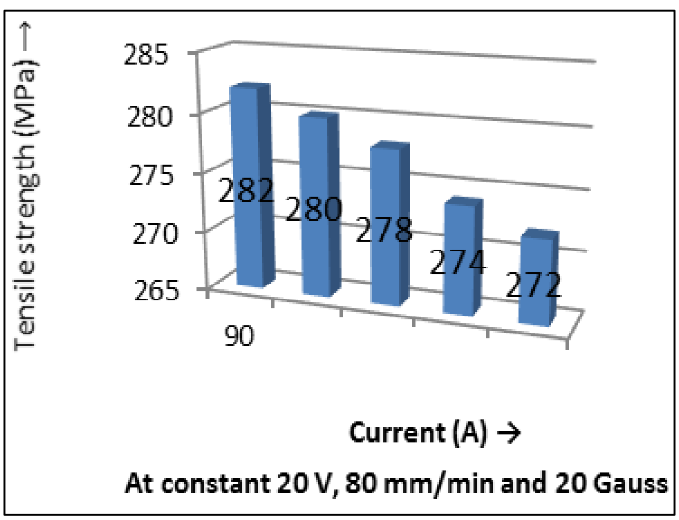


Fig. 6: Tensile Strength Vs Current

B. Depth of Penetration

The depth of penetration of the weld cross-section was measured and the results were displayed in table 1. There was generally no effect of magnetic field on depth of penetration if the strength of the field was less than 40 gauss and if it was increased from 40 gauss to 80 gauss the depth of penetration decreased from 0.80 mm to 0.76 mm. If the speed of welding was increased from 40 mm /min to 80 mm/ min the depth of penetration decreased from 0.83 mm to 0.76 mm. If the voltage was increased from 20 V to

24 V the depth of penetration decreased from 0.78 mm to 0.72 mm. If the current was increased from 90 V to 110 V, the depth of penetration increased from 0.70 mm to 0.75 mm. The variation of depth of penetration with magnetic field, voltage, welding speed and current were shown in figures 7, 8, 9 and 10 respectively.

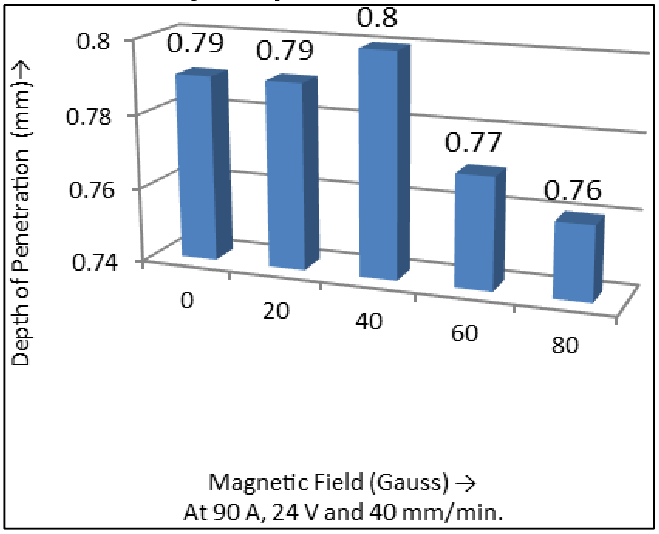


Fig. 7: Depth of Penetration Vs Magnetic Field

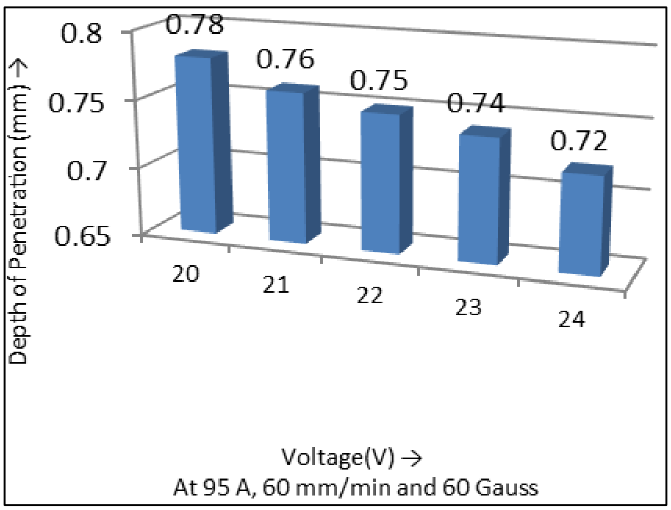


Fig. 8: Depth of Penetration Vs Voltage

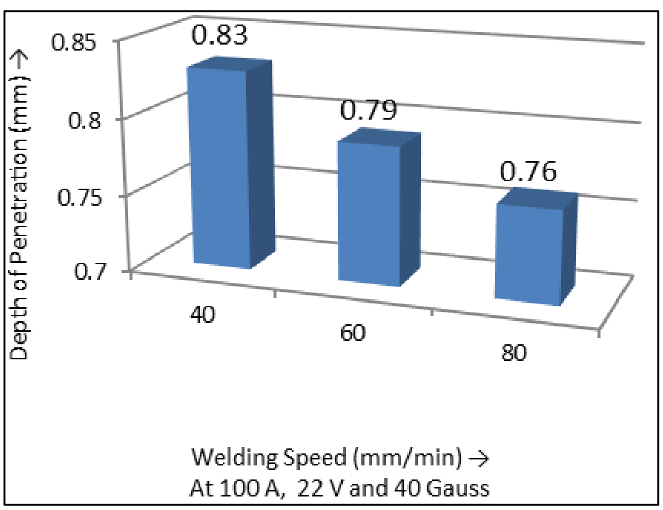


Fig. 9: Depth of Penetration Vs Welding Speed

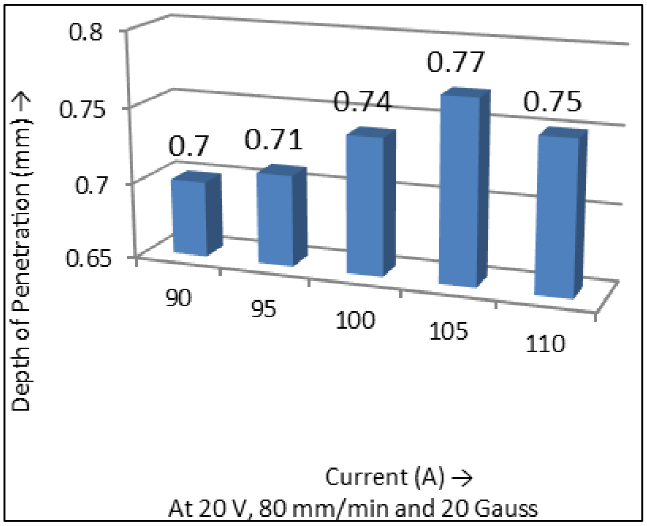


Fig. 10: Depth of Penetration Vs Current

C. *Prediction Made by Artificial Neural Network*

The developed neural network architecture was trained with help of back propagation algorithm using 18 data sets. The developed network was tested out of 7 datasets. The training data sets and testing data sets are shown in table 1; the testing data were not used for training the network. The % error was calculated between the experimental and predicted values as shown in table-2. The % error is ranging between -6.41 to 8.45. The other predictions are in between the above ranges and hence are very close to the practical values, which indicate the super predicting capacity of the artificial neural network model.

V. Discussion

In this investigation, an attempt was made to find out the best set of values of current, voltage, speed of welding and external magnetic field to produce the best quality of weld in respect of depth of penetration and tensile strength. Shielded metal arc welding is a universally used process for joining several metals. Generally in this process speed of welding and feed rate of electrode both are controlled manually but in the present work the speed of welding was controlled with the help of cross slide of a lathe machine hence only feed rate of electrode was controlled manually which ensures better weld quality. In the present work external magnetic field was utilized to distribute the electrode metal and heat produced to larger area of weld which improves several mechanical properties of the weld. The welding process is a very complicated process in which no mathematical accurate relationship among different parameters can be developed. In present work back propagation artificial neural network was used efficiently in which random weights were assigned to co-relate different parameters which were rectified during several iterations of training. Finally the improved weights were used for prediction which provided the results very near to the experimental values.

VI. Conclusions

The experimental analysis confirms that, artificial neural networks are power tools for analysis and modeling. Results revealed that an artificial neural network is one of the alternatives methods to predict the weldbead geometry and mechanical properties. Hence it can be proposed for real time work environment. Based on the experimental work and the neural network modeling the following conclusions are drawn:

1) A strong joint of mild steel is found to be produced in this work by using the SMAW technique.
2) If amperage is increased, tensile strength of weld generally decreases and depth of penetration generally increases.
3) If voltage of the arc is increased, tensile strength and depth of penetration of weld both decrease.
4) If travel speed is increased, tensile strength of weld generally increases but depth of penetration of weld generally decreases.
5) If magnetic field is increased, tensile strength of weld generally increases but depth of penetration of weld decreases.
6) Artificial neural networks based approaches can be used successfully for predicting the output parameters like tensile strength and depth of penetration of weld as shown in table 2. However the error is rather high as in some cases in predicting tensile strength, it is more than 8 percent. Increasing the number of hidden layers and iterations can minimize this error.

References

[1] R.P. Singh, R.C. Gupta And S. C. Sarkar, Prediction Of Weld Bead Geometry In Shielded Metal Arc Welding Under External Magnetic Field Using Artificial Neural Networks, International Journal Of Manufacturing Technology And Research, Vol. 8 Number 1, Pp. 9-15, 2012.

[2] R.P. Singh, R.C. Gupta And S. C. Sarkar, Application Of Artificial Neural Network To Analyze And Predict The Mechanical Properties Of Shielded Metal Arc Welded Joints Under The Influence Of External Magnetic Field, International Journal Of Engineering Research & Technology (IJERT), Pp. 1-12, Vol. 8, Issue 1, October, 2012.
[3] A. K. Hussain, Influence Of Welding Speed On Tensile Strength Of Welded Joint In Tig Welding Process, International Journal Of Applied Engineering Research, Dindigul Volume 1, No 3, 2010.
[4] J. Hak Pak, Modeling Of Impact Toughness Of Weld Metals, Master Of Engineering Thesis, Pohang University Of Science And Technology, Pohang, Korea, 2007.
[5] R.S. Parmar, Welding Engineering and Technology, (Ed. 1st Delhi: Khanna Publishers, 1997).
[6] American Welding Society, Welding Hand Book, (Vol. 2, Welding Processes, Eighth Edition, 1991).
[7] D. G. Karalis, V. J. Papazoglou, And D. I. Pantelis, Mechanical Response Of Thin Smaw Arc Welded Structures: Experimental And Numerical Investigation, Theoretical And Applied Fracture Mechanics, 51 (2009), Pp. 87-94, Elsevier.
[8] V. Rao, C++ Neural Networks And Fuzzy Logic (First Indian Edition:Bpb Publications, 1996).
[9] Md. Ibrahim Khan, “Welding Science and Technology” New Age International (P) Limited Publishers, 2007.
[10] Yousif. K. M. Daws. KM, Kazem. BI, 2008. “Prediction of Friction Stir Weldingm Characteristic Using Neural Network”. Jourdan J, 2008, Mech & Indus. Engg. 2, pp. 151-155.
[11] Abdullah. AF, Hasib. MA, “Prediction of Weld Bead Geometry and Penetration in Electric Arc Welding using Artificial Neural Networks". Int. Jour. of Mech. & Mechatronics Engg., 2010, Vol. 10, No: 04.