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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

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Abstract

The present study is concerned with the effect of welding current, welding voltage, welding speed and external magnetic field on hardness, impact strength 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 obtained by bar magnets. Tensile, impact and hardness properties of the joints fabricated by E-6013 electrodes as filler metals were evaluated and the results were reported. From this investigation, it was found that the joints fabricated have increased hardness, tensile strength and impact strength if either speed of weld or external magnetic field was increased and these mechanical properties decreased if either voltage or current was increased. An artificial neural network technique was used to predict the mechanical properties of weld for the given welding parameters after training the network.

Key Words-Shielded metal arc Welding, Tensile properties, Impact toughness, Artificial neural network.

1.0 Introduction

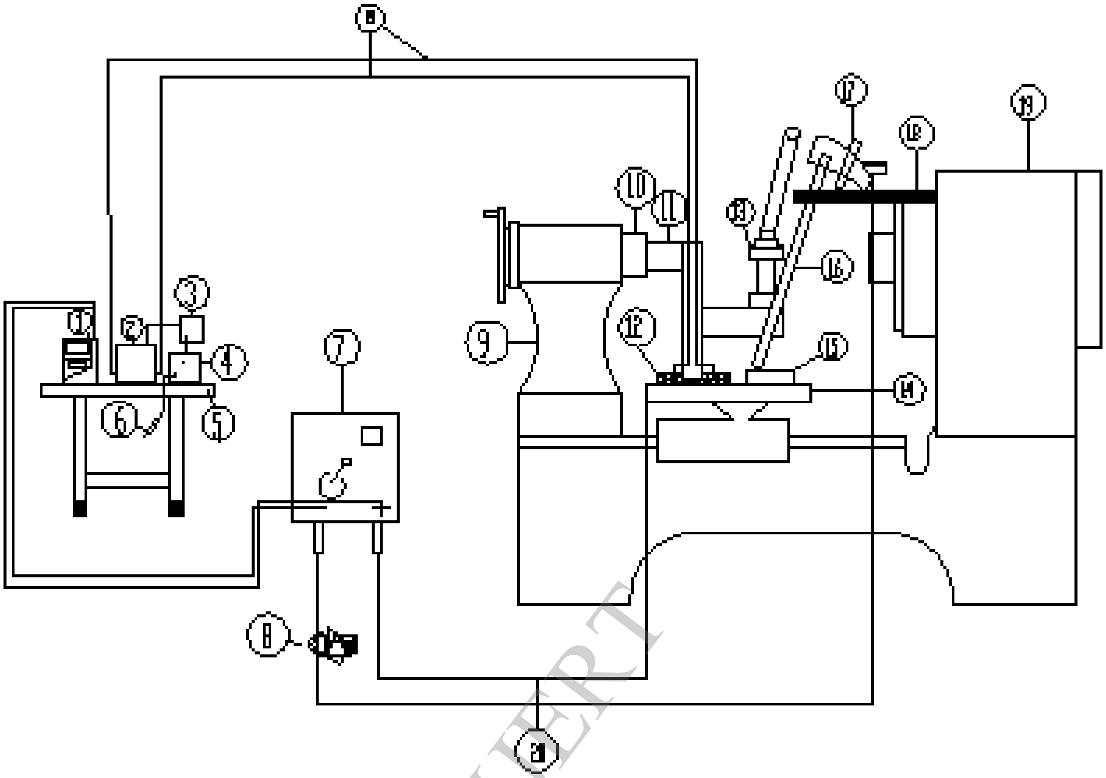
Shielded metal arc welding (SMAW) is a metal joining technique in which the joint is produced by heating the work piece with an electric arc set up between a flux coated electrode and the work piece. The advantages of this method are that it is the simplest of the all arc welding processes. The equipment is often small in size and can be easily shifted from one place to the other. Cost of the equipment is also low [1 & 2]. This process finds 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 any position with highest weld quality by SMAW 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 [3]. As steels are still the most shielded metal arc welded materials, the present work was therefore aimed at characterization of a mild steel weld produced by SMAW technique in terms of its mechanical properties and associated micro-structures. 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. Welding provides continuous strong joints, alleviates crevice and galvanic corrosion problems often associated with fasteners, and also offers enhanced aesthetics to the application. The SMAW process is used extensively in fabricating various structural components due to its ability to produce a good quality weld deposit and ease of application. One major drawback of the SMAW process is that the electrodes are changed while the work is incomplete and welding is going on.

Welding process parameters such as heat input (which is a function of welding current, voltage and travel speed), external magnetic field, machine characteristics, electrode size, flux and electrode chemistries control the microstructures developed in the weld metal (WM) and heat affected zone (HAZ). The variations in the microstructures of the HAZ and WM are very critical for the life of welded components in service because the failure of these components is usually to be initiated in these two zones. The WM microstructure depends on the chemistry of the base metal, the welding electrode and the welding flux [4]. Good weld design and selection of appropriate and optimum combinations of welding parameters are imperative for producing high quality weld joints with the desired strength, hardness and toughness. Improper welding practice which resulted in inadequate toughness, hardness and strength of the welded joints has been linked to several catastrophic service failures [5]. Understanding the correlation between the process parameters and mechanical properties is a precondition for obtaining high productivity and reliability of the welded joints. 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 mechanical properties like hardness, impact strength and tensile strength 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 properties of this versatile structural steel [6 and 7]. Back propagation artificial neural network having one input layer, one output layer and two hidden layers was used to predict the mechanical properties 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 mechanical properties (hardness, impact strength and tensile strength) 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 mechanical properties of weld for given sets of input welding parameters [8 and 9]. In this way the desired mechanical properties of the weld could be obtained by applying needed input welding parameters.

2.0 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 specimens were etched with 5 ml hydrochloric acid, 1 g picric acid and 100 ml methanol applied for 10–15 s. The welded joints were sliced using power hacksaw and then machined to the required dimensions (100 mm x 10mm) for preparing tensile tests, (55mm x 10mm) for impact test and (10mm x 6mm) for hardness test.

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. Impact test was conducted at room temperature using pendulum type impact testing machine with a maximum capacity of 300 Joule and least count of 2 Joule. The amount of energy absorbed in fracture was recorded and the absorbed energy was defined as the impact toughness of the material [1]. The hardness test was conducted on Rockwell (B scale) hardness testing machine.



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

Figure-1 Welding Set-up (Line Diagram)

Figure-2 Experimental Set-up Work in in Progress

Table-1 Data for Training and Prediction

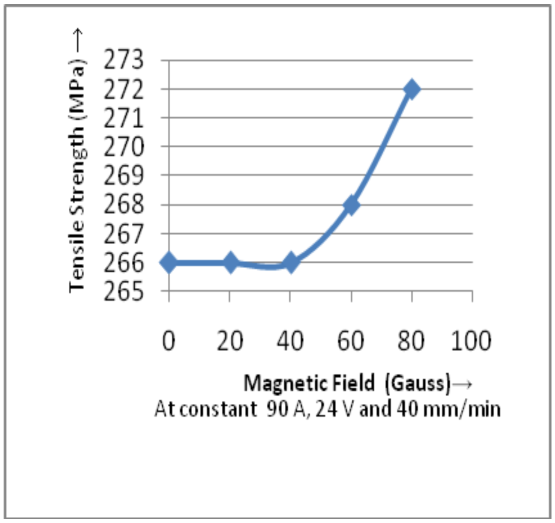
	Serial Number	Current (A)	Voltage (V)	Welding Speed (mm/min)	Magnetic Field (Gauss)	Rockwell Hardness (B)	Tens. Strength. (MPa)	Charpy Imp.Strength. (J)
Data for Training	1	90	24	40	0	90	266	131
	2	90	24	40	20	90	266	131
	3	90	24	40	40	90	266	131
	4	90	24	40	60	91	268	134
	5	90	24	40	80	92	272	135
	6	95	20	60	60	89	284	138
	7	95	21	60	60	88	282	136
	8	95	22	60	60	87	280	135
	9	95	23	60	60	86	278	133
	10	95	24	60	60	85	276	131
	11	100	22	40	40	90	254	132
	12	100	22	60	40	91	258	133
	13	100	22	80	40	92	262	134
	14	90	20	80	20	88	282	134
	15	95	20	80	20	86	280	132
	16	100	20	80	20	84	278	130
	17	105	20	80	20	82	274	129
	18	110	20	80	20	80	272	127
Data for Prediction	1	90	23	40	0	91	268	132
	2	95	22	60	40	86	278	135
	3	95	21	80	60	89	284	137
	4	100	24	40	40	89	252	131
	5	105	21	60	40	81	272	128
	6	105	22	60	20	78	270	127
	7	110	21	60	20	79	270	126

Table-2 Measured and Predicted Values with percentage Error

S.N.	Current (A)	Voltage (V)	Welding Speed (mm/min)	Magnetic Field (Gauss)	Measured Rockwell Hardness(B)	Predicted Rockwell Hardness(B)	% age Error in Hardness	Measured Tensile Strength(MPa)	Predicted Tensile Strength(MPa)	% age Error in Tensile Strength	Charpy Imp. Strength (J) Measured	Charpy Imp. Strength (J) Predicted	% age Error in Impact Strength
1	90	23	40	0	91	85.6	-5.53	268	274.5	2.43	132	131.8	-0.15
2	95	22	60	40	86	85.1	-1.05	278	275.2	-1.01	135	132.1	-2.15
3	95	21	80	60	89	85.4	-4.04	284	276.1	-2.78	137	132.3	-3.43
4	100	24	40	40	89	85.2	-4.27	252	273.3	8.45	131	131.7	0.53
5	105	21	60	40	81	84.8	4.44	272	274.1	0.77	128	130.8	2.19
6	105	22	60	20	78	84.6	8.46	270	273.3	1.22	127	130.6	2.63
7	110	21	60	20	79	83.9	6.20	270	273.6	1.33	126	130.9	3.68

3.0 Results

3.1 Tensile property



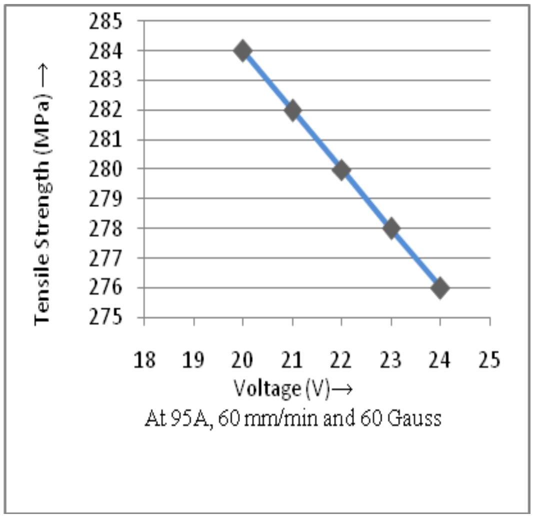
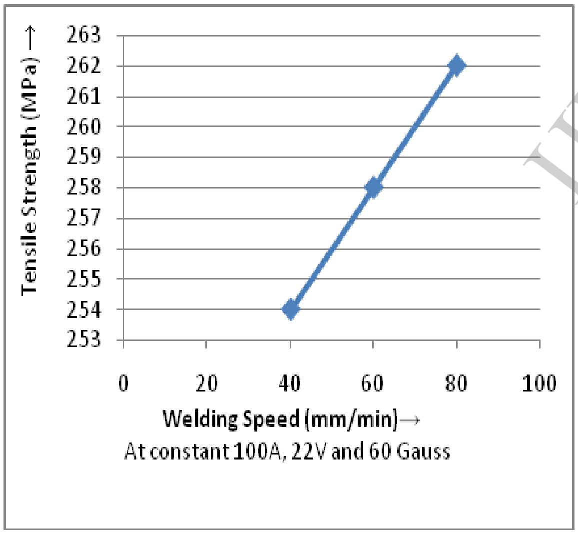


Figure-3 Tensile Strength vs Magnetic Field

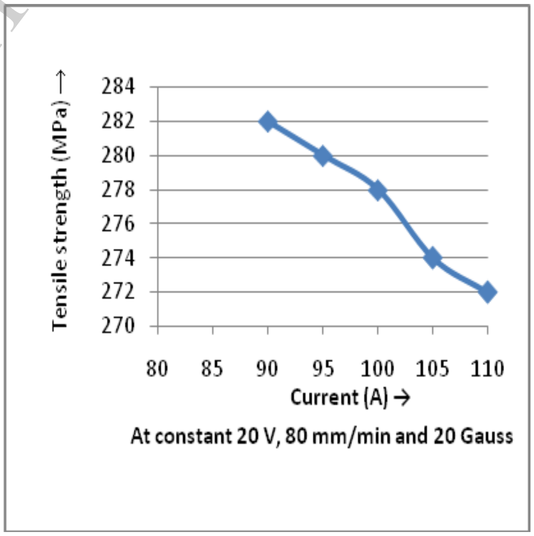
Figure-4 Tensile Strength vs Voltage

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.



At constant 100A, 22V and 60 Gauss

Figure-5 Tensile Strength vs Welding Speed



At constant 20 V, 80 mm/min and 20 Gauss

Figure-6, Tensile Strength vs Current

3.2 Impact Strength property

Charpy impact strength (toughness) values of all the joints were evaluated and they were presented in table 1. The magnetic field had no effect on impact strength if it was changed in between 0 and 40 gauss, the impact strength remained constant at 131 J, and after this the impact strength increased if magnetic field was increased upto 80 gauss which was our investigation range. If the magnetic field was increased from 40 gauss to 60 gauss the impact strength increased from 131 J to 134 J and if it was increased from 60 gauss to 80 gauss the impact strength increased from 134 J to 135 J. If the speed of welding was increased from 40 mm/ min to 80 mm/min the impact strength continuously increased. Increment in voltage from 20 to 24V, decreased the impact strength from 138 J to 131 J., if the increment in current was from 90 A to 110 A, the impact strength of weld decreased from 134 J to 127 J. The variation of toughness (impact strength) properties with magnetic field, voltage, welding speed and current were shown clearly in figures 7, 8, 9, & 10 respectively.

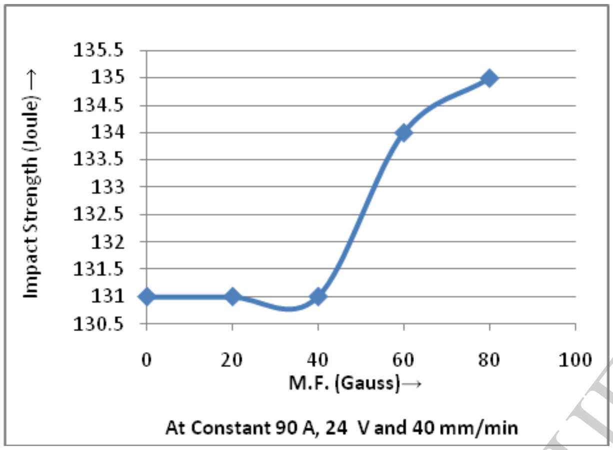


Figure-7 Impact strength vs Magnetic Field

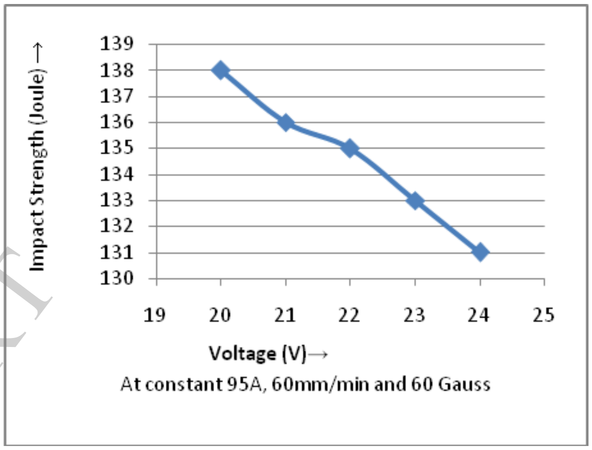


Figure-8 Impact Strength vs Voltage

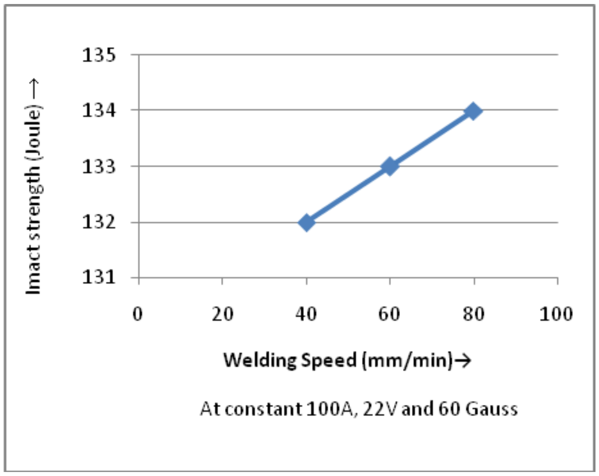


Figure-9 Impact Strength vs Welding Speed

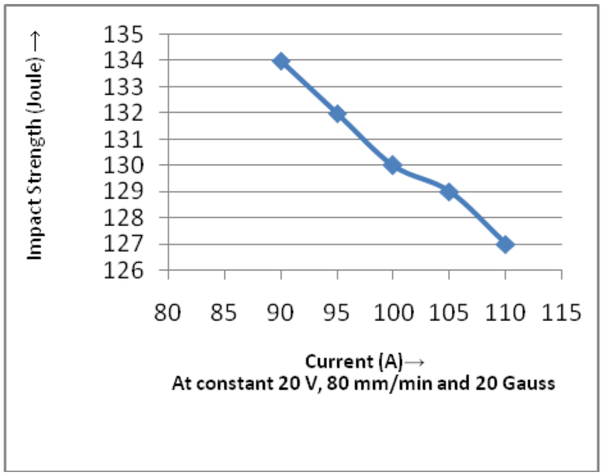
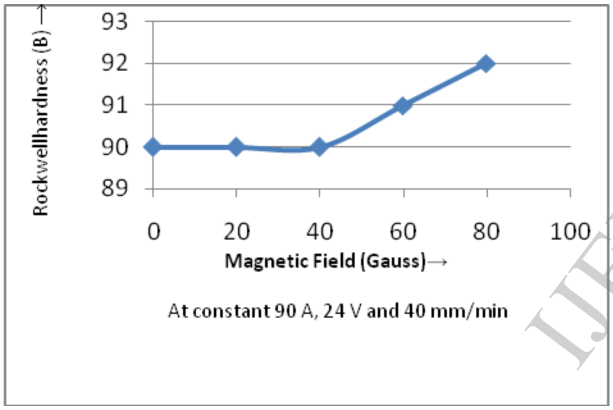


Figure-10 Impact Strength vs Current

3.3 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 HAZ region, but lower than the base metal (BM) 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 V to 110 V, 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 11, 12, 13 and 14 respectively.



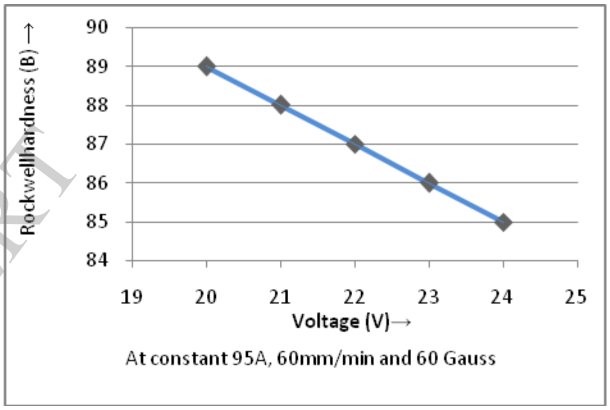
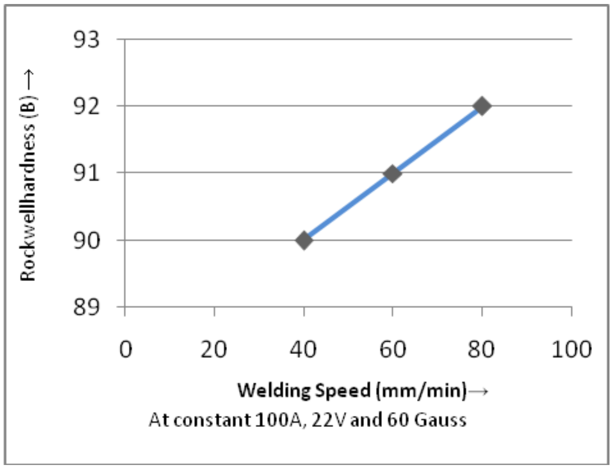


Figure-11 Rockness vs Hardness Magnetic Field

Figure-12 Rockwell vs Hardness Voltage



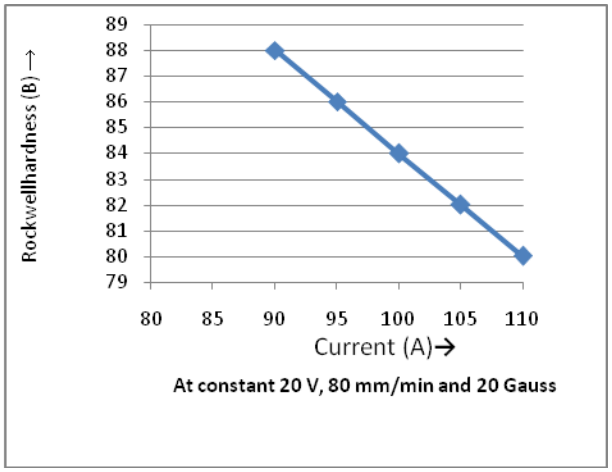


Figure-13 Rockwell Hardness vs Welding Speed

Figure-14 Rockwell Hardness vs Current

3.4 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.

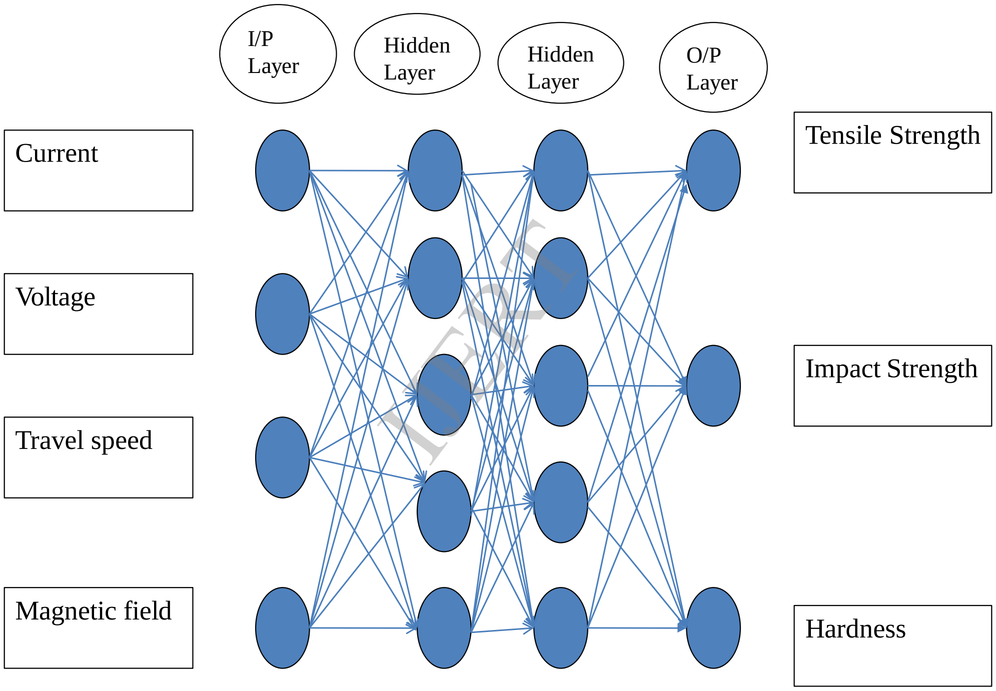


Figure-15, 4-5-5-3, Artificial Neural Network Diagram

4.0 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. 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 [9]. 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.

5.0 Conclusions

Based on the experimental work and the neural network modeling the following conclusions are drawn:

(I) A strong joint of mild steel is found to be produced in this work by using the SMAW technique.

(II) If amperage is increased, hardness, tensile strength and impact strength of weld, all generally decrease.

(III) If voltage of the arc is increased, hardness, tensile strength and impact strength of weld, generally decrease.

(IV) If travel speed is increased, hardness, tensile strength and impact strength of weld, generally increase.

(V) If magnetic field is increased, hardness, tensile strength and impact strength of weld, generally increase.

(VI) Artificial neural networks based approaches can be used successfully for predicting the output parameters like hardness of weld, strength of weld and impact 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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