Prediction of Weld Bead Geometry and its Optimization During TIG Welding Process

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology

In

Industrial Design

By

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(Roll: 213ID1360)

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National Institute of Technology
Rourkela-769008, Orissa, India
May 2015

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Under the supervision of

Prof. B.B.V.L Deepak

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CERTIFICATE

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ORISSA, INDIA – 769008

This is to certify that the thesis entitled "***Prediction of weld bead geometry and its optimization during TIG welding process***", being submitted by **SHYAM NARAYAN DIVAKAR**, Roll No. **213ID1360,** to the National Institute of Technology, Rourkela for the award of the degree of ***Master of Technology*** in Industrial Design, is a bona fide record of research work carried out by him under my supervision and guidance.

The candidate has fulfilled all the prescribed requirements.

The thesis, which is based on candidate's own work, has not been submitted elsewhere for the award of a degree.

In my opinion, the thesis is of the standard required for the award of degree of Master of Technology in Industrial Design.

To the best of my knowledge, he bears a good moral character and decent behaviour.

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For each and every new activity in the world, the human being needs to learn or observe from Somewhere else. The capacity of learning is the gift of GOD. To increase the capacity of learning and gaining the knowledge is the gift of GURU or Mentor. That is why we chanted in Sanskrit "*Guru Brahma Guru Vishnu Guru Devo Maheswara, Guru Sakshat Param Brahma Tashmey Shree Guruve Namoh*". That means the Guru or Mentor is the path to your destination.

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SHYAM NARAYAN DIVAKAR

ABSTRACT

TIG welding is used for nonferrous material like aluminium, copper or thin plate of stainless steel. This paper presents measurement of weld bead geometry of aluminium sheet, which is output of TIG welding. Optimization of welding parameters is evaluated by genetic algorithm. ANN is used for prediction of output data i.e. front height, front width, back height and back width of TIG welding. Welding parameters for experiments are welding current, travel speed and electrode feed consumption rate. This paper presents a neural network and genetic algorithm for optimization and prediction on experimental data available from manual TIG welding experimentation. Quality of weld is affected by welding parameters. In the current investigation, physical experiments were conducted to optimize several input process parameters (welding current, welding speed and feed consumption rate) to get optimum parameters in aluminium plates using TIG welding. By using ANN models the welding output parameters predicted. Using Genetic Algorithm (GA) the weld bead geometry was optimized to get optimum weld bead geometry (front height, front width, back height and back width).

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CHAPTER 1

INTRODUCTION

When two pieces are joined by heat and or pressure after getting the pieces softening or melting, the weld is formed. Welding provides permanent joint and it joint different materials such as metals, alloys and plastics, by application of heat and or pressure. Filler material is fed to strengthen the joint. Welding provides joint for similar metals. Welding is possible between steel and steel or between aluminium and aluminium, but welding between steel to aluminium cannot be possible by using manual welding process. Welding may be sub-divided into welding by machines, welding by semi-autonomous systems, and robotic welding. In machine welding, operator performs the welding by welding machine or equipment. In automatic welding, if the equipment provides welding the without the help of operator, it is said that automatic welding. In manual welding, pieces to be weld will vibrate, which is controlled by automatic welding. Automatic welding needs fixture, higher consistency and accuracy in the parts to be welded. Therefore automatic welding is used only for large scale production. In robotic welding, robot kept in automatic control on the movement relative to the work .The versatility of the welding by robots is use to simple fixtures, and the capacity of the robot machinery to be reprogrammed for new part configurations therefore it is used for relatively low production quantities. A typical robotic arc welding has “2” welding fixtures and a human welder to place and remove the parts while the robot is operation. In addition to arc welding, industrial robots can be found more in automobile for final assembly plants to perform resistance welding on car bodies. In contrast, Soldering and Brazing does not melt the work-piece, although lower-melting-point material is melted between the work-pieces to bond them together. Welding is widely used in all field of manufacturing, from earth moving equipment to the aerospace industry.

Different types of welding

- Gas welding,
- Arc welding,
- Resistance welding etc.

Arc welding- An electric arc is generated between electrode and base material to melt metals at the welding point. Electric arc generated by power supply AC or DC, electrode could be consumable or non-consumable and a filler wire may or may not be used.

1.1 Introduction of TIG welding

Gas Tungsten Arc Welding (GTAW) uses an arc between non-consumable tungsten electrode and workpiece. An inter gas sustains the arc and protects the molten metal from atmospheric contamination. The inert gas used in TIG welding may be argon, helium or a mixture of argon and helium. Filler material may or may not be used. A constant-current welding power supply produces energy which is conducted across the arc through a column of highly ionized gas and metal vapours known as plasma.

GTAW is used for thin section of stainless steel and non-ferrous metals (aluminium, magnesium and copper alloys). The operator should have greater control during TIG welding. Therefore, GTAW is difficult for operator and slower than other welding techniques.

1.2 Working principle of TIG welding-

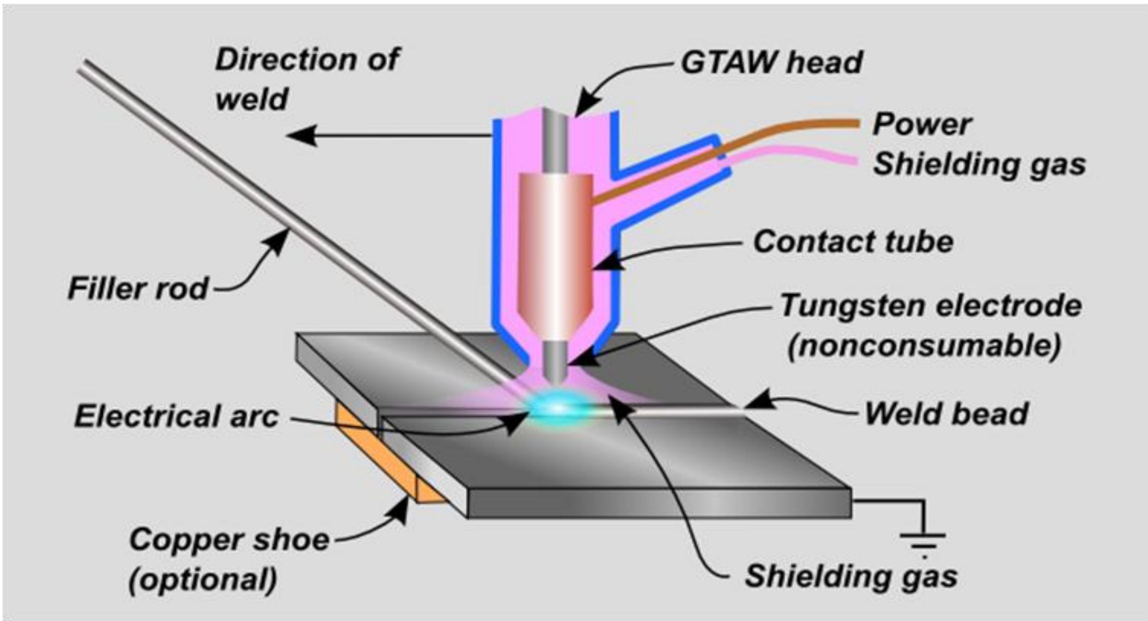


Figure 1. TIG Welding

TIG welding has non-consumable electrode. Shielding gas passes through a torch for protecting the electrode. The generated molten weld pool gets solidifying weld metal from atmospheric contact. Current passes through ionized shielding gas, by which electric arc is produced. The arc should be maintained between the electrode tips to the work. Work-piece is melted by the heat of arc. When the arc is established between weld pool and tip of electrode, the torch should be moved lengthwise the joint and the work-piece get melted by arc. Filler wire kept at the leading edge of torch and moved at the end of joint. Manual tungsten arc welding requires short arc length, so operator should have great care and skill to maintain the arc between electrode tip and work-piece. In manual TIG welding, operator kept the filler wire with one hand and torch with other hand for maintaining the arc. So, TIG welding is difficult for operator. Filler rod is used to strengthen the weld. Thin plate of some material requires no filler wire. In TIG welding high frequency generator is used to generate electrical spark. Electrode tip and work-piece kept 1.5-3 mm apart in TIG welding. High frequency and high voltage in TIG welding can damage the vehicle electrical or electronics parts.

1.3 Applications of TIG welding

Aerospace uses the tungsten inert gas welding in large scale. TIG welding is used for thin sheet of stainless steel or non-ferrous metals in many industries. It is used in manufacturing of space vehicle and small diameter pipe of stainless steel in bicycle industry. Piping work in much industry is accomplished by TIG welding. It can be used in maintenance and repairing work of dies and tools made of non-ferrous metals, especially magnesium and aluminium.

Aerospace industry is among the major users of gas tungsten arc welding, the process is used in various other areas also. Some of the industries use GTAW for the welding of thin work pieces, mainly non-ferrous metals. It is used widely in the manufacturing of space vehicles, and is also used to weld small diameter, thin wall tubing similar to those used in the bicycle industry. Moreover, GTAW is also used for making root or first pass welds for piping of different size. In the maintenance work, process is generally used to repair the tools and dies, generally for the components made of aluminium and magnesium.

1.4 Advantages of TIG welding

a. Produces high quality, low-distortion welds

b. Free from spatter

c. Can be used with or without filler wire

d. Can be used with a range of premier supplies

e. Welds almost all metals

f. Give precise control of welding heat

1.5 Limitations

a. Produces lower deposition rates than consumable electrode arc welding process

b. Requires slightly more skill as compared to GMAW or shielded metal arc welding (SMAW)

c. Less economical for section thickness greater than 9.5 mm

d. Tungsten inclusion if the electrode is allowed to contact the weld pool

e. Contamination of the weld metal, if proper shielding of the filler metal by the gas stream is not maintained

f. Low tolerance for contaminants on filler or base metals

g. Arc blow or arc deflection, as with other processes

1.6 Effect of welding parameters

a. Arc current-In general, arc current pedals the weld penetration, the effect is directly proportional. The process can be run with support of DC or AC, the choice depends majorly on the type of metal and its behaviour to be welded. DC with the –ve electrode offers the advantages of deep penetration and greater welding speeds. AC offers a cathodic cleaning, that removes refractory oxides from the surfaces of aluminium and magnesium, allowing superior welds to be made.

- Arc current
- Tn. electrode tip shape
- Air gap between the electrode and the metallic work
- Shielding gas type and behaviour

When the other variables such as the shield gas, electrode and current have been predetermined, arc voltage becomes a way to control the arc length. Arc length is important with this process because pool width is proportional to arc length. Therefore, in most applications other than those involving sheet, the desired arc length is as short as possible. Care should be taken to avoid the possibility of short circuiting the electrode to the pool or filler wire if the arc is too short.

c. Travel speed

d. Feed rate of wire

e. Arc length

f. Shielding gas

1.7 Objective

- Graphs produced by neural network training
- Simulation by neural network
- Graph between experimental output and ANN output
- Optimum output by genetic algorithm

CHAPTER 2

LITERATURE SURVEY

The literature review on the welding behaviour characterization using NN is encapsulated in below tabular form

Reference	Prediction Technique	Optimization Technique	Objective	Type of Welding
[1]	ANN	-	Prediction	Laser welding
[2]	ANN	GA	Optimal Process parameters	GTAW
[3]	BPNN	GA	Optimal Process parameters	GTAW
[4]	ANN	GA	Optimal Process parameters	GTAW
[5]	NN		Prediction	GTAW
[6]		PSO	-	-
[7]	NN			
[8]	GRNN	GP	Prediction	SPOT WELDING
[9]	GRNN	DEA		SPOT WELDING

Table 1. Literature Survey

CHAPTER 3

EXPERIMENTAL ANALYSIS

3.1Selection of material

Aluminium plate used in TIG welding, has thickness 3mm.Welded specimen dimension is 140 mm in length and 30 mm in width. Filler rod of aluminium diameter is 3 mm. All specimens are welded by butt-joint. Aluminium is difficult to be welded, because of its low melting. Aluminium has low melting point-1200 degree Fahrenheit compared to 2600 degree Fahrenheit to 2700 degree Fahrenheit for steel.

3.2Welding parameters used in experiment

Manual TIG welding is used for experiment. In experiment, welding parameters are welding current, welding speed, feed consumption rate, welding voltage. Welding current, welding speed and feed consumption rate are variables, whereas current voltage is constant. Current voltage is 16.5 V

3.3Mesurement of welding weld bead geometry

Weld bead geometry is measured by welding gage. Weld bead geometry is front height, front width, back height and back width. Weld bead dimension is 140 mm length and 30 mm width. Data after measurement of weld bead geometry and dimensions are given in table below.

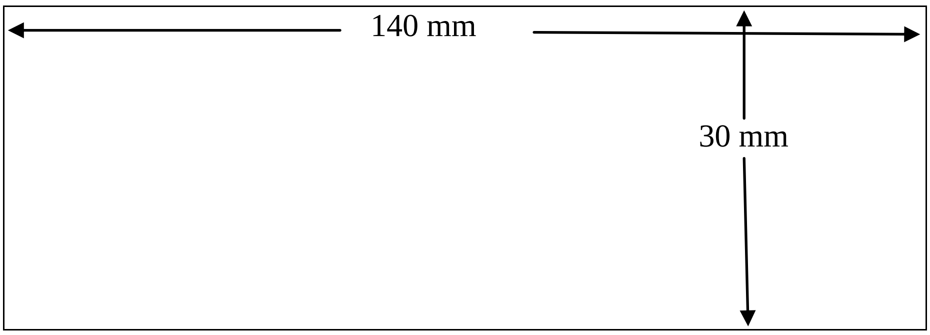


Figure 2. Dimension of welded piece

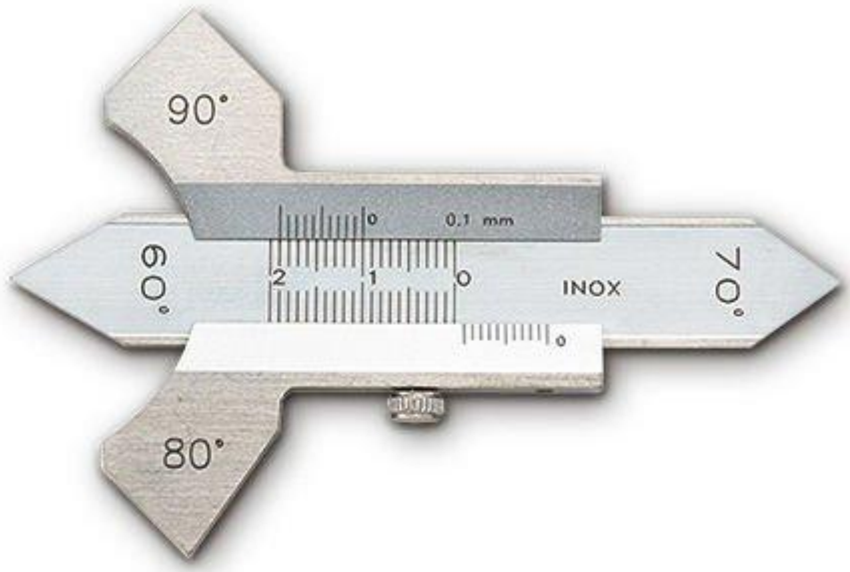


Figure3 Welding gage

Current	speed	Feed consumption rate	Front height	Front width	Back height	Back width
40	.4	57	2	9	.8	9
45	.5	52.5	2.9	7.6	1	7
50	.6	51.8	.9	9	.2	8.5
55	**.7**	51.2	.5	9.5	.5	8.2
60	.8	38.4	.5	9.5	1	7.5
65	.9	32	1.3	11	.4	8
70	1.0	28.8	1.8	10.5	.7	10
75	1.2	19.2	1.5	10	.2	7
80	1.3	18.6	2.5	12	.5	10.9

85	1.4	18	2	12.5	.5	11
90	1.6	15	2.2	11.2	.6	11.5

Table 2 Data obtained after measurement of weld bead geometry

CHAPTER 4

PREDICTION BY NEURAL NETWORK

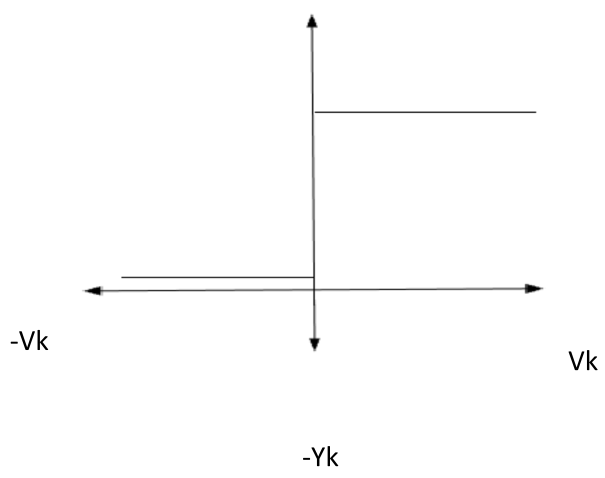
4.1 Introduction of neural network

We study artificial intelligence as intelligent character and we want to know how computer perform the intelligent character. It can be divided in two parts. One is symbolism, and the other is connectionism. For symbolism, intelligence uses symbols and for connectionism, intelligence uses network connections and associated weights. Both have been applied in practical problems. Connectionism follow brain metaphor, therefore intelligence is interconnected by many processing elements in which any individual processing element has simple computational task. The weights are encoded for acquiring knowledge of a network. Multi-layered perceptions are most common and widely used method. The artificial neural network is based on connectionism. Now a day's artificial neural network is dominant upon symbolism, because it can achieve knowledge and manipulate easily. Neural network comes out from biological terms and how the intelligent character suit to construction of artificial intelligent system. In artificial neural network, we study how to implement the intelligent character into the system as neuron like construction in brain.

4.2Functions used in neural network

Threshold function-if vk≥0; $Yk = \emptyset(Vk) = 1$

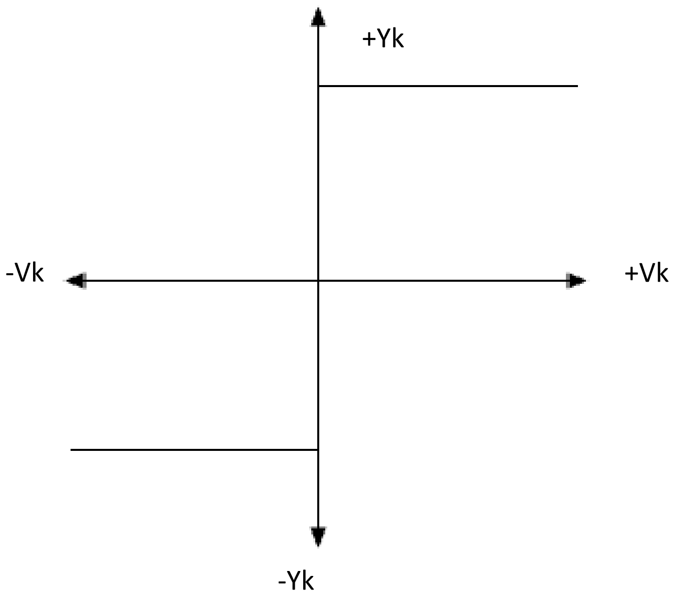
; $Yk = \emptyset(Vk) = 0$, otherwise



Threshold function as signal function-

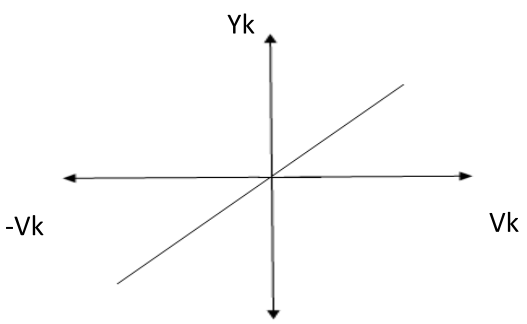
If Vk≥0; $Yk = \emptyset(Vk) = 1$

; $Yk = \emptyset(Vk) = -1$



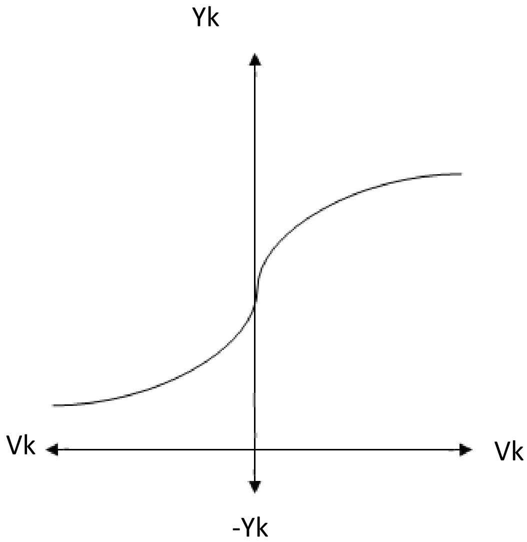
Linear model

If $Yk = Vk \neq \emptyset(Vk)$



Sigmoidal (non-linear) function

Ø(.)=1/(1+exp(-x)); where 0<ø<1



Tan-sigmoid function

Ø(.)=tanh(x); where, -1<ø<+1

4.3 Feed forward algorithm

A feed forward neural network is a biologically inspired algorithm. It consists of a (possibly large) number of simple neuron-like processing units. Neuron is arranged in different layers. Every unit in a layer is connected with all the units of the previous layer. Each connection can have a different strength or weight. The weights on these connections are encoded for the knowledge of a network. Although, the units in a neural network are also called node. Data fed at the inputs and passes through different layers until it reaches at outputs. There is no feedback between layers in normal operation. Therefore it is called feed forward neural networks. In the figure, there are one input layer, one hidden layer and one output layer. Input layer has 3 nodes, hidden layer has 4 nodes and output layer has 5 nodes.

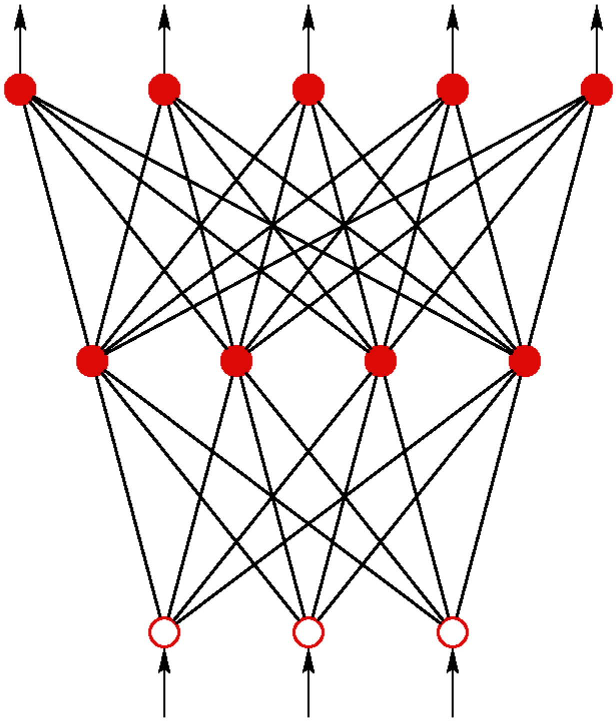


Figure 4 Feed forward neural network

The 3 inputs are shown in circles, these layers cannot be belonging to the other layers. Sometimes, input layer taken as virtual layer such as 0 layers. Between the output layer and input layer, all layers are called hidden layer. So, hidden layer may be one or more than one layer.

4.4 Back propagation algorithm

The feed forward neural network uses a supervised learning algorithm: besides the input pattern, the neural net also needs to know to what category the pattern belongs. Learning proceeds as follows: a pattern is fed at the inputs. The pattern is passes through all the layers until it reaches the output layer. The units in output layer may belong to different category. Output of the one unit may give large output, whereas output of the other unit of output layer may give small output. Synaptic weights are modified of different pattern, then output of different units of output layer would have little difference. (The difference between actual output and idealised output is to be small by varying synaptic weights from top to bottom layer, therefore it is called back propagation algorithm. We perform above procedure for every pattern and every category, then it is called 1 epoch of learning. After many epochs of learning, learning phase is terminated and we can find correct output by neural nets for unknown patterns also. We need three different objects for learning: a feed forward neural network (the classifier), a Pattern (the inputs) and a Categories (the correct outputs).

We choose synaptic weights randomly, the back propagation algorithm may be decomposed in following steps:

i) Feed-forward algorithm

ii) Back propagation to the output layer

iii) Back propagation to the hidden layer

iv) Weight modification

The algorithm is stopped when the value of the error function has become sufficiently small.

$$\frac{d(E)}{d(Wj)} = \frac{d}{dWj\left(\frac{Err^2}{2}\right)} = Err \times \left(\frac{dErr}{dwj}\right)$$

$$= Err \times ((\frac{dErr}{dwj})(Y - g(\sum wj \times xj))) ;$$

Since Err=Y- $g(\sum wjxj)$

$$= \text{Err} \times (\frac{dg(in)}{dwj}) \times xj$$

For threshold function

$$\frac{\text{dg(in)}}{\text{dwj}} = 1$$

For sigmoid function-

$$\frac{\text{dg(in)}}{\text{dwj}} = \text{g}(1 - \text{g})$$

$$wj \longleftarrow wj + \left(\frac{£ \times Err \times dg(in)}{dwj} \times xj\right);$$ where £ is learning rate

4.5 Process used in MATLAB for ANN

Workspace → control N → data entry (i.e. input, output, sample etc.)

Command window → nn tool → import (i.e. input, target) → new → create → network → train → Simulate

4.6 Application of neural network

Neural network has wide application in business world. Many industries successfully applied neural network. Neural network are best for recognising their patterns and output, so it is used for prediction and forecasting in many areas.

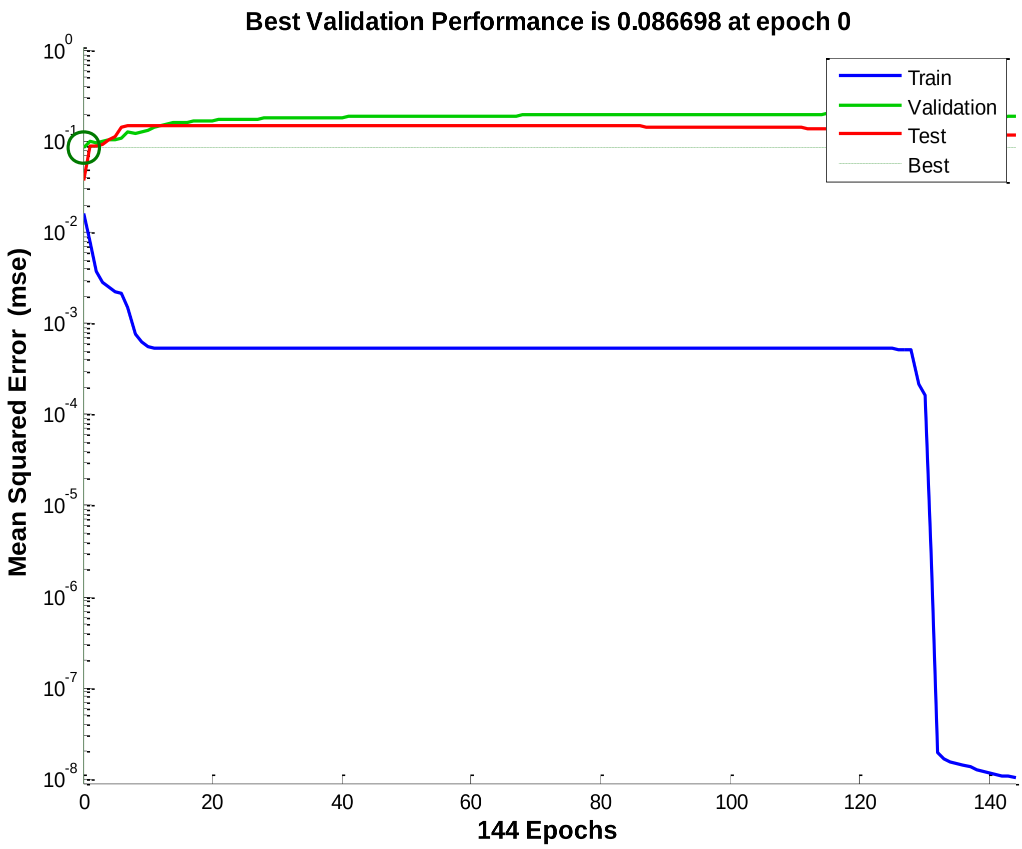
- Forecasting for selling
- Control of process in industry
- Recognition of customer
- Validation of data
- Management for risk

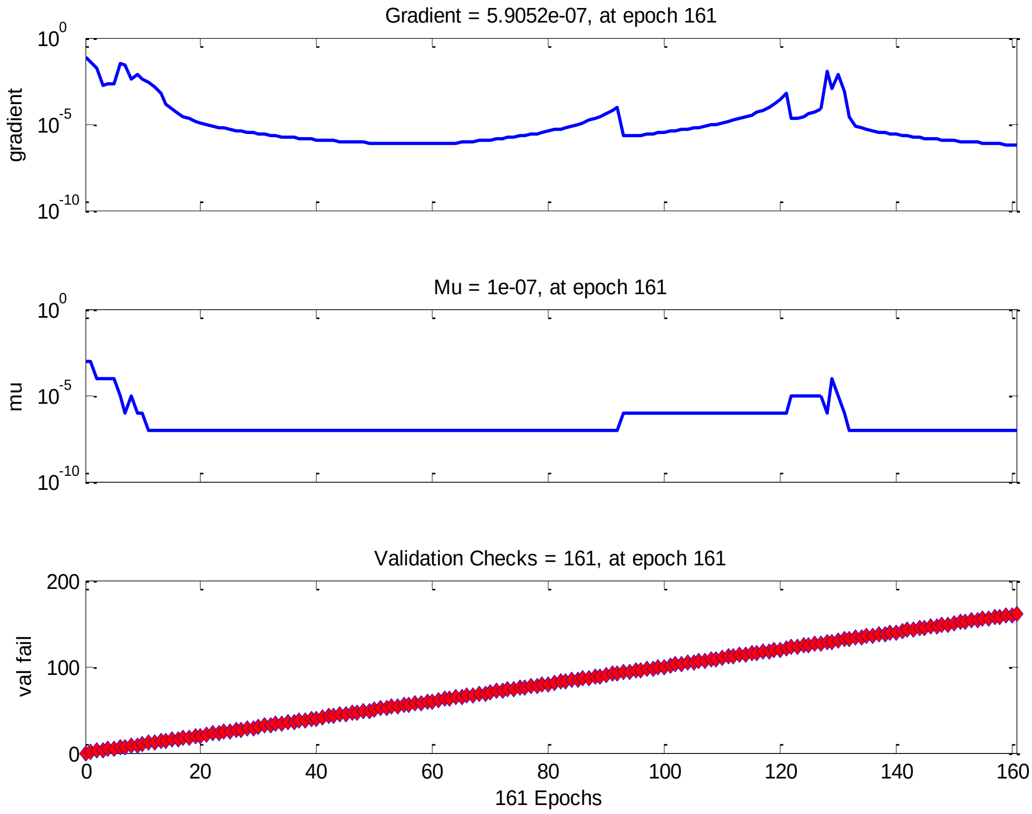
ANN is also used in the different areas like identifying the speaker's voice in communication: hepatitis diagnosis; detection of undersea mine; analysis of texture; recognition of three dimensional objects; recognition of hand-written word; and facial recognition.

4.6.1 Marketing

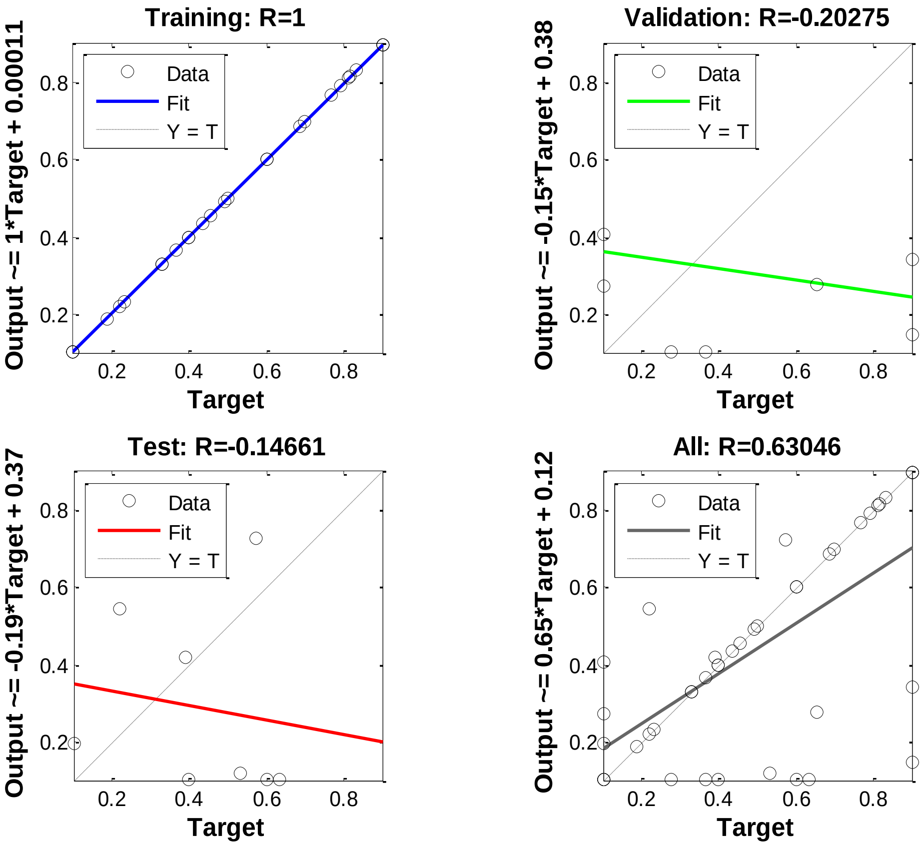
In modern marketing, we want to know how customer gives positive response for the product. For solicitation of customer can be made by advertisement, who gives the positive response for product. In market segmentation, customer is divided into groups according to their behaviour. Neural network helps in market segmentation, customer divided into groups according to their character by using geographic location, demographics, attitude for buying product. Unsupervised neural network automatically divide the customer into segmentation according to similarity in their characteristic towards product. Supervised neural network after training can divide the customer as occasional customer, frequent customer and rare customer. After segmentation of customer, we can sell the product to the customer without advertising or sales discount. So, we save the money and time. Bounds and Ross showed that neural networks can be used to improve response rates from the typical one to two percent, up to 95%, simply by choosing which customers to send direct marketing mail advertisements to Neural networks can also be used to monitor customer behaviour patterns over time, and to learn to detect when a customer is about to switch to a competitor.

4.7 Result of prediction by neural network





Gradient = 5.9052e-07, at epoch 161
gradient
10^0
10^-5
10^-10
Mu = 1e-07, at epoch 161
mu
10^0
10^-5
10^-10
Validation Checks = 161, at epoch 161
val fail
200
100
0
0
20
40
60
80
100
120
140
160
161 Epochs



current	Speed	Feed consumption rate	f.height	f.width	b.height	b.width
.1	.1	.9	.64314	.31619	.60285	.46521
.18	.166	.814	.51941	.37928	.14802	.40801
.26	.233	.800	.21577	.32169	.14314	.35457
.34	.30	.789	.10402	.22211	.41994	.3845
.42	.366	.545	.14955	.25954	.65073	.30852
.50	.433	.423	.37557	.43524	.59252	.55029
.58	.50	.362	.53268	.57315	.60015	.63306
.66	.633	.180	.43309	.48978	.10041	.10142
.74	.700	.168	.41032	.88307	.12472	.19181
.82	.766	.157	.59986	.8954	.39845	.8116
.90	.90	0.100	.83284	.68682	.49905	.89683

Table 3 Normalised value of output by ANN

current	speed	Feed consumption rate	f.height	f.width	b.height	b.width
40	.4	57	2.13	9.00	.70	9.00
45	.5	52.5	1.76	9.31	.25	8.70
50	.6	51.8	.85	9.00	.24	8.45
55	**.7**	51.2	.51	8.35	.52	8.60
60	.8	38.4	.65	8.60	.75	8.10
65	.9	32	1.33	9.65	.70	9.54
70	1.0	28.8	1.80	10.50	.70	10.00
75	1.2	19.2	1.50	10.00	.20	7.00
80	1.3	18.6	1.43	12.40	.23	7.52
85	1.4	18	2.00	12.50	.50	11
90	1.6	15	2.70	11.20	.60	11.50

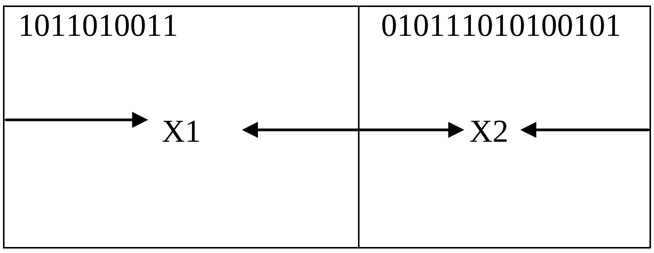
Table 4 Non-normalised value of output by ANN

CHAPTER 5

OPTIMIZATION BY GENETIC ALGORITHM

5.1 Introduction of genetic a algorithm

Genetic Algorithm is heuristic search algorithms, which is found from evolutionary ideas of natural selection and genetics. This is an intelligent exploitation of random search to optimize the problem. GA is based on Charles Darwin "survival of the fittest" principle. Competition among the individuals for bread give result stronger is dominating over weaker ones. By nature, fittest person or animal has more probability to come in next generation. The GA is a stochastic global search method that mimics the metaphor of natural biological evolution. GA operated for a population of potential solutions by applying the principle of survival of the fittest to produce (hopefully) better and better approximations to a solution. At each generation, a new set of approximations is created by the process of selecting individuals according to their fitness value in the problem domain and breeding them together using operators borrowed from natural genetics. This process gives the evolution of populations of individuals which is better for their environment than the individuals that they were created from, just as in natural adaptation. Structure in the following way:



When x1 is encoded as 10 bits and x2 as 15 bits, it may be exhibit level of accuracy or range of the individual variables. We can't solve the problem because they have different bits. It will be only possible, when bits are decoded in phenotypic values. The search process started with encoded value of individual variables rather than real value of individual variables. After decoding the chromosome into real value, we can assess the fitness of individual in population. It is possible by objective function, which gives the characteristics of individual's performance. This represents the survival of individual in the present environment.

5.2Genetic algorithm overview

GA gives the survival of fittest among the individuals in the next generation. Each generation have population of string, which is analogy of chromosome like our DNA. Individual indicates a point in a search space and possible solution. Individual go through evolution. GA is established like genetic structure and genetic behaviour with following conditions:

- Individual in population should be strongest to get resources.
- Individual, who is fittest in all competition produces more offspring than less fit individual.
- Genes of individual propagated through population, so offspring may be better than their parents.
- Each next generation would be good for present environment.

GA has maintained population of individual in a search space, each may represents a possible solution of a given problem. Usually binary alphabet is indicated as (0,1). Individual are analogous to chromosome and variables are analogous to genes. That is why a chromosome (solution) has several genes (variables). Fitness value is evaluated for each individual to get the target. The optimum value of the individual has to be evaluated. GA aims to make offspring from given chromosome, so that offspring give more accurate optimum value than the parents. Parents are arranged on their fitness value, after crossover they produce offspring and offspring again arranged according to their fitness value, after crossover they produce another offspring. Therefore, offspring carry inherit properties of their parents. Since population should be in static size, so offspring replaces the individuals and individuals in population is to be exhausted. Therefore successive generation has better solution and least fit solution is to be exhausted. Individuals of new generation with fittest value have good genes. When making of offspring is stopped, then algorithm could be said, it has a set of solution of given problem.

5.3 Traditional genetic algorithm chart

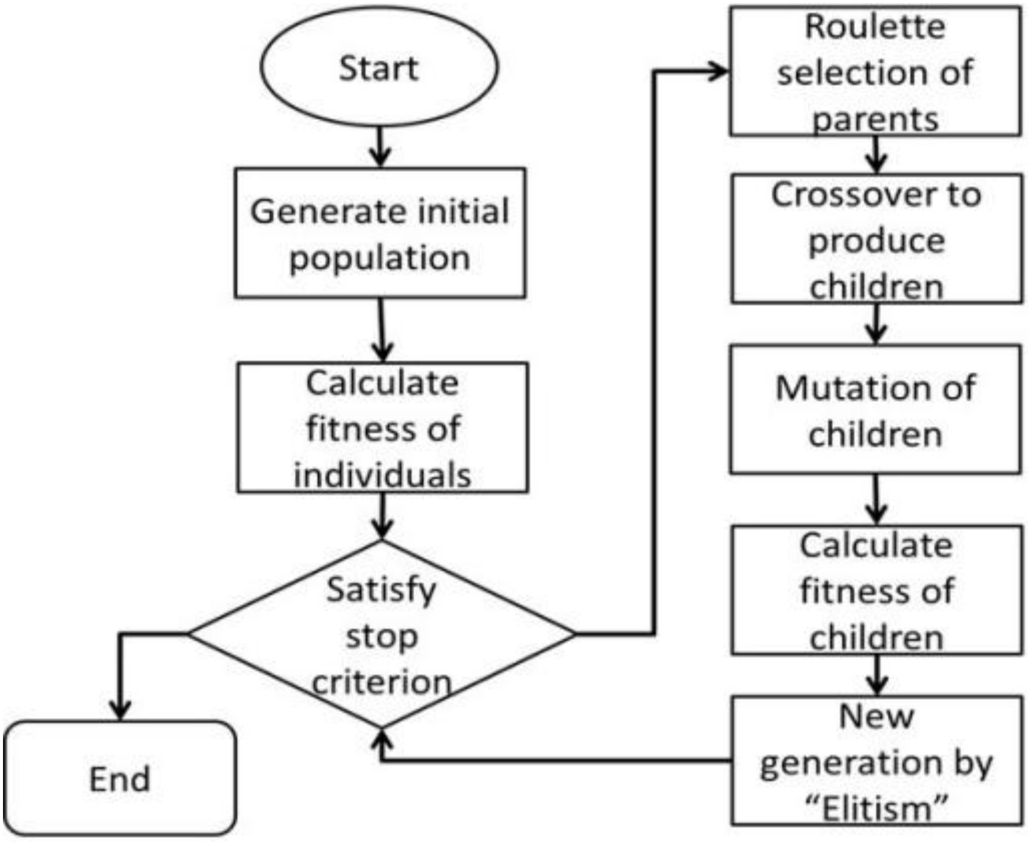


Figure 5 Genetic algorithm chart

5.4 Process used for optimization in genetic algorithm

The **fitness evaluation** is a procedure to decide the survival of each individual. Individuals with large fitness values are what the user wants to maximize. Considering the minimization of an objective function, during the evaluation operation, a proper fitness index is assigned to each candidate set in such a way that the lower the value of the objective function associated to an individual candidate, the higher the fitness index given to it. The responses used in this study were used to make the fitness function, as shown below:

$$Of(i) = cp\frac{\left(P_t - P_{\exp(i)}\right)^2}{P_t} + cd\frac{\left(d_t - d_{\exp(i)}\right)^2}{d_t} + cw\frac{\left(w_t - w_{exo(i)}\right)^2}{w_t} + cr\frac{\left(r_t - r_{\exp(i)}\right)^2}{r_t}$$

where:

Of(i)-Value of the objective function for the "i" experiment;

p_t -Target (desirable) value of the font height

$p_{exp(i)}$ -Experimental value of the front height for the "i" experiment;

d_t -Target value of the front width;

$d_{exp(i)}$ -Experimental value of the front width for the "i" experiment;

w_t -Target value of the back height;

$w_{exp(i)}$ -Experimental value of the back height for the "i" experiment;

r_t -Target value of the back width;

$r_{exp(i)}$ -Experimental value of the back width for the "i" experiment;

cp,cd,cw and cr -Weights that give different status (importance) to each response.

The responses evaluated in this work do not have equal importance. The most important response is the front height, back height, front width and back width. In order to transpose these statuses to the objective function, weights were included. These weights are the values put in front of each response term (0.5, 0.3, 0.1 and 0.1) respectively.

X(normalised)=0.1+[(x-x(minimum))/1.25(x(maximum)-x(minimum))]

X(normalised)=Normalised value between 0 and 1

X= data, which is to be normalised

X(min)=minimum value in the data

X(max)=maximum value in the data

Normalised value of data

Current	Speed	Feed consumption	f.height	f.width	b.height	b.width	Obj.function
.1	.1	.9	.60	.328	.7	.4555	.1011
.18	.166	.814	.90	.100	.9	.1	.4275
.26	.233	.800	.233	.328	.1	.3666	.1219
.34	.30	.789	.100	.2216	.4	.390	.2350
.42	.366	.545	.100	.2216	.9	.1888	.3627
.50	.433	.423	.366	.655	.3	.2777	.0232

.58	.50	.362	.533	.573	.6	.6333	.0451
.66	.633	.180	.433	.491	.1	.1	.0463
.74	.700	.168	.7666	.818	.4	.7933	.1368
.82	.766	.157	.600	.900	.4	.8111	.1006

Arrange the string according to their objective function value for front height, f.width, b.height and b.width

f.height	f.width	b.height	b.width	Obj.function value
.366	.655	.3	.2777	.0232
.533	.573	.6	.6333	.0451
.433	.491	.1	.1	.0463
.600	.900	.4	.8111	.1006
.60	.328	.7	.4555	.1011
.233	.328	.1	.3666	.1219
.7666	.818	.4	.7933	.1368
.100	.2216	.4	.390	.2350
.100	.2216	.9	.1888	.3627
.90	.100	.9	.1	.4275

After crossover and mutation

f.height	f.width	b.height	b.width	Obj. Function value
.36	.65	.60	.63	.0641
.53	.57	.31	.27	.0056
.43	.49	.40	.81	.0563
.60	.90	.11	.12	.0866
.60	.32	.10	.36	.0629
.23	.32	.71	.45	.1688
.76	.81	.40	.39	.0930
.10	.22	.41	.79	.2743

.10	.22	.90	.11	.3732
.91	.10	.91	.18	.4292

Arrange according to obj. Function

f.height	f.width	b.height	b.width	Obj. Function value
.53	.57	.31	.27	.0056
.43	.49	.40	.81	.0563
.60	.32	.10	.36	.0629
.36	.65	.60	.63	.0641
.60	.90	.11	.12	.0866
.76	.81	.40	.39	.0930
.23	.32	.71	.45	.1688
.10	.22	.41	.79	.2743
.10	.22	.90	.11	.3732
.91	.10	.91	.18	.4292

After crossover and mutation

f.height	f.width	b.height	b.width	Obj.function value
.54	.58	.41	.80	.0458
.44	.48	.32	.26	.0158
.61	.33	.62	.62	.0948
.37	.64	.11	.35	.0304
.61	.92	.42	.38	.0682
.78	.82	.11	.11	.1357
.25	.333	.42	.78	.1398
.11	.23	.72	.44	.2798
.11	.23	.91	.17	.3578
.89	.11	.91	.11	.4172

Arrange according to objective function value

f.height	f.width	b.height	b.width	Obj. Function value
.44	.48	.32	.26	.0158
.37	.64	.11	.35	.0304
.54	.58	.41	.80	.0458
.61	.92	.42	.38	.0682
.61	.33	.62	.62	.0948
.78	.82	.11	.11	.1357
.25	.333	.42	.78	.1398
.11	.23	.72	.44	.2798
.11	.23	.91	.17	.3578
.89	.11	.91	.11	.4172

After crossover and mutation

f.height	f.width	b.height	b.width	Obj. Function value
.42	.50	.10	.37	.0250
.35	.66	.31	.28	.0279
.52	.56	.39	.40	.0039
.59	.91	.39	.80	.0989
.59	.32	.10	.10	.0831
.77	.80	.61	.64	.1393
.24	.32	.71	.46	.1637
.10	.21	.39	.80	.2788
.10	.21	.89	.10	.3746
.91	.10	.89	.19	.4202

Arrange according to obj. Function value

f.height	f.width	b.height	b.width	Obj.function value
.52	.56	.39	.40	.0039
.42	.50	.10	.37	.0250
.35	.66	.31	.28	.0279
.59	.32	.10	.10	.0831
.59	.91	.39	.80	.0989
.77	.80	.61	.64	.1393
.24	.32	.71	.46	.1637
.10	.21	.39	.80	.2788
.10	.21	.89	.10	.3746
.91	.10	.89	.19	.4202

After crossover and mutation

f.height	f.width	b.height	b.width	Obj.function
.54	.56	.10	.37	.0160
.44	.50	.39	.40	.0113
.36	.66	.10	.10	.0572
.60	.33	.31	.28	.0501
.60	.91	.61	.64	.1045
.76	.80	.39	.80	.1303
.23	.32	.39	.80	.1548
.10	.21	.89	.19	.3631
.91	.10	.89	.10	.4316

Arrange according to objective function value

f.height	f.width	b.height	b.width	Obj. Function value
.44	.50	.39	.40	.0113
.54	.56	.10	.37	.0160
.60	.33	.31	.28	.0501
.36	.66	.10	.10	.0572
.60	.91	.61	.64	.1045
.76	.80	.39	.80	.1303
.23	.32	.39	.80	.1548
.10	.21	.71	.46	.2930
.10	.21	.89	.19	.3631
.91	.10	.89	.10	.4316

After crossover and mutation

f.height	f.width	b.height	b.width	Obj. Function value
.44	.50	.10	.37	.0222
.54	.56	.39	.40	.0051
.60	.33	.10	.10	.0823
.36	.66	.31	.28	.0250
.60	.91	.39	.80	.1008
.76	.80	.61	.64	.1340
.23	.32	.71	.46	.1690
.10	.21	.39	.80	.2788
.10	.21	.89	.10	.3746
.91	.10	.89	.19	.4202

Arrange according to objective function

f.height	f.width	b.height	b.width	Obj. Function value
.54	.56	.39	.40	.0051
.44	.50	.10	.37	.0222
.36	.66	.31	.28	.0250
.60	.33	.10	.10	.0823
.60	.91	.39	.80	.1008
.76	.80	.61	.64	.1340
.23	.32	.71	.46	.1690
.10	.21	.39	.80	.2788
.10	.21	.89	.10	.3746
.91	.10	.89	.19	.4202

After crossover and mutation

Arrange according to obj.function

f.height	f.width	b.height	b.width	Obj. Function value
.44	.50	.39	.40	.0113
.54	.56	.10	.37	.0160
.60	.33	.31	.28	.0501
.36	.66	.10	.10	.0572
.60	.91	.61	.64	.1045
.76	.80	.39	.80	.1303
.23	.32	.39	.80	.1548
.10	.21	.71	.46	.2930
.10	.21	.89	.19	.3631
.91	.10	.89	.10	.4316

After crossover and mutation

f.height	f.width	b.height	b.width	Obj. Function value
.44	.50	.10	.37	.0222
.54	.56	.39	.40	.0051
.60	.33	.10	.10	.0823
.36	.66	.31	.28	.0250
.60	.91	.39	.80	.1008
.76	.80	.61	.64	.1340
.23	.32	.71	.46	.1690
.10	.21	.39	.80	.2788
.10	.21	.89	.10	.3746
.91	.10	.89	.19	.4202

I find minimum objective function is .0039. According to objective function, normalised value of front height, front width, back height and back width is

Front height	Front width	Back height	Back width
.52	.56	.39	.40

So, optimum output is

Front height	**Front width**	**Back height**	**Back width**
1.8	**10.5**	**.5**	**8.2**

Table 5 Optimum output

CHAPTER 6

CONCLUSION

Optimization of front height, back height, front height, back width yielded satisfactory results and it is felt that GA can be effectively used for optimization of weld bead geometry. The proposed methods could be effectively used in determining the weld bead geometric descriptors for tungsten inert gas welding process. ANN tool available in MATLAB software was efficiently employed for prediction of weld bead geometry during TIG welding process.

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