International Journal of Mechanical Engineering (IJME)
ISSN(P): 2319-2240 ; ISSN(E): 2319-2259
Vol. 5, Issue 1, Dec – Jan 2016, 63-72

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

MODELLING & ANALYSIS OF 'ASTM 500 GRADE B' WELDMENTS

ALLADI PREM KUMAR[1] & CH. SIVA RAMAKRISHNA[2]

[1]PG Student, Vignan's Institute of Information Technology, Visakhapatnam, Andhra Pradesh, India

[2]Associate Professor, Vignan's Institute of Information Technology, Visakhapatnam, Andhra Pradesh, India

ABSTRACT

This study aims to examine the mathematical modeling and analysis of process parameters and bead geometry. To perform the research to predict optimal bead geometry (Bead width, Depth of Penetration, Reinforcement height) through the analysis of experimental data. For this, curvilinear equations were developed to predict bead geometry, but also interactions between process parameters and bead geometry were analyzed through Experimental analysis. The data generated through experimental studies conducted in this study has employed to validate its effectiveness for the optimization of bead geometry on process parameters (welding current, Gas flow rate and welding speed), and to present the criteria to control the process parameters to achieve a good bead geometry. By applying Taguchi method, process parameters (welding current, Gas flow rate and welding speed) and bead geometry (Bead width, Depth of Penetration, Reinforcement height,) were analyzed. This study has developed mathematical models and Regression analysis is used to predict or control the bead geometry in TIG welding process, to which Taguchi theory was applied for sensibly to the process parameters. In this case study, the influence of type of current, gas flow rate, TIG Machines settings and shielding gases which are most important in determine arc stability, arc penetration and good bead geometry. Thorough literature survey is carried out on various aspects of the proposed topic to identify the suitable range of current, gas flow rate and welding speed required for high quality TIG welding process.

KEYWORDS: Modeling, Process Parameters, Taguchi Method, TIG Welding, Welding Optimization

INTRODUCTION

TIG welding is one of the most popular welding methods, especially in industrial environments due to the wide range of weldable metals, low in cost, high level of productivity and easy to learn. It is also popular in robot welding, in which robot handles the work pieces and the welding gun to quicken the manufacturing process. TIG welding was like MIG/MAG developed during 1940 at the start of the Second World War. TIG welding development came about to help in the welding of difficult types of material, example aluminum and magnesium. The use of TIG today has spread to a variety of metals like stainless mild and high tensile steels. Arc welding is a technique to melt and join different materials that is widely used in the industry. The gas tungsten arc welding (GTAW) process is sometimes referred to as TIG. The term TlG is short for tungsten inert gas welding. Under the correct welding conditions, the tungsten electrode does not melt and is considered to be non consumable. To make a weld, either the edges of the metal must melt and flow together by themselves or filler metal must be added directly into the molten pool. Filler metal is added by dipping the end of a filler rod into the leading edge of the molten weld pool. Most metals oxidize rapidly in their molten state. To prevent oxidation from occurring, an inert gas flows out of the welding torch, surrounding the hot tungsten and molten weld metal shielding it from atmospheric oxygen. GTA welding is efficient for welding metals ranging from sheet metal up to 1/4 in. The eye-hand coordination required to make TIG welds is very similar to the coordination required for oxy- fuel gas welding. Although most other welding processes are faster and less expensive, the clean, neat, slag-free welds GTAW produces are used because of their appearance and ease of finishing. The TIG welding process is so good that it is widely used in the high-tech industry applications such as, nuclear industry, aircraft, food industry, maintenance and repair work and some manufacturing areas. TIG welding is a welding process that uses a power source, a shielding gas and a TIG hand piece. An electric arc is then created between the tungsten electrode and the work piece. The tungsten and the welding zone are protected from the surrounding air by a gas shield (inert gas). The electric arc can produce required temperatures fr the weld and this heat can be much focused local heat.

Principle of TIG Welding

During TIG welding, an arc is maintained between a tungsten electrode and the work piece in an inert atmosphere (Ar, He, or Ar-He mixture). Depending on the weld preparation and the work-piece thickness, it is possible to work with or without filler. The filler can be introduced manually or automatically with regarding two types of process. The process itself can be manual, partly mechanized, fully mechanized or automatic. The welding power source delivers direct or alternating current.TIG (Tungsten Inert Gas) welding also known as GTA (Gas Tungsten Arc) in the USA and WIG (Wolfram Inert Gas) in Germany, is a welding process used for high quality welding of a variety of materials, especially, Stainless Steel, Titanium and Aluminium.

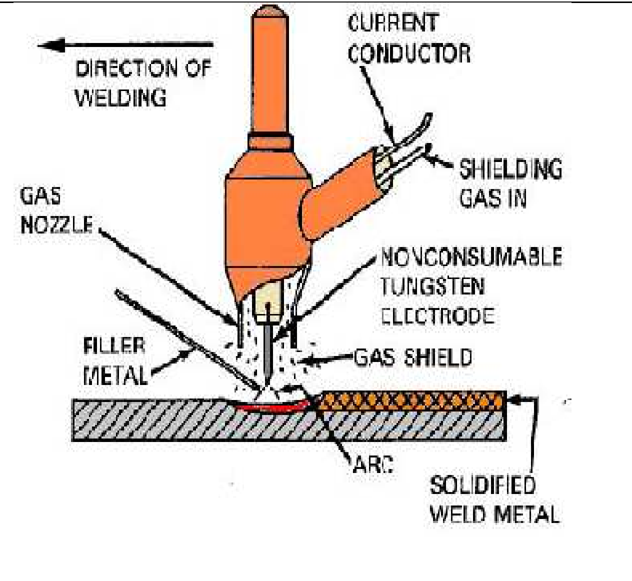


Figure 1: TIG Welding Process

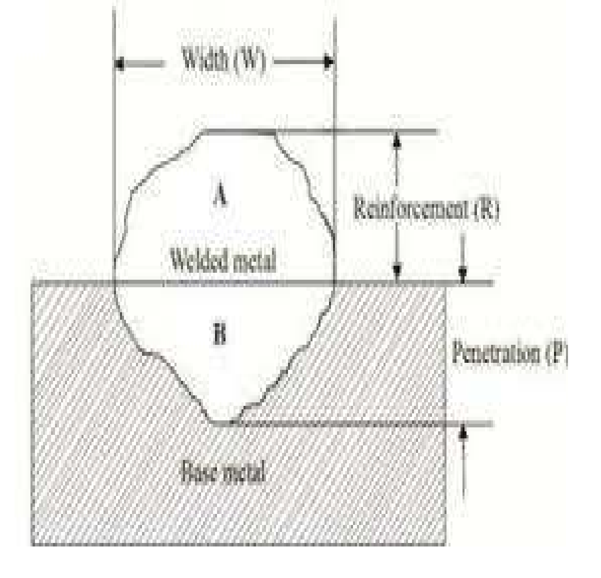


Figure 2: Bead Geometry

Welding Process

In most Arc welding processes, the arc is struck from a consumable electrode to the work piece and metal has been melted from electrode, transferred across the arc and finally incorporated into the molten pool as shown in Figure 1. TIG process employs on electrode made from high melting point metal, usually a type of tungsten, which is not melted. The electrode and the molten pool are shielded from the atmosphere by a stream of inert gas which flows around the electrode and is directed onto the work piece by a nozzle which surrounds the electrode.

Table 1: Mechanical Properties & Composition of Grade B Material

Tensile Strength Ultimate (MPa)	Tensile Strength yield(MPa)	Elongation at break (%)	Bulk modulus(GPa)	Shear modulus(GPa)
400	315	23.0	140	80.0

Table 2: Chemical Composition of Grade B Material

Carbon, C	Copper ,Cu	Iron Fe	Phosphorous P	Sulphur
<0.30%	<0.18%	99%	<0.050%	<0.0630%

Material Applications

ASTM 500 GRADE B material is used for welding process with different process parameters to investigate best conditions for welding.' This material is used for ship outré hulls, boilers, vessels, supporting beams, the constructive machine defect on according the impacted load of workplace resulted in frequent failure of the important mathematical models, which can be programmed easily and fed to the robot. It should give a high degree of confidence in predicting the bead shape to accomplish the desired mechanical properties of the weldments. In TIG welding, the process parameters are known to include welding current, Gas flow rate and welding speed. Not only the process parameters are interdependent, but also the effect of one process parameter might affect another. In addition, interrelationships between process parameters and bead geometry are generally complex so that the required control system will be dependent on a realistic model of the welding process.

Applications

TIG welding has become indispensible as a tool for many industries because of the high quality welds produced at relatively low equipment cost. It is used extensively in the aerospace and nuclear industries, also often used for small jobs, maintenance and repair work because of its flexibility and ease of control, however requiring great care and skill from the welder. It provides precise control of heat input, for that reason it is preferred for joining thin gage metal and to produce weld close to heat sensitive components. Furthermore then the manual welding technique TIG welding can be applied on semiautomatic, automatic and machine welding, it can be also be used for spot welding in sheet metal applications.

LITERATURE REVIEW

[1] Nagesh and Datta applied the back-propagation neural network to predict the bead geometry in shielded metal-arc welding process. They claimed that the neural network is a workable model to predict the bead geometry and penetration under a given set of welding conditions.[2] Li et al. modelled the non-linear relationship between the five geometric variables (bead height, bead width, penetration, fused and deposited areas) and process parameters (welding current, welding voltage and welding speed) of Submerged Arc Welding (SAW) process using the self-adaptive offset network.[3] Tarng et al. predicted the welding parameters in laser butt welding using the back-propagation and Learning Vector Quantization (LVQ) neural network. They considered the input parameters of the neural network were to be work piece thickness and welding gab, while the output parameters were to be the optimal focused position, acceptable welding parameters of laser power and welding speed.[4] The bead geometry of an underwater weld is important in determining the mechanical properties of a weld joint .The paper gives a background for the design of an artificial neural network control of the welding process parameters as it affects the weld bead geometry. The optimization of the welding parameters which

are nonlinear multivariable inputs will be discussed in the subsequent paper by the author.[5] Taguchi design, developed by Dr. Genichi Taguchi, is a set of methodologies by which the inherent variability of materials and manufacturing processes has been taken into account at the design stage.[6].Although similar to design of experiment (DOE), the Taguchi design only conducts the balanced (orthogonal) experimental combinations, which makes the Taguchi design even more effective than a fractional factorial design. By using the Taguchi techniques, industries are able to greatly reduce product development cycle time for both design and production, therefore reducing costs and increasing profit .[7] The objective of the parameter design is to optimize the settings of the process parameter values for improving performance characteristics and to identify the product parameter values under the optimal process parameter values. The parameter design is the key step in the Taguchi method to achieving high quality without increasing cost.[8] The shielding in FCAW is achieved either by an additional gas shield supplied from an external source or by the decomposition of the fluxing agent within the wire also known as self-shielding. The need for automation, out of position welding proficiency, high deposition rate and self shielding capability has led to the development of underwater FCAW welding process.[9] The effect of welding parameters on the size of the heat affected zone (HAZ) and its relative size as compared to the weld bead of submerged arc welding. It is discovered that the welding parameters influences the size of weld bead and HAZ differently which can be relate to the effect of welding parameters on the various melting efficiencies. This difference in behavior of HAZ and weld bead can be explored to minimize the harmful effect of HAZ in future welds. [10] The weld bead geometry plays an important role in determining the mechanical properties of the weld. Hence the input welding process variables which influence the bead geometry must therefore be properly selected to obtain an acceptable high quality joint. The depth of penetration for weld bead. [11, 12], TIG welding is a welding process gives better results. The weld pool can be used to join the base metal with or without filler material.[13,14] use of different major components make up a GTA welding stations ,and their performance evaluation[15] During TIG welding, an arc is maintained between a tungsten electrode and the work piece in an inert atmosphere (Ar, He, or Ar-He mixture) is an important . The composition of gas mixtures and n and the work-piece thickness influential parameters are identified. The process itself can be manual, partly mechanized, fully mechanized or automatic. The welding power source delivers direct or alternating current. The above review papers helped to initiate this work.

EXPERIMENTATION

The experimental procedure included experimental design by Taguchi method. Taguchi method can study data with minimum experimental runs. In this paper, the design of experiment work can be decided by using orthogonal array. According to the experiment conditions in TIG welding process for butt welding, the number of level settings and their levels by butt welding for each process parameter is chosen to WPS and listed in Table.3. Based on Taguchi method, (L9) orthogonal array with three levels and nine rows was employed. The assigned process parameters are listed in Table 4.in coded form. Each process parameter is assigned to a column and each row corresponds to one experimental run. For example, weld run No. 1 in the design matrix and the treatment combinations was made under the welding conditions coded as 1, 1, 1, which means that the welding current, travel speed and Gas flow rate were 240 A, 40mm/min and 10 lit/min respectively.

Table 3: Process Parameters and its Levels for TIG Welding

Process Parameter	Symbol	Low	Medium	High
Welding current(Amp)	I	240	260	280
Travel speed(mm/min)	S	40	45	50

Gas flow rate(lit/min)	G	10	12	14

Experimental Test Setup

The Taguchi experimental procedure is used for bead geometry using input weld conditions .In this experimental work and the welding machine was employed shown in Figure 3. In addition, the welding carriage and guide rail, wire feeder and fixed jig of welding specimen for the experimental configuration in shown in Figure 4. The basic setting on the welding machine was carried before welding process. The experimental material ASTM 500Grade B plates were fixed by the prepared vice. The required input parameters were set through the specified experimental test setup. The welding processes were started by turning on the welding machine and shield gas. After the welding process, the material plates were removed from the vice and new plates were then fixed on the worktable. In this way the nine experimental runs were carried out. To measure the bead geometry, the bead section was cut transversely from the middle position using the cutting machine the specimen and then it was polished. In order to assure the precision of the specimen dimensions, it was etched by HNO_3 3% and H_2O 97%. The respose parameters of weld bead are shown in Figure 1.for measurements of the bead geometry. To evaluate the quality of TIG welding, the measurements of the bead geometry were performed namely bead width, Depth of penetration and reinforcement height. The butt welding schematic diagram of bead geometry is shown in Figure .2

Figure 3: TIG Welding Machine & Filler Rods

Figure 4: Experimental Setup

The coded values of Taguchi L9 orthogonal array is shown in Table 4. With three input parameters and three levels.

Table 4: Experimental Layout Using Orthogonal Array

Expt. No.	Welding Current (Amps)	Welding Speed (mm/min)	Gas Flow Rate (Lit/min.)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1

7	3	1	3
8	3	2	1
9	3	3	2

Nine test specimen are made according to design of experiments and are marked with paint 1, 2…up to 9 as detailed in Figure 5

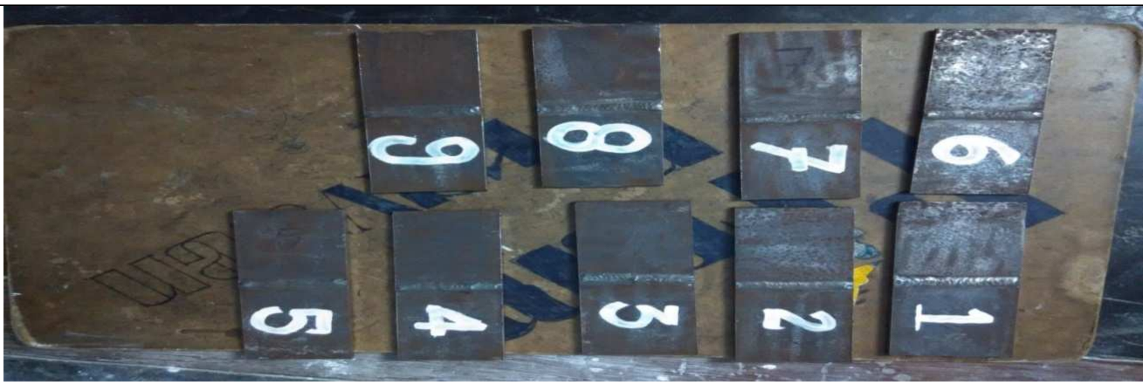


Figure 5: Welded Test Specimens

The experiment results of the TIG welding were obtained and are shown in Table 5 .which includes three responses namely bead width, Depth of penetration and Reinforcement Height.

Table 5: Experimental Results of the Weld Bead

Expt .No.	Bead Width(mm)	Depth of Penetration(mm)	Reinforcement Height(mm)
1.	10.25	3.19	1.89
2.	10.56	3.13	1.65
3.	10.74	3.85	1.73
4.	10.35	3.26	1.90
5.	10.76	3.69	1.45
6.	10.88	3.35	1.36
7.	10.91	4.35	1.65
8.	10.90	3.19	1.69
9.	10.86	3.36	1.29

RESULTS & DISCUSSIONS

The mathematical modeling was developed using experimental design. Quantification of each bead parameters was examined through the significance of the variables for the better and analysis of the interaction between process parameters and for optimal best fitment for bead geometry. Adequacy of alignment was calculated by multiple correlation coefficients using the experimental results obtained from the least squares regression and analysis based on bead geometry from 5% significance level, the following equation can be calculated.

$$\text{Bead Width (BW)} = -0.19+0.0696I+0.529S-0.165G-0.000101I^2-.0054S^2+0.0175G^2+0.000005IS-0.00101IG$$

$$\text{Depth of penetration (DP)} =69.1-0.304I-0.751S-2.13G+0.000492I^2+0.00873S^2+0.0429G^2-0.000006IS+0.00493IG$$

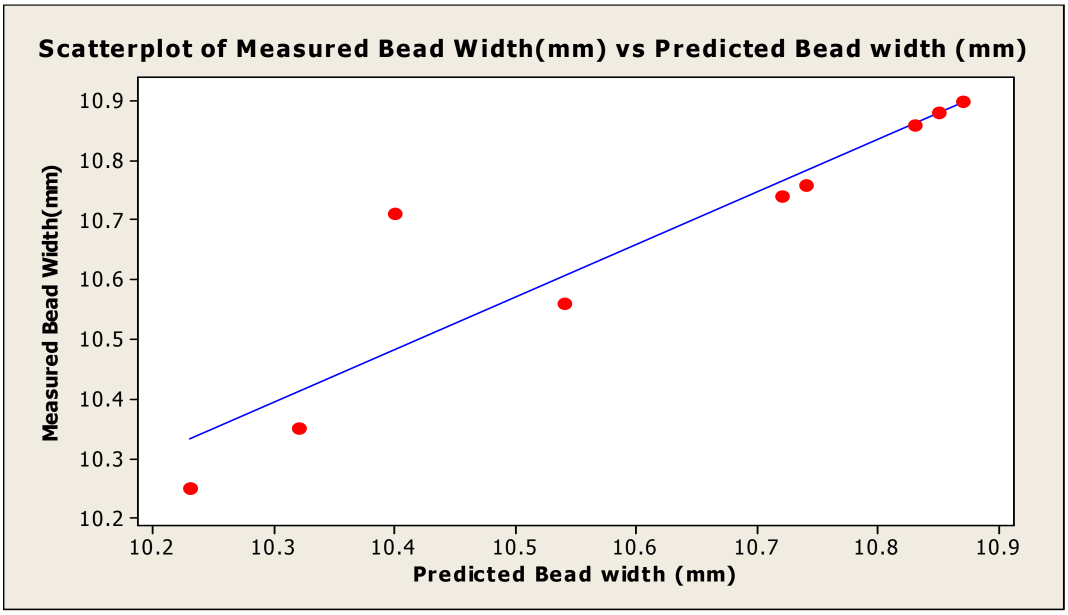
Reinforcement height (RH) = 12.9-0.0340I-0.5988S+1.42G+0.000187I^2+0.00600S^2+0.00250G^2+0.000002IS-0.00576IG

Where I=Current (Amps), S= Welding Speed (mm/min), G= Gas flow Rate (lit/min.)

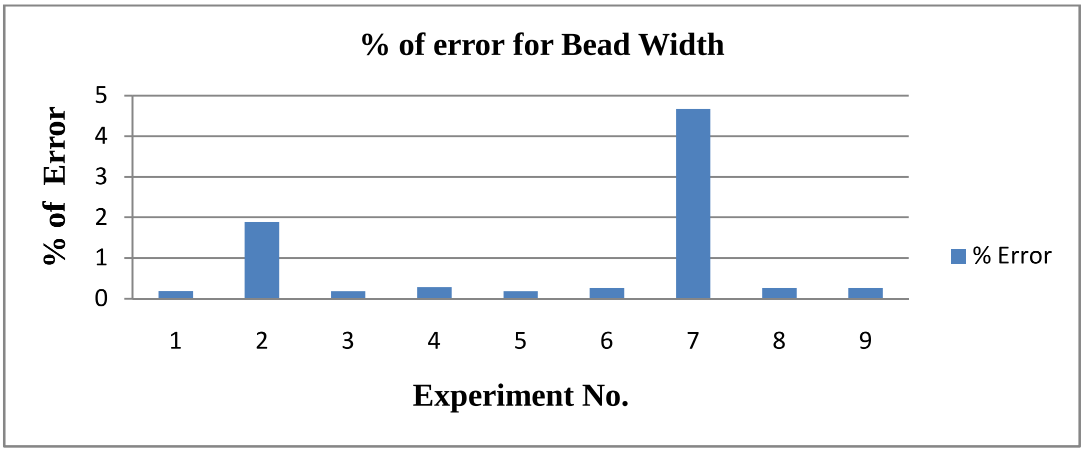
Suitability of curvilinear equations is analyzed by using error calculation. Multiple correlation coefficient of developed linear equation is 95% match. Comparison between the predicted and measured bead geometry based on each linear equations is shown in Graph 1, 3 and 6. Most of the values converge within 5% margin of errors that could be confirmed. To determine the accuracy and efficiency of developed bead geometry, percentage deviation equation was employed, e is percentage error, b is calculation result, a *is* experimental result. The relation between actual values and predicted values of responses are shown in graph and understood all points are closer to straight line which shows for better validation. After analysis the responses are mostly less than 5% of error values .Therefore the measured value are validated. The error percentage for bead width, depth of penetration and reinforcement height are detailed experiment wise are shown in graph 2, 4 and 6. The Table 6 details the error calculation for bead width

Table 6: Comparison of Actual values & Predicted Values of Bead Width

Exp. No.	Bead Width		
	Actual Values (a) mm	Predicted Values (b) mm	Percentage of Error $(e = \frac{a-b}{a} \times 100)$
1	10.25	10.23	0.19
2	10.56	10.54	1.89
3	10.74	10.72	0.18
4	10.35	10.32	0.28
5	10.76	10.74	0.18
6	10.88	10.85	0.27
7	10.91	10.40	4.67
8	10.90	10.87	0.27
9	10.86	10.83	0.19



Graph 1: Comparison of Actual Values & Predicted Values of Bead Width

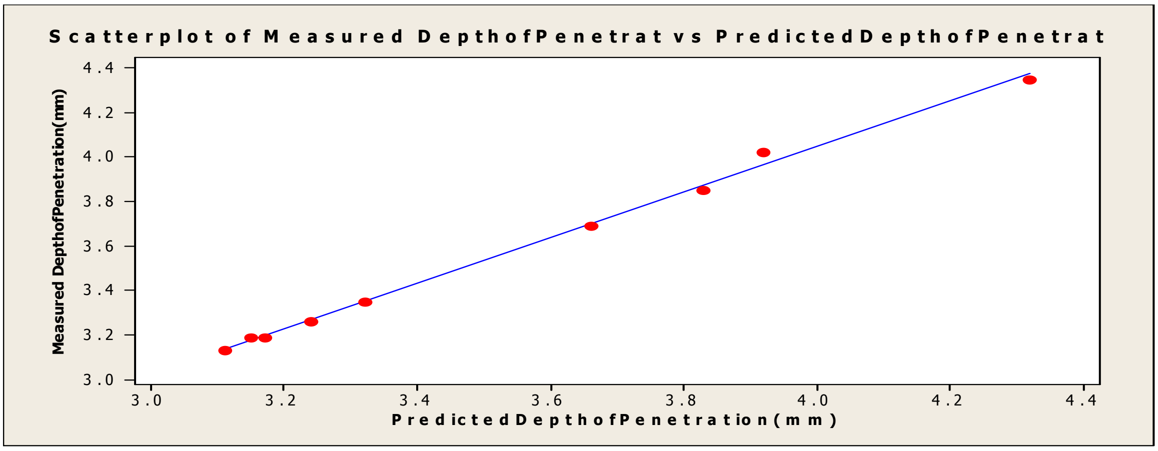


Graph 2: Experimentation Wise % of Error for Bead Width

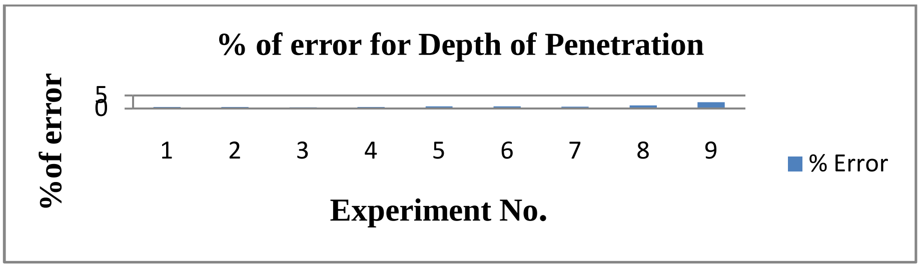
From the graph 2, the experiment No: 7 input parameters produces high percentage of error for bead width and for experiment no: 9 for depth of penetration and experiment no.6 for reinforcement height.

Table 7: Comparison of Actual values & Predicted Values Depth of Penetration

Exp. No.	Depth of Penetration		
	Actual Values (a) mm	Predicted Values (b) mm	Percentage of Error $(e = \frac{a-b}{a} \times 100)$
1	3.19	3.17	0.62
2	3.13	3.11	0.63
3	3.85	3.83	0.51
4	3.26	3.24	0.61
5	3.69	3.66	0.81
6	3.35	3.32	0.89
7	4.35	4.32	0.68
8	3.19	3.15	1.25
9	4.02	3.92	2.48



Graph 3: Comparison of Actual Values & Predicted Values of Depth of Penetration

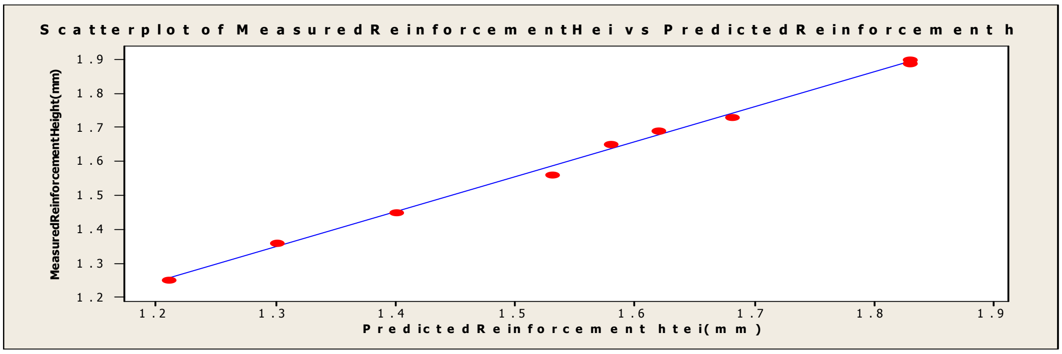


Graph 4: Experimentation wise % of Error for Depth of Penetration

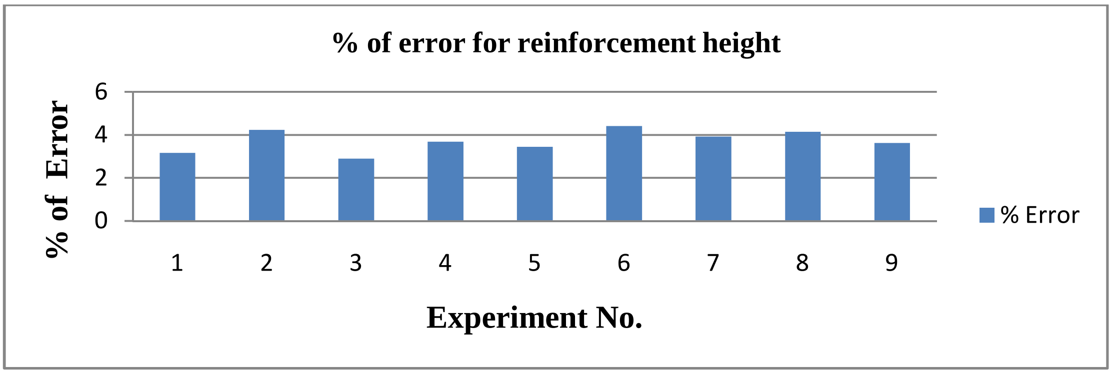
The Table 8 details the error calculation for depth of penetration and Table 9 for Reinforcement height. The percentage of error for Depth of penetration is lies below 5% .Hence the results are validated.

Table 8: Comparison of Actual Values & Predicted Values of Reinforcement Height

Exp. No.	Reinforcement Height		
	Actual values (a) mm	Predicted Values (b) mm	Percentage of Error $(e = \frac{a-b}{a} \times 100)$
1	1.89	1.83	3.17
2	1.65	1.58	4.24
3	1.73	1.68	2.89
4	1.90	1.83	3.68
5	1.45	1.40	3.44
6	1.36	1.30	4.41
7	1.56	1.53	1.92
8	1.69	1.62	4.14
9	1.25	1.21	3.20



Graph 5: Comparison of Actual Values & Predicted Values of Reinforcement Height



Graph 6: Experimentation Wise % of Error for Reinforcement Height

The percentage of error for Reinforcement Height is lies below 5% .Hence the results are validated or adequate

CONCLUSIONS

The developed quadratic curvilinear is successfully modeled with process parameters and bead geometry. The percentage of error for bead width, Depth of penetration and reinforcement height values are mostly less than 5%, Hence the modeling values are validated with experimental values. The percentage of error for bead width, depth of penetration and reinforcement height are based on experimental design

REFERENCES

1. D.S. Nagesh, G.L. Datta, *Prediction of weld bead geometry and prediction in shielded metal-arc welding using artificial neural networks*, Journal of Materials Process Technology 79 (2002) 1-10.
2. P. Li, M.T.C. Fang, J. Lucas, *Modelling of submerged arc welding bead using self-adaptive offset neural network*, Journal of Materials Process Technology 71 (1997) 228-298.
3. M. Ushio, W. Mao, *Dynamic Characteristics of Arc Sensor in GMA Welding in Dip Transfer Mode: A Study of the Improvement of the Sensitivity and the Reliability of Arc Sensor in GMA Welding* (3rd Report), Journal of the Japan Welding Society 15/2 (1997) 272-280.
4. S. Kodama, Y. Ichiyama, Y. Ikuno, N. Baba, *Arc sensor sensitivity in short circuiting metal active gas welding with high speed torch oscillation*, Science and Technology of Welding and Joining 11/1 (2006) 25-32.
5. M. Guazzato, M. Albakry, *Influence of Surface and Heat Treatments on the Flexural Strength of A Glass-infiltrated Alumina*, conference on Zirconia-reinforced Dental Ceramic, Dental Materials 21 (2005) 454-463.
6. WeiMin Zhang , GuoRong Wang, YongHua Shi & BiLiang Zhong, *"LSSVM Model for Penetration Depth Detection in Underwater Arc Welding Process,"* Journal of Information and Computing Science, vol. 5, no. 4, pp. 271-278, 2010.
7. Lee et al, "*Effect of Welding Parameters on the Size of Heat Affected Zone of Submerged Arc Welding", Division* of Material Engineering, School of Applied Science Nanyang Technological University, Singapore.
8. Erdal Karadeniz, Ugur Ozsarac , Ceyhan Yildiz, **—***The effect of process parameters on penetration in gas metal arc welding processes*, Materials and Design 28 (2007), 649–656.
9. Larry F. Jeffus (2002). Welding Principles and Applications Publisher Cengage Learning.
10. Larry F. Jeffus (2012). Welding and Metal Fabrication Publisher Cengage Learning
11. www.Google.Com. TIG welding Hand Book
12. Miller: Guidelines for gas tungsten arc welding (GTAW**).**
13. Roshan W.Ttulankar and Suraj S. Dehankar: *Automation in Sheet Metal Tig Welding Process*, International Journal of Engineering Trends and Technology (IJETT) - Volume4 Issue7- July 2013.