PREDICTION AND OPTIMIZATION OF MIG WELDING PROCESS PARAMETERS FOR BEAD GEOMETRY USING ANN AND GENETIC ALGORITHM

A DISSERTATION

SUBMITTED IN IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE
OF

MASTER OF TECHNOLOGY

IN

PRODUCTION ENGINEERING

Submitted by:

Himanshu Yadav

2K18/PIE/03

Under the supervision of

Dr. M.S. Niranjan

MECHANICAL ENGINEERING DEPARTMENT

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

JUNE 2020

CANDIDATE'S DECLARATION

I, Himanshu Yadav, 2K18/PIE/03 student of M.tech. (Production Engineering), hereby declare that the Major project Dissertation titled "PREDICTION AND OPTMIMIZATION OF MIG WELDING PROCESS PARAMETERS FOR BEAD GEOMETRY USING ANN AND GENETIC ALGORITHM" which is submitted by me to the Department of Mechanical Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology. This work has not previously formed the basis for the award of any degree, diploma Associateship, Fellowship or other similar title or recognition.

Place: Delhi HIMANSHU YADAV

Date: 26/06/2020

MECHANICAL ENGINEERING DEPARTMENT

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

CERTIFICATE

I hereby certify that the Project Dissertation titled "PREDICTION AND OPTMIMIZATION OF MIG WELDING PROCESS PARAMETERS FOR BEAD GEOMETRY USING ANN AND GENETIC ALGORITHM" which is submitted by Himanshu Yadav, 2K18/PIE/03, Department of Mechanical Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge, this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi | Dr. M.S. Niranjan

SUPERVISOR

Date: 26/06/2020 | Associate Professor

MECHANICAL ENGINEERING DEPARTMENT

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

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HIMANSHU YADAV

ABSRACT

Welding is the most practical and productive approach to join metals for all time. It is the main method for joining at least two bits of metal to make them go about as a solitary piece. Almost everything we use today which we call them as necessities such as car which is our mode of transport, mobile phones, metal doors and all other stuff made of metal involve some sort of welding. It has been classified in number of processes and one of them is Metal Inert Gas welding(MIG) also known as Gas Metal Arc welding(GMAW) by American welding society.

This report examines the research work done in the prediction and optimization of process parameters of MIG welding for bead geometry using ANN and GA.

MIG welding also known as MAG welding by American Welding Society is a form of arc welding in which a solid electrode wire is used as an electrode and is feed by a spool mounted on the welding gun or torch. Shielding gas is released through the nozzle in the nozzle from an eternal high-pressurised cylinder. The gases used for the shielding purposes are mostly inert in nature. The material selected to carry out the study is AA6082.

We all are aware of the fact that various welding parameters govern the welding process and each of them affects the property of the welded joint in a different way. The process parameters selected for the study are welding voltage, gas flow rate and wire feed rate. The response parameter is bead geometry i.e. bead width, reinforcement height and penetration. Design expert software is used to create the design matrix using central composite design for doing the experiment. After the experimentation, samples are created by polishing the cross sectional area using emery paper. Then bead geometry is measured using Image J software. After measurement, prediction of bead geometry is done using the Matlab software and percentage error is calculated. For obtaining optimum value of bad geometry, optimization is done by genetic algorithm using Matlab software. Optimization of process parameters is also done using

RSM and then compared with the result of genetic algorithm. For result analysis, perturbation plots and 3D surface response graphs are plotted to study the interaction effect of various process parameters on the response parameters.

Keywords- MIG welding, aluminium alloy 6082, bead geometry, response surface methodology (RSM), central composite design, genetic algorithm (GA), artificial neural network (ANN), voltage, WFR, GFR

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CHAPTER-1
INTRODUCTION

The method, which comes into our minds to join two pieces of metals, is welding. It is the oldest and most efficient way to join similar or dissimilar metals depending upon the application. Welding can be performed with or without the supplication of heat. Over time, a number of welding processes have been developed to curb the restrictions of older method. Each method has its own speciality and its own limitations. The different types of welding developed for different applications are arc welding, metal inert gas welding, tungsten inert gas welding, submerged arc welding, cold metal transfer welding and many more.

1.1 METAL INERT GAS WELDING

With the advent of aluminium, it gathers attention in the research community. Due to its favourable properties and strength comparable, to steel and lighter in weight it quickly finds its use in many applications both industrial and structural. Soon the research community realises that it is difficult though not impossible to weld with the existing technology.

This difficulty becomes the basis of development of welding processes like MIG and TIG Welding. However, the less complex system and higher welding efficiency makes MIG a highly popular process for welding aluminium.

MIG welding also known as MAG welding by American Welding Society is a form of arc welding in which a solid electrode wire is used as an electrode and is feed by a spool on the welding gun or torch. Shielding gas is passed from the nozzle in the nozzle from an eternal high-pressurised cylinder. The gases used for the shielding purposes are mostly inert in nature. In many cases, depending upon the application Carbon dioxide is utilized as a protective gas. [18]

MIG/MAG welding is an adaptable system appropriate for both meagre sheet and thick area segments. An arc segment is ignited between the wire terminal and the metal piece, dissolving them two to shape a weld pool. The wire fills in (through the curve at the wire tip) and filler metal for the joint. The wire is taken care of through a copper-contact tube (contact tip) which allows welding current into the wire. The weld pool is shielded from the encompassing air by a protecting gas supplied through a spout encompassing the wire. Protecting gas choice relies upon the material being welded and the application. The wire is taken care of from a reel by an engine drive, and the welder moves the weld gun along the joint. The technique results in high productivity, as the wire is consistently drawn and fed.

Manual MIG/MAG welding is regularly alluded as a self-loader process, as the wire feed rate and circular segment length are constrained by the force source, however the movement speed and wire position are under manual control. The procedure can likewise be motorized when all the procedure parameters are not straightforwardly constrained by a welder, however may in any case require manual modification during welding. At the point when no manual mediation is required during welding, the procedure can be alluded to as programmed. [18]

The procedure for the most part works with the wire emphatically charged and associated with a force source conveying a steady voltage. Determination of wire dia. (for the most part somewhere in the range of 0.6 and 1.6mm) and wire feed speed decide the welding current, as the consume off pace of the wire will shape a harmony with the feed speed.

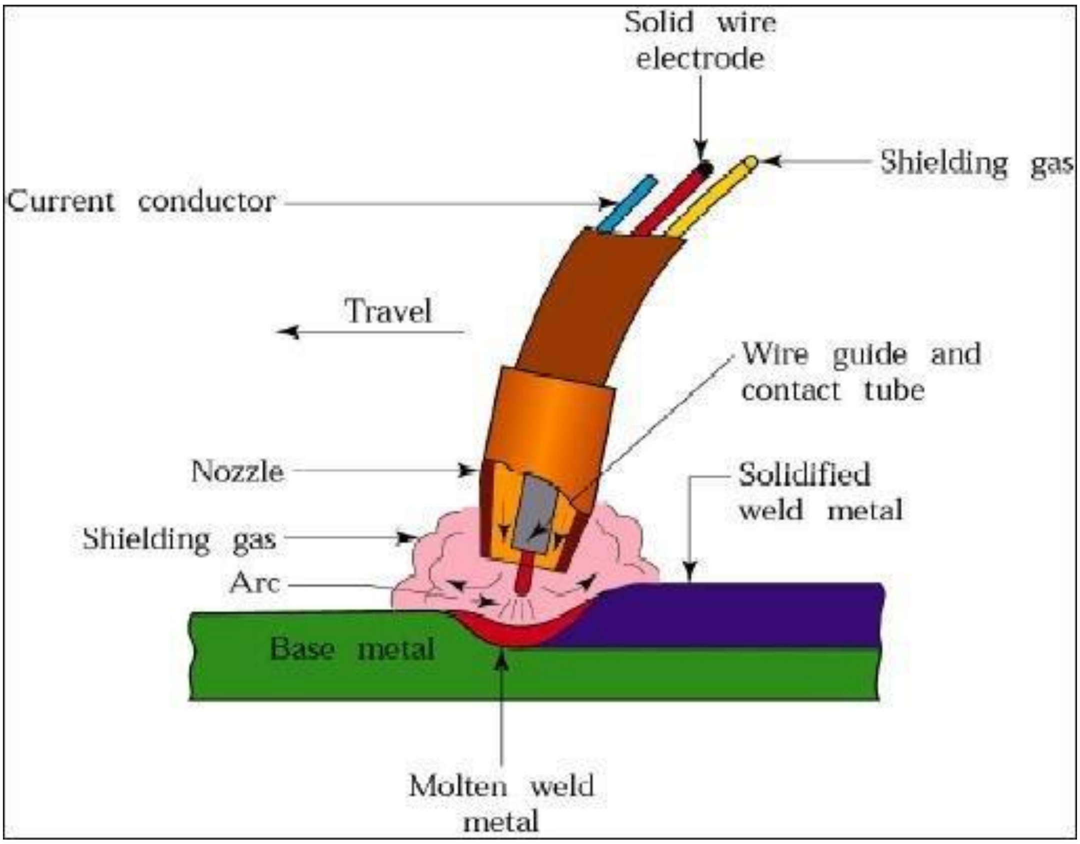


Fig. 1.1: Metal Inert Gas Welding [18]

1.2 METAL TRANSFER MODES

The medium of transferring molten metal to the weld pool is called mode of metal transfer. It is an important characteristic, which determines the operating features of the welding process. In MIG, it occurs in three ways:

- Short circuiting
- Droplet/spray
- Pulsed

1.2.1 SHORT CIRCUITING MODE

In this type of metal transfer, the liquefied metal at the end terminal of the solid wire electrode is devolve to the poll of molten metal. This transfer occurs by dipping the end terminal of the solid wire electrode into the weld pool. Fig. 1.2 shows the short circuit mode.

This mode of metal transfer requires the voltage to be set at low value and in close relation to wire feed rate to avoid spatter. Inductance is also used to prevent sudden increase in the current when the wire comes in close contact with the molten metal pool. [19]

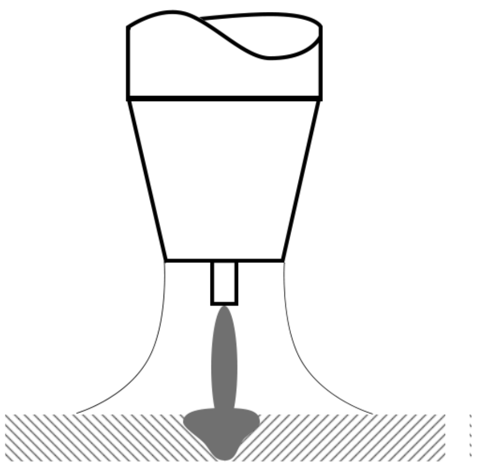


Fig 1.2: Short circuit metal transfer [19]

1.2.2 SPRAY MODE

In spray mode of metal transfer, the molten metal from the consumable electrode is sprayed to the pool of molten metal in the form of tiny metal droplets of constant volume. It is a constant voltage process and requires large heat input and therefore it is not suitable for welding of thin sheets. Recommended positions for this transfer medium of metal is flat and horizontal. Fig. 1.2 shows the spray mode. [19]

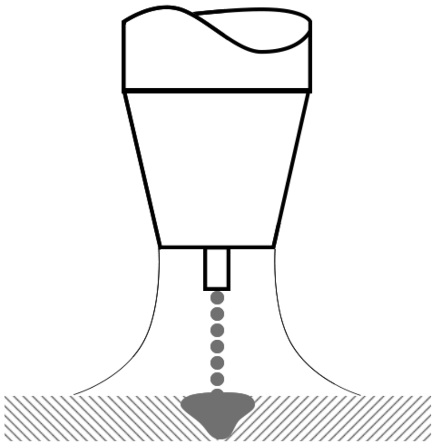


Fig. 1.3: Spray mode [19]

1.2.3 PULSED MODE

It is an advanced form of spray arc mode of metal transfer, which requires a special power source to pulse the voltage numerous times in a second. In this mode, a droplet of molten metal is constituted on the end terminal of the solid wire electrode and then the current transfer the droplet into the molten weld pool. A droplet is generated at every pulse. The main advantage of this type of metal transfer is that it reduces the HAZ in the weld region. [19]

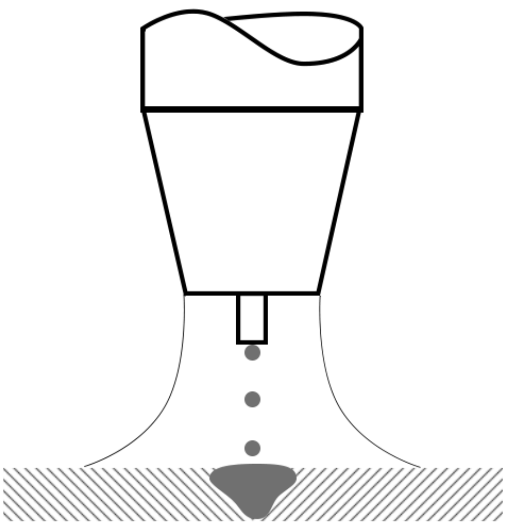


Fig. 1.4: Pulsed mode [14]

In addition, spatter is considerably less in this mod of metal transfer and weld positions are not limited too. Fig. 1.2 shows the pulsed mode.

1.3 WELDING POSITION

Welding position refers to the position of the weld gun/torch w.r.t the base plate where the joint is to be made. A number followed by alphabet F or G stating the type of weld represents the weld position. F stands for fillet while G stands for groove weld. In general, there are four positions in which welding could be accomplished by MIG welding. All the positions are listed below:

1. Flat position
2. Horizontal position
3. Vertical position
4. Overhead position

1.3.1 FLAT POSITION

It is denoted by 1F or 1G depending upon the type of weld. This type of weld takes place on the upper position of the weld joint. The weld bead quality depends upon combination of factors and some of them are tip angle, flare position and position of flame above the weld pool. To obtain a successful and a high quality weld the tip angle should be 45 degree with the base plate surface. [20]

Table 1: Number of passes for different thickness

Plate thickness (inch)	Number of passes
1/8 to ¼	1
1/4 to 5/8	2
5/8 to 7/8	3
7/8 to 1-1/8	4

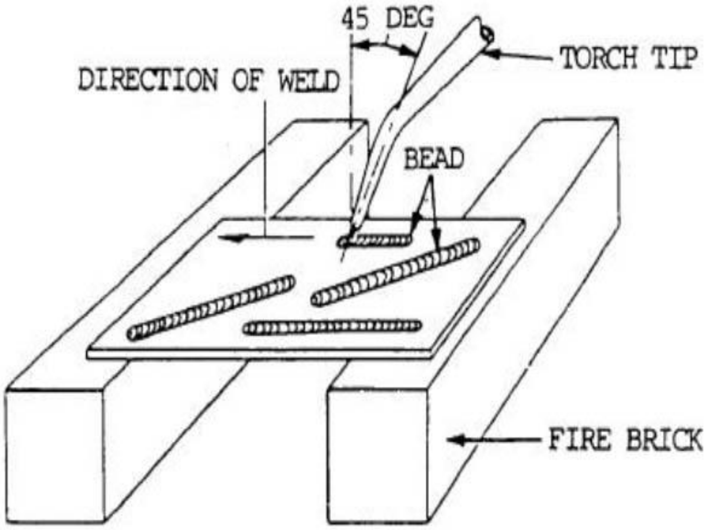


Fig 1.5: Flat Position [20]

1.3.2 HORIZONTAL POSITION

It is represented by 2G or 2F depending upon the type of weld. In this position, the welding axis is almost horizontal to the base plate but the complete definition is incomplete without the weld type as the axis of welding is different for different weld types. [20]

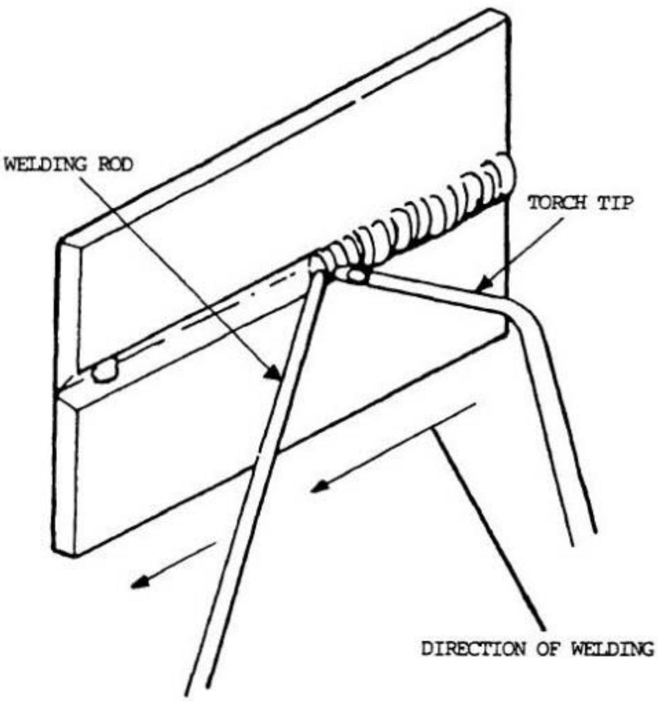


Fig 1.6: Horizontal Butt Weld [20]

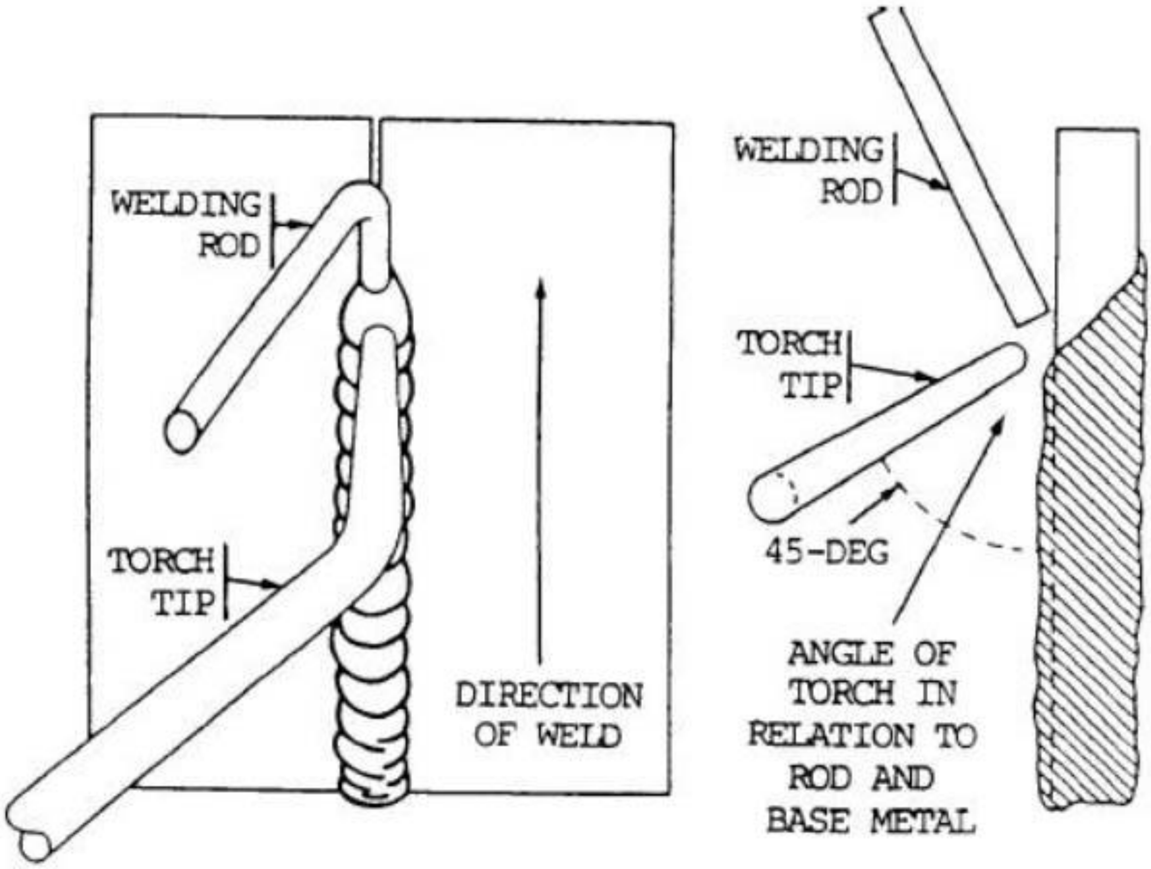
In fillet weld, the welding takes place against the vertical surface. In case of butt joint, the plates are aligned against a vertical plane and welding takes place in a horizontal axis on the base plates that are to be welded.

1.3.3 VERTICAL POSITION

It is denoted by 3G or 3F depending if the weld is grove or fillet weld respectively. This position is referred to as vertical as the welding axis is vertical. As a result, the molten metal tend to flow in a downward direction. [20]

To eliminate this effect, the welder should keep the flame upwards at an inclination of 45 degree to the plate and keeping the rod between molten weld pool and flame.

The way of preparation of butt joint in vertical position to the joint preparation in flat position.



(i) (ii)

Fig 1.7: (i) - Front view, (ii) – side view vertical position butt weld [20]

1.3.4 OVERHEAD POSITION

It is denoted by 4F or 4G depending on the type of weld being employed in application. The highlight of this position is that it is performed underside of the joint.

However, this position is complex in nature compared to other positions, as the metal droplets tend to fall downwards due to gravity action. In addition, it is a difficult task for the welder to achieve weld in the desired position. [20]

Due to the falling action of the droplets, the reinforcement of the weld becomes large and therefore consumes high amount of filler metal. [20]

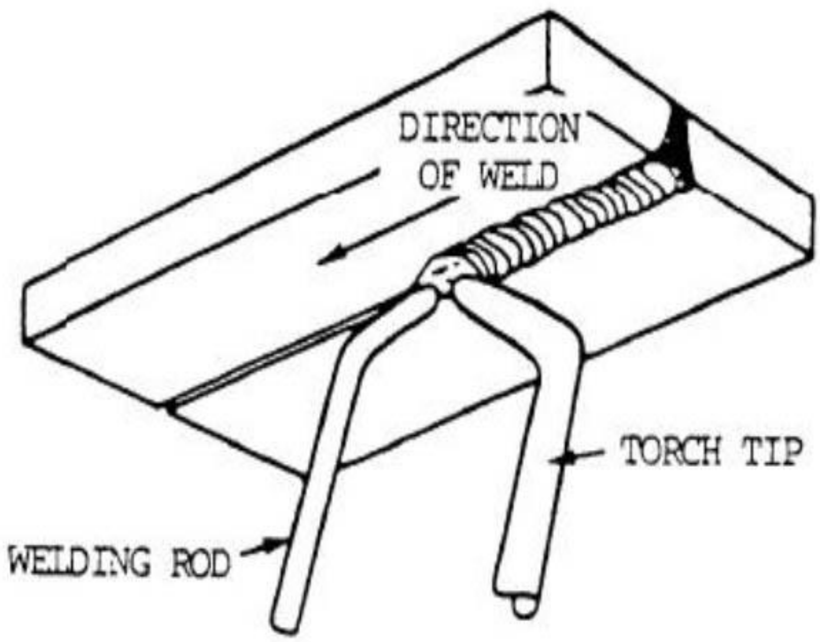


Fig 1.8: Overhead butt weld [20]

1.4 APPLICATIONS

Following are the applications of metal inert gas (MIG) welding:-

1. Automotive Industry

It is used for the welding of chassis components and to carry out various repair works. In fact, automotive industry is the largest employer of MIG welding in the current time. The reason for such high demand is that most of the vehicles are made up of aluminium to reduce the vehicle weight by not comprising with the structural integrity of the vehicle. And MIG welding is most efficient and highly productive method to weld aluminium.

Fig. 1.9: Automotive repair [21]

2. Construction Sector

Of all the commercial available materials present on earth, steel is considered to be of the highest strength. The desirable properties of steel has make it the most used material in the construction industry. However, MIG was developed for aluminium, but now the trend has been shifted and it is finding increased usage in the construction of buildings as it is a speedy process.

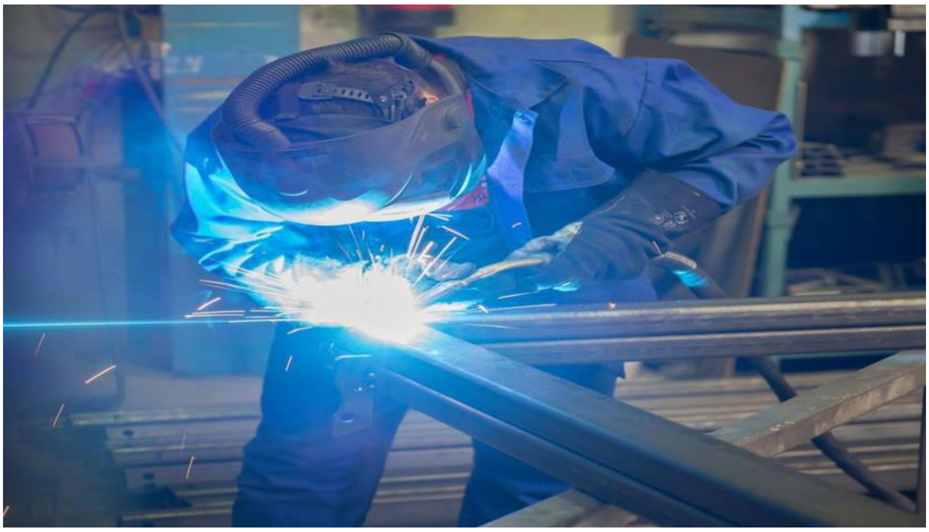


Fig. 1.10: Construction industry [22]

3. Overlay of wear resistant coatings

Fig. 1.11: overlay of coatings [22]

1.5 ADVANTAGES OF MIG WELDING

Some of the advantages of MIG welding are discussed below:

1. Higher productivity- The plus point of not changing the electrode or filler wire makes the MIG welding an ideal process for most of the welders as a considerable amount of time is saved, which was used earlier. This will consequently improve productivity and saves time and capital.
2. Simple to learn- MIG welding is contemplated to be the most simple and easy welding technique after arc welding and any person can achieve expertise in a short period of time and less resources.
3. Clean and efficient- Since inclusion of slag is less or not even present welder don't have to clean it with the help of wire brush and the working keeps neat and clean.
4. Versatile- it is an extremely flexible system because it can weld a huge range of commercial available welds and alloys including aluminium and steel which are very difficult to weld. Also finds its use for small college projects as well as big industrial projects.

1.6 LIMITATIONS OF MIG WELDING

The various limitations of MIG are listed below.

1. Cost- MIG equipment is more expensive compared to other equipment's while sacrificing portability.
2. Limited welding positions- the high thermal heat energy and fluidity of the poll of molten metal rules out the overhead and vertical position of welding as it possess a serious threat to the welder and will also result in poor productivity.
3. Fast cooling rates- The pool of molten metal cools at a considerable high rate due to the absence of slag which provides a blanket.
4. Unsuitable for thick sections- It is not preferred for thick sections specially in case of steel welding.

CHAPTER-2
LITERATURE REVIEW

2.1 METAL INERT GAS WELDING

A.A. Shukla et al analysed the MIG welding parameter on depth of penetration using response surface methodology. The testing material selected was steel AISI 1020 of dimension 100*60*150 mm. The MIG machine used for the experiments was of Lincoln Electric Company. The process parameters are polarity, current and torch angle. The response parameter for which input were optimize was weld penetration. Full factorial CCD was used for the experimentation. Out of the three input three parameters current and torch angle were quantifiable factors. Maximum value of penetration obtained with welding current at 120 A and 90 degree torch angle respectively for DCEN polarity. **[1]**

Amit Kumar et al determined the out turn of input process parameters over ultimate tensile strength for MIG welding. They have used the artificial neural network and genetic algorithm approach for optimization purpose. Welding of two dissimilar materials i.e. stainless steel 304 and stainless steel 316 has taken place for experimentation purpose. Taguchi full factorial model is selected for conducting the experiments. Argon has been used for shielding purpose. Stainless steel 309L is used as wire electrode. The welding process parameters selected for optimization are voltage, current and travel speed. The three levels of all these parameters are 100-110-120A, 16-18-20 V and 40-45-50 cm/min respectively. ANN and GA has been used for prediction and optimization respectively. **[3]**

Amit Kumar et al investigates the variation of welding parameters on response parameters and optimize them for better results for TIG welding. The material selected for this investigation is Ferritic stainless steel 409L. The process parameters identified for the investigation are current (ampere), weld time (sec.) and GFR (l/min). The response parameters selected are weld penetration, weld bead width and tensile strength of the joint. The optimization approach used for the study is response surface methodology based on design of experiments. In addition, micro hardness and microstructure study of certain samples was carried out. All the input parameters were divided into three levels. The end results shows that weld time has the most significant impact on weld performance compared to the remaining input parameters i.e. current and gas flow rate. Micro hardness testing showed that heat affected zone accounts for the least hardness of the test sample. **[4]**

D.S. Nagesh et al predicted the geometric properties of the weld i.e. penetration, reinforcement and width for MIG welding using ANN. Bead geometry is a property considered to depict the quality of weld. The material finalised for testing was grey cast iron of dimensions 15cm*12cm*1.2cm. The welding parameters selected for optimization were electrode feed rate, arc power, arc voltage, arc current, and arc travel rate and arc length. The response parameters were bead height, reinforcement, penetration and area of dilution. After welding samples preparation was done and then etched with a chemical solution. These samples are watch with toolmaker microscope and necessary properties were measured. These measurement are then entered into the system and optimization and prediction was done using ANN. **[7]**

Jigar shah et al aims to optimize and predict the process parameters for MIG welding using ANN and genetic algorithm (GA). The scholars showed the impact of welding input parameters on response parameters of MIG welding. The welding parameters employed for the study are welding current, travel speed and gas pressure. The response parameters were hardness and tensile strength. The optimization technique employed for the investigation is Taguchi L9 full factorial using design of experiments (DOE). According to ANOVA analysis current & gas, pressure has the highest impact of the response parameters. In addition, microstructure study was also done for one sample. However, the material selected for the investigation not mentioned in the paper. **[8]**

K Siddharth Kumaran et al aims to optimize the parameters involved in the MIG welding and its influence on quality responses. They performed the optimization of the welding input process parameters for quality responses parameters such as weld penetration, weld depth and weld width. The material finalised for the study was IS2062 (commercial mild steel) of Grade A quality of 5mm thickness. The robotic machine employed for performing experiments was ABB IRB 1520 MIG welding machine. The process parameter chosen for the study were welding voltage, WFR and GFR. The shielding gas used for the experiments was a mixture of carbon dioxide and argon (88% argon+12%CO_2). In order to complete the optimization in a fewer experiments, response surface methodology was selected for the research work. For all the input process parameters 5 levels were defined and experiments were performed based on a full factorial design matrix. The software used for optimization was Minitab. After the sample preparation, the response parameters were measured using an imaging software and fed into the software for optimization. For the optimized values of voltage 16.9V, wire feed rate 2.6324 m/min and gas flow rate 8.2955 l/min the values of response parameters were 2.0505 mm, 1.1219 mm, 4.1619 mm for penetration, reinforcement and weld width respectively. **[9]**

Kamaleshwar Dhar Dwivedi et al deals with the parametric optimization of dissimilar metals for MIG welding using Taguchi design method. The testing material selected for experiments was stainless steel 304 and carbon steel C-25. Stainless steel wire of diameter 0.8mm was used as the electrode. The dimension of the plates used was 80mm*30mm*5mm. The input parameters selected for the study were voltage, current and wire feed rate. The response parameter for which input parameters were optimized was hardness. The Taguchi model was used therefore three levels of each parameter clearly defined. From the analysis researchers found out that wire feed rate has the highest impact on the hardness value of the weld. **[10]**

Sahil Angaria et al used an application of response surface methodology (RSM) to optimize input welding parameters for MIG welding. The testing material used for the study is MS IS 2062 of dimensions 60mm*40mm*5mm. The experiments were performed on the power compact 255 MIG machine. The protecting gas used for shielding purpose was carbon dioxide (100%). The filler wire material used was ES70S-3. The welding process parameters chosen to be optimize were voltage, current and GFR. The response parameter of the investigation was hardness. In this paper, the researchers employed box behnken design, which is an application of response surface methodology. As per ANOVA analysis, voltage has the highest impact on the hardness value of weld compared to current and gas flow rate. The conclusion of the research was that with the enhancement in the values of voltage and gas flow rate hardness rises and for current, it was indirectly proportional. The highest value of hardness obtained was 230 HV for welding voltage 25.18 V, current 145.71 Ampere, GFR 15.72 l/min respectively. **[14]**

Sreeharan B N et al have optimised the process parameters for GMAW over AA6351 using ANN. The material selected for carrying out the research work is AA6351. Taguchi L9 orthogonal array optimising technique is selected for optimizing the welding parameters. The paper focusses on the optimization of welding parameters for the geometry of the weld. The response parameters that are link to weld bead geometry are weld width, reinforcement height, weld penetration and dilution percentage. The welding parameters that are need to be optimized are current, GFR and electrode feed rate. The optimization is carried out using Matlab software since it has an in built library for optimized using ANN. Three levels of each parameter is selected i.e. 120, 130, 140 A as welding current, 10, 13, 16 l/min as GFR and 5, 5.5, 6 m/min as WFR. The optimized parameters that give the best weld bead geometry are 140A, 13.84 l/min and 5.442 m/min. **[15]**

2.2 RESEARCH GAP

After the in-depth review of the literature, it is observed that most of the research or investigation has been done on DOE or optimization of Process parameter for the response such as mechanical Properties and tensile strength of the weld. However, it has been seen that very few literature is available on Aluminium alloy 6082. On the basis of literature review, following gaps have been identified.

1. An in-depth review of literature showed that a very few investigations are available on MIG welding of AA6082.
2. Almost all the researchers have tested the weld mechanical properties and very few literature is available on the bead geometry of AA66082 which gives direct indication of strength of the joint.
3. Researchers have either used the taguchi methodology or response surface methodology for the optimization of the process parameters of the MIG welding. Some advanced methodologies are required for optimization of process parameters in MIG.
4. Optimization of process parameters using genetic algorithm is still at an early stage. Multi objective optimization needs to be done using this budding technique as literature review repots about the limitations of traditional optimization techniques.
5. Prediction of response parameters using ANN is another important aspect found missing in the literature survey.

Therefore, I have decided to do experimental study on AA 6082 to see its complete behaviour and optimize and predict the response parameters using ANN and GA for bead geometry.

2.3 RESEARCH OBJECTIVE

On the study of various research papers available in the literature, the following research objectives are drawn.

1. To prepare the samples of AA 6082 for the experimental study in MIG welding.
2. To study the composition and mechanical properties of samples.

3. To conduct the experiments on MIG welding setup to optimize the process parameters such as welding Voltage, gas flow rate and wire feed rate for the response weld bead geometry using response surface methodology.
4. To optimize the process parameters such as welding Voltage, gas flow rate and wire feed rate for the response weld bead geometry using Artificial Neural Network (ANN) and Genetic algorithm (GA).
5. To compare the results obtained from statistical analysis using RSM and with the result obtained from genetic algorithm.
6. To predict the value of response parameters using artificial neural network (ANN).

CHAPTER-3

MACHINE DESCRIPTION AND ACCESSORIES

3.1 MIG MACHINE

Phoenix 521 Force Arc Plus manufactured by EWM High-tech Welding UK Ltd. is used to execute the welding work for the project. EWM is a multi-national company headquartered at London, England and has made its name its name as a leading manufacturer in the welding industry. Phoenix 521 force arc plus is the most advanced MIG machine of EWM and can be operated in two modes. It can be run in conventional as well as pulse mode. In fact there is an also a provision to run the power source as TIG just by changing the welding torch. The machine is water-cooled which adds to the complexity compared to the air-cooled machines

.

Fig. 3.1: Phoenix force arc 521[23]

The numbers in the above image identifying the parts of the machine has been described in the below table.

Table 2: Numbers representing pats of MIG machine

Item	Description
1.	Wire feed unit
2.	Lifting lug
3.	Carrying handle
4.	Main switch, machine ON/OFF
5.	Cooling air inlet
5.	Automatic cut-out of coolant pump key button
6.	Conveyer rolls, guide castors
8.	Coolant tank
9.	Coolant tank cap
10.	Connection socket, “-“ welding current
11.	Connection socket, “+” welding current
12.	Key switch for protecting against unauthorised use Position 1 > changes possible Position 0 > changes not possible
13.	Control / operating elements

3.1.1 TECHNICAL DESCRIPTION OF MIG MACHINE

The technical details of the Phoenix force arc 521 MIG machine is discuss below in detail.

Table 3: Technical description

Adjusting Range Welding Current/Voltage:	
TIG	5A/10.2V-520A/40.8V
MMA	5A/20.2V-520A/40.8V
MIG/MAG	5A/14.3V-520A/40.0V
Duty cycle at 20C	
80% DC	520A
100% DC	450A
Duty cycle at 40C	
60% DC	520A
100% DC	420A
Load alternation	10 min.
Open circuit voltage	79V
Mains voltage (tolerances)	3*400V (-25% to +20%)
Frequency	50/60 Hz
Mains fuse (safety fuse, slow – blow)	3*35A

Mains connection lead	H07RN-F4G4
Max. connection power	31.6 kVA
Recommended generator rating	42.8 kVA
Cos fi/ efficiency	0.99/89%
Insulation class/ protection classification	H/IP 23
Ambient temperature	-10C to +40C
Machine/ torch cooling	Water
Cooling capacity at 1l/min	1200W
Max. flow rate	5 l/min
Max. initial coolant pressure	3.5 bar
Max. tank capacity	12 l
Coolant	KF 23 E (-10C to +40C)
Workpiece lead	95 mm^2
Dimensions L/W/H[mm]	1100*455*950
Weight in Kg	109/124.5
Protection classification	IP 23
Constructed to standards	IEC 60974/ EN 60974/ VDE 0544 EN 50199/ VDE 0544 Part 206

3.2 WIRE FEED UNIT

The wire feed unit used in Phoenix Puls Force Arc is Phoenix expert drive 4L. The unit is very sophisticated to use. It is provided with four rollers to draw the wire from the spool and supply it through the weld gun. The wire electrode is held between four rollers: two rollers below the wire and two above the wire. Push pull system is use to move the wire at constant rate without nay fluctuations. A plastic casing is also provided for the wire spool to protect it from any chemicals and pollutants present in the atmosphere.

3.2.1 MACHINE DESCRIPTION

Fig. 3.2: Phoenix expert drive 4L [23]

All the numbers marked in the aforementioned image of the wire feed unit Phoenix expert drive 4L has been discussed below.

Table 4: Numbers specifying parts of wire feed unit

Item	Description
1	Slide latch, lock for the for protective cap
2	Cover for wire delivery unit and operating elements
3	Carting handle with integrated lifting lug
4	Wire spool casing
5	Operating elements
6	Spool holder
7	Wire delivery unit
8	Euro-central connector
9	Label
10	Control/ operating elements
11	19 pole connection socket (analogue)
12	7 pole connection socket (digital)
13	Rapid-action closure coupling, blue (coolant supply)
14	Rapid-action closure coupling, red (coolant return)

There is a control panel provided on the wire feed unit to control the various functions of the machine. Two digital screens are there on the control panel and button is there to select various parameters to be displace don the screen. Only quantitative data is displaced on the screens. The parameters that can be set from the knobs provided on the control panel are wire feed rate, voltage and some more. A button is also there to check whether the protective gas supply in the machine is OK or not. In addition the button to select the conventional and pulse mode of the MIG Machine is also present on this wire feed unit.

Push system- In the push system, the wire is pushed by the wire feed drive rolls along the conduit to the welding torch. The flexibility of aluminium wire means the wire can buckle and jam inside the conduit, leading to irregular wire feeding at the welding torch and, in extreme cases, a nest of bird of tangled wire at the wire feed unit. This system is limited to a wire dia. of 1.6 mm and therefore the wire feed conduit to a length of 3.5 m.

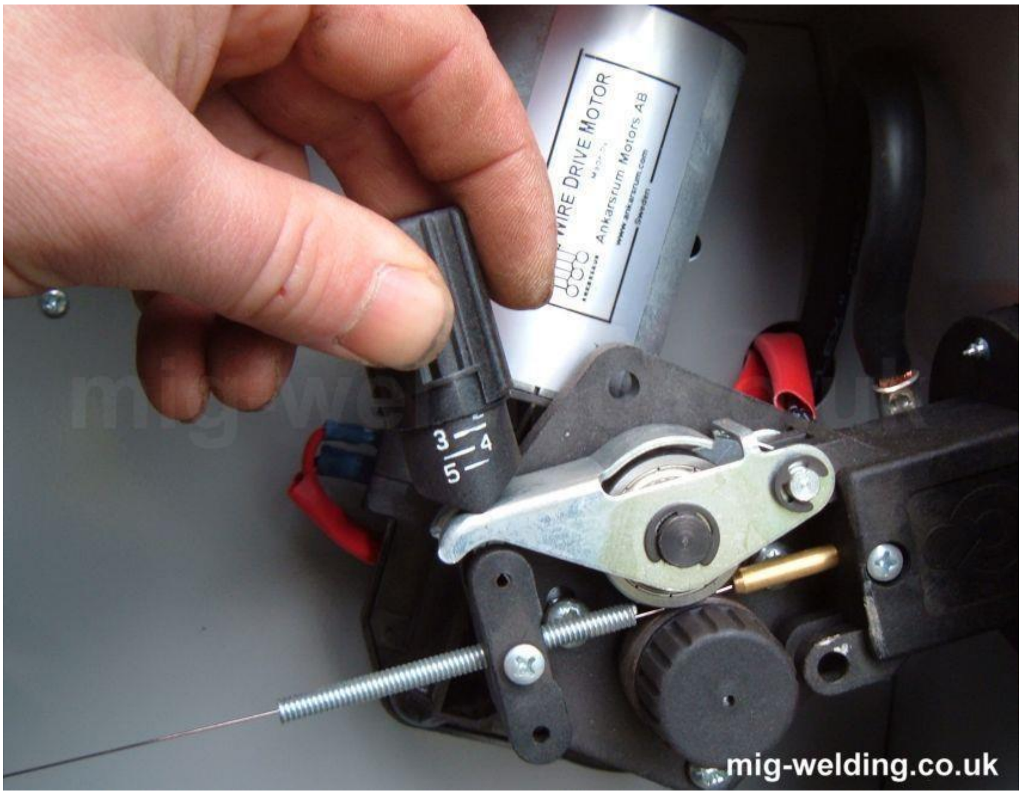


Fig. 3.3: Push system [23]

3.2.2 TECHNICAL DESCRIPTION

The detailed technical description of the wire feed unit is tabled below.

Table 5: Technical description

Phoenix Expert Drive 4L	
Supply voltage	42 VAC / 60 VDC
Max. welding current at 60% DC	520A
Wire feed speed	0.5 m/min to 24 m/min
Standard WF roller fitting	1.0+1.2 mm (for steel wire)
Drive	4- roller (37 mm)
Torch connection	Euro-central or Dinse-central
Protection classification	IP 23
Ambient temperature	-10^{0}C to +40^{0}C
Dimensions (L*W*H) [mm]	690*300*410
Weight	18 g (approx.)

3.3 SHIELDING GAS EQUIPMENT

The shielding gas plays a very crucial role in MIG welding. It protects the molten weld pool from the gases and water vapours present in the immediate surrounding and in atmosphere. The gas forms an outer cover around the weld pool and prevent any reaction between the oxygen and molten metal. Any reaction will reduce the strength of the joint formed and will result in a number of defects.

Apart from the protective shield around the weld pool, it also performs a number of other functions.

- It helps in the formation of arc plasma.
- It also stabilises the roots of arc on the material to be welded.
- Transmission of molten metal droplets from the solid wire end terminal to the weld pool is also a function if the shielding gas.

Each material has a requirement of different shielding gas.

- For welding of steel any gas cannot be used. Only certain gases are considered good for steel welding. These are CO_2, mixture of argon & oxygen and mixture of argon plus CO_2.
- For Non-ferrous alloys (e.g. Aluminium, copper or nickel alloys) argon and helium are considered as good choices.

3.3.1 PRESSURIZED GAS CYLINDER

It is a receptacle for storing the gases in compressed state above air pressure. It appears to be like a cylinder from where it has derived its name. it has a control valve on the top and a connector for refilling purposes. It has a flat bottom which prevents it from falling while standing. The weight of the full cylinder is very much therefore care should be taken while handling it. With the help of a special key its valve can be opened and closed after using to prevent leakage. Also no person should be standing in front of the cylinder while it is tested as he or she can get hurt. Depending upon the threads of the valve a pressure gauge is connected to it which will tell the gas pressure while using it for experimentation.

Fig. 3.4: Argon cylinder [24]

The regulator is adjusted to regulate the downstream pressure, which can limit the utmost flow of gas out of the cylinder at the pressure shown by the downstream gauge. For some purposes, like welding, the regulator also will have a flowmeter on the downstream side.

The valves on cylinders of different applications are of different shapes and sizes and are different for different gases. For example, a hydrogen cylinder doesn't fit an oxygen supply route, which might end in catastrophic failure.

Table 6: Valve connections values

Gas	CGA value outlet (USA)	BS value outlet (UK)
Acetylene	510	2,4

Argon	580, 718,680 (3500 psi), 677 (6000 psi)	3
Carbon dioxide	320, 716	8
Helium	580, 718, 680 (3500 psi)	3

In USA, valve connections are marked as CGA termed as Compressed Gas Association. In UK, British Standards sets the values.

3.3.2 PRESSURE GAUGE/REGUALTOR

This device is to regulate the circulation of inert gas or shielding gas to the MIG welding machine from the pressurized cylinder. It is also equipped with a flow meter to control the rate of the gases. It is different for different gases in construction.

The attachment consist of a regulator, upstream and downstream pressure gauges and an extra downstream needle valve and outlet connection to connect it to the machine. The regulator is altered to manage to oversee the pressure, which may limit the utmost circulation of gas out of the cylinder at the pressure shown by gauge. The outlet port connection is fasten up to the MIG welding machine. For some purposes, like welding, the regulator also will have a flowmeter.

It is attached to the outlet port of the cylinder. Then the knob is rotated to allow the passage of gas until a sufficient pressure as indicated in the dial. After the passage of gas from the cylinder to the machine is ON, flow meter is regulated by a rotating thimble alongside it to adjust the flow of gas as per the requirement.

The pressure regulator is mad up from brass and manufactured by different companies
The flowmeter has a mercury ball in it. A cylinder test tube engraved with markings represents it. When the flow of gas is allowed through the pressure regulator, it also is flowed in flow meter. As a result the, mercury ball in the flowmeter is lifted by the gas in the cylinder test tube to a certain height which represents the flow rate of gas. A rotating thimble is provided to adjust the flow rate of gas. The gas flow rate is denoted by l/min.

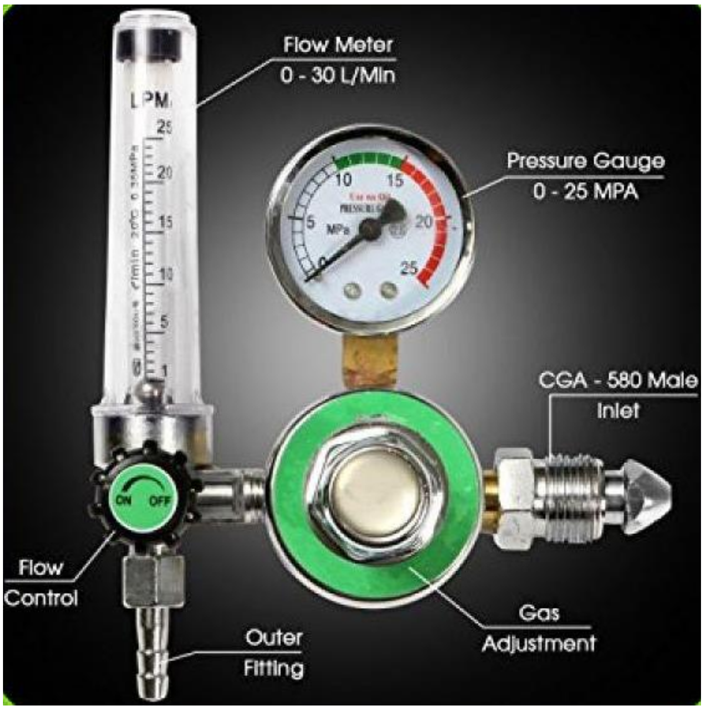


Fig. 3.5: Pressure regulator with flow meter [24]

3.4 CONDUIT

The conduit can serve to 5m long, and to facilitate feeding, should be kept as short and straight as possible. The conduit for steel wire has a spiral wound steel liner inside it and for aluminium wire it is only PTFE because aluminium is soft in nature and prevent breaking of it.

I II

Fig. 3.6: I- Steel liner, II- Aluminium liner [24]

CHAPTER-4

WORK MATERIAL

4.1 INTRODUCTION

The name aluminium has derived from the Latin word alumen, wont to describe aluminium. Aluminium is the second abundant element buried in the crust of the planet earth after silicon. It has excellent malleability and ductility and has strength compared to that of steel with weight lesser than that of steel. Due to high reactive nature it can never exist as metal in nature but only as compounds in animals and rocks.

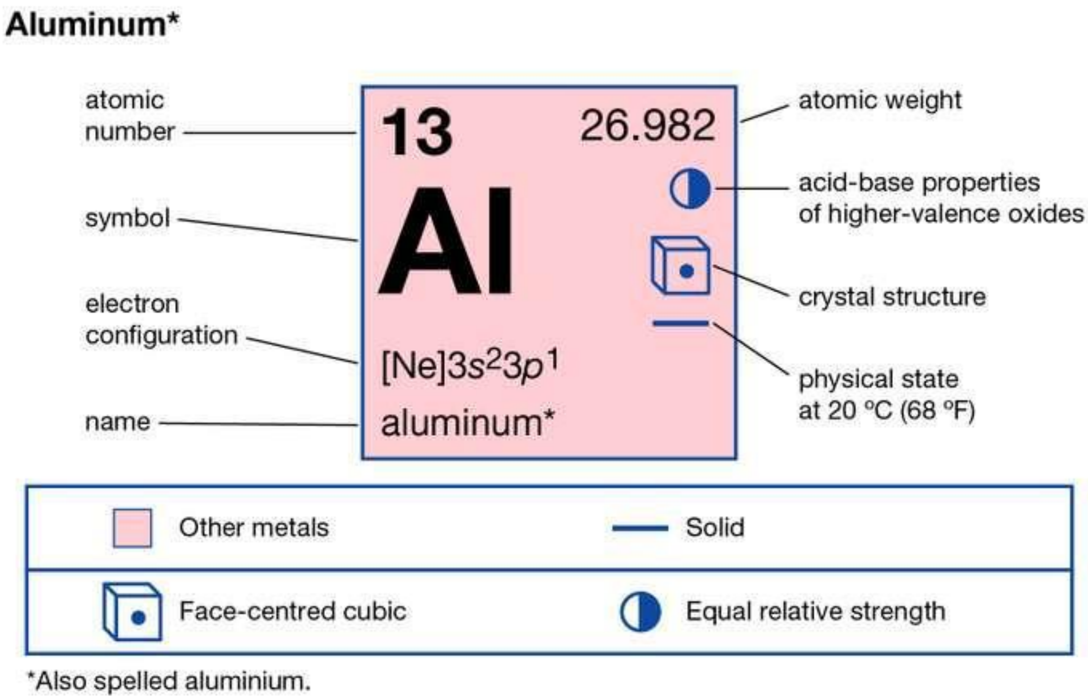


Fig. 4.1: Aluminium Symbol Square [24]

4.2 ALUMINIUM ALLOY 6082

A new addition to the medium strength alloy category is AA6082. It is developed to have excellent corrosion resistance and offers the highest strength in the 6000 series. As a result, it has known as structural alloy. It has find its use for machining in the plate form. Being comparatively a new alloy, it has replaced AA6061 in most if the applications. The incorporation of an outsized amount of chemical element manganese sway the structure of grain that consequently leads to a stronger alloy with higher strength.

Table 7 shows the tempers for AA 6082 .

Table 7: temper for AA6082

Temper	Description
O	Annealed wrought alloy
T4	Heat treatment and aged naturally
T6	Heat treatment and aged superficially
T651	heat treated, stress relieved by stretching and then artificially aged.

AA6082 has find its use in many applications. These include:

- High stress applications such as bridges
- Ore skips
- Trusses in bridges and high stress applications
- Beer barrels for storing and fermentation purposes
- Bridges for transportation
- Milk churns
- Cranes to uplift heavy objects involving high strength with light weight
- Transport applications

Fig. 4.2: AA6082 [24]

4.2.1 CHEMICAL COMPOSITION OF AA6082

Table 7: Chemical composition

ELEMENT	% PRESENT
Silicon (Si)	0.7-1.3
Iron (Fe)	0.0-0.5
Copper (Cu)	0.0-0.1
Manganese (Mn)	0.4-1.0
Magnesium (Mg)	0.6-1.2
Zinc (Zn)	0.0-0.2
Tin (Ti)	0.0-0.1
Chromium (Cr)	0.0-0.25
Aluminium (Al)	Balance

4.2.2 PHYSICAL AND MECHANICAL PROPERTY

Table 8: Mechanical property

	O	T4	T6/ T651
Proof stress	60	170	310
Tensile strength (Mpa)	130	260	340
Shear strength (Mpa)	85	170	210
Elongation A5 (%)	27	19	11
Hardness Vickers (HV)	35	75	100

Table 9: Physical property

Physical Property	
Density	2700 kg/m^3
Melting Point	555°C
Modulus of Elasticity	70 GPa
Electrical Resistivity	0.038×10^{-6} Ω.m
Thermal Conductivity	180 W/m.K
Thermal Expansion	24×10^{-6} /K

CHAPTER-5

EXPERIMENTATION & METHODOLOGY

4.1 INTRODUCTION

The method that comes to our kind for welding aluminium is MIG welding. Various welding parameters govern the process. These parameters include current, welding voltage, welding speed, WFR and GFR. These parameters ascendants the mechanical properties of the weld. Therefore, to obtain desired values of the above-mentioned properties the aforementioned welding parameters need to be optimized. Optimization is done by several methods like Taguchi optimization, Response Surface Methodology and by hit and trial method. Now days everything has found its place online and artificial intelligence is gaining a lot of interest in the research community. So, I have make my mind to optimize the welding parameters for the desired response using artificial neural network and genetic algorithm. Both of these technologies are applied using Matlab software. Bead geometry is selected for optimization, as it is an indication of the strength of the weld. The input parameters that need to be optimize are voltage (V), wire feed rate (m/min) and gas flow rate (l/min). Pure argon is selected as the shielding gas.

In the present work, experiments are performed on Phoenix 521 Force Arc Plus manufactured by EWM High-tech Welding UK Ltd. along with all the accessories as shown in the fig. 5.1, which is available at Advanced Welding Lab, Mechanical Engineering Department, Delhi Technological University. Table 3 provides the detailed technical description of the MIG welding machine used for the experiments.

4.2 SPECIFICATION OF THE WORK PIECE MATERIAL

Aluminium alloy 6082 is selected for the experimentation work based on the literature review. It was procured from Chawri Bazar, New Delhi. The sheet is cut into pieces of 150*_*6 mm^3 using power hacksaw by the dealer himself at his shop. Table7 and table8 shows the chemical structure and property of AA6082.

The cut pieces are cleaned using acetone to remove any kind of dirt from the surface to carry out the experimentation work.

Bead on plate approach is selected to carry out the project work because sectional cut of the bead on pate will directly shows the bead geometry.

4.3 DESIGN MATRIX

Central composite design of Response Surface Methodology (RSM) is selected to carry out the project work. The advantage of CCD is that it provides high quality predictions over the factors range.

4.3.1 EXPERIMENTAL PLANNING

In the present study, central composite design is used for planning the experiments. The software used for this purpose is Design Expert V10.0. For the present work, three levels of process parameters are selected based on literature review with five levels each. The parameters selected has shown in table 11.

Table 11: Welding parameters and their respective levels

Parameters	Levels						
	UNITS	NOTATION	-2	-1	0	1	2
Welding Voltage	V	V	15	17	19	21	23
Wire feed rate	m/min	WFR	4	5	6	7	8
Gas flow rate	l/min	GFR	9	11	13	15	17

The design matrix according to central composite design based on the no of parameters and their respective levels is shown in table 13. Each row of the developed design matrix signifies an experiment. There are fourteen distinct number of experiments and six are repetitive in nature consisting of all factors at central levels. Thus, in total 20 experiments need to be performed according to full factorial design.

Table 12: Fixed parameters

S. No.	Fixed parameters	Units	Fixed operating conditions
1.	Electrode wire dia.	mm	1.2
2.	Work material	-	AA6082
3.	Work material size	mm	150*45*6
4.	Travel speed	mm/sec	8

Table 13: Design matrix layout for main experimentation (coded form)

Standard	Run	A	B	C
5	**1**	-1	-1	1
12	**2**	0	2	0
4	**3**	1	1	-1
13	**4**	0	0	-2
19	**5**	0	0	0
7	**6**	-1	1	1
15	**7**	0	0	0
9	**8**	-2	0	0
18	**9**	0	0	0
17	**10**	0	0	0
16	**11**	0	0	0
14	**12**	0	0	2
20	**13**	0	0	0
2	**14**	1	-1	-1
11	**15**	0	-2	0
1	**16**	-1	-1	-1
6	**17**	1	-1	1
8	**18**	1	1	1
10	**19**	2	0	0
3	**20**	-1	1	-1

Table 14: Design matrix for main experimentation (Actual form)

Standard	Run	Voltage	WFR	GFR
5	**1**	17	5	15
12	**2**	19	8	13
4	**3**	21	7	11
13	**4**	19	6	9
19	**5**	19	6	13
7	**6**	17	7	15
15	**7**	19	6	13
9	**8**	15	6	13
18	**9**	19	6	13
17	**10**	19	6	13
16	**11**	19	6	13
14	**12**	19	6	17
20	**13**	19	6	13
2	**14**	21	5	11
11	**15**	19	4	13
1	**16**	17	5	11
6	**17**	21	5	15
8	**18**	21	7	15
10	**19**	23	6	13
3	**20**	17	7	11

In the design matrix , A, B and C represents the welding parameters and -2,-1,0,+1,+2 depicts the low, central and supreme levels of welding parameters or control factors respectively. The three control factors/ welding parameters selected based on literature review and preliminary study as shown in table 11 are used in design matrix for final experimentation and are varied at five levels (-2,-1,0,+1,+2). The actual set of experimentations with their respective levels for different run of main experimentation is shown in table 14. In total 20 experimentations are there but six of them are repetitive in nature. Therefore, it is decided to perform only three experiments out of those six experiments.

4.3.2 EXPERIMENTS CONDUCTED

Commercial grade aluminium alloy 6082 of thickness 6mm is selected as test material for carrying out the project. The plate is cut into samples of required size by the power hacksaw at the dealer’s shop. The sample size selected to carry out the experimentation work is 150*_*6mm^3.

The sample surface was cleaned with acetone to remove any kind if dirt present on the surface as it can contaminate the weld bead.

By the time samples were cleaned with acetone, rail was placed on a metal bench like structure, which was built to place the rail. Earthing cable was attached to the metal bench to complete the circuit. Wire brush was used to clean the surface of the metal bench from rusting and dirt and to form an even surface.

On the rail, the torch traveller was placed carefully so that wheels on the torch traveller fits on either end of the rail. The torch traveller was connected to the power supply.

Aluminium wire spool was fit into the wire spool casing on the wire feed unit. Then the wire electrode was made to flow through the conduit and appear from the nozzle. The electrode stick out is taken in the range of 11-14mm.

After this step, the torch was fit in the torch traveller. Since the nozzle of the torch is lesser in diameter compared to that of torch traveller wooden blocks were fitted along with the nozzle in the gun in the torch holder. It is further tighten with a wrench. Next step is the travel speed calibration.

The traveller has speed selector I terns if percentage. Therefore, it is important to done the speed calibration. First two points of known distance is marked on the bench. Then the traveller is set at particular at a particular percentage and traveller is switched ON. When the wire electrode from the gun reaches the first point stop is made to start and when it reaches the end it is stopped. Since the distance between the two pints was known and time was determined from the stopwatch speed of the traveller can easily be find out.

After the setup is completed, sample is placed on the metal bench. Based on the literature survey the nozzle to plate distance was 14mm.

Based on the design matrix as shown in table 14 experiments were started one by one. The parameters for each experiment is set up on the MIG machine carefully checked and then the experiments were conducted. Bead on plate approach was considered to carry out the project. Fig. 5.2 to Fig. 5.10 shows the final bead on plate samples in which numerals on the samples represent their run number as per table 14.

Fig. 5.2: Weld bead obtained by run no. 1 & 2

Fig. 5.3: Weld bead obtained by run no. 3 & 4

Fig. 5.4: Weld bead obtained by run no. 5 & 6

Fig. 5.5: Weld bead obtained by run no. 7 & 8

Fig. 5.6: Weld bead obtained by run no. 9 & 12

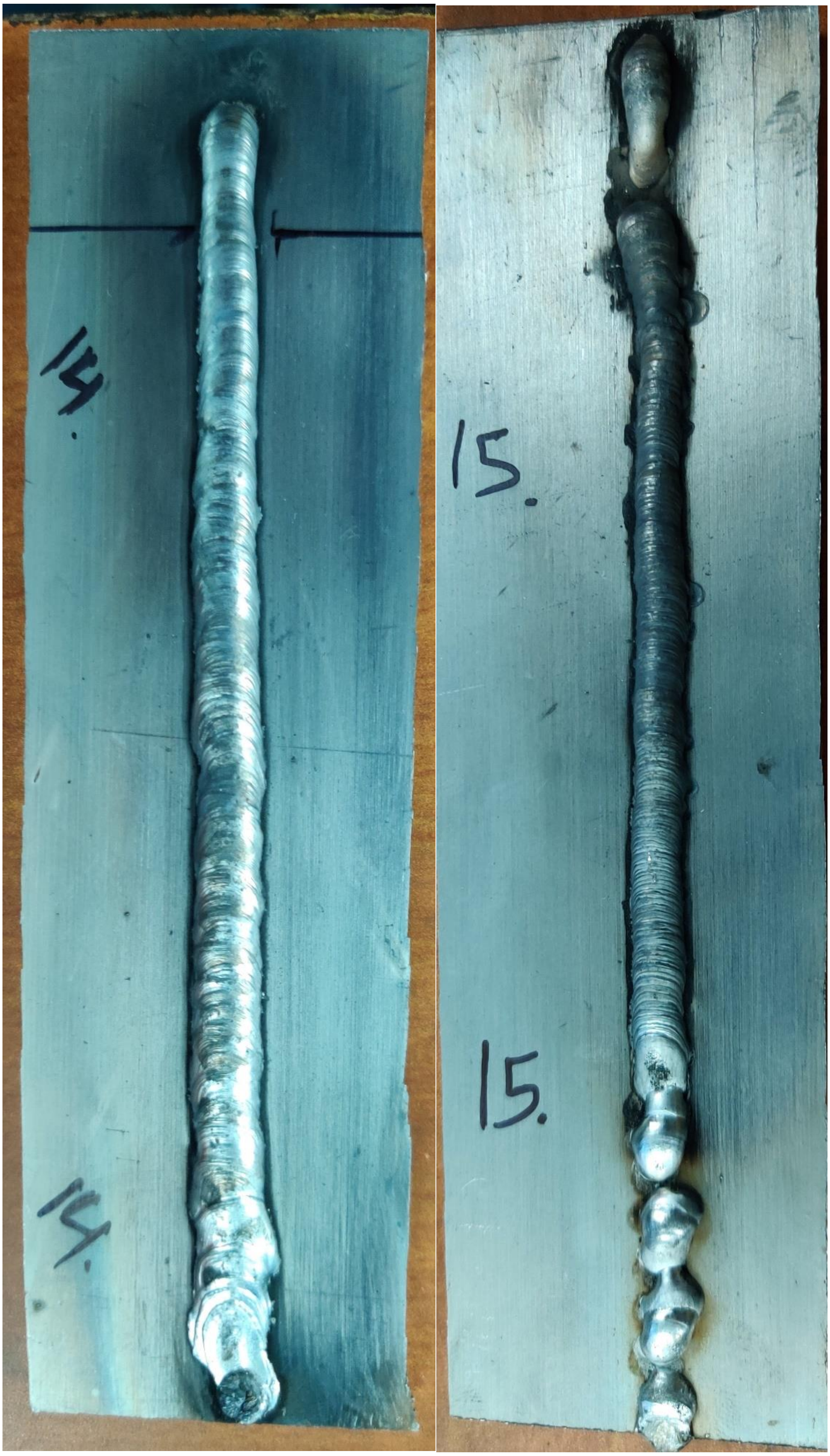


Fig. 5.7: Weld bead obtained by run no. 14 & 15

Fig. 5.8: Weld bead obtained by run no. 16 & 17

Fig. 5.9: Weld bead obtained by run no. 18 & 19

Fig. 5.10: Weld bead obtained by run no. 20

CHAPTER-6
RESULTS AND DISCUSSIONS

6.1 INTRODUCTION

The previous chapter focussed on identifying the important welding input factors and their levels that has the most influence on the bead geometry of AA6082. The information obtained is then used for planning the experiment and are performed as per the design matrix suggest by central composite design as shown in Table 13. Table 15 indicates the values of responses i.e. reinforcement height, bead width and bead penetration for the corresponding experiments as per table 14.

The chapter focusses on the result analysis of the experimentation to find out the individual as well as interrelation effects of process parameters on response parameters i.e. bead width, reinforcement & penetration. Design expert version 11.0 is used to obtain the regression equations for individual response parameters and check the adequacy of the model. In addition, prediction of values of response parameters is also done using ANN using Matlab software. From the predicted and experimental values of the responses, percentage error is computed to check if the experimented values are correct or not.

After the regression equations are obtained, these are used in developing of genetic algorithm which is used for optimization the welded parameters for the response parameters. Fig. 6.1 shows the methodology of experimentation and analysis of result.

6.2 SAMPLE PREPARATION

For the measurement of bead geometry, the weld samples need to be cut into cross sectional way. The samples were cut in a length that can made easy for the human investigator to hold them for polishing. The samples were first fitted in the bench wise and then cut using hand saw by hand. Since the material is aluminium, cutting of it is relatively easier when compared to steel.

After cutting the samples, they were polished using emery paper. The paper comes in different numbers as per their grain size. First no. 80 is used then no 100 no 220, no 320, no. 400, no 600, no 800 and at the last no 1000 is used. Polishing has to be done with care because all the papers had to be used in fixed sequence and cannot be used one before the other.

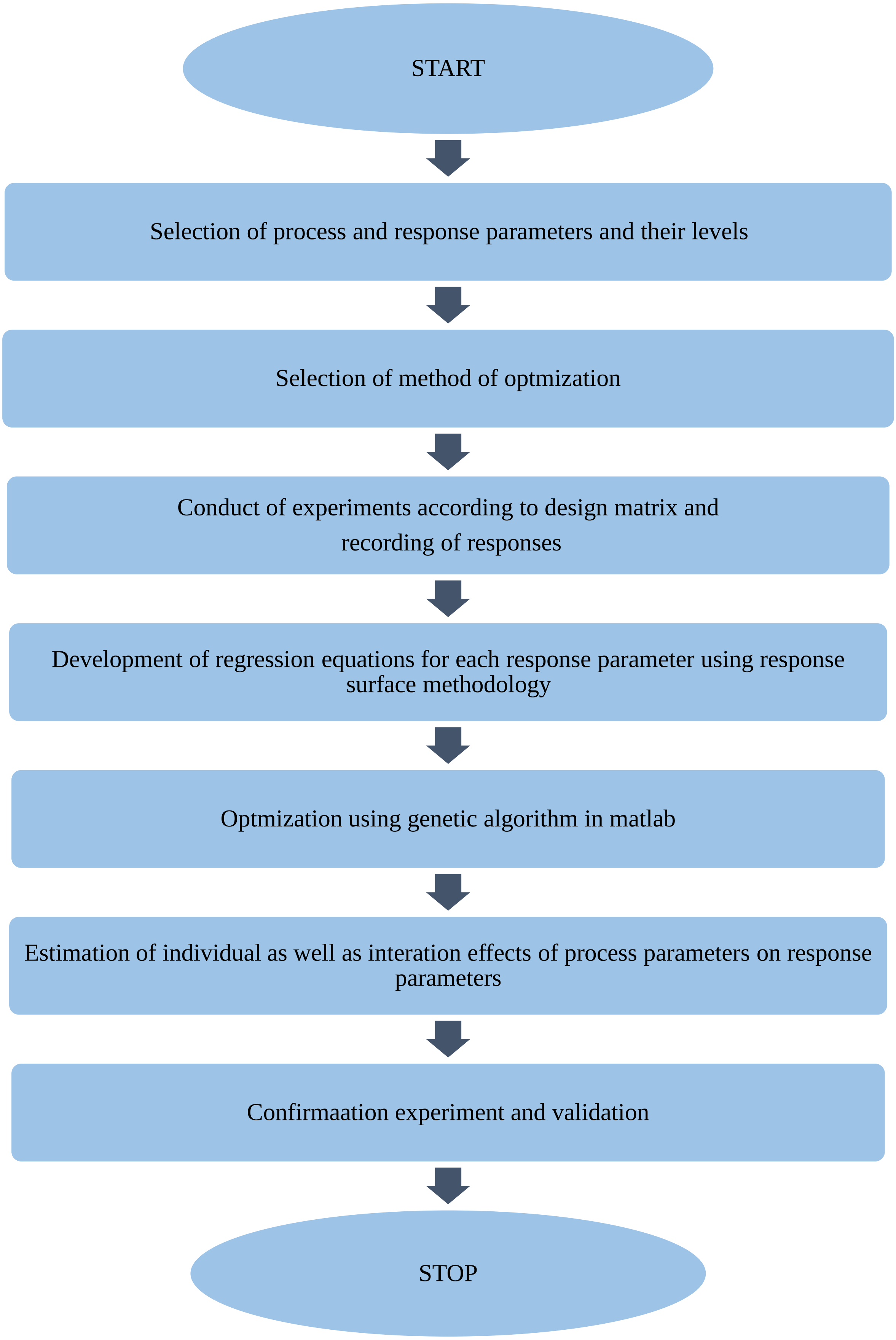
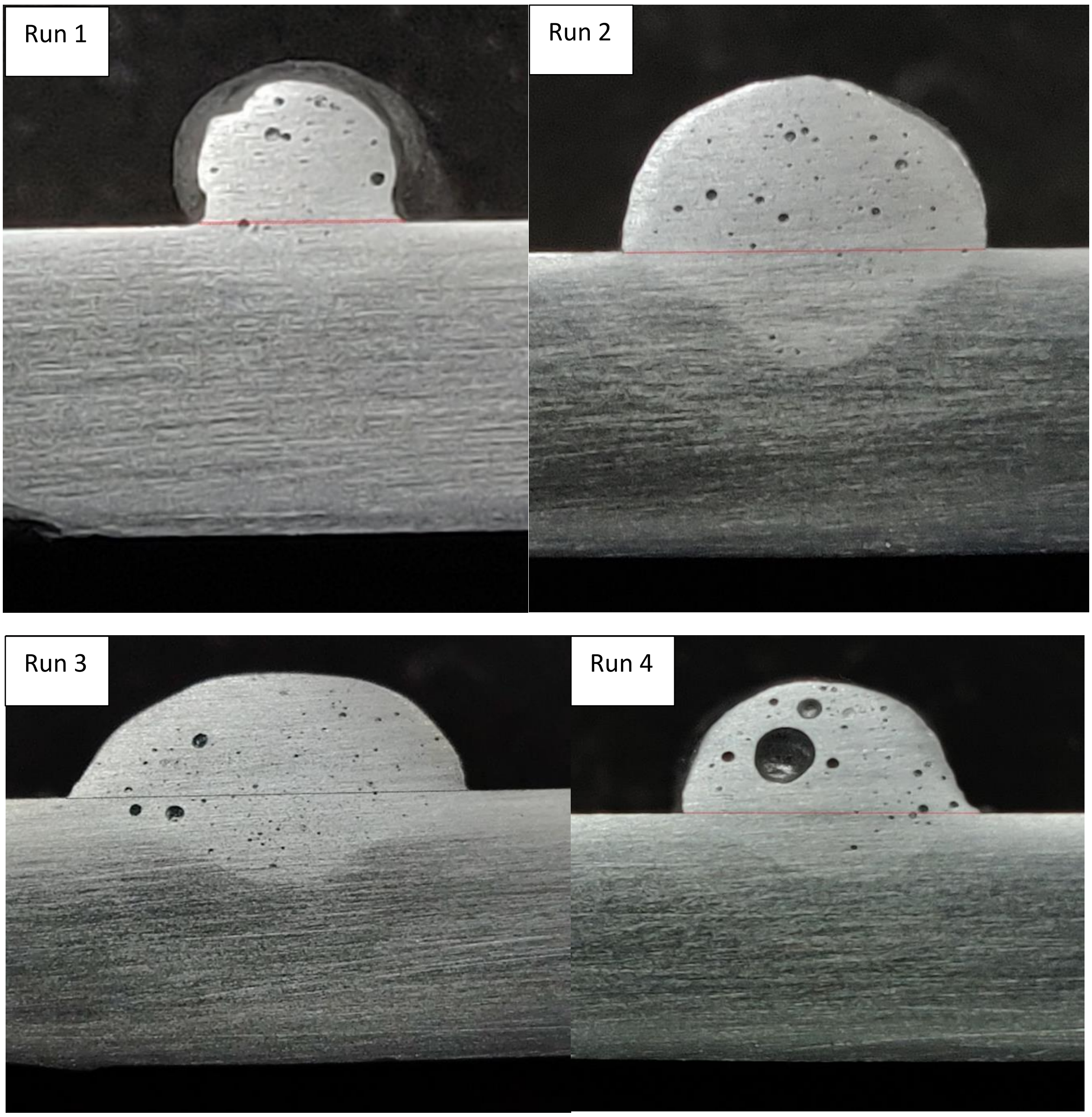


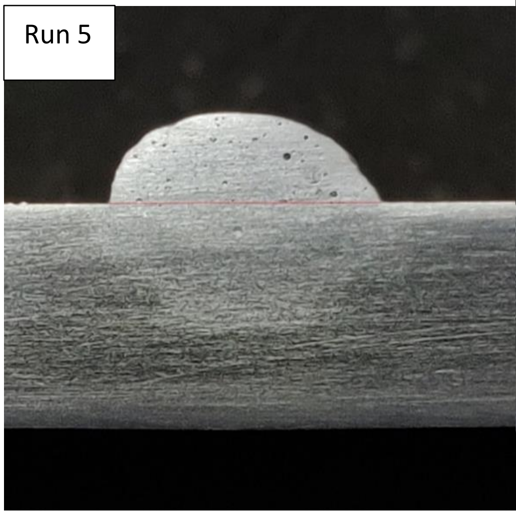
Fig. 6.1: Methodology of the experimentation and analysis of result

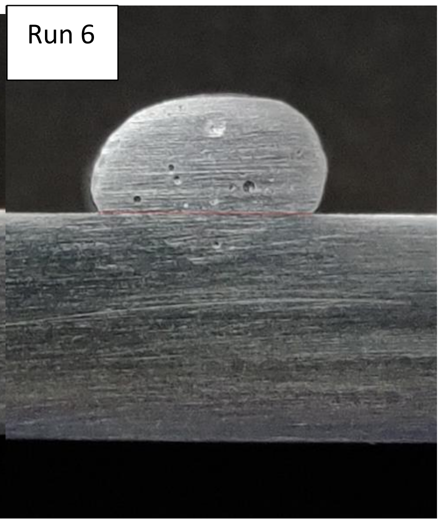
6.3 BEAD IMAGING AND MEASUREMENT

After preparation of sample, now is the time for measurement of bead geometry. The sample are placed on a dark surface when cross sectional surface facing to the top. Then it was magnified to a magnification level of 8x using oneplus 7 pro camera having a 48 megapixel Sony lens (f/1.6). The bead of all the samples are shown in Fig. 6.2.

The image was analysed using Image J software. The bead width, reinforcement height and penetration is measured using the software. First, the image is scaled and then the aforementioned response parameters are measured. Table 15 indicates the values of responses i.e. reinforcement height, bead width and bead penetration for the corresponding experiments as per table 14.




Run 5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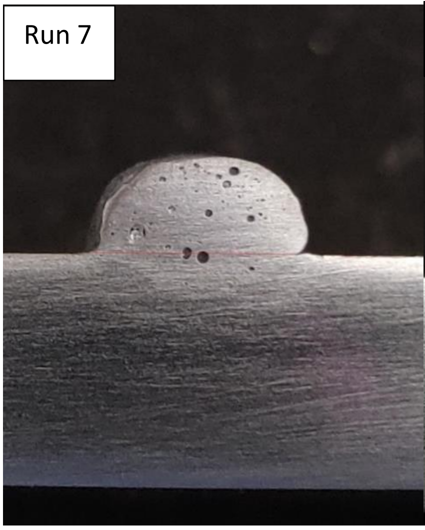
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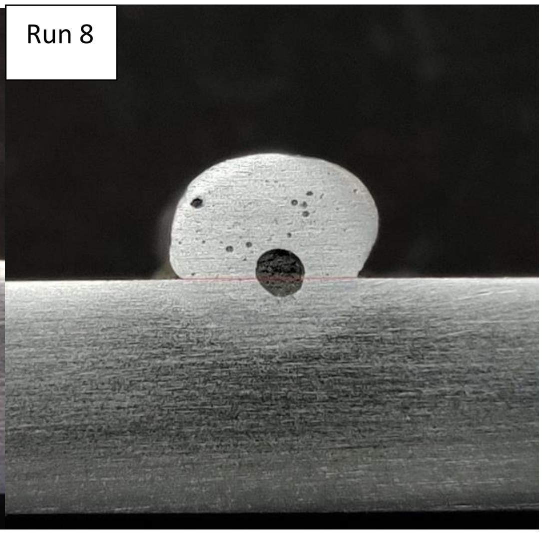
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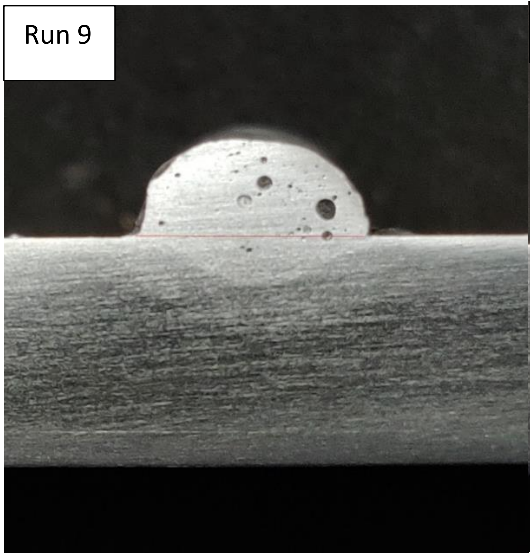
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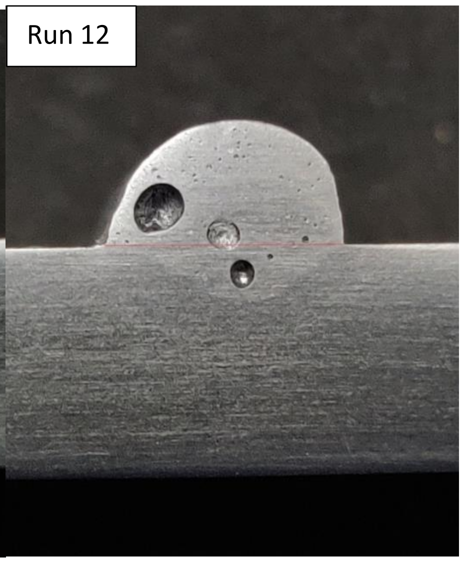
Run 12

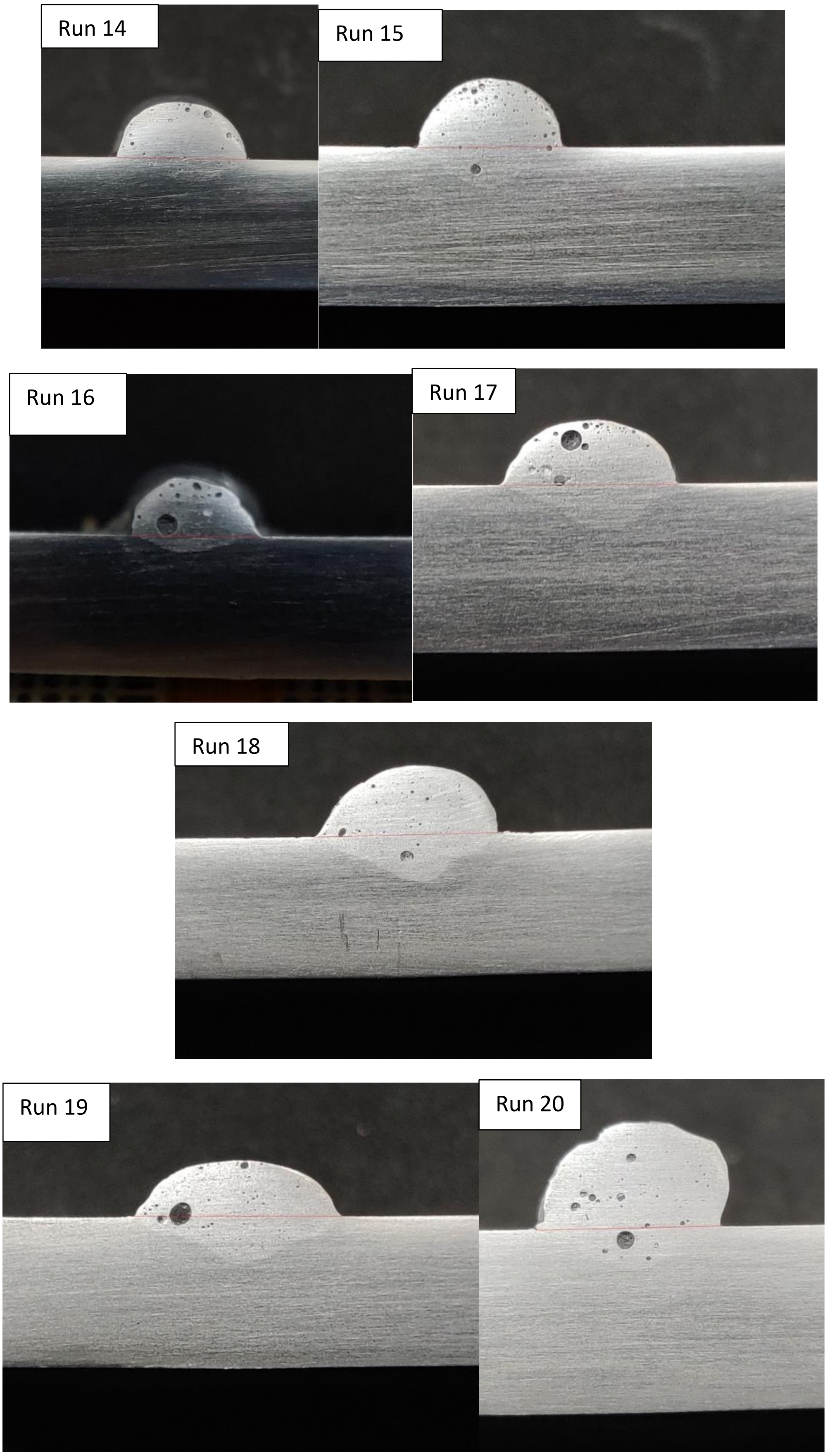

Fig. 6.2: Bead geometry of the samples

Table 15: Design matrix and output responses

Std	Run	Voltage	WFR	GFR	Bead Width	Bead height	Bead Penetration
5	**1**	17	5	15	4.212	2.819	0.66
12	**2**	19	8	13	6.287	3.503	2.321
4	**3**	21	7	11	8.58	2.743	2.026
13	**4**	19	6	9	5.331	3.278	1.723
19	**5**	19	6	13	6.411	2.438	1.428
7	**6**	17	7	15	5.677	3.095	1.371
15	**7**	19	6	13	5.527	2.552	1.205
9	**8**	15	6	13	4.696	3.269	0.979
18	**9**	19	6	13	5.319	2.607	1.578
17	**10**	19	6	13	5.712	2.408	1.171
16	**11**	19	6	13	6.012	2.701	1.251
14	**12**	19	6	17	5.451	3.328	1.519
20	**13**	19	6	13	5.479	2.399	1.501
2	**14**	21	5	11	5.214	2.642	1.055
11	**15**	19	4	13	5.69	2.681	1.631
1	**16**	17	5	11	5.664	2.518	0.735
6	**17**	21	5	15	5.527	2.372	1.721
8	**18**	21	7	15	6.964	3.001	2.118
10	**19**	23	6	13	8.426	2.252	1.919
3	**20**	17	7	11	5.167	3.552	1.429

6.4 OPTMIZATION USING RESPOSNE SURFACE METHODOLOGY

Table 16: ANOVA analysis of width

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	20.24	9	2.25	5.61	0.0034	significant
A-V	14.11	1	14.11	41.47	< 0.0001	
B-W	5.02	1	5.02	14.76	0.0033	
C-G	0.2513	1	0.2513	0.7384	0.4103	
AB	0.4209	1	0.4209	1.24	0.2921	
AC	0.3358	1	0.3358	0.9869	0.3439	
BC	0.0001	1	0.0001	0.0004	0.9844	
A^2	0.0061	1	0.0061	0.0180	0.8959	
B^2	0.0286	1	0.0286	0.0841	0.7777	
C^2	0.0849	1	0.0849	0.2496	0.6282	
Residual	3.40	10	0.3403			
Lack of Fit	1.32	5	0.2642	0.6345	0.6851	not significant
Pure Error	2.08	5	0.4163			
Cor Total	23.64	19				

Table 17: ANOVA analysis of height

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	2.71	9	0.3012	8.32	0.0014	significant
A-V	0.6642	1	0.6642	18.35	0.0016	
B-W	0.8482	1	0.8482	23.44	0.0007	
C-G	0.0003	1	0.0003	0.0080	0.9306	
AB	0.0421	1	0.0421	1.16	0.3064	
AC	0.0026	1	0.0026	0.0716	0.7944	
BC	0.0066	1	0.0066	0.1827	0.6781	
A^2	0.0730	1	0.0730	2.02	0.1859	
B^2	0.4703	1	0.4703	12.99	0.0048	
C^2	0.9030	1	0.9030	24.95	0.0005	
Residual	0.3619	10	0.0362			

Lack of Fit	0.2867	5	0.0573	3.81	0.0842	not significant
Pure Error	0.0752	5	0.0150			
Cor Total	3.07	19				

Table 18: ANOVA analysis of penetration

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	3.04	9	0.3375	5.50	0.0068	significant
A-V	1.32	1	1.32	21.59	0.0009	
B-W	1.08	1	1.08	16.56	0.0019	
C-G	0.0030	1	0.0030	0.0484	0.8303	
AB	0.0002	1	0.0002	0.0026	0.9600	
AC	0.0990	1	0.0990	1.61	0.2327	
BC	0.0389	1	0.0389	0.6343	0.4443	
A^2	0.0004	1	0.0004	0.0071	0.9346	
B^2	0.4644	1	0.4644	6.57	0.0204	
C^2	0.0559	1	0.0559	0.9113	0.3623	
Residual	0.6136	10	0.0614			
Lack of Fit	0.4701	5	0.0940	3.27	0.1094	not significant
Pure Error	0.1435	5	0.0287			
Cor Total	3.65	19				

The table 16, 17 and 18 shows that all the models are significant in nature.

The regression equation obtained from ANOVA analysis for the response parameters are as follows:

Bead width= 15.8921 + -0.736108*V + -1.2407*W + -0.670449*G + 0.114688*V*W + 0.0512187*V*G + 0.0020625* W*G + -0.00390341*V^2 + -0.033738*W^2 + -0.0145284*G^2

Bead height= 15.7368 + -0.454795*V + -0.535261*W + -1.2332*G + -0.03625*V*W + 0.0045 *V*G + -0.014375*W*G + 0.0134716*V^2 + 0.136761*W^2 + 0.0473778*G^2

Penetration= 8.09163 + -0.243699*V + -0.875284*W + -0.618909*G + -0.00225*V*W + 0.0278125*V*G + -0.034875*W*G + 0.00103977*V^2 + 0.135909*W^2 + 0.0117898*G^2

The optimum process parameters obtained from RSM is shown in table 19.

Table 19: optimum result obtained from RSM

V	WFR	GFR	BW	BH	BP
21.5884	4	13.7575	5.934	2.66071	1.85226

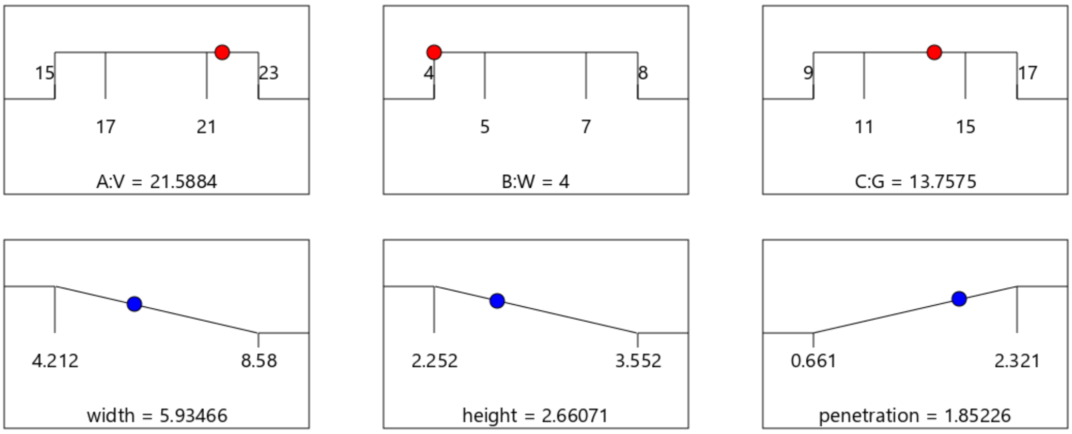

Fig. 6.3: results for bead geometry

6.5 PERTURBATION PLOTS

Perturbation plots shows the influence of individual process parameters on the output response parameters. These plots shows the effect of individual process parameters on the response parameters while keeping the other process parameters constant. The X-axis of the plot represents the process parameter while the Y-axis represents the response parameters. -1, -0.5, 0, 0.5, 1 represents the levels of the process parameters selected for the investigation. A steep slope indicates that the output response parameter is highly sensitive to the corresponding process parameter. However, a flat curve indicates that the process parameter has no ascendancy on the response parameter. Fig. 6.4 shows the perturbation plots for bead width, reinforcement height and depth of penetration for MIG welding. The codes A, B and C in the graph represents the welding voltage, wire feed rate and gas flow rate respectively. Fig.6.4A represents the plot for width. The trend inferred from the graph that width increases with increase in welding voltage and WFR. This is because as the voltage increase current also increases which in turn will increase the heat input. Also with high WFR, more melted wire electrode deposits resulting in high bead width. Since the WFR causes the increase in current, the temperature of the molten droplet increases and causes greater penetration. However, with the increase in gas flow rate bead width decrease because the turbulence of the gas will reduce the heat input. The input welding parameters shows similar trend for depth of penetration in fig. 6.4C. Fig. 6.4B shows the perturbation plot for reinforcement height. The trend that has observed from the graph is that height decreases with increase in voltage. Nevertheless, increases as the wire feed rate approaches a higher value. However, for gas flow rate reinforcement height increases at first to a certain value of gas flow rate i.e. 13 l/min and then starts decreasing as the GFR (l/min) is increased further.

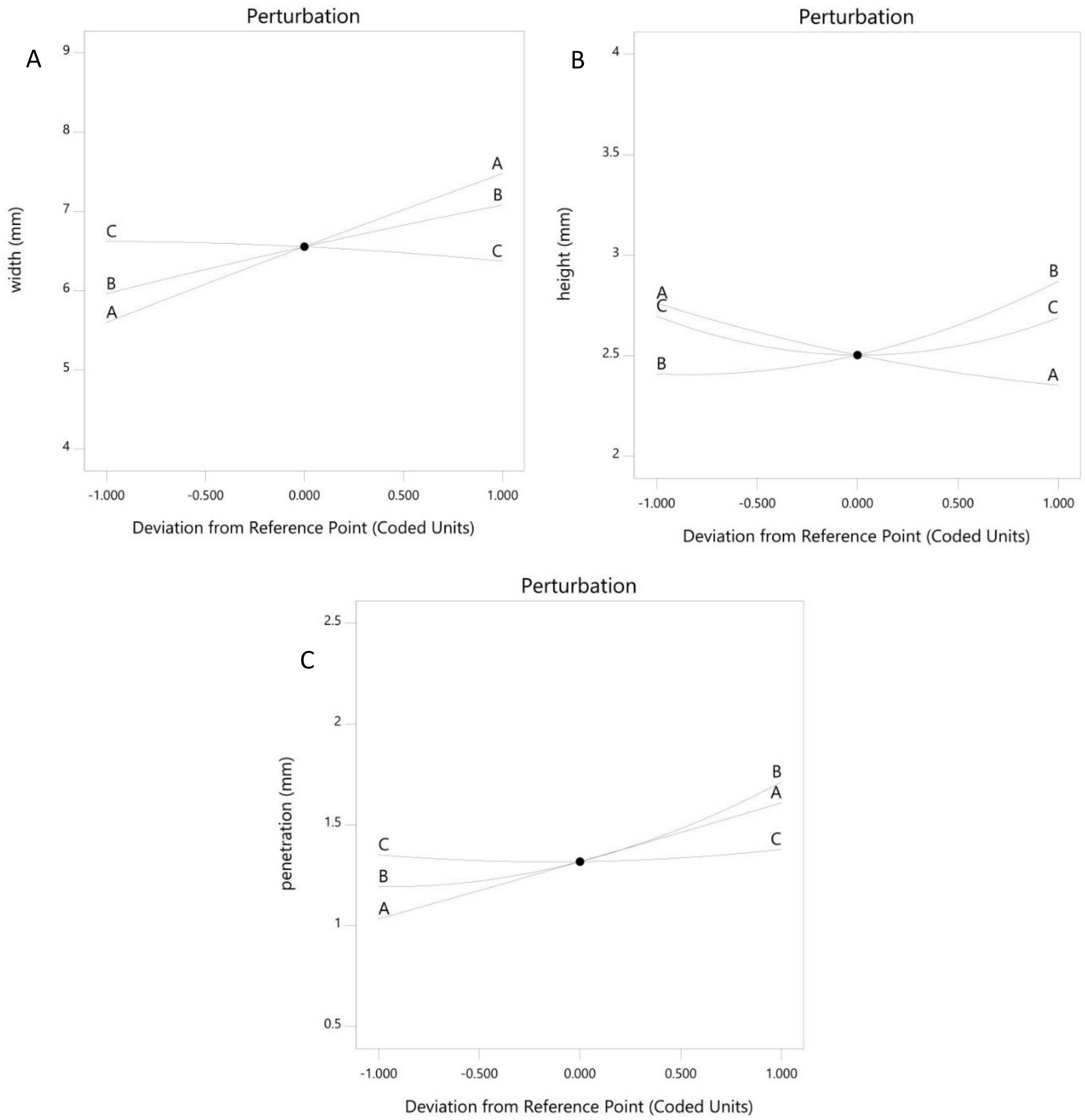

Fig. 6.4: Perturbation plots for bead width, reinforcement height and depth of penetration for MIG welding

6.6 RESPONSE SURFACE PLOTS

To study the collaborative out turn of process parameters on the responses these 3D surface graphs are plot using the design expert software. Fig. 6.5 shows the combined effect of voltage and WFR on the bead height, width & penetration.

Both bead width & penetration enhances with increase in values of voltage and WFR. The reason for such behaviour us that arc length increases with increase in voltage and causes larger arc on the surface. When voltage increases current also increases accordingly and result in higher heat generation. The ramification of this is deep penetration. Also at high WFR, more volume of metal deposits per unit length leading to increase in bead width, height and penetration. Another logic is that welding current increase with increase in WFR. This increases the temperature of the molten droplet and causes deeper penetration on the base plate. However increasing the voltage will result in flatter bead because of the increase in bead width.

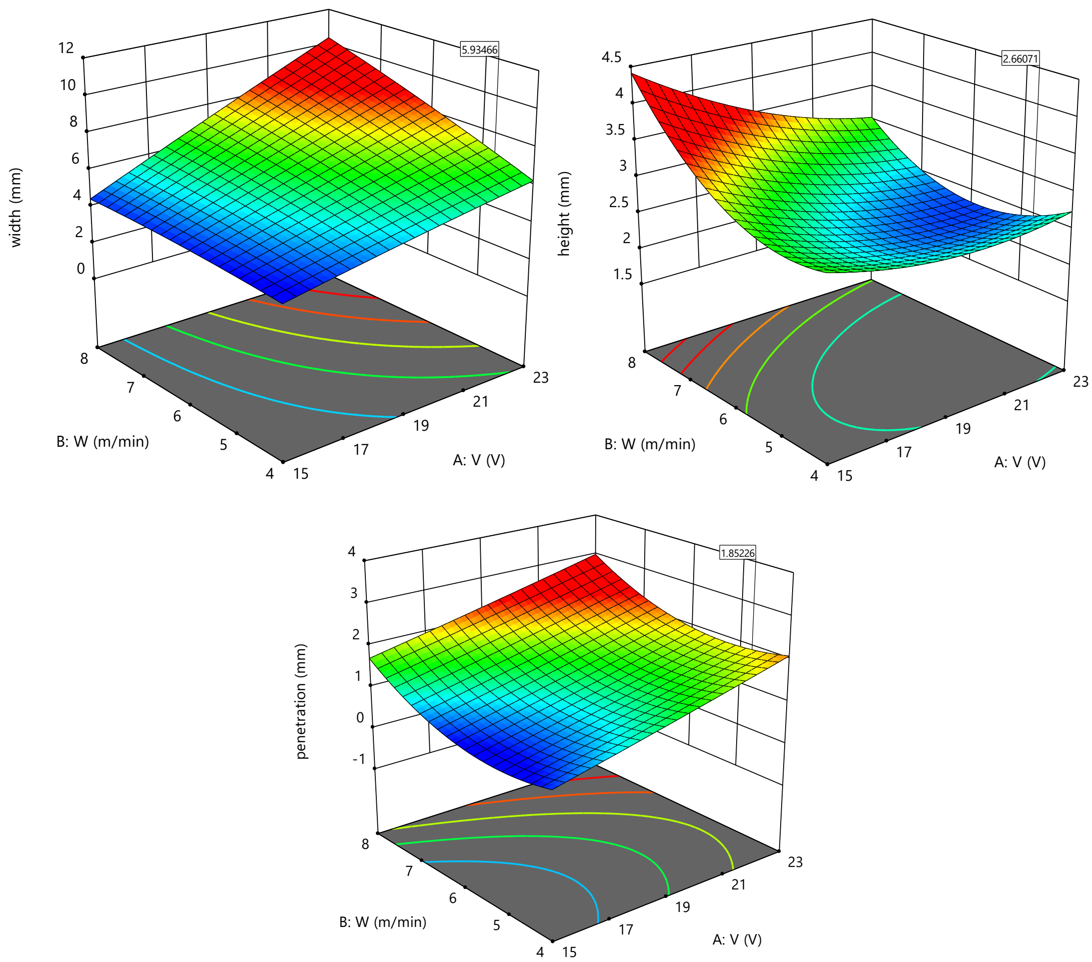

Fig. 6.5: 3D surface plots showing combined effect of welding voltage and wire feed rate on response parameters

Fig. 6.6 shows the combined effect of welding voltage and GFR on the response parameters. The trend observed from the graph is that width and penetration increases with increase in voltage as the amount of heat generation increases. However, reinforcement height decreases with increasing voltage. GFR shows no or little effect on the bead penetration and width. However, height first decreases with increase in GFR and then increases as GFR increases further. The dark red point signifies that the design point is higher than the predicted values whereas lighter point indicated that the design point is lower than the predicted values.

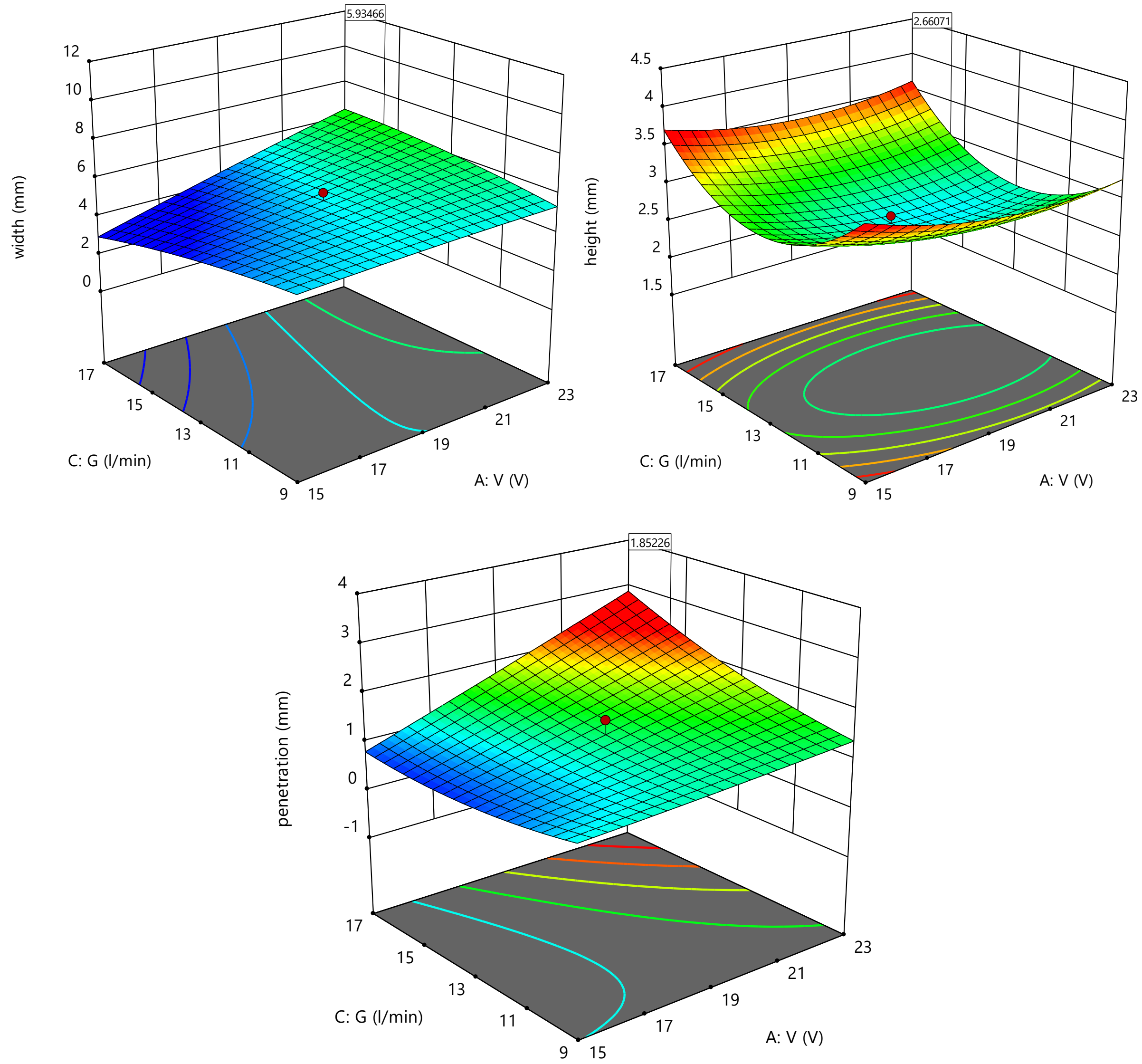

Fig. 6.6: 3D surface plots showing combined effect of welding voltage and gas flow rate on response parameters

The combined effect of GFR and WFR on response parameters i.e. width, penetration and height is represented by fig. 6.7. The trend inferred from the graphs is that width, height and penetration increases with increase in WFR as the amount of metal of metal deposited per unit length increases with higher WFR. GFR shows no or little effect on the bead penetration and width. However, height first decreases with increase in GFR and then increases as GFR increases further.

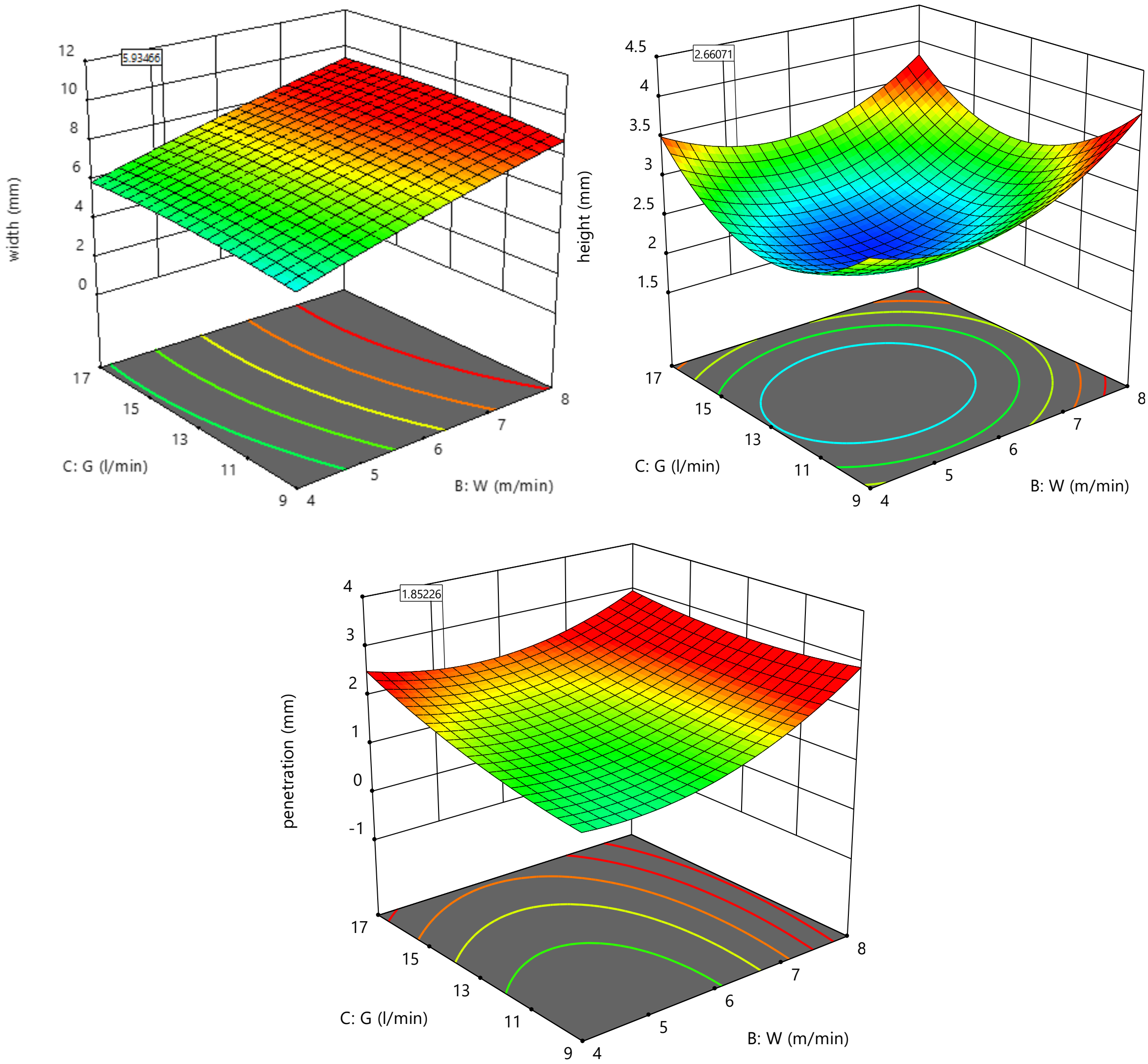

Fig. 6.7: 3D surface plots showing combined effect of gas flow rate and wire feed rate on response parameters

6.7 OPTIMIZATION USING GENETIC ALGORITH

The values of the response parameters are put into design expert software in central composite design corresponding to the run of the experiment. After this step ANOVA, analysis is done to get the regression equations and to check the model validation.

These equations are used for coding of genetic algorithm for optimizing the process parameters. Fig. 6.8 shows the code for genetic algorithm.

```
[function y = project(x)
%UNTITLED Summary of this function goes here
% It is a multi objective function i.e. more than 1 function
%y(1)---objective 1 ----equation for BW minimize
%y(2)---objective 2 ----equation for BH minimize
%y(3)---objective 3 ----equation for BP maximixe

% x(1)---voltage
% x(2)---WFR
% X(3)---GFR


%BW
y(1)= 15.8921-0.736108*x(1)-1.2407*x(2)-0.670449*x(3)+0.114688*x(1)*x(2)
+0.0512187*x(1)*x(3)+0.0020625*x(2)*x(3)-0.00390341*(x(1)^2)
-0.0337386*(x(2)^2)-0.0145284*(x(3)^2) ;
%BH
y(2)= 16.7368-0.454795*x(1)-0.535261*x(2)-1.2332*x(3)-0.03625*x(1)*x(2)
+0.0045*x(1)*x(3)-0.014375*x(2)*x(3)+0.0134716*(x(1)^2)
+0.136761*(x(2)^2)+0.0473778*(x(3)^2) ;
%BP
y(3)= 8.09163-0.243699*x(1)-0.875284*x(2)-0.618909*x(3)-0.00225*x(1)*x(2)
+0.0278125*x(1)*x(3)-0.034875*x(2)*x(3)+0.00103977*(x(1)^2)
+0.135909*(x(2)^2)+0.0117898*(x(3)^2) ;

end
```

Fig. 6.8: Code for genetic algorithm

Matlab software is used for optimizing the process parameters. Optim tool is used for this purpose. After Optim tool is typed in the command window a dialogue box appears in which we genetic algorithm was selected. The code was typed in the window and was saved as Matlab file. The optimized result is exported to the workspace. The maximum and minimum value of each response parameter is displayed along with its corresponding process parameters.

Table 20: Optimum result from genetic algorithm

V	WFR	GFR	BW	BH	BP
15	5.483963	15.66261	3.372672	3.558603	0.497657
22.25697	5.582623	12.80397	6.624711	2.290065	1.693881
15.77246	4.590164	15.64699	3.626827	3.398515	0.79144
15	4.023727	15.99855	2.961904	3.709976	0.805141
16.86635	5.101666	12.8196	5.623867	2.503702	1.029016
22.28822	5.601666	12.67897	6.641087	2.290889	1.68801
21.14698	5.452713	12.8655	6.085409	2.303479	1.521042
19.73318	5.070416	14.31226	5.206808	2.465831	1.399662
15.4375	4.922196	12.42897	5.105407	2.678276	0.846635
21.14698	5.452713	12.52272	6.066533	2.308135	1.494168
15	5.452713	12.8655	4.582908	2.964915	0.663915
16.8976	4.056442	14.26538	4.881156	2.726132	1.238662
15.4375	4.023727	14.26538	4.392405	2.843344	0.986579
16.86635	4.595047	14.31226	5.157619	2.623906	1.107822
15	4.023727	14.34351	3.889097	3.01601	0.732213
15	5.483963	15.99855	3.245049	3.676268	0.498962
19.73318	5.070416	12.52272	5.276873	2.369028	1.275346
15	5.070416	14.31226	4.110552	2.968878	0.552107

We know that width and height need to be minimize and penetration need to be maximize for the best bead geometry profile in order to increase the strength of the joint and overall cost of welding operation. From table 20, if we select the minimum value of bead width we are getting 0.9mm as the penetration, which is not good. Similarly, for minimum reinforcement height i.e. 2.3 mm penetration obtained is 1.2 mm. Therefore, the best-optimized result selected is shown in table 21.

Table 21: best (optimum) result obtained from GA

V	WFR	GFR	BW	BH	BP
22.25697	5.582623	12.80397	6.624711	2.290065	1.693881

6.8 COMPARISON BETWEEN RSM AND GA RESULT

Table 19 and table 21 shows the optimum results by using RSM and GA respectively. It is observed that RSM give only one set of parameters unlike GA. Genetic algorithm gives a whole set of parameters consisting of maximum, minimum and intermediate values. The researcher can select any set of parameter depending upon the application. The maximum penetration obtained from RSM is 1.85mm and from GA is 1.693mm. There is also a slight variation in the values of response and process parameters obtained from both techniques

6.9 PREDICTION USING ARTIFICIAL NEURAL NETWORK (ANN)

Artificial intelligence has become so common in 21st century that it does not haunt people anymore. It has become a part of our daily lives and is used in many products from mobile phones to self-driving cars.

ANN is an integral part of artificial intelligence. It is similar to the nervous system of human brain and helps to optimize the result when it is influence by a number of factors.

Instead of writing the code in python, I have used the Matlab software. Matlab has an inbuilt tool that helps in building the network. The tool used is NN tool. All the coding for the prediction purpose is present in the Matlab library.

After typing ‘nntool’ in the command tab a window pops up. In the window, input data has to be imported and then target data has to be imported. After this step click on the new tab and then create network dialogue box opens up. For the network creation, feed forward backdrop model is used and training function is TRAINLM and performance function is MSE.

In the network creation number of hidden layers and number of neurons is a crucial step as it can affect the efficiency of the network. For the investigation, the numbers of layers and neurons are 2 and 15 respectively. Fig. 6.9 shows the network formed for the prediction of the output response i.e. bead geometry.

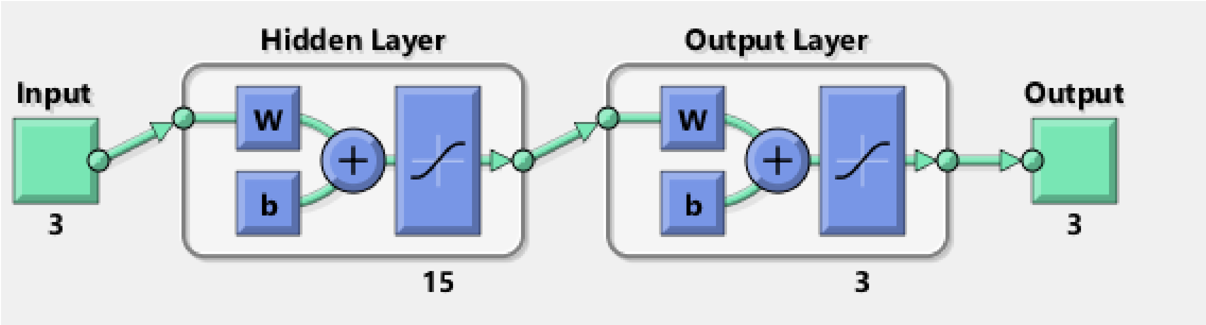

Fig. 6.9: Neural network model for bead geometry prediction

Fig. 6.10 shows the feed forward backdrop model for prediction of bead geometry. The input layers serves the purpose of introduction of input parameters to the network. The input parameters selected for the investigation is welding voltage (V), gas flow rate (l/min) and wire feed rate (m/min). The output layer consist of the output response parameters. They are weld bead width, depth of penetration and reinforcement height.

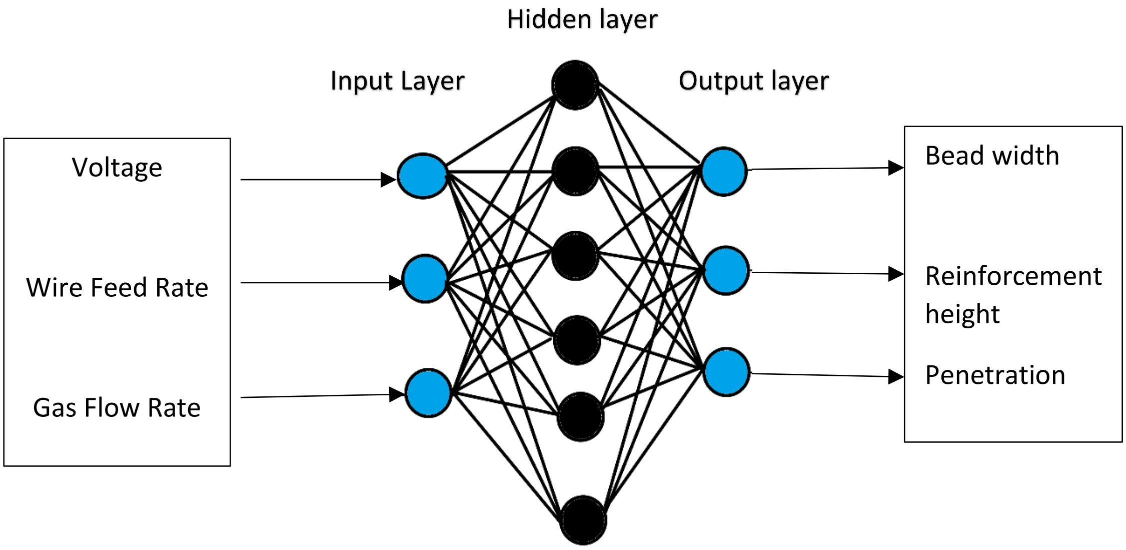

Fig. 6.10: feed forward backdrop model for prediction of bead geometry

After the network creation, next step is to train the neurons. They are trained until maximum epoch is reached. The number of iterations selected for the investigation is 1000. Maximum epoch is reached at 528 iteration and a linear relationship is obtained in the regression graph. Linear regression graph signifies that accuracy of predicted values to the experimental values is high and error is very less. It also signifies that the network works correctly and the experimental values are correct. Fig. 6.11 shows the neural network training.

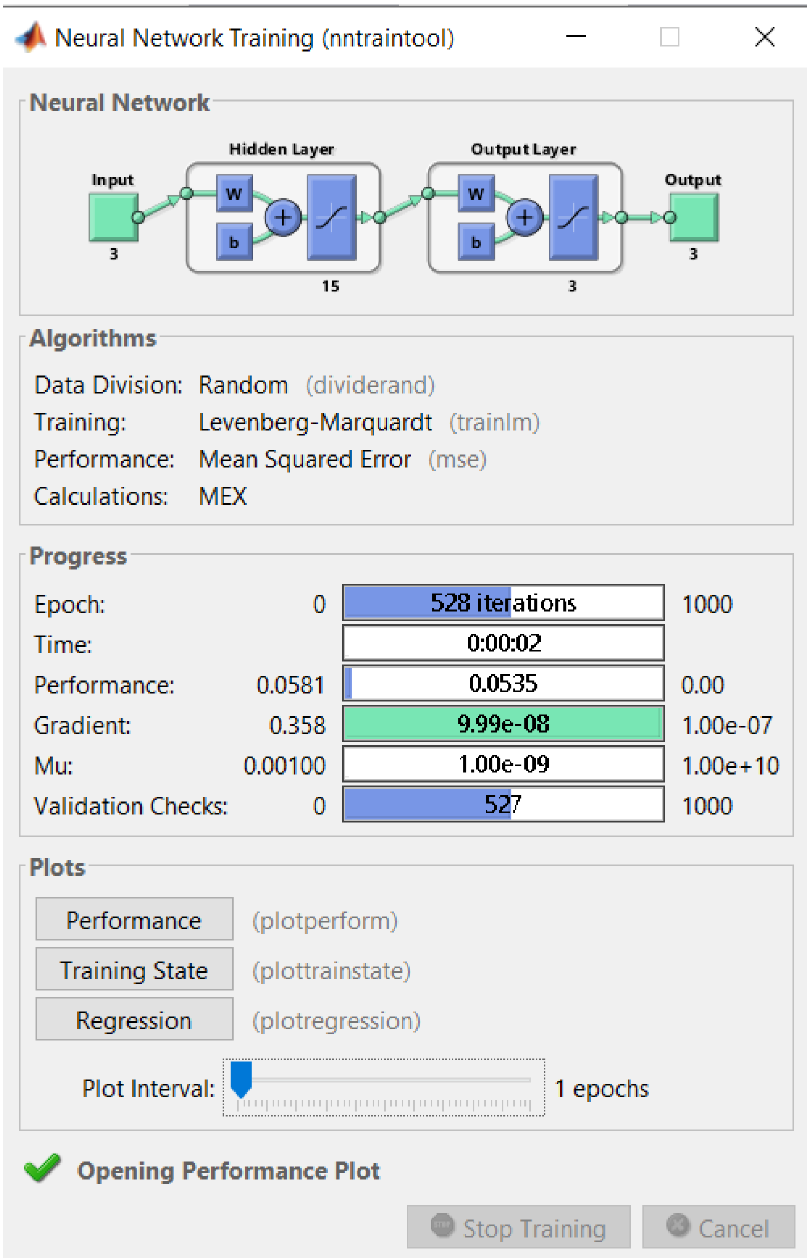

Fig. 6.11: Neural network training

Fig. 6.12 shows the plot of neural network training regression.

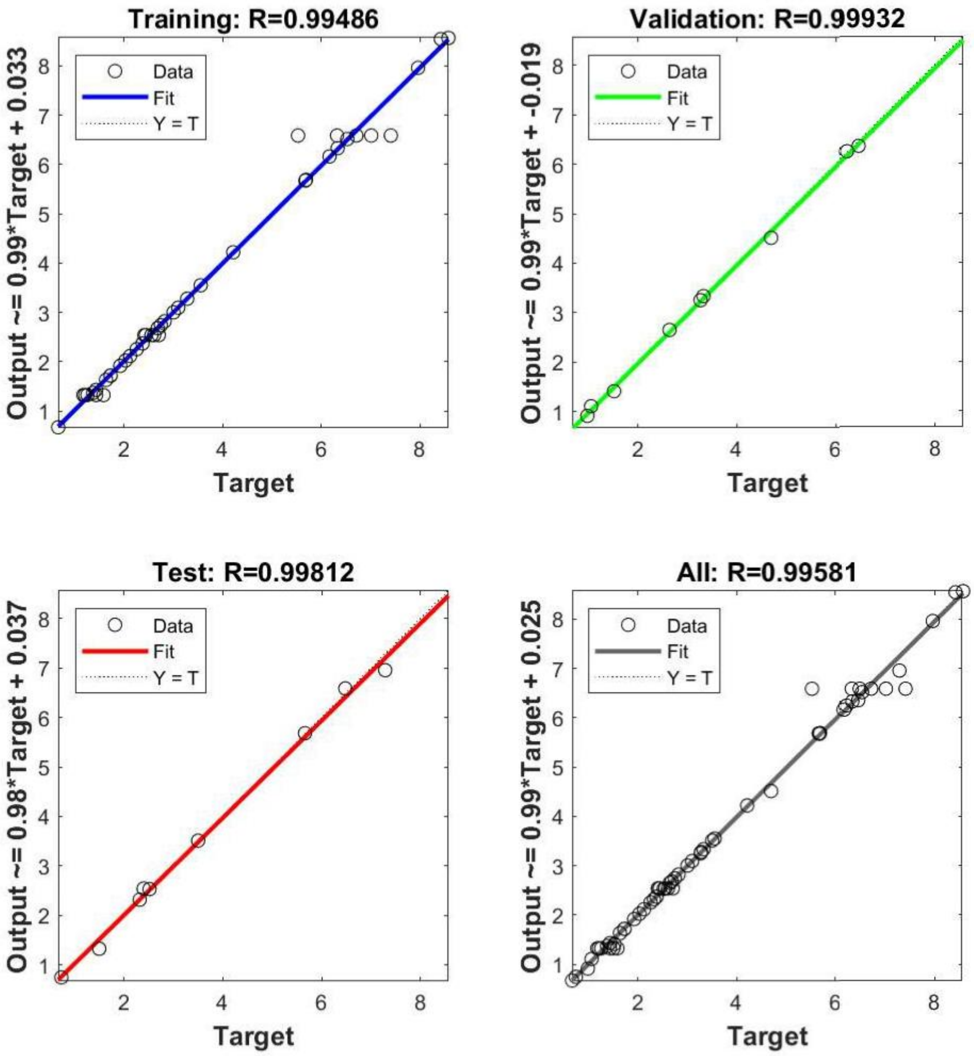

Fig. 6.12: Plot of neural network training regression

After the maximum epoch, condition is achieved output data and error is exported to the workspace. The predicted values and percentage error is shown in table 22.

Table 22: Predicted values of output responses

RUN	EXPERIMENTAL			PREDICTED			PERCENTAGE ERROR		
	Bead Width	Bead height	Bead Penetration	Bead width	Bead height	Bead Penetration	Bead width	Bead height	Bead Penetration
1	4.212	2.819	0.66	4.220919	2.820693	0.671133	-0.0089	-0.00169	-0.011133
2	6.287	3.503	2.321	5.956153	3.510613	2.318536	0.3308	-0.00761	0.0024634
3	8.58	2.743	2.026	8.566957	2.743166	2.024875	0.0130	-0.00016	0.0011242
4	5.331	3.278	1.723	5.331184	3.278518	1.717286	-0.0001	-0.00051	0.0057130
5	6.411	2.438	1.428	5.588281	2.541225	1.325524	0.8227	-0.10322	0.1024759
6	5.677	3.095	1.371	5.674479	3.095824	1.371483	0.0025	-0.00082	-0.0004836
7	5.527	2.552	1.205	5.588281	2.541225	1.325524	-1.0612	0.010774	-0.1205240
8	4.696	3.269	0.979	4.513714	3.252668	0.913372	0.1822	0.016331	0.0656273
9	5.319	2.607	1.578	5.588281	2.541225	1.325524	-0.2692	0.065774	0.2524759
10	5.712	2.408	1.171	5.588281	2.541225	1.325524	0.1237	-0.13322	-0.154524
11	6.012	2.701	1.251	5.588281	2.541225	1.325524	0.4237	0.159774	-0.074524
12	5.451	3.328	1.519	5.35529	3.334759	1.4121773	0.0957	-0.00675	0.1068226
13	5.479	2.399	1.501	5.588281	2.541225	1.325524089	-0.1092	-0.14222	0.1754759
14	5.214	2.642	1.055	5.245798	2.650732	1.108467577	-0.0318	-0.00873	-0.053467

15	5.69	2.681	1.631	5.690229	2.682475	1.631841 201	-0.0002	-0.00147	-0.000841
16	5.664	2.518	0.735	5.683126	2.531195	0.746164 787	-0.0191	-0.01319	-0.011164
17	5.527	2.372	1.721	5.517097	2.371378	1.720460 21	0.0099	0.000621	0.0005397
18	6.964	3.001	2.118	6.962537	3.002723	2.116823 963	0.0014	-0.00172	0.0011760
19	8.426	2.252	1.919	8.54463	2.256482	1.917596 112	-0.1186	-0.00448	0.0014038
20	5.167	3.552	1.429	5.164018	3.551343	1.429992 697	0.0029	0.000657	-0.000992

6.10 CONCLUSION

The following conclusions are drawn from the investigations:

1. It has been found that with increase in voltage, the bead width increases because of the high heat generation. Since arc length depends upon the voltage in MIG, increasing the voltage will increase the arc length and causes wider spread of the arc cone the base. More amount of molten metal will deposit per unit length with increase in WFR. Hence, result in a wider bead width. GFR has a low or no ascendancy on width of the bead.
2. With increase in voltage, the heat generation and arc length increases resulting in a deeper penetration. With increase in WFR, current also increases accordingly. As a result, the temperature of the molten droplet of the wire electrode becomes very high and results in a larger thermal energy addition to the base plate causing deeper penetration. GFR shows no or little ascendancy on the penetration. However, in some cases, penetration decreases slightly due to enhancement of turbulence of the shielding gas supplied at high pressure.
3. With increase in voltage, the reinforcement height of the bead decreases because of the increase in the bead width. With increase in WFR keeping the other parameters constant, reinforcement increases because more metal will deposit per unit length of the base plate. The reinforcement height first decreases and then increases with increase in GFR.

4. The optimum values of bead width is 5.93 mm, bead height is 2.66 mm and weld bead penetration is 1.852 mm for voltage 21.58V, WFR 4 m/min and GFR 13.75 l/min using response surface methodology.
5. The optimum values of bead width is 6.62mm, bead height is 2.29mm and weld bead penetration is 1.693mm for voltage 22.25V, WFR 5.58 m/min and GFR 12.8 l/min using Genetic algorithm.
6. Unlike RSM that gives only one optimum value of response parameters, Genetic algorithm gives a whole set of optimum values consisting of maximum, minimum and intermediate values and the investigator can select the set of parameters depending upon the application.
7. Voltage has the highest ascendancy on the bead geometry after wire feed rate. GFR has no or little influence on the response parameter.

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