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APPLICATION OF ANN TO ANALYZE AND PREDICT IMPACT STRENGTH AND HARDNESS OF SHIELDED METAL ARC WELDED JOINTS UNDER THE INFLUENCE OF EXTERNAL MAGNETIC FIELD

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Abstract

Purpose The prediction of the optimal impact strength and hardness of weld simultaneously is an important aspect in any welding process. Therefore, the artificial neural networks (ANN) models that predict and control these properties are required to be developed. This paper focuses on investigation of the development of the simple and accuracy interaction model for prediction of impact strength and hardness for butt joint in shielded metal arc welding (SMAW) process. **Design/methodology/approach** The experiment has been conducted with a simple shielded metal arc welding machine by welding mild steel plates with four welding input process parameters to obtain impact strength and hardness of the weld bead. The analysis and prediction of impact strength and hardness properties has efficiently been done for identifying the significance of main and interaction effects of process parameters. Eighteen sets of experimental input-output variables have been employed as the guide to achieve the trained ANN model. The prediction of the properties given by the model was also carried out with the help of other seven experimental sets. **Findings** The prediction capability of ANN model is reliable. It was found that welding voltage, arc current, welding speed and external magnetic field all affect the properties of the weld. **Practical implications** The developed model should also cover a wide range of material thicknesses and be applicable for all types of welding processes and positions. **Originality/value** It has been realized that with the use of the developed model, the prediction of optimal impact strength and hardness becomes much simpler to even a novice user who has no prior knowledge of any welding process and optimization techniques.

INTRODUCTION

Welding is the process used to join two or more pieces of metal together by applying thermal energy or pressure. It is a precise, reliable, cost-effective method for joining materials. This technique is widely used by manufacturers to join metals and alloys. In this way welding is essential to produce most of usual objects, from big structures such as bridges and ships to microelectronic components. In comparison to other joining methods, welded structures are stronger, cheaper and lighter in weight. Welding adds value in manufacturing process. Moreover, welding is frequently used to repair fix structures that were not originally welded, increasing the life of this structures. In this work Shielded Metal Arc Welding (SMAW) was used to produce all welds for analysis. SMAW is an arc welding process in which coalescence of metals is produced by heat from an electric arc that is maintained between the tip of a covered electrode and the surface of the base metal in the joint being welded. SMAW is also called Manual Metal Arc (MMA) welding since welding is normally carried out by a welder manually guiding a stick electrode. At first glance, a normal stick electrode basically consists of a metallic wire which is surrounded by a coating. Within the electrode, there are filler materials for the joint and intricate compounds required to control the arc and to create a protective slag and generate a protective gas shroud that shields the weld pool from the atmosphere. Shielded metal arc welding is the most widely used arc welding process. It employs the heat of the arc to melt the base metal and the tip of a consumable covered electrode. The electrode and the work are part of an electric circuit. This circuit begins with the electric power source and includes the welding cables, an electrode holder, a work piece connection, the work piece (weldment), and an arc welding electrode. One of the two cables from the power source is attached to the work. The other is attached to the electrode holder. Welding commences when an electric arc is struck between the tip of the electrode and the work. The intense heat of the arc melts the tip of the electrode and the surface of the work close to the arc. Tiny globules of molten metal are rapidly formed on the tip of the electrode and are transferred through the arc stream into the molten weld pool[1]. In this manner, filler metal is deposited as the electrode is progressively consumed. The arc is moved over the work at an appropriate arc length and travel speed, melting and fusing a portion of the base metal and continuously adding filler metal. The temperature of arc is about 5000°C at its center and hence melting of the base metal takes place almost instantaneously upon arc initiation. The process requires sufficient electric current to melt both the electrode and a proper amount of base metal. It also requires an appropriate gap between the tip of the electrode and the base metal or the molten weld pool. These requirements are necessary to set the stage for coalescence. The sizes and types of electrodes for shielded metal arc welding define the arc voltage requirements (within the overall range of 16 to 40 V and the amperage requirements within the overall range of 20 to 550 A[2]. The mechanical properties of a weld metal can be affected by the welding parameters like welding current, arc voltage, welding speed, plate thickness, preheating and interpass temperatures etc.

Toughness or impact strength is a measure of the amount of energy a material can absorb before fracturing. It becomes of engineering importance when the ability of a material to withstand an impact load without fracturing is considered. It is the capability of the material in withstanding by the suddenly applied loads in terms of energy. Often measured with the Izod impact strength test or Charpy impact test, both of which measure the impact energy required to fracture a sample. Impact testing ascertains the fracture characteristics of materials. It is used when laboratory tensile test results cannot be used to predict fracture behavior[3]. One of the most common impact testing techniques, Charpy method was used to measure impact energy, or the toughness of the metal in the present work. The V-notch bar-shaped specimen was placed in the test machine as a simply supported beam where it was struck by a weighted pendulum hammer that deformed cracked and fractured the specimen at the notch. The notch was located on tension side of specimen during impact loading. The impact strength of a metal was then determined by measuring the amount of energy absorbed in the fracture.

Hardness is the property of a material to resist permanent indentation. Because there are several methods of measuring hardness, the hardness of a material is always specified in terms of the particular test that was used to measure this property. Rockwell, Vickers, or Brinell are some of the methods of testing. Of these tests, Rockwell is the one most frequently used. For the measuring the hardness of the metals, that are softer, a metal ball is used and the hardness is indicated by a Rockwell "B" number. Hardness test was conducted using the Rockwell 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.

Magnetic fields and electric currents in conductors interact and some of this interaction as it pertains to welding arcs is detrimental and some is beneficial. Magnetic field may be applied or induced but interact with arc current to produce a force that causes the arc to deflect. This phenomenon is known as arc blow when it becomes severe. Arc blow arises from two basic conditions, (i) the change in direction of current flow as it leaves the arc and enters the work-piece to seek the ground and (ii) the asymmetrical arrangement of magnetic material around the arc as it is easier for magnetic flux to pass through certain materials (especially ferromagnetic materials) than through air[4]. Magnetic field can be applied to the welding arc in three different modes. If the direction of the magnetic field is parallel to the direction of electrode travel it is considered to be a parallel field. If the field is perpendicular to the direction of electrode travel and electrode axis it is referred to as a transverse field. If the field is parallel to the axis of electrode it is termed as longitudinal or axial field[5]. According to the Fleming's left hand rule the arc under the influence of parallel field will be deflected towards right or left across the weld bead length depending upon the direction of the parallel field (forward or backward). If field strength is increased, depth of penetration will be decreased but weld width will be increased. In the present work the parallel external magnetic field was produced by bar magnets which were assembled on a lathe machine.

A neural network is a computational structure inspired by the study of biological neural processing. There are many different types of neural networks, from relatively simple to very complex, just as there are many theories on how biological neural processing works[6]. Artificial neural networks are the result of academic investigations that use mathematical formulations to model nervous system operations. Neural networks represent a meaningfully different approach to use computers in the workplace, and have been used to recognize patterns and relationships in data[7].

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 tag 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 different 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 second. The welded joints were sliced using power hacksaw and then machined to the required dimensions (55mm x 10mm) for impact test and (10mm x 6mm) for hardness test[8].

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

RESULTS

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.

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 [9].

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.

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, 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.

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 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[10]. 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.

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 impact strength of weld generally decrease.
3. If voltage of the arc is increased hardness and impact strength of weld generally decrease.
4. If travel speed is increased hardness and impact strength of weld generally increase.

5. If magnetic field is increased hardness and impact strength of weld, generally increase.
6. Artificial neural networks based approaches can be used successfully for predicting the output parameters like hardness 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 it is more than 8 percent. Increasing the number of hidden layers and iterations can minimize this error.

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Figure 1: Experimental Welding Set-up

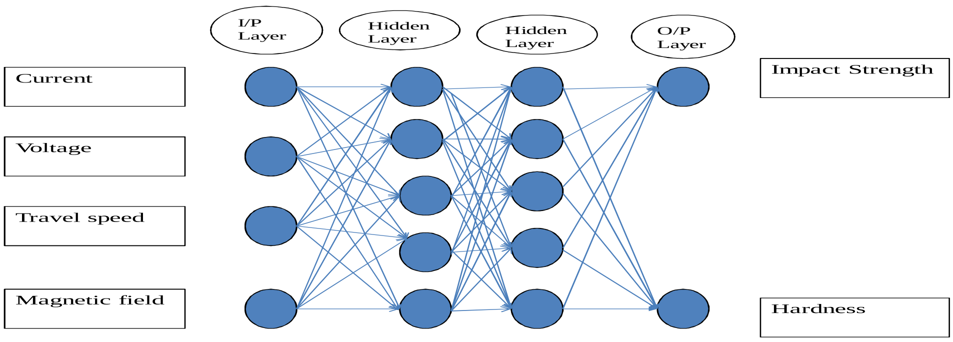

Figure 2, 4-5-5-2 ANN Diagram

Table 1 Data for Training and Prediction

	Serial Number	Current (A)	Voltage (V)	Welding Speed (mm/min)	Magnetic Field (Gauss)	Rockwell Hardness (B)	Charpy Imp.Strength. (J)
Data for Training	1	90	24	40	0	90	131
	2	90	24	40	20	90	131
	3	90	24	40	40	90	131
	4	90	24	40	60	91	134
	5	90	24	40	80	92	135
	6	95	20	60	60	89	138
	7	95	21	60	60	88	136
	8	95	22	60	60	87	135
	9	95	23	60	60	86	133
	10	95	24	60	60	85	131
	11	100	22	40	40	90	132
	12	100	22	60	40	91	133
	13	100	22	80	40	92	134
	14	90	20	80	20	88	134

	15	95	20	80	20	86	132
	16	100	20	80	20	84	130
	17	105	20	80	20	82	129
	18	110	20	80	20	80	127
Data for Prediction	1	90	23	40	0	91	132
	2	95	22	60	40	86	135
	3	95	21	80	60	89	137
	4	100	24	40	40	89	131
	5	105	21	60	40	81	128
	6	105	22	60	20	78	127
	7	110	21	60	20	79	126

Table 2 Measured and Predicted Values with percentage Error

Sr. No.	Current (A)	Voltage (V)	Welding Speed (mm/min)	Magnetic Field (Gauss)	Rockwell Hardness (HRB) Measured	Rockwell Hardness (HRB) Predicted	Error in Hardness % age	Charpy Impact Strength (J) Measured	Charpy Impact Strength (J) Predicted	Error in Impact Strength % age
1	90	23	40	0	91	85.6	-5.53	132	131.8	-0.15
2	95	22	60	40	86	85.1	-1.05	135	132.1	-2.15
3	95	21	80	60	89	85.4	-4.04	137	132.3	-3.43
4	100	24	40	40	89	85.2	-4.27	131	131.7	0.53
5	105	21	60	40	81	84.8	4.44	128	130.8	2.19
6	105	22	60	20	78	84.6	8.46	127	130.6	2.63
7	110	21	60	20	79	83.9	6.20	126	130.9	3.68

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