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Application of ANN to Analyze and Predict Tensile Strength and Hardness of Shielded Metal Arc Welded Joints under the Influence of External Magnetic Field

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***Abstract*—Nowadays Artificial Neural Networks (ANN) is widely used for modeling and investigation of the effects of process parameters in welding. The applications of external magnetic field in welding processes have drawn much attention of researchers. However, the effect of external magnetic field on properties of weld is still lack of understanding. The present study is concerned with the effect of welding current, welding voltage, welding speed and external magnetic field on hardness, and tensile strength of shielded metal arc welded mild steel joints. Mild steel plates of 6 mm thickness were used as the base material for preparing single pass butt welded joints. Speed of weld was provided by cross slide of a lathe, external magnetic field was produced by bar magnets. Tensile strength and hardness properties of the joints fabricated by E-6013 electrodes as filler metals were evaluated and the results were reported. An artificial neural network technique was used to predict these mechanical properties of weld for the given welding parameters after training the network. From this investigation, it was found that the joints fabricated have increased hardness and tensile strength if either speed of weld or external magnetic field was increased and these mechanical properties decreased if either voltage or current was increased.**

Keywords—Artificial neural network, shielded metal arc welding, tensile strength, welding current.

I INTRODUCTION

The history of joining of metals is as old as our civilization, with the earliest examples of welding from the Bronze Age and the Iron Age. From that time the process of welding has seen several phases, world wars caused a major surge in the use of welding processes, with the various military powers attempting to determine which of the several new welding processes would be the best. Now many sophisticated welding methods for different alloys of various applications are available. Joining method has been used in the material technology because materials having different mechanical properties are required to be efficiently joined to increase the performance. According to Anik [1] the most suitable way of joining two different alloyed steel is welding. After welding process, the properties of welding zone become different from the properties of alloyed steels and this difference may create some problems. Yılmaz [2] investigated that using melting method of welding, among many kinds of welding methods, also increases these problems. Bargel and Schulze [3] analyzed that phase diagrams and properties of joining materials are important factors in determining welding properties. Some problems also arise because the materials to be joined are different alloys and some other components are needed to join them effectively. Several zones appear at connecting region according to the composition and properties of the material. Creation of porosity is the important disadvantage of this method due to which strength of weld is reduced. Tulbentci and Yılmaz [4] described that solid state welding methods are more suitable since melting welding faults do not significantly occur there. Kim and Kim [5] told that arc welding involves a large number of interdependent variables that can affect product quality, productivity and cost effectiveness. Many studies and researches have been done so far to determine the effect of welding parameters on weld properties and quality. Funderburk [6] studied that heat input affects the mechanical properties of the weld for shielded metal arc welding. Cavaliere, Campanile, Panella and Squillace [7] wrote that the welding parameters affect the mechanical properties of the weld. Shielded metal arc arc welding is one of the most common joining processes used in the world. Most of the engineering materials require high tensile strength and sufficient amount of hardness for their performance. The welding parameters in electric arc welding influence the tensile strength and hardness of the weld metal. In order to optimize these properties, in this study four welding parameters current, voltage, speed of welding & external magnetic field were taken.

If an external magnetic field is applied to the welding arc, it deflects by electromagnetic force (Lorentz force) in the plane normal to the field lines. The magnetic field exerts force on the electrons and ions within the arc, which causes the arc to be deflected away from the normal arc path. A transverse external magnetic field deflects the arc in the direction of welding, whereas a longitudinal external magnetic field deflects the arc perpendicular to the bead. Hughes and Walduck [8] saw that If unidirectional magnetic field is applied to an AC arc, or an alternating field is applied to a DC arc, then the arc can be oscillated in the position normal to the direction of welding.

Recently, computer aided artificial neural network (ANN) modeling has gained increased importance, in the fields of materials joining. Some researchers like Dutta and Pratihar [9] modeled the welding process applying conventional regression analysis and neural network-based approaches and found that the performance of ANN was better compared with that of the regression analysis. Ates [10] told that the welding parameters can be predicted efficiently with the use of artificial neural network. Okuyucu, Kurt and Arcaklioglu [11] described that the ANN can be used for the calculation of the mechanical properties incorporating process parameters such as rotational speed and welding speed.

Stretching a material subjects it to a force called tension. Tensile strength is the amount of tension a material can endure without breaking apart. The tensile strength varies from material to material, as it depends upon the structure of material. Due to welding of the work-pieces, the alignment of the molecules of the material changes and hence the tensile strength also changes.

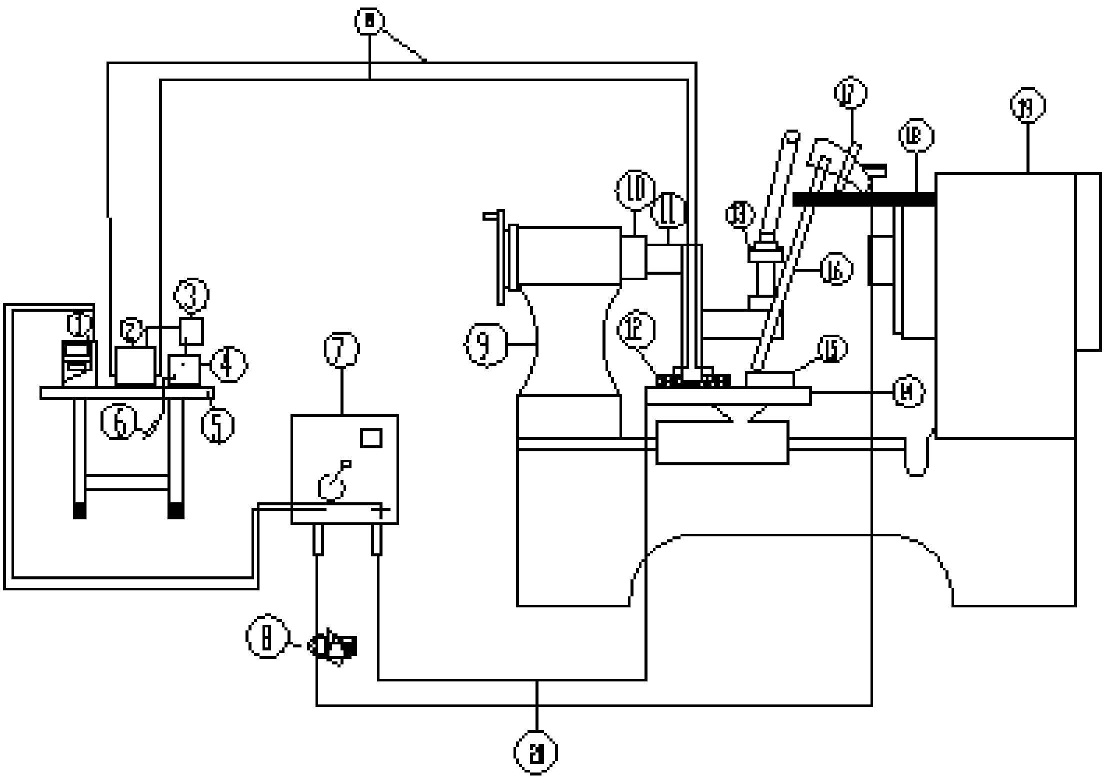
The hardness in the heat-affected zone (HAZ) of a weld is critical to the performance of that weld in the field. In case the weld is too hard it will lose ductility and will be susceptible to cracking; if it is too soft then it will be susceptible to collapse or tensile failure. Hardness has a close relationship with the strength. Very much or very less heat during the welding process can change hardness and thus the strength of the weld. Thus the hardness must be right; it should not be more or less than the required value. Experience has indicated that limitations should be placed on the hardness of the base metal, heat affected zone (HAZ), weld interface and weld metal. If the hardness is too much, these will not have sufficient ductility for the service conditions, their corrosion resistance may be impaired or some other factor may dictate this limitation.

II. EXPERIMENTATION

The mild steel plates of 6 mm thickness were cut into the required dimension (150 mm×50 mm) by oxy-fuel cutting and grinding. The initial joint configuration was obtained by securing the plates in position using tack welding. Single ‘V’ butt joint configuration was used to fabricate the joints using shielded metal arc welding process. All the necessary cares were taken to avoid the joint distortion and the joints were made with applying clamping fixtures. The specimens for testing were sectioned to the required size from the joint comprising weld metal, heat affected zone (HAZ) and base metal regions and were polished using diferent grades of emery papers. Final polishing was done using the diamond compound (1µm particle size) in the disc polishing machine. The welded joints were sliced using power hacksaw and then machined to the required dimensions (100 mm x 10mm) for preparing tensile tests and (10mm x 6mm) for hardness test.

Hardness test was conducted using the Rockwell hardness testing machine. The standard method was used in which the test specimen was placed with the surface on the anvil, and by slowly turning the hand wheel; the specimen was raised until it touched the indenter. The numbers were read directly from the dial indicator and converted to the Rockwell number. The etching of the prepared test area was done carefully. The acid for etching purpose was prepared by taking 96 cubic centimeter of 95% denatured ethanol and 4 cubic centimeter of 65% nitric acid. A wad of cotton wool was impregnated with the readymade acid. The impregnated cotton wool was then lightly dabbed onto the test surface. The complete test area was covered with acid. After etching the individual weld components could be clearly distinguished from each other. Unclean etchings cause phantom structural formations. After etching was completed the affected area was Rinsed off with Ethanol and dried off using a dryer.

Singh, Gupta and Sarkar [12] told that the un-notched smooth tensile specimens can be 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.



1. Multi-meter
2. Battery Eliminator
3. Electric Board
4. Gauss Meter
5. Table
6. Measuring Prob
7. Transformer Welding Set
8. Clamp meter
9. Tail Stock
10. Sleeve
11. Link (Wood)
12. Solenoid
13. Tool post
14. Iron sheet
15. Workpiece
16. Electrode
17. Electrode Holder
18. Metal Strip Connected with head stock
19. Head stock
20. Connecting Wires

Fig. 1 Welding Set-up (Line Diagram)

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Fig. 2 Experimental Set-up

TABLE I
DATA FOR TRAINING AND PREDICTION

	Serial Number	Current (A)	Voltage (V)	Welding Speed (mm/min)	Magnetic Field (Gauss)	Rockwell Hardness (B)	Tensile Strength. (MPa)
Data for Training	1	90	24	40	0	90	266
	2	90	24	40	20	90	266
	3	90	24	40	40	90	266
	4	90	24	40	60	91	268
	5	90	24	40	80	92	272
	6	95	20	60	60	89	284
	7	95	21	60	60	88	282
	8	95	22	60	60	87	280
	9	95	23	60	60	86	278
	10	95	24	60	60	85	276
	11	100	22	40	40	90	254
	12	100	22	60	40	91	258
	13	100	22	80	40	92	262
	14	90	20	80	20	88	282
	15	95	20	80	20	86	280
	16	100	20	80	20	84	278
	17	105	20	80	20	82	274
	18	110	20	80	20	80	272
Data for Prediction	1	90	23	40	0	91	268
	2	95	22	60	40	86	278
	3	95	21	80	60	89	284
	4	100	24	40	40	89	252
	5	105	21	60	40	81	272
	6	105	22	60	20	78	270
	7	110	21	60	20	79	270

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TABLE II
MEASURED AND PREDICTED VALUES WITH PERCENTAGE ERROR

S.N.	Current (A)	Voltage (V)	Welding Speed (mm/min)	Magnetic Field (Gauss)	Rockwell Hardness(B) Measured	Rockwell Hardness(B) Predicted	Error in Hardness % age	Tensile Strength (M Pa) Measured	Tensile Strength (M Pa) Predicted	Error in Tensile Strength % age
1	90	23	40	0	91	85.6	-5.53	268	274.5	2.43
2	95	22	60	40	86	85.1	-1.05	278	275.2	-1.01
3	95	21	80	60	89	85.4	-4.04	284	276.1	-2.78
4	100	24	40	40	89	85.2	-4.27	252	273.3	8.45
5	105	21	60	40	81	84.8	4.44	272	274.1	0.77
6	105	22	60	20	78	84.6	8.46	270	273.3	1.22
7	110	21	60	20	79	83.9	6.20	270	273.6	1.33

III. RESULTS

A. TENSILE PROPERTY

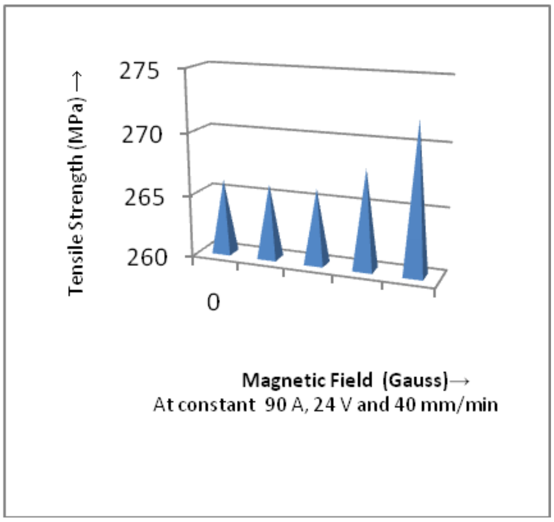

Fig.3 Tensile Strength vs Magnetic Field

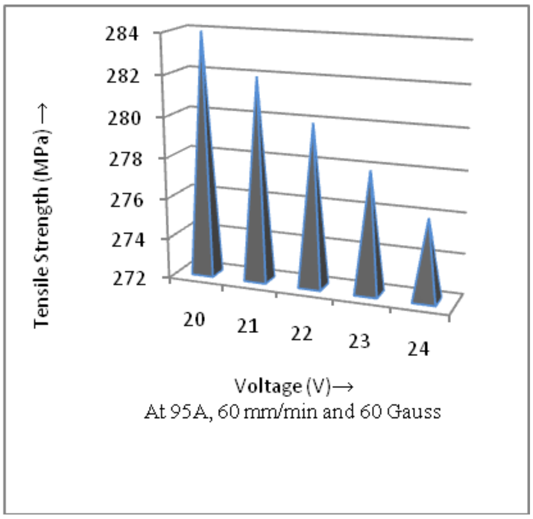

Fig. 4 Tensile Strength vs Voltage

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.

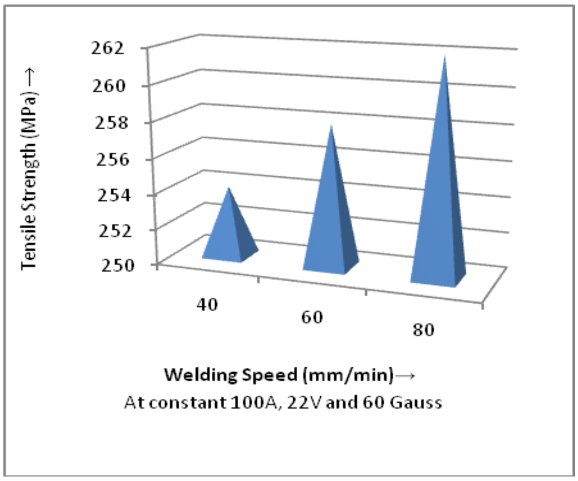

Fig. 5 Tensile Strength vs Welding Speed

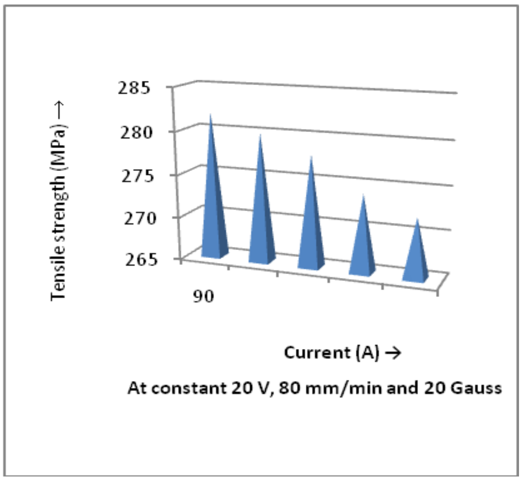

Fig. 6 Tensile Strength vs Current

B HARDNESS PROPERTY

The hardness across the weld cross-section was measured using a rockwell hardness testing machine, and the results were displayed in table 1. The hardness of weld metal (wm) region was found greater than the affected zone region, but lower than the base metal region, irrespective of filler metals used. There was no effect of magnetic field on hardness if the strength of the field was less than 40 Gauss and if it was increased from 40 Gauss to 80 Gauss the hardness increased from 90 RHB to 92 RHB. If the speed of welding was increased from 40 mm /min to 80 mm/ min the hardness increased from 90 RHB to 92 RHB. If the voltage was increased from 20 V to 24 V the hardness decreased from 89 RHB to 85 RHB. If the current was increased from 90 A to 110 A, the hardness decreased from 88 RHB to 80 RHB. The variation of hardness properties with magnetic field, voltage, welding speed and current were shown in figures 7, 8, 9 and 10 respectively.

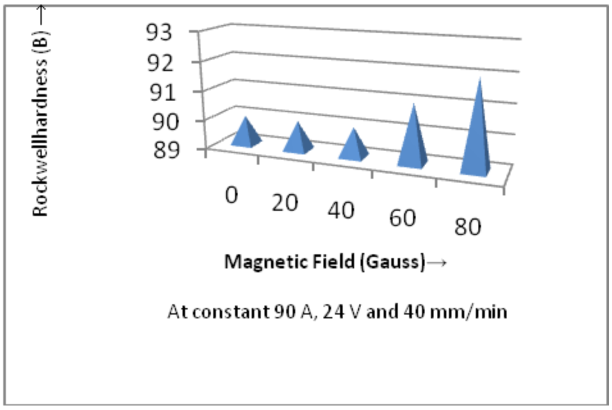

Fig. 7 Rockness Hardness vs Magnetic Field

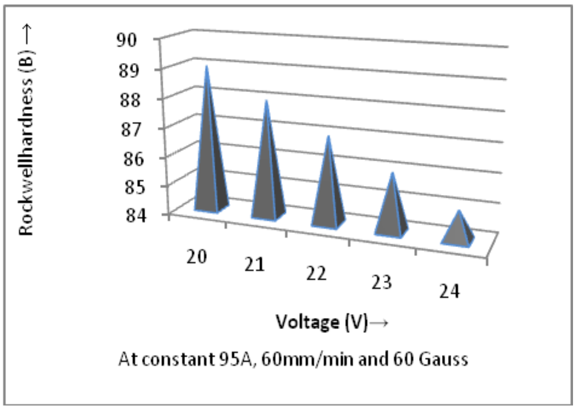

Fig. 8 Rockwell vs Hardness Voltage

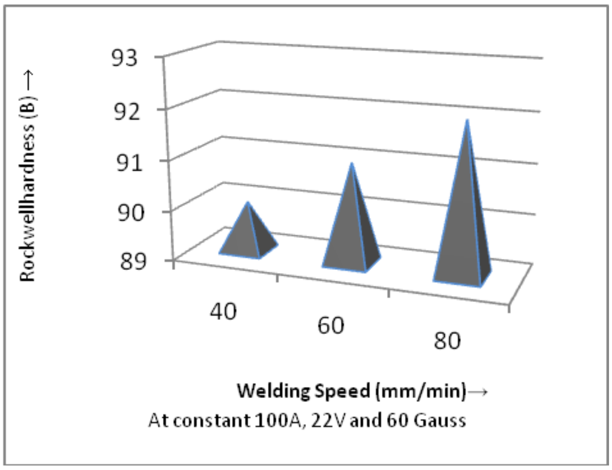

Fig. 9 Rockwell Hardness vs Welding Speed

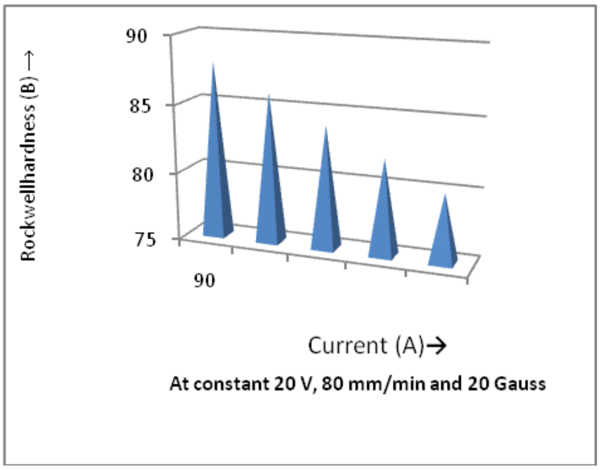

Fig. 10 Rockwell Hardness vs Welding Current

C PREDICTION MADE BY ARTIFICIAL NEURAL NETWORK

From the table 2, it is clear that the prediction made by artificial neural network is almost the real value. The maximum positive and negative percentage errors in prediction of Rockwell hardness are 8.46 and 5.53 respectively. In the prediction of tensile strength these values are 8.45 and 2.78 respectively while in predicting the impact strength these values are 3.68 and 3.43 respectively. 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.

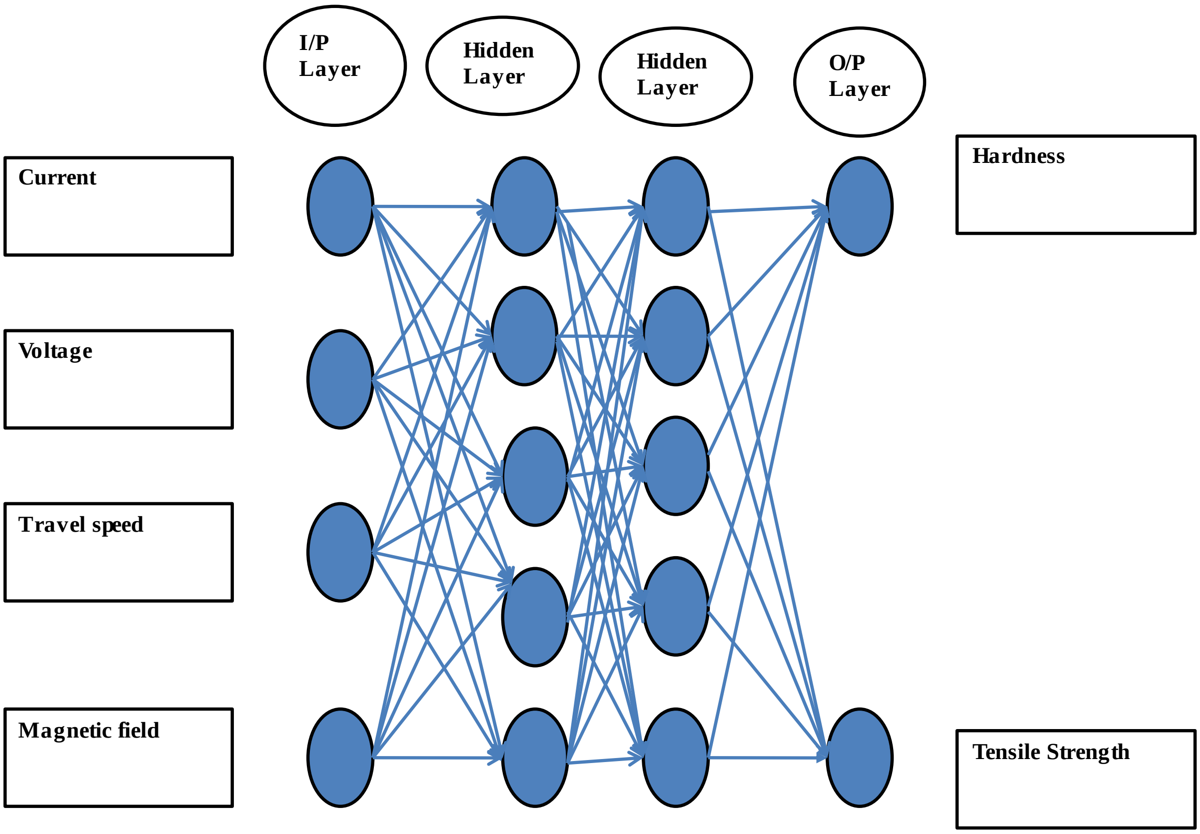

Fig. 11 4-5-5-2 ANN Diagram

IV 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 hardness, tensile strength and impact strength. R. P. Singh, R. C. Gupta and S. C. Sarkar [13] told that the 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.

V CONCLUSIONS

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, hardness and tensile strength of weld, both generally decrease.
3 If voltage of the arc is increased, hardness and tensile strength of weld, both generally decrease.
4 If travel speed is increased, hardness and tensile strength of weld, both generally increase.
5 If magnetic field is increased, hardness and tensile strength of weld, both generally increase.
6 Artificial neural networks based approaches can be used successfully for predicting the output parameters like hardness of weld and strength of weld as shown in table 2. However the error is rather high as in some cases in predicting hardness and tensile strength, it is more than 8 percent. Increasing the number of hidden layers and iterations can minimize this error.

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