ISSN: 2278 – 7798
International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 5, Issue 5, May 2016

OPTIMIZATION OF PROCESS PARAMETERS FOR GAS METAL ARC WELDING OF ALUMINIUM ALLOY A6063 BY ANN METHOD

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Abstract— **Aluminum alloy 6063 is widely used in boat truck, tower building, ships, electric car, furniture, machine parts, automobile frames and aero plane industrial application due to its high strength, excellent machining performance, good welding characteristics and excellent oxidation resistance .Gas metal arc welding (GMAW) process is used for welding of aluminum alloy 6063.The present work is carried out to analyze the effect of welding parameters on mechanical properties of MIG welded aluminum alloy 6063. GMAW process is used to weld the specimens by using a consumable electrode & argon inert gas. The filler metal is used for joining the plate is aluminum alloy 4043 grade. Current, voltage, gas flow, root gap are the parameters which play a significant role in the assessment of mechanical properties (Hardness & Tensile Strength). Experiments has been carried out and nine joints have been made with 6063 Al Alloy and tested for its tensile and hardness properties. The results were analyzed using ANOVA technique and artificial neural network (ANN). Based on the results, optimum parameters determined.**

Key Terms: GMAW, MIG, ANN, ANOVA, Taguchi

I. INTRODUCTION

Welding is a process of permanent joining two metals through localized coalescence resulting from a suitable combination of temperature and pressure. Depending upon the combination of temperature and pressure from a high temperature with low pressure to a high pressure with low temperature, a wide range of welding processes has been developed using different energy sources, from a Gas Flame or Electric Arc to a Laser or Ultrasound. Aluminium is the most difficult alloy to weld. Aluminium oxide should be cleaned from the surface prior to welding. Aluminium comes in heat treatable and non heat treatable Alloys. Heat treatable Aluminium Alloys get their strength from a process called Ageing. Significant decrease in Tensile Strength can occurs when Welding Aluminium due to over aging Aluminium possesses a number of properties that make welding it difficult than the welding of steels.These are: Aluminium Oxide Surface Coating; High Thermal Conductivity; High Thermal Expansion Coefficient; Low Melting Temperature; and the absence of colour change as temperature approaches the melting point.

I.I Gas Metal Arc Welding (GMAW)

The GMAW process is quite often a viable option for Welding Aluminium. It was developed in 1944, and is still extensively used to successfully weld Aluminium Alloys today. The principle of MIG welding shows Figure I. The arc is struck between the work piece and a wire that is continually fed forward to replace the metal that is melted away. The wire is supplied on a reel or drum, and is fed to the welding gun by drive rollers, which push the wire through a flexible conduit in the hose Package to the gun. Electrical energy for the arc is supplied by a welding power source. The welding current is passed to the electrode through a contact tip in the welding gun. This contact tip is normally connected to the positive pole of the power source, and the work piece to the negative pole. Striking the arc completes the circuit.

The small diameter wire, typically around I mm, is fed by the wire feeder with a speed of several meters per minute. Arc length is then self -adjusted depending on the voltage setting of the constant potential power source.

A shielding gas that protects the electrode, the arc and the weld pool from the effects of the surrounding air, flows through the shielding gas nozzle that surrounds the contact tip. This shielding gas may be either inert, which means that it is inactive and does not participate in the processes occurring in the weld pool, or active.

As the filler wire is fed through repeatedly while the welding gun is moved over the work piece manually, MIG welding is usually referred to as being a semi-automatic method. However, the method lends itself easily to automation by mechanizing the movements of the welding gun or arranging for the work piece to move.

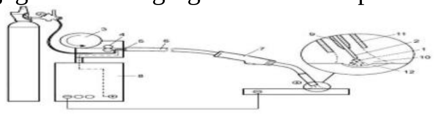

Fig: I The principle of MIG welding

II. LITERATURE SURUEY

Zhang Y.M. and S.B. Zhang S.B. [1] carried out welding of Aluminium Alloy AA6061 using Opposing Dual torch GTAW process. They disconnected the work piece from the power supply and placing a second torch on the opposite side of the work piece. Such a modification changed the direction of current flow, improved the weld penetration and reduced the heat input. This reduced the crack sensitivity of AA6061 and the alloy could be welded without filler metal.

Balasubramanian M. [2] developed mathematical models to predict the tensile properties of pulsed current GTA welded Ti-6Al-4V alloy weldments. Four factors peak current, background current, pulse frequency and pulse on time were selected along with five levels and rotatable design matrix to optimize the number of experiments. Mathematical models were developed by response surface method and their adequacy was checked by ANOVA technique.

Juang S.C., Tarng Y.S. (3) in this paper Taguchi technique is applied to select the process parameters in order to obtain optimum weld pool geometry in TIG welding of stainless steel. Arc gap, flow rate welding current and welding speed are the parameters selected. Modified Taguchi method is applied to analyses the effect of each welding process parameter on the weld pool geometry and to determine the process parameters with the optimal weld pool geometry.

Balasubramanian M. et.al (4) in this paper mathematical model was developed to predict grain size and hardness of argon tungsten pulse current arc welded titanium alloy weldment. Four factors peak current, base current, pulse frequency and pulse on time were taken. Five levels and rotatable design matrix is used to optimize the required number of experiments. Numerical models were developed by response surface method and their adequacy is checked by ANOVA technique. The termination is that the developed models are effective for predicting the grain size and hardness of Ti-6Al-4V alloy within the range of parameters.

A. K. Lakshminarayanan et.al studied the effect of welding processes such as GTAW, GMAW and FSW on mechanical properties of AA6061 Aluminium Alloy. Rolled plates of 6 mm thickness have been used as the base material for preparing single pass butt welded joints. The filler metal used for joining the plates is AA4043 (Al-5Si (wt %)) grade Aluminium Alloy. Tensile properties, micro hardness, microstructure and fracture surface morphology of the GMAW, GTAW and FSW joints have been evaluated, and the results are compared. From this investigation, it is found that FSW joints of AA6061Aluminium Alloy showed superior mechanical properties.

III. METHODOLOGY-EXPERIMENTAL SETUP

III.I Process Involved

The following procedure was adopted while carrying out the experimentation in the welding.

III.I.I. Cutting Aluminium strip

The base metal sheets of dimensions 150 x 40 x 6.0mm were cut on shearing machine.

III.I.I.II. Job preparation

a. As the thickness of the plates is 6.0mm a V groove butt joint of 60^o groove angle is required. Edge training is done as per dimensions is shown in Figure - II.

b. The designed V groove butt joint with its arrangement is as shown in Figure- III

Figure -I I: V-groove butt joint

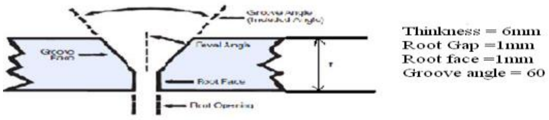

Figure - III: Configuration of designed V- groove butt joint

III.I.I.III. Welding

previous to welding, edges were cleaned in order to remove dirt, oil and grease. The plates are then kept on backing bars and ends were clamped in order to maintain the root gap and alignment as shown in figure -IV and its welding situation are shown in Table –I.

Figure - IV: Tack welds on plates

Table –I. welding conditions

Polarity	Pulsed DC
Welding current	85A-105Apulsed current
Electrode wire	25kg
Wire diameters	1.6mm
Welding operation	Manual
Upslope time	1 sec
Down slope time	5sec
Gas Pre-flow time	0.5 sec
Gas Post-flow time	1.5 sec

III.I.I.IV. Joint Fabrication

The methodology for joint considered in GMAW process consists 6063 Al Alloy of 6mm thickness plate (150 x 70mm).the joint configuration is shown in Figure - V.

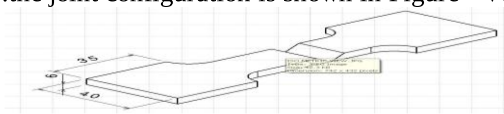

Figure - V. Single V- Butt Joint

III.II Plan of investigation Methodology

In order to achieve the desired objectives, the investigations were planned to be carried out in the following steps:

1.Identifying the welding variables and outputs .
2.Selection of the useful limits of the welding parameters,viz current, voltage, gas flow and root gap
3.Establishing the design matrix.
4.Conducting the experiment as per Taguchi design matrix.
5.Testing the significance of regression co-efficient and arriving at the final form of the mathematical models.
6.Presenting the main effects and the significant interactions between different parameters in graphical forms.
7.Analysis of results and conclusions

IV. DESIGN OF EXPERIMENT

In this chapter, mathematical models were developed to predict the tensile properties. Design of Experiments (DOE) concept is explained to optimize the number of experimental parameters. The effect of welding parameters like current, voltage, gas flow, and root gap on the above properties were studied and analyses by using Taguchi approach, ANOVA technique, and artificial neural network(ANN).

IV.I DESIGN MATRIX

The following table numbers of experiments conduct in orthogonal array

Trial no.	1	2	3	4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table – II Design Matrix of L09 (3^4) Standard Array

In this array the columns are mutually orthogonal. That is for any pair of columns all combination of factors occurs; and they occur an equal number of times. Here there are 4 parameters, A, B, C and D each at three levels. This is called an ‘L_9’ design; with the 4indication the nine rows, configurations, or prototypes to be tested. Specific test characteristics for each experimental evaluation are identified in the associated row of the table. Thus L_9 (3^4) means that nine experiments are to be carried out to study four variables with three levels. There are greater savings in testing for larger arrays.

IV.II. Artificial Neural Networks (ANN)

Artificial Neural Networks (ANN) is computational systems whose building and operation are inspired by the knowledge of biological neural cells (neurons) in the brain. ANNs can be described either as numerical and computational models for non-linear function approximation, data classification, clustering and non-parametric regression or as simulations of the performance of collections of biological neurons. These are not simulations of real neurons in the sense that they do not model the biology, chemistry, or the physics of a real neuron. They do, however, model several aspects of the information combining pattern recognition performance of real neurons in a meaningful way. Neural network modeling has shown incredible capability for emulation, analysis, prediction, and association.

The building of neural network for the production of clad bead parameters consists of three parts,

1. Input layer for providing specification of the welding parameters.
2. Hidden layer regarded as black box.
3. Output layer for obtaining the values of the clad bead geometry.

IV-III important specifications used for ANN modeling

Some of the important specifications of parameters that are frequently required throughout the modeling process as shown in Table III

S.no	Parameter	Technique used/ Type of Parameter Used
1	Nos. of input neuron	4 (current, Voltage, Gas flow rate, Root Gap)
2	Nos. of output neuron	2 (Ultimate tensile strength, Hardness)
3	Total nos. of data set	9 nos.
4	Data normalization	Between (0 – 1)
5	Transfer function of hidden layer	Tansig
6	Transfer function of	Purelin
7	Error function	Mean squared error
8	Learning rule	Back propagation
9	Algorithm	Levenberg-Marquardt

Table –III important specification used in ANN modeling

Before applying inputs and outputs for ANN training, data have to be converted into a range of 0 to 1 or -1 to 1 i.e. Data should be normalized for ANN training.

IV.IV Neural Network Design

The network is trained using a suitable supervised learning algorithm, in this case, the Levenberg-Marquardt algorithm. In the case of supervised learning, the network is presented with both the input data and the target data called the training set. The network is adjusted based on comparison of the output and target values until the outputs match the targets.

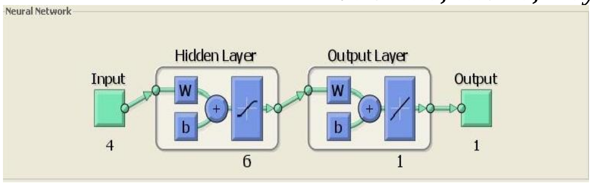

Figure: VI ANN model Training

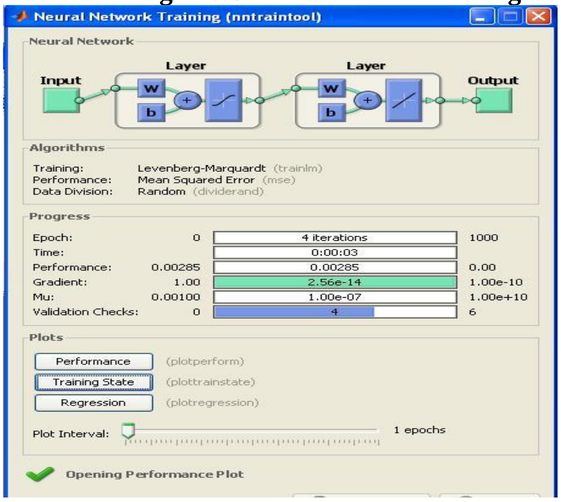

Figure: VII. ANN Model Training

Figure.VII shows neural network toolbox model creation and training window of ANN model. It is back propagation model type used LM training algorithm which has 6 neurons in hidden layer, MSE performance function, Tansig and Purelin transfer function is used in between input and hidden layer, and in between hidden and output layer respectively.

V. RESULT AND DISCUSSIONS

GMAW technique is employed on 6063 Aluminium alloys and tested using different parameters Current(C), Voltage(V), Gas Flow(GF), Root gap(R). This chapter deals with the results and discussion of the above mentioned Welding Technique. Tables are presented for re Below tables shows the effects of factors on the Current(C), Voltage (V), Gas Flow (GF), Root gap(R).

Taguchi orthogonal array

Variables	Code	Unit	Level1	Level2	Level3
current	C	amp	85	95	105
voltage	V	volt	20	22	24
gas flow	GF	Lit/ min	23	24	25
root gap	R	mm	1	2	3

Table –IV Process parameters and design levels used

V-II EXPERIMENTAL RESULTS

The Hardness and Tensile Strength, of each Specimen is recorded and Presented in the below table-V and table-VI

Table – V Design Matrix and Experimental Results of 6063 Al Alloy

The following table hardness test results verse current, voltage, gas flow, root gap parameters of 6063 Al Alloy due MIG welding.

Original Value				WZ (BHN)	HAZ (BHN)	PM (BHN)	Hardness S/N ratio
C (amp)	V (volt)	GF (lit\min)	R (mm)				
85	20	23	1	71.58	71.58	86.11	19.1904
85	22	24	2	64.12	62.40	54.55	21.4602
85	24	25	3	47.74	54.55	56.03	21.5372
95	20	24	3	62.40	54.55	73.61	16.43154
95	22	25	1	81.27	71.58	73.61	23.3884
95	24	23	2	62.90	54.55	56.03	22.2646
105	20	25	2	53.83	71.58	63.26	17.0026
105	22	23	3	75.70	81.27	73.61	25.7168
105	24	24	1	42.89	49.03	49.69	21.9988

C= Current; V= voltage; GF=Gas Flow; R=Root gap; WZ=Weld Zone; PM=Parent Metal; HAZ=Heat Affected Zone.

Normal is better

The main effect of hardness for signal to noise ratio verse current, voltage, gas flow, root gap parameters. Which is generate from the means & signal to noise ratio of hardness values by using Minitab17 software is useful to find out optimum parameters response for response various as shown figure VIII.

Response Table for Signal to Noise Ratios

Main effects of Hardness for S/N ratio

The following table main effects of hardness for S/N ratio verse current, voltage, gas flow, root gap by using Minitab 17 software.

MAIN EFFECTS OF PLOTS FOR HARDNESS

The hardness is calculated experimentally and Taguchi method is applied for analysis with help of ANOVA on basis of data analyzed, The main effect of hardness for means and signal to noise ratio verse current, voltage, gas flow, root gap parameters. Which is generate from the means & signal to noise ratio of hardness values by using Minitab17 software is useful to find out optimum parameters response for response various. The figure generated by use of as shown Figures: IV-II.

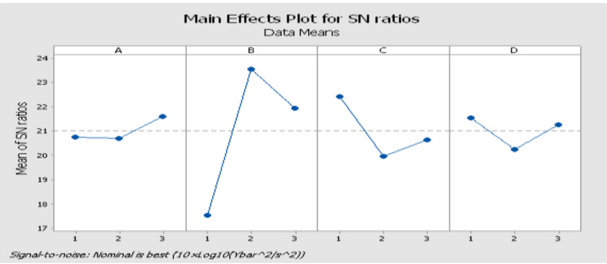

Figure VIII Main Effects of Plots for S/N Ratio Hardness
(A = Current, B=Voltage, C=Gas Flow, D=Root gap)

Table-VI Design Matrix and Experimental Results of 6063 Al Alloy.

Original Value				Tensile Strength Mpa	Tensile S/N ratio
Current(amp)	Voltage(volt)	Gas Flow (lit\min)	Root gap(mm)		
85	20	23	1	91.66	39.2436
85	22	24	2	100.00	40.00
85	24	25	3	116.66	41.3384
95	20	24	3	166.66	44.4366
95	22	25	1	191.66	45.6506
95	24	23	2	150	43.5218
105	20	25	2	91.66	39.2436
105	22	23	3	108.33	40.6950
105	24	24	1	125.00	41.9382

Larger is better

Response Table for Signal to Noise Ratios

Main effects of tensile strength for S/N ratio

The following table main effects of tensile strength for S/N ratio verse current, voltage, gas flow, root gap by using Minitab 17 software. The optimum parameter shown in figure IX .

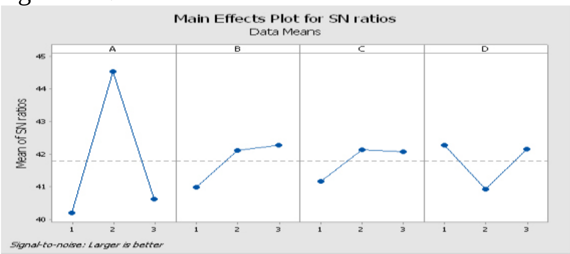

Figure IX Main Effects of Plots for S/N Tensile Strength
(A = Current, B=Voltage, C=Gas Flow, D=Root gap)

Table – VII Hardness versus Current(C), Voltage (V), Gas Flow (GF), Root gap(R).

The following table shows ANOVA analysis for hardness verses current, voltage, gas flow, root gap.

Source	DOF	Sum of squares	Mean of squares	Percentage of Contribution (%)
Current(C)	2	52.7914	26.3957	1.526
Voltage (V)	2	1711.3164	855.6582	49.49
Gas Flow (GF)	2	779.6038	389.8019	22.54
Root gap(R)	2	168.080106	84.40053	4.882
Error	0	744.86234	0	
Total	8	3457.375		

Table – VIII Tensile versus Current(C), Voltage (V), Gas Flow (GF), Root gap(R).

The following table shows ANOVA analysis for tensile strength verses current, voltage, gas flow, root gap.

ISSN: 2278 – 7798
International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 5, Issue 5, May 2016

V.III ARTIFICIAL NEURAL NETWORK (ANN)

Artificial neural network input parameters ranges from 0 to 1 and usually the output parameter range from 0 to 1 continuously. The input and output values are converted in the range of 0 to 1 .

Table –IX Normalized Experiment Result versus Current(C), Voltage (V), Gas Flow (GF), Root gap(R), Tensile Strength and Hardness.

Original Value				UTS Mpa	Hardness S/N ratio
Current (amp)	Voltage (volt)	Gas Flow (lit\min)	Root gap (mm)		
0	0	0	0	0	0.29713
0	0.5	0.5	0.5	0.084	0.54158
0	1	1	1	0.25	0.54988
0.5	0	0.5	1	0.75	0.000
0.5	0.5	1	0	1	0.74924
0.5	1	0	0.5	0.584	0.62821
1	0	1	0.5	0	0.06151
1	0.5	0	1	0.167	1.0000
1	1	0.5	0	0.334	0.59959

V.III.I Result and Analysis

Accuracy of ANN model prediction is depending upon the Root mean square error (RMSE), the Coefficient of multiple determination (R^2) values has been used for making comparisons. These values are determined by the following equations RMSE= $[1/n\sum_{j=1}^{n}(a_j\text{-}p_j)^2]^{1/2}$

$$R^2=1-[\sum_{j=1}^{n}(a_j\text{-}p_j)^2/\sum_{j=1}^{n} pj)^2]$$

Where aj = Experimental Value, pj = predicted value by ANN model.

Table –X Data sets used for ANN analysis for Tensile Strength (UTS)

The following table shows training data for tensile test using ANN results.

EXPT NO	UTS Mpa	ANN Result Mpa	error Mpa	RMSE	R^2
1	91.66	103.351	-11.691	4.00825	0.99907
2	100.00	99.9947	0.0053		
3	116.66	117.084	-0.424		
4	166.66	166.66	0		
5	191.66	191.62	0.04		
6	150	149.75	0.25		
7	91.66	93.1405	-1.4806		
8	108.33	105.989	2.341		
9	125.00	125.027	-0.027		

Table- XI Data sets used for ANN analysis for Hardness

The following table shows training data for hardness test using artificial neural network results.

Source	DOF	Sum of squares	Mean of squares	Percentage of Contribution (%)
Current(C)	2	8209.75309	4104.876545	82.35
Voltage (V)	2	478.6234	239.3117	4.801
Gas Flow (GF)	2	478.2902	239.1451	4.797
Root gap(R)	2	802.27166	401.135833	8.077
Error	0	0.00044	0	--
Total	8	9968.9384	--	--

EXPT. No	Hardness S/N ratio	ANN result	error	RMSE	R^2
1	19.1904	18.89	0.30359	0.6483902447	0.9990551028
2	21.4602	19.768	1.69182		
3	21.5372	22.096	-0.5582		
4	16.4316	17.15	-0.71823		
5	23.3884	23.3875	0.00091		
6	22.2646	22.2215	0.04333		
7	17.0026	17.00365	-0.00105		
8	25.7168	25.7094	0.007429		
9	21.9988	21.9990	-0.0002		

V.III.II Linear Regression analysis of ANN Model (Tensile Strength):

The regression analysis (Tensile Strength) has performed to obtain correlation coefficient and line of best fit for training, testing and validation data utilized to build up the neural network model. A correlation coefficient has calculated to show the relationship between experimental value and value predicted by neural network model. The line of best fit was determined for the training, testing, validation and overall data utilized to train the neural network are shown in figure: X, which show the accuracy of the prediction.

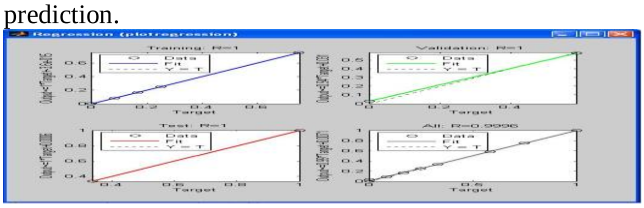

Figure: X Plot Regression analyses for tensile strength

V.III.III Linear Regression analysis of ANN Model (Hardness)

The regression analysis (Hardness) has performed to obtain correlation coefficient and line of best fit for training, testing and validation data utilized to develop the neural network model. A correlation coefficient has calculated to show the relationship between experimental value and value predicted by neural network model. The line of best fit was determined for the training, testing, validation and overall data utilized to train the neural network are shown in figure: XI.

Test	max.value of weld parameters			
	Current (amp)	Voltage (volts)	Gas flow (lit/min)	root gap (mm)
tensile strength	95	22	25	1
hardness	105	22	23	3

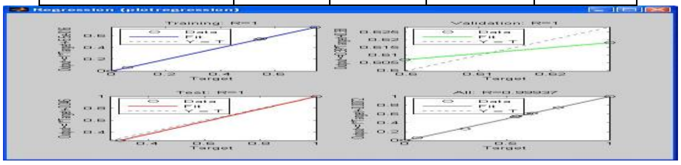

Figure: XI Plot Regression analyses for Hardness

V.III.IV Performance of ANN Model (Tensile Strength):

The performance of ANN model (Tensile strength) network has trained for several times by fixing 1000 epoch to obtain best validation performance. The best validation performance of mean square error of 0.00011273 was obtained at 0 epochs.

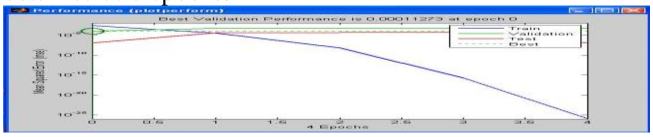

Figure: XII Plot Performances for Tensile Strength

V.III.V Performance of ANN Model (Hardness)

The performance of ANN model (Tensile strength) network has trained for several times by fixing 1000 epoch to obtain best validation performance. The best validation performance of mean square error of 1.0896e-005 was obtained at 0 epochs as shown figure XIII. The lower value of the mean square error indicates the neural network model developed will predicted better results. The simulation results of the developed network from the network/data manager are exported to the MATLAB work space.

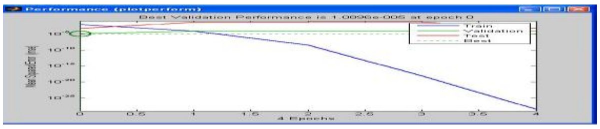

Figure: XIII Plot Performance analyses for Hardness

V.IV Comparison of Mechanical properties by various models

The comparison of mechanical properties such as Tensile strength and Hardness of MIG welded joints of Aluminum alloy 6063 series that are obtained by neural network modeling are compared with experimentally measured values graphically as shown in figure XIV and XV. Both models value are closer to experimental values.

Figure: XIV Comparison of Experimental results and Predicted ANN Results for Tensile strength

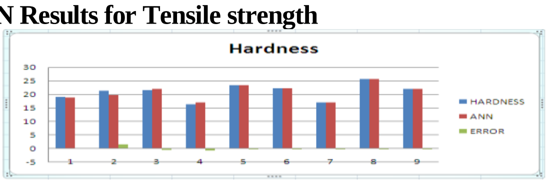

Figure: XV Comparison of Experimental results and Predicted ANN Results for Hardness.

VI. CONCLUSIONS AND SCOPE OF FUTURE WORK

- Tensile test & hardness test were conducted on the welded joint and the maximum values of weld parameters were shown in the below table.
- The ANOVA Analysis is conducted to know the percentage contribution of the input parameter & output parameter and is shown in below table

Test	Percentage contribution of weld parameters (%)			
	current (amp)	voltage (volts)	GF (lit/min)	R (mm)
tensile strength	82.35	4.801	4.797	8.077
hardness	1.526	49.49	22.54	4.882

- The MIG welding process uses Al Alloy 6063. Four parameters are taken as input parameters and two parameters are taken as output parameters. Data is classified by using ANOVA, ANN & Optimized by using Taguchi method.
- The developed ANN model is successfully integrated with optimization algorithm like Taguchi method to optimize the welding parameter. Based optimized welding parameters given by the Taguchi the MIG welding joints were processed

6.1 SCOPE OF FUTURE WORK

- The weld joint geometry may be analyses for varying diameter of wire.
- Attempts can be made to study the effect of impact test and fracture test behavior.
- Apply different prediction software for prediction of parameter and compare that model with ANN

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