OPTIMIZATION OF WELD BEAD PARAMETERS IN GTAW OF STAINLESS STEEL USING BEAD ON PLATE METHOD

A PROJECT REPORT

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BONAFIDE CERTIFICATE

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ABSTRACT

Gas tungsten arc welding (GTAW) is fundamental in those applications where it is important to control the weld bead shape and the metallurgical characteristics. This project presents measurements and predictions of the bead geometry generated by laying a single weld bead on a flat, austenitic stainless steel plate. The effects of various input parameters on the weld bead geometry have been studied in reference to the depth, width and depth-width ratio. The experiments were conducted based on central composite rotatable design with full replications technique and mathematical model was developed using multiple regression method. The developed mathematical model was checked for its adequacy and significance. This mathematical model is very useful for predicting the weld bead depth-width ratio. The depth-width ratio was posed as a constrained optimization problem and solved utilizing a Genetic Algorithm. The Genetic Algorithm was able to determine optimal weld bead geometry and recommend the necessary process parameters for the same.

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LIST OF ABBREVIATIONS AND SYMBOLS

Ar	Argon
AWS	American Welding Society
CRES	Corrosion Resistance Steel
CTWD	Contact tip to Work piece Distance
D	Depth of Penetration
DCEN	Direct Current Electrode Negative
DCEP	Direct Current Electrode Positive
DF	Degree of Freedom
DOE	Design of Experiments
D/W	Depth to Width Ratio
F	Shielding gas flow rate
FCAW	Flux-Cored Arc Welding
GA	Genetic Algorithm
GMAW	Gas Metal Arc Welding
GTAW	Gas Tungsten Arc Welding
I	Welding current
MIG	Metal Inert Gas welding
PAW	Plasma Arc Welding
S	Welding Speed
SAW	Submerged Arc Welding
SMAW	Submerged Metal Arc Welding
SS	Sum of Square
T	Welding torch angle
TIG	Tungsten Inert Gas Welding
W	Bead Width

CHAPTER 1

INTRODUCTION

1.1 WELDING

The American Welding Society (AWS) defines welding process as "A localized coalescence of metals or nonmetals produced either by heating the materials to the required welding temperatures, with or without the application of pressure, or by the application of pressure alone, and with or without the use of filler materials".

1.2 CLASSIFICATION OF WELDING

Welding is one of the metal joining processes which are used to produce welds. There are three major types of welding processes.

They are:

1. Fusion welding
2. Solid state welding
3. Semi-liquid welding

Most of the welding processes utilize heat and / or pressure for making a weld joint. A weld is made when separate pieces of material to be joined combine and form one piece when heated to a temperature high enough to cause softening or melting and flow together. Based on the method of heat generation and its application, the three major welding processes can be divided into several classes.

1.3 FUSION WELDING

1.3.1 ARC WELDING

Arc welding is a welding process, in which heat is generated by an electric arc struck between an electrode and the work piece. Electric arc is luminous electrical discharge between two electrodes through ionized gas. Electric arc between the electrode and work piece closes the electric circuit. The arc temperature may reach 10000°F (5500°C), which is sufficient for fusion the work piece edges and joining them.

When a filler metal is required for better bonding, filling rod (wire) is used either as outside material fed to the arc region or as consumable welding electrode, which melts and fills the weld pool. Chemical compositions of filler metal are similar to that of work piece.

1.3.1.1 Carbon Arc Welding

Carbon Arc Welding is a welding process, in which heat is generated by an electric arc struck between a carbon electrode and the work piece. The arc heats and melts the work pieces edges, forming a joint. Carbon arc welding is the oldest welding process. If required, filler rod may be used in Carbon Arc Welding. End of the rod is held in the arc zone. Carbon Arc Welding has been replaced by Tungsten Inert Gas Arc Welding (TIG, GTAW) in many applications.

1.3.1.2 Shielded Metal Arc Welding (SMAW)

Shielded metal arc welding (Stick welding, manual metal arc welding) uses a metallic consumable electrode of a proper composition for generating arc between itself and the parent work piece. The molten electrode metal fills the weld gap and joins the work pieces. This is the most popular welding process capable to produce a great variety of welds. The electrodes are coated with a shielding flux of a suitable composition.

1.3.1.3 Metal Inert Gas Welding (MIG, GMAW)

Metal Inert Gas Welding (Gas Metal Arc Welding) is a arc welding process, in which the weld is shielded by an external gas (Argon, helium, CO_2, argon + Oxygen or other gas mixtures). Consumable electrode wire, having chemical composition similar to that of the parent material, is continuously fed from a spool to the arc zone. The arc heats and melts both the work pieces edges and the electrode wire. The fused electrode material is supplied to the surfaces of the work pieces, fills the weld pool and forms joint. Due to automatic feeding of the filling wire (electrode) the process is referred to as a semi-automatic. The operator controls only the torch positioning and speed.

1.3.1.4 Flux-cored arc welding

Flux-cored arc welding (FCAW) is a semi-automatic or automatic arc welding process. FCAW requires a continuously-fed consumable tubular electrode containing a flux and a constant-voltage or, less commonly, a constant-current welding power supply. An externally supplied shielding gas is sometimes used, but often the flux itself is relied upon to generate the necessary protection from the atmosphere. The process is widely used in construction because of its high welding speed and portability

1.3.1.5 Submerged arc welding

Submerged Arc Welding (SAW) is a common arc welding process. It requires a continuously fed consumable solid or tubular (flux cored) electrode. When molten, the flux becomes conductive, and provides a current path between the electrode and the work. This thick layer of flux completely covers the molten metal thus preventing spatter and sparks.

1.3.1.6 Tungsten Inert Gas Arc Welding (TIG, GTAW)

Tungsten Inert Gas Arc Welding (Gas Tungsten Arc Welding) is a welding process, in which heat is generated by an electric arc struck between a tungsten non-consumable electrode and the work piece. The weld pool is shielded by an inert gas (Argon, helium, Nitrogen) protecting the molten metal from atmospheric contamination. The heat produced by the arc melts the work pieces edges and joins them. Filler rod may be used, if required. Tungsten Inert Gas Arc Welding produces a high quality weld of most of metals. Flux is not used in the process.

1.3.1.7 Plasma Arc Welding (PAW)

Plasma Arc Welding is the welding process utilizing heat generated by a constricted arc struck between a tungsten non-consumable electrode and either the work piece (transferred arc process) or water cooled constricting nozzle (non-transferred arc process). Plasma is a gaseous mixture of positive ions, electrons and neutral gas molecules.

1.3.2 Gas welding

Gas Welding is a welding process utilizing heat of the flame from a welding torch. The torch mixes a fuel gas with Oxygen in the proper ratio and flow rate providing combustion process at a required temperature. The hot flame fuses the edges of the welded parts, which are joined together forming a weld after Solidification. The flame temperature is determined by a type of the fuel gas and proportion of oxygen in the combustion mixture: 4500°F - 6300°F (2500°C - 3500°C). Filler rod is used when an additional supply of metal to weld is required.

1.3.3 Resistance Welding

Resistance Welding is a welding process, in which work pieces are welded due to a combination of a pressure applied to them and a localized heat generated by a high electric current flowing through the contact area of the weld. Heat produced by the current is sufficient for local melting of the work piece at the contact point and formation of small weld pool ("nugget"). The molten metal is then solidifies under a pressure and joins the pieces.

1.3.4 Stud welding

Stud welding is a form of spot welding where a bolt or specially formed nut is welded onto another metal part. The bolts may be automatically fed into the spot welder. Weld nuts generally have a flange with small nubs that melt to form the weld. Studs have a necked down, unthreaded area for the same purpose.

1.3.5 Electroslag Welding

Electroslag Welding is a welding process, in which the heat is generated by an electric current passing between the consumable electrode (filler metal) and the work piece through a molten slag covering the weld surface. Prior to welding the gap between the two work pieces is filled with a welding flux. Electroslag Welding is initiated by an arc between the electrode and the work piece (or starting plate).

1.3.6 Electron Beam Welding

Electron Beam Welding is a welding process utilizing a heat generated by a beam of high energy electrons. The electrons strike the work piece and their kinetic energy converts into thermal energy heating the metal so that the edges of work piece are fused and joined together forming a weld after Solidification. The process is carried out in a vacuum chamber. Such high vacuum is required in order to prevent loss of the electrons energy in collisions with air molecules. The electrons are emitted by a cathode (electron gun).

1.3.7 Solid State Welding

Solid State Welding is a welding process, in which two work pieces are joined under a pressure providing an intimate contact between them and at a temperature essentially below the melting point of the parent material. Bonding of the materials is a result of diffusion of their interface atoms.

1.3.8 Laser Welding

Laser Welding is a welding process, in which heat is generated by a high energy laser beam targeted on the work piece. The laser beam heats and melts the work pieces edges, forming a joint.

1.3.9 Brazing

Brazing is a method of joining two metal work pieces by means of a filler material at a temperature above its melting point but below the melting point of either of the materials being joined. Flow of the molten filler material into the gap between the work pieces is driven by the capillary force. The filler material cools down and solidifies forming a strong metallurgical joint, which is usually stronger than the parent (work piece) materials. The parent materials are not fused in the process. Brazing is similar to Soldering.

1.3.10 Soldering

Soldering is a method of joining two metal work pieces by means of a third metal (solder) at a relatively low temperature, which is above the melting point of the solder but below the melting point of either of the materials being joined. Flow of the molten solder into the gap between the work pieces is driven by the capillary force. The solder cools down and solidifies forming a joint. The parent materials are not fused in the process.

CHAPTER 2

GAS TUNGSTEN ARC WELDING

2.1 INTRODUCTION

Gas tungsten arc welding (GTAW), also known as tungsten inert gas (TIG) welding, is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmospheric contamination by a shielding gas (usually an inert gas such as argon), and a filler metal is normally used, though some welds, known as autogenous welds, do not require it. A constant-current welding power supply produces energy which is conducted across the arc through a column of highly ionized gas and metal vapors known as plasma. GTAW is most commonly used to weld thin sections of stainless steel and light metals such as aluminum, magnesium, and copper alloys.

2.2 OPERATION

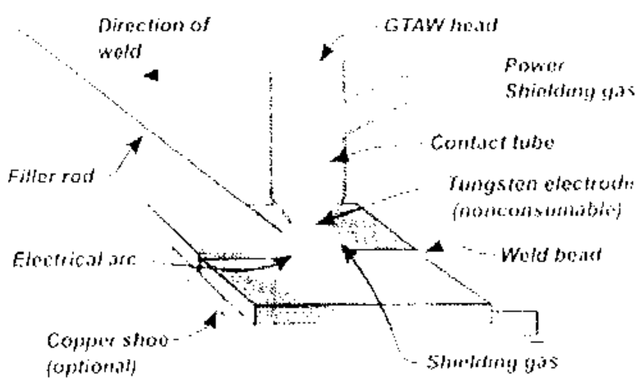


FIG. 2.1 GTAW OPERATION

Manual gas tungsten arc welding is often considered the most difficult of all the welding processes commonly used in industry. Because the welder must maintain a short arc length, great care and skill are required to prevent contact between the electrode and the workpiece. Unlike most other welding processes, GTAW normally requires two hands, since most applications require that the welder manually feed a filler metal into the weld area with one hand while manipulating the welding torch in the other. However, some welds combining thin materials (known as autogenous or fusion welds) can be accomplished without filler metal; most notably edge, corner, and butt joints.

To strike the welding arc, a high frequency generator provides a path for the welding current through the shielding gas, allowing the arc to be struck when the separation between the electrode and the workpiece is approximately 1.5–3 mm (0.06–0.12 in). Bringing the two into contact in a "touch start" ("scratch start") also serves to strike an arc. This technique can cause contamination of the weld and electrode. Once the arc is struck, the welder moves the torch in a small circle to create a welding pool, the size of which depends on the size of the electrode and the amount of current. While maintaining a constant separation between the electrode and the workpiece, the operator then moves the torch back slightly and tilts it backward about 10–15 degrees from vertical. Filler metal is added manually to the front end of the weld pool as it is needed.

Welders often develop a technique of rapidly alternating between moving the torch forward (to advance the weld pool) and adding filler metal. The filler rod is withdrawn from the weld pool each time the electrode advances, but it is never removed from the gas shield to prevent oxidation of its surface and contamination of the weld. Filler rods composed of metals with low melting temperature, such as aluminum, require that the operator maintain some distance from the arc while staying inside the gas shield. If held too close to the arc, the filler rod can melt before it makes contact with the weld puddle. As the weld nears completion, the arc current is often gradually reduced to allow the weld crater to solidify and prevent the formation of crater cracks at the end of the weld.

2.2.1Operation Modes

GTAW can use a positive direct current, negative direct current or an alternating current, depending on the power supply set up. A negative direct current from the electrode causes a stream of electrons to collide with the surface, generating large amounts of heat at the weld region. This creates a deep, narrow weld. In the opposite process where the electrode is connected to the positive power supply terminal, positively charged ions flow from the tip of the electrode instead, so the heating action of the electrons is mostly on the electrode. This mode also helps to remove oxide layers from the surface of the region to be welded, which is good for metals such as Aluminium or Magnesium. A shallow, wide weld is produced from this mode, with minimum heat input. Alternating current gives a combination of negative and positive modes, giving a cleaning effect and imparts a lot of heat as well.

2.3 Applications

While the aerospace industry is one of the primary users of gas tungsten arc welding. the process is used in a number of other areas. Many industries use GTAW for welding thin workpieces, especially nonferrous metals. It is used extensively in the manufacture of space vehicles. and is also frequently employed to weld small-diameter, thin-wall tubing such as those used in the bicycle industry. In addition. GTAW is often used to make root or first pass welds for piping of various sizes. In maintenance and repair work, the process is commonly used to repair tools and dies. especially components made of aluminum and magnesium.

2.4 Quality

Engineers prefer GTAW welds because of its low-hydrogen properties and the match of mechanical and chemical properties with the base material. Maximum weld quality is assured by maintaining the cleanliness of the operation—all equipment and materials used must be free from oil, moisture, dirt and other impurities, as these cause weld porosity and consequently a decrease in weld strength and quality.

To maintain a clean weld pool during welding, the shielding gas flow should be sufficient and consistent so that the gas covers the weld and blocks impurities in the atmosphere. GTA welding in windy or drafty environments increases the amount of shielding gas necessary to protect the weld, increasing the cost and making the process unpopular outdoors.

2.5 Equipment

The equipment required for the gas tungsten arc welding operation includes a welding torch utilizing a non-consumable tungsten electrode, a constant-current welding power supply, and a shielding gas source.

2.5.1 Welding torch

GTAW welding torches are designed for either automatic or manual operation and are equipped with cooling systems using air or water. The automatic and manual torches are similar in construction, but the manual torch has a handle while the automatic torch normally comes with a mounting rack. The angle between the centerline of the handle and the centerline of the tungsten electrode, known as the head angle, can be varied on some manual torches according to the preference of the operator.

The internal metal parts of a torch are made of hard alloys of copper or brass in order to transmit current and heat effectively. The tungsten electrode must be held firmly in the center of the torch with an appropriately sized collet, and ports around the electrode provide a constant flow of shielding gas. Collets are sized according to the diameter of the tungsten electrode they hold.

The size of the welding torch nozzle depends on the amount of shielded area desired. The size of the gas nozzle will depend upon the diameter of the electrode, the joint configuration, and the availability of access to the joint by the welder. The inside diameter of the nozzle is preferably at least three times the diameter of the electrode, but there are no hard rules. Hand switches to control welding current can be added to the manual GTAW torches.

2.5.2 Power supply

Gas tungsten arc welding uses a constant current power source, meaning that the current (and thus the heat) remains relatively constant, even if the arc distance and voltage change. This is important because most applications of GTAW are manual or semiautomatic, requiring that an operator hold the torch. Maintaining a suitably steady arc distance is difficult if a constant voltage power source is used instead, since it can cause dramatic heat variations and make welding more difficult.

The preferred polarity of the GTAW system depends largely on the type of metal being welded. Direct current with a negatively charged electrode (DCEN) is often employed when welding steels, nickel, titanium, and other metals.

Alternating current, commonly used when welding aluminum and magnesium manually or semi-automatically, combines the two direct currents by making the electrode and base material alternate between positive and negative charge.

2.5.3 Electrode

ISO Class	ISO Color	AWS Class	AWS Color	Alloy
WP	Green	EWP	Green	None
WC20	Gray	EWCe-2	Orange	~2% CeO2
WL10	Black	EWLa-1	Black	~1% La2O3
WL15	Gold	EWLa-1.5	Gold	~1.5% La_2O_3
WL20	Sky-blue	EWLa-2	Blue	~2% La_2O_3
WT10	Yellow	EWTh-1	Yellow	~1% ThO2
WT20	Red	EWTh-2	Red	~2% ThO_2
WT30	Violet			~3% ThO_2
WT40	Orange			~4% ThO_2
WY20	Blue			~2% Y2O3
WZ3	Brown	EWZr-1	Brown	~0.3% ZrO2
WZ8	White			~0.8% ZrO_2

Table 2.1 Electrode nomenclature

The electrode used in GTAW is made of tungsten or a tungsten alloy, because tungsten has the highest melting temperature among pure metals, at 3,422 °C (6,192 °F). As a result, the electrode is not consumed during welding, though some erosion (called burn-off) can occur. Electrodes can have either a clean finish or a ground finish—clean finish electrodes have been chemically cleaned, while ground finish electrodes have been ground to a uniform size and have a polished surface, making them optimal for heat conduction. The diameter of the electrode can vary between 0.5 millimeter and 6.4 millimeters, and their length can range from 75 to 610 millimeters.

2.5.4 Shielding gas

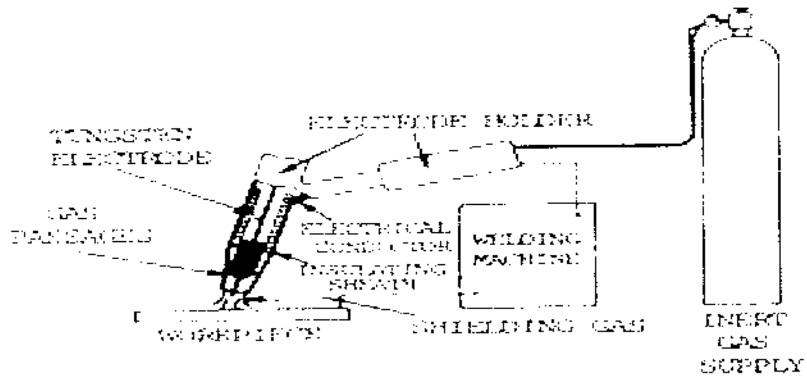


FIG. 2.2 GTAW SHIELDING GAS SETUP

Shielding gases fall into two categories- inert or semi-inert. Only two of the noble gases, helium and argon, are cost effective enough to be used in welding. These inert gases are used in gas tungsten arc welding, and also in gas metal arc welding for the welding of non-ferrous materials. Semi-inert shielding gases, or active shield gases, include carbon dioxide, oxygen, nitrogen, and hydrogen. Most of these gases, in large quantities, would damage the weld, but when used in small, controlled quantities, can improve weld characteristics.

2.5.4.1 Properties of shielding gases

The important properties of shielding gases are their thermal conductivity and heat transfer properties, their density relative to air, and how easy they undergo ionization. Shielding gases can be used pure, or as a blend of two or three gases.

2.5.4.2 Helium

It is lighter than air; larger flow rates are required. It is an inert gas, not reacting with the molten metals. Its thermal conductivity is high. It is not easy to ionize, requiring higher voltage to start the arc. Other gases are often added. Blends of helium with addition of 5-10% of argon and 2-5% of carbon dioxide can be used for welding of stainless steel.

2.5.4.3 Argon

It is heavier than air; lower flow rates are needed to blanket the weld. It is an inert gas, not reacting with the molten metals. It has low thermal conductivity. It ionizes easily. It is often used as pure when welding aluminium and other nonferrous metals, though other gases can be added. A blend of argon with 25-50% of helium is used for some nonferrous metals, as helium improves heat transfer into the base material and makes the molten metal more fluid. An oxidizing component (oxygen, carbon dioxide) is usually added to stabilize the arc for welding of steels; without it the arc control can be difficult as the arc tends to stray. In industrial gas business it is known as "the big A".

2.5.4.4 Carbon dioxide

It has good heat transfer properties; it dissociates in the weld and recombines in contact with the colder metal. Due to the presence of dissociated oxygen, the weld zone has oxidizing properties, producing more slag. Carbon dioxide can be used as pure, or in a mixture with argon as 5 to 25%. Increasing percentage of carbon dioxide increases width and depth of the weld penetration.

2.5.4.5 Oxygen

It is used in small amounts as an addition to other gases; typically as 2-5% addition to argon. It enhances arc stability and reduces the surface tension of the molten metal, increasing wetting of the solid metal. Its presence increases the amount of slag.

2.5.4.6 Nitrogen

It is used for welding of some stainless steels. It increases the weld penetration and enhances arc stability. It however can cause porosity in carbon steels. Argon-carbon dioxide-nitrogen blends can be used. Pure nitrogen is also used, or can be blended with 10% of hydrogen, depending on application.

2.5.4.7 Hydrogen

It is used for welding of some stainless steels. It improves the molten metal fluidity, and enhances cleanness of the surface. It can however cause hydrogen embrittlement of many alloys and especially carbon steel, so its application is usually limited only to some stainless steels.

2.5.4.8 Nitric oxide

Its addition serves to reduce production of ozone. It can also stabilize the arc when welding aluminium and high-alloyed stainless steel.

Other gases can be used for special applications, pure or as blend additives; e.g. sulfur hexafluoride or dichlorodifluoromethane. Sulfur hexafluoride can be added to shield gas for aluminium welding to bind hydrogen in the weld area to reduce weld porosity.

Dichlorodifluoromethane with argon can be used for protective atmosphere for melting of aluminium-lithium alloys.

2.6 Materials

Gas tungsten arc welding is most commonly used to weld stainless steel and nonferrous materials, such as aluminum and magnesium, but it can be applied to nearly all metals, with notable exceptions being lead and zinc. Its applications involving carbon steels are limited not because of process restrictions, but because of the existence of more economical steel welding techniques, such as gas metal arc welding and shielded metal arc welding.

Aluminum and magnesium are most often welded using alternating current, but the use of direct current is also possible, depending on the properties desired.

Direct current of either polarity, positive or negative, can be used to weld aluminum and magnesium as well. Direct current with a positively charged electrode (DCEP) allows for high penetration. Short arc length (generally less than 2 mm or 0.07 in) gives the best results, making the process better suited for automatic operation than manual operation.

2.6.1 Steels

For GTA welding of carbon and stainless steels, the selection of a filler material is important to prevent excessive porosity. Preheating is generally not necessary for mild steels less than one inch thick, but low alloy steels may require preheating to slow the cooling process and prevent the formation of martensite in the heat-affected zone. Tool steels should also be preheated to prevent cracking in the heat-affected zone.

Austenitic stainless steels do not require preheating, but martensitic and ferritic chromium stainless steels do.

2.6.2 Copper alloys

TIG welding of copper and some of its alloys is possible, but in order to get a seam free of oxidation and porosities, shielding gas needs to be provided on the root side of the weld. Alternatively, a special "backing tape", consisting of a fiberglass weave on heat-resistant aluminum tape can be used, to prevent air reaching the molten metal.

2.7 Process variations

2.7.1 Pulsed-current

In the pulsed-current mode, the welding current rapidly alternates between two levels. The higher current state is known as the pulse current, while the lower current level is called the background current. During the period of pulse current, the weld area is heated and fusion occurs. Upon dropping to the background current, the weld area is allowed to cool and solidify. Pulsed-current GTAW has a number of advantages, including lower heat input and consequently a reduction in distortion and warpage in thin workpieces.

2.7.2 Dabber

The dabber variation is used to precisely place weld metal on thin edges. The automatic process replicates the motions of manual welding by feeding a cold filler wire into the weld area and dabbing (or oscillating) it into the welding arc. It can be used in conjunction with pulsed current, and is used to weld a variety of alloys, including titanium, nickel, and tool steels.

2.7.3 Hot Wire

Welding filler metal can be resistance heated to a temperature near its melting point before being introduced into the weld pool. This increases the deposition rate of machine and automatic GTAW welding processes. More pounds per hour of filler metal is introduced into the weld joint than when filler metal is added cold and the heat of the electric arc introduces all of the heat.

This process is used extensively in base material build up before machining, clad metal overlays, and hard facing operations.

2.8 STAINLESS STEEL

2.8.1 INTRODUCTION

In metallurgy, stainless steel is defined as a steel alloy with a minimum of 10% chromium content by mass. Stainless steel does not stain, corrode, or rust as easily as ordinary steel (it stains less), but it is not stain-proof. It is also called corrosion-resistant steel or CRES when the alloy type and grade are not detailed, particularly in the aviation industry. There are different grades and surface finishes of stainless steel to suit the environment to which the material will be subjected in its lifetime. Common uses of stainless steel are cutlery and watch straps.

Stainless steel differs from carbon steel by amount of chromium present. Carbon steel rusts when exposed to air and moisture. This iron oxide film is active and accelerates corrosion by forming more iron oxide. Stainless steels have sufficient amount of chromium present so that a passive film of chromium oxide forms which prevents further surface corrosion and blocks corrosion spreading in the metal's internal structure.

2.8.2 Properties

High oxidation-resistance in air at ambient temperature are normally achieved with additions of a minimum of 13% (by weight) chromium, and up to 26% is used for harsh environments. The chromium forms a passivation layer of chromium(III) oxide (Cr_2O_3) when exposed to oxygen. The layer is too thin to be visible, and the metal remains lustrous. It is impervious to water and air, protecting the metal beneath. Also, this layer quickly reforms when the surface is scratched. This phenomenon is called passivation and is seen in other metals, such as aluminium and titanium. Corrosion resistance can however be adversely affected if the component is used in a non-oxygenated environment.

2.8.3 Applications

Stainless steel's resistance to corrosion and staining, low maintenance, relatively low cost, and familiar luster make it an ideal base material for a host of commercial applications, some which are listed below:

1. Surgical instruments

2. Industrial equipments

3. Automotive and aerospace structural alloys

4. Storage tanks and tankers used to transport food items

5. Jewellery and watches

6. Firearms

2.8.4 Types of stainless steel

There are different types of stainless steels: when nickel is added, for instance, the austenite structure of iron is stabilized. This crystal structure makes such steels non-magnetic and less brittle at low temperatures. For greater hardness and strength, carbon is added. When subjected to adequate heat treatment, these steels are used as razor blades, cutlery, tools, etc.

Significant quantities of manganese have been used in many stainless steel compositions. Manganese preserves an austenitic structure in the steel as does nickel, but at a lower cost.

Stainless steels are also classified by their crystalline structure:

- **Austenitic, or 300 series**, stainless steels comprise over 70% of total stainless steel production. They contain a maximum of 0.15% carbon, a minimum of 16% chromium and sufficient nickel and/or manganese to retain an austenitic structure at all temperatures from the cryogenic region to the melting point of the alloy. A typical composition of 18% chromium and 10% nickel, commonly known as 18/10 stainless, is often used in flatware. Similarly, 18/0 and 18/8 are also available.

- **Ferritic stainless steels** are highly corrosion-resistant, but less durable than austenitic grades. They contain between 10.5% and 27% chromium and very little nickel, if any, but some types can contain lead.

- **Martensitic stainless steels** are not as corrosion-resistant as the other two classes but are extremely strong and tough, as well as highly machineable, and can be hardened by heat treatment.

- **Precipitation-hardening martensitic stainless steels** have corrosion resistance comparable to austenitic varieties, but can be precipitation hardened to even higher strengths than the other martensitic grades. The most common, 17-4PH, uses about 17% chromium and 4% nickel.

- **Duplex stainless steels** have a mixed microstructure of austenite and ferrite, the aim being to produce a 50/50 mix, although in commercial alloys, the mix may be 40/60 respectively. Duplex steels have improved strength over austenitic stainless steels and also improved resistance to localised corrosion, particularly pitting, crevice corrosion and stress corrosion cracking.

CHAPTER 3

LITERATURE SURVEY

S.W. Shyu et al (2007) had investigated the effect of oxide fluxes on weld morphology, arc voltage, mechanical properties, angular distortion and hot cracking susceptibility obtained with TIG welding, which applied to the welding of 5 mm thick austenitic stainless steel plates. A novel variant of the autogenous TIG welding process, oxide powders (Al_2O_3, Cr_2O_3, TiO_2, SiO_2 and CaO) was applied on a type 304 stainless steel through a thin layer of the flux to produce a bead on plate welds. The experimental results indicated that the increase in the penetration is significant with the use of Cr_2O_3, TiO_2, and SiO_2. A-TIG welding can increase the weld depth to bead-width ratio, and tends to reduce the angular distortion of the weldment. It was also found that A-TIG welding can increase the retained delta-ferrite content of stainless steel 304 welds and, in consequence, the hot-cracking susceptibility of as-welded is reduced. Physically constricting the plasma column and reducing the anode spot are the possible mechanism for the effect of certain flux on A-TIG penetration.

R.-I. Hsieh et al (2006) gave effects of minor elements and shielding gas on the penetration of TIG welding in type 304 stainless. The bead-on-plate test was performed, then the depth and width of the weld were measured using an optical projection machine. The arc voltage was measured with an arc data monitor. In addition, the metallurgical characteristics of weld were examined using OM and SEM. The results show that oxygen and sulfur are beneficial in increasing a depth/width ratio because of the increased surface tension/temperature gradient.

Elements, such as aluminum, that have a deleterious effect on the depth/width ratio will combine with oxygen and reduce the soluble oxygen content in the weld pool. On the other hand, silicon and phosphorus have a minor effect on the depth/width ratio. Shielding gas using Ar + 1% O_2 or Ar + 5% H_2 can significantly promote the depth/width ratio. The former contains increased soluble oxygen content in the weld pool, and the latter produces an arc that is hotter than that produced by pure argon.

Y. S. Tarng et al (2005) had optimized the Weld Bead Geometry in Gas Tungsten Arc Welding by the Taguchi Method. In this work; determination of the welding process parameters for obtaining optimal weld bead geometry in gas tungsten arc welding is presented. The Taguchi method is used to formulate the experimental layout, to analyze the effect of each welding process parameter on the weld bead geometry, and to predict the optimal setting for each welding process parameter. Experimental results are presented to explain the proposed approach.

Shanping Lu et al (2003) studied the Mechanism and Optimization of Oxide Fluxes for Deep Penetration in Gas Tungsten Arc Welding. Five single oxide fluxes- Cu_2O, NiO, SiO_2, CaO, and Al_2O_3 were used to investigate the effect of active flux on the depth/width ratio in SUS304 stainless steel. The flux quantity, stability, and particle size effect on the weld-pool shape and oxygen content in the weld after welding was studied systematically. The results showed that the weld depth/width ratio initially increased, followed by a decrease with the increasing flux quantity of the Cu_2O, NiO, and SiO_2 fluxes. The depth/width ratio is not sensitive to the CaO flux when the quantity is over 80 X 10^{-5} mol on the (5 X 0.1 X 50) mm slot. The Al_2O_3 flux has no effect on the penetration. The oxygen content dissolved in the weld plays an important role in altering the liquid-pool surface-tension gradient and the weld penetration. The effective range of oxygen in the weld is between 70 and 300 ppm. A too-high or too-low oxygen content in the weld pool does not increase the depth/width ratio. The decomposition of the flux significantly depends on the flux stability and the particle size. Cu_2O has a narrow effective flux-quantity range for the deep penetration, while the Al_2O_3 flux has no effect. The SiO_2 flux with a small particle size (0.8 or 4 μm) is a highly recommended active flux for deep penetration in actual gas tungsten arc welding (GTAW) applications.

Shanping Lu et al (2002) studied Marangoni convection and weld shape variations in He–CO_2 shielded gas tungsten arc welding on SUS304 stainless steel. Bead-on-plate GTA welding (gas tungsten arc welding) on a SUS304 substrate is carried out to investigate the effect of carbon dioxide gas in the helium base shielding on the oxygen content in the weld pool and the weld shape variations. Experimental results show that small addition of carbon dioxide to the shielding gas can precisely adjust the weld metal oxygen content and change the weld shape from wide shallow type to narrow deep one when the weld pool oxygen content is over the critical value, which is from 68 to 82 ppm, due to the Marangoni convection reversal from the outward to inward mode on the pool surface. The weld depth/width ratio increases two times suddenly when the carbon dioxide content in the torch gas is over 0.4 or 0.2% for 1 mm or 3 mm arc length, respectively. The GTA weld shape depends to a large extent on the pattern and magnitude of the Marangoni convection on the pool surface, which is influenced by the active element oxygen content in the SUS304 pool, temperature coefficient of the surface tension (dr/dT), and the temperature gradient on the pool surface (dT/dr, r is the radius of the weld pool surface). Changing the welding parameters will alter the temperature distribution and gradient on the pool surface, and thus, affect the magnitude of the Marangoni convection and the final weld shape.

S.K. Samanta et al (2001) had investigated Microstructure and Oxidation Characteristics of Laser and GTAW Weldments in Austenitic Stainless Steels. The investigation reports microstructure and high-temperature oxidation behavior of GTAW and laser weldments of 316L stainless steel. The microstructure and oxidation behavior of composite laser weldment are found to be influenced by the welding speed. In GTAW weldment, weld metal shows higher oxidation rate as compared to base metal of same weldment. Furthermore, the inoculation of Ce in GTAW weld influences the microstructure and oxidation characteristics. The scale morphologies, scale adherence, and spallation have been characterized by SEM and EDAX.

CHAPTER 4

EXPERIMENTAL DESIGN PROCEDURE

4.1 FACTORIAL DESIGN:

Factorial design is a tool that researchers can use to design experiments. An experiment using factorial design allows one to examine simultaneously the effects of multiple independent variables and their degree of interaction. In the design of experiments, independent variables are those whose values are controlled or selected by the person experimenting (experimenter) to determine its relationship to an observed phenomenon (the dependent variable).

4.2 STEPS IN EXPERIMENTAL DESIGN PROCEDURE:

The various steps in experimental design procedure are as follows:

a. Identification of factors and responses

b. Development of design matrix

c. Conducting experiments as per the design matrix

d. Recording the response

e. Development of mathematical models

f. Checking adequacy of the developed models

g. Conducting conformity tests

4.2.1 IDENTIFICATION OF FACTORS AND RESPONSES:

The input parameters were identified based on the literature survey. Welding current (I), Welding speed (S), Shielding gas flow-rate (F) and Welding gun angle (T) were found to be the vital independently controllable process parameters affecting the process parameters. The responses chosen were bead width (W), depth of penetration (D) and Depth-Width ratio (D/W). The responses were chosen based on the impact these parameters are having on the final composition and properties of the composite material.

4.2.1.2 FINDING THE LIMITS OF THE PROCESS VARIABLES:

The working ranges of all selected factors were fixed by conducting trial runs. This was carried out by varying one of the factors while keeping the rest of them as constant values. The working range of each process parameter was decided upon by visual inspection of the bead for a smooth appearance without any visible defects such as surface porosity, undercut. etc. the upper limit of a given factor was coded as +2 and the lower limit as -2.The coded values for intermediate values were calculated using the equation (**4.1**):

$$X_i = 2\,[\,2X - (X_{max} + X_{min})\,] / [\,(X_{max} - X_{min})\,] \quad \longrightarrow \quad \textbf{(4.1)}$$

Where.

X_i -> *required coded value of a parameter X;*

X -> *any value of the parameter from X_{min} to X_{max};*

X_{min} -> *lower limit of the parameter;*

X_{max} -> *upper limit of the parameter;*

The chosen levels of the process parameters with their units and notations are given in Table (**4.1**):

TABLE 4.1 WELDING PARAMETERS AND THEIR LEVELS

PARAMETER	UNIT	NOTATION	LEVELS				
			-2	-1	0	+1	+2
Welding current	amp	I	70	80	90	100	110
Welding speed	mm/min	S	170	180	190	200	210
Shielding gas flow-rate	l/min	F	5	10	15	20	25
Welding gun angle	Degree	T	50	60	70	80	90

4.2.2 DEVELOPMENT OF DESIGN MATRIX:

The design matrix chosen to conduct the experiments was a central composite rotatable design. In statistics, a central composite design is an experimental design, useful in response surface methodology, for building a second order (quadratic) model for the response variable without needing to use a complete three-level experiment. After the designed experiment is performed, linear regression is used, sometimes iteratively, to obtain results. Coded variables are often used when constructing this design.

This design matrix comprises a full replication of $2^4 = 16$ factorial design plus 7 center points and 8 star points which is shown in Table 4.2. All welding parameters in the intermediate levels (0) constitute the center points and the combination of each welding parameters at either its highest value (+2) or lowest value (-2) with other three parameters of the intermediate levels (0) constitute the star points.

TABLE 4.2 DESIGN MATRIX

TRIAL No.	DESIGN MATRIX			
	I	S	F	T
1	-1	-1	-1	-1
2	+1	-1	-1	-1
3	-1	+1	-1	-1
4	+1	+1	-1	-1
5	-1	-1	+1	-1
6	+1	-1	+1	-1
7	-1	+1	+1	-1
8	+1	+1	+1	-1
9	-1	-1	-1	+1
10	+1	-1	-1	+1
11	-1	+1	-1	+1
12	+1	+1	-1	+1
13	-1	-1	+1	+1
14	+1	-1	+1	+1
15	-1	+1	+1	+1
16	+1	+1	+1	+1
17	-2	0	0	0
18	+2	0	0	0
19	0	-2	0	0
20	0	+2	0	0
21	0	0	-2	0
22	0	0	+2	0
23	0	0	0	-2
24	0	0	0	+2
25	0	0	0	0
26	0	0	0	0
27	0	0	0	0
28	0	0	0	0
29	0	0	0	0
30	0	0	0	0
31	0	0	0	0

4.2.3 CONDUCTING THE EXPERIMENTS AS PER THE DESIGN MATRIX:

The experiments were conducted in the Welding Laboratory at Kumaraguru College of Technology, Coimbatore. In this work, thirty one experimental runs were allowed for the estimation of the linear, quadratic and two-way interactive efforts of the process parameters on the bead geometry corresponding to each treatment combination of parameters as shown in Table 4.2 at random. At the end of each run, settings for all parameters were disturbed and reset for the next deposit. This is essential to introduce variability caused by errors in experimental settings.

4.2.3.1 EXPERIMENTAL SETUP:

The following machines and consumables were used for the purpose of conducting the experiments:

1. A constant voltage gas metal arc welding machine (Fig 4.1)
2. Welding manipulator (Fig 4.2)
3. TIG high frequency attachment (Fig 4.3)
4. Gas cylinder consisting of 100% Argon (Fig 4.4)
5. Stainless steel plate (Grade: 202) of 5 mm thickness
6. TIG torch with 2mm (dia.) zirconiated tungsten electrode

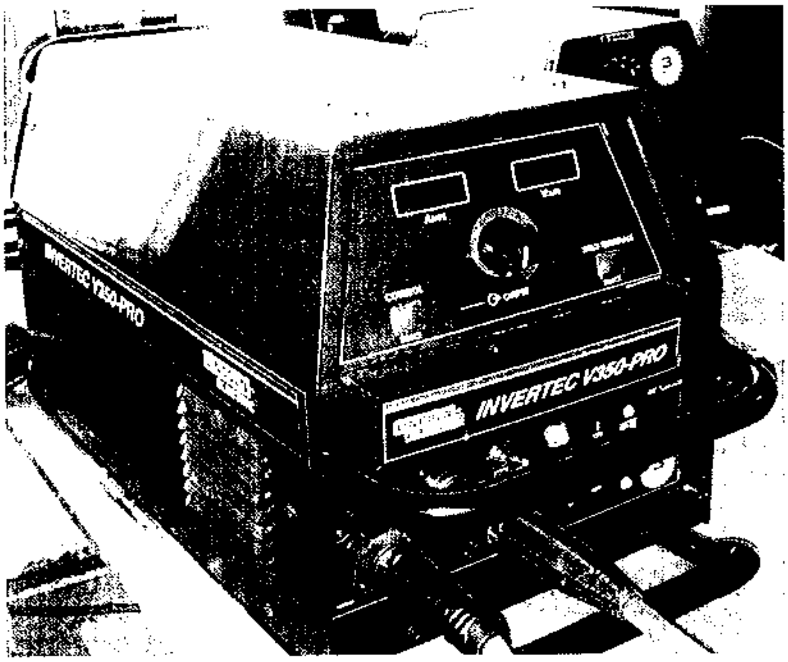


FIG. 4.1 INVERTEC V-350 PRO (ADVANCED PROCESS) MACHINE

The power source used for conducting the experiments was Invertec V-350 Pro (Advanced Process) machine (Fig 4.1). This machine is extremely flexible and is easy to handle. The main experimental set up consists of a traveling carriage with a table (Fig 4.3) for supporting the specimens. The welding gun is held stationary in a specially designed frame (Fig 4.5) above the table, and it is provided with an attachment for setting the required welding gun angle. The nozzle to plate distance was kept constant at 2.5mm throughout the experimentation process. The high frequency attachment was used to generate the arc at this distance.

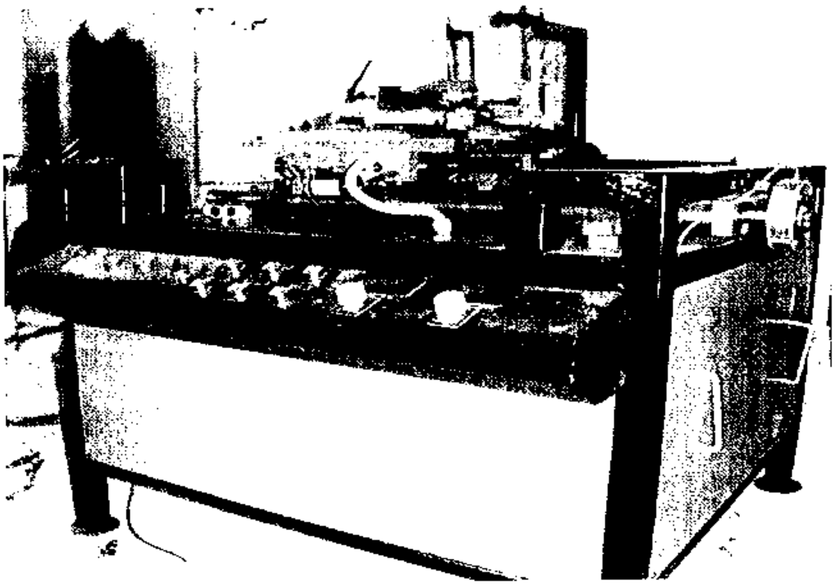


FIG. 4.2 MANIPULATOR

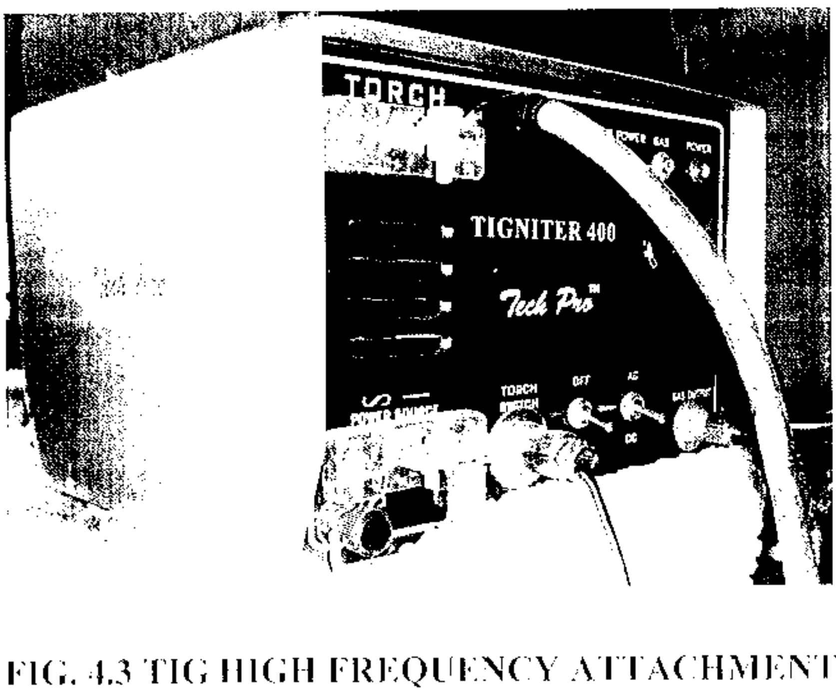


FIG. 4.3 TIG HIGH FREQUENCY ATTACHMENT

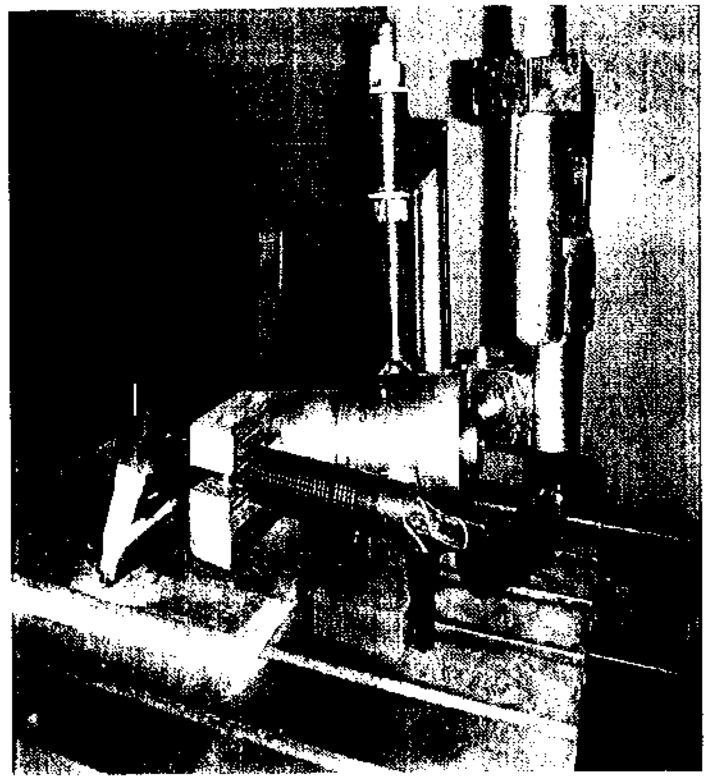


FIG. 4.4 ARGON CYLINDER **FIG. 4.5 TIG TORCH HOLDER FRAME**

The experiments were conducted using the constant voltage welding machine (Fig 4.1). Test plates of size 100 x 30 x 5 mm of stainless steel type 202 were used. The surface of the plates was cleaned to remove oxide scale and dirt. The composition of Type 202 austenitic stainless steel has been given in table 4.3:

Argon gas with flow rates between 5-25 litres per minute was used for shielding. The purpose of using the shielding gas is to protect the weld area from atmospheric gases, such as oxygen, nitrogen, carbon dioxide, and water vapour

Table 4.3 MATERIAL COMPOSITION

SAE designation	UNS designation	% Cr	% Ni	% C	% Mn	% Si	% P	% S	% N
AUSTENTIC									
202	S20200	17-19	4-6	0.15	7.5-10.0	0.75	0.06	0.03	0.25

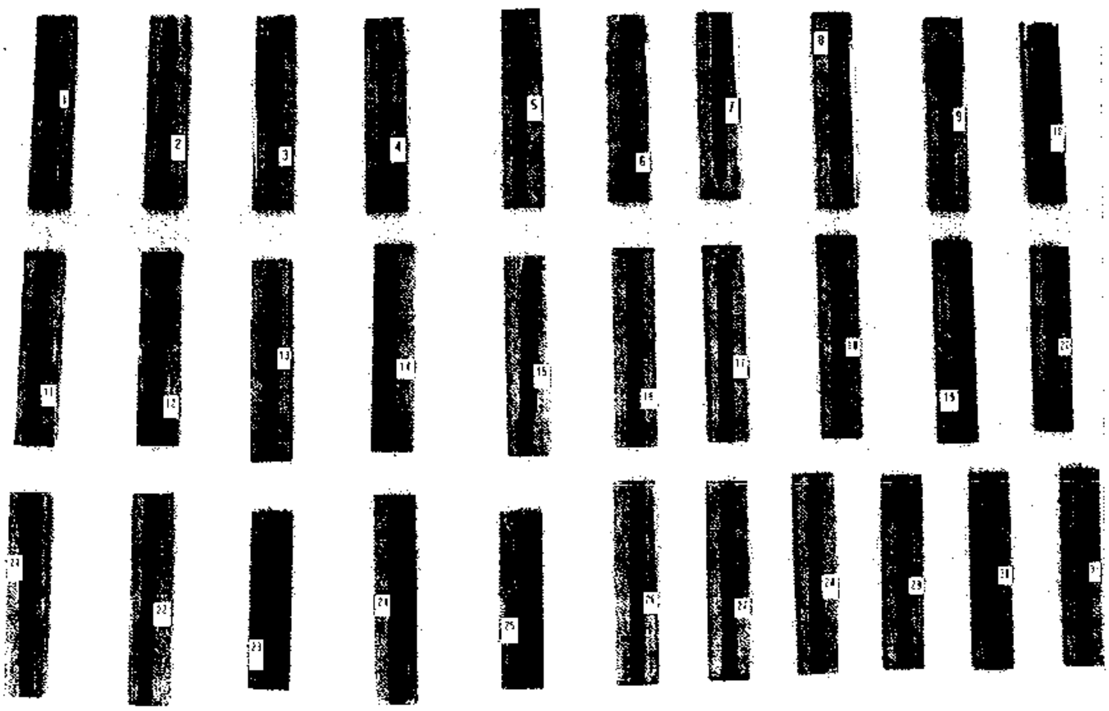


FIG. 4.6 WELD-BEAD ON PLATES

4.2.4 RECORDING THE RESPONSES:

Unlike carbon, alloy and tool steels, etching techniques are more difficult due to the high corrosion resistance of stainless steels and the various second phases that may be encountered. The procedure followed for etching of the specimens used in this project work has been listed below:

4.2.4.1 SECTIONING:

To measure the bead geometry, transverse sections of each weld overlay were cut using band saw. Care was taken to avoid deformation of the sensitive austenitic grade metal.

4.2.4.2 GRINDING:

Grinding was performed in order to remove the cold work from cutting. The operation was carried out at S M S Industries, Coimbatore on a surface grinding machine (Fig 4.7) at speeds of approximately 300 rpm.

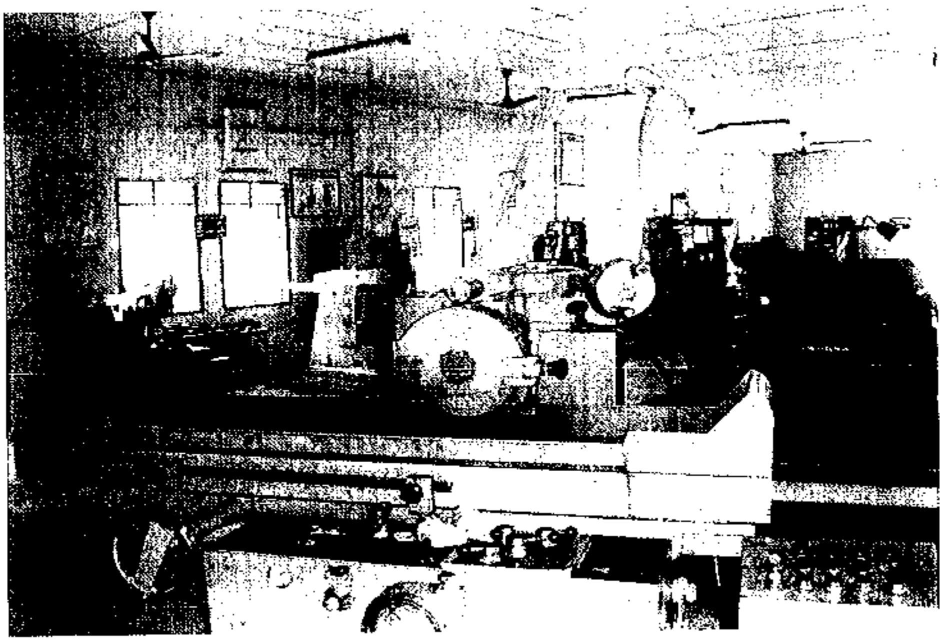


FIG. 4.7 GRINDING MACHINE

4.2.4.3 POLISHING:

After grinding, the specimens were rough polished by hand. In order to obtain better edge flatness, the specimens were polished using Silicon carbide abrasive papers of grades 100, 220, 400, 600 & 800 respectively. Specimen rocking was avoided to obtain better results. The final abrasive - slurry of Alumina (Al_2O_3) and Water (H_2O), was used for polishing on a Polishing machine (Fig 4.8).

4.2.4.4 ETCHING:

Etching is necessary for examining the microstructure of the weld bead. The etchant used was Marble's reagent (fig 4.9) which is a mixture of HCl (50 ml), $CuSO_4$ (10 g) and H_2O (50 ml). The reagent was prepared in the Chemistry Laboratory at KCT. The polished faces of each specimen were swabbed using the etchant for about 50-60 seconds to reveal the weld bead.

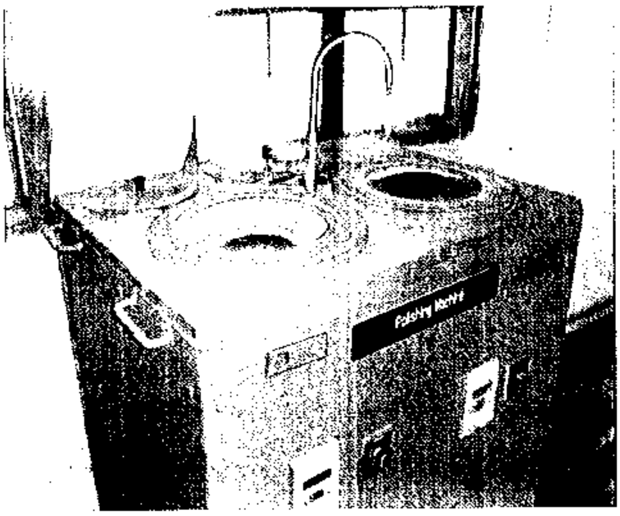


FIG 4.8 POLISHING MACHINE

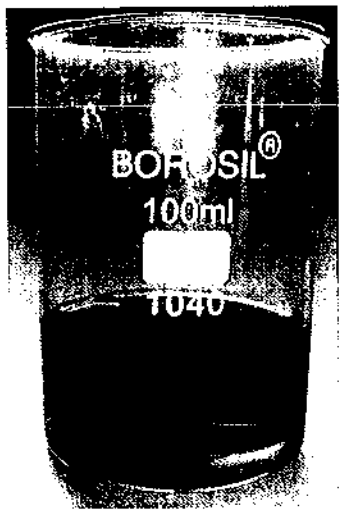


FIG. 4.9 MARBLE'S REAGENT

4.2.4.5 PROFILE TRACING:

The bead profiles were traced using a reflective type optical profile projector (Fig. 4.10) with a magnification of 10X, in the Advanced Manufacturing Technology Lab at Coimbatore Institute of Technology, Coimbatore. The traced bead profiles were scanned in order to find the various bead parameters and the depth/width ratio with the help of AUTOCAD software (Fig 4.11). Then the bead dimensions such as depth, width and depth/width ratio were measured. The measured bead dimensions and the depth/width ratio are shown in Table 4.4.

FIG. 4.10 PROFILE PROJECTOR

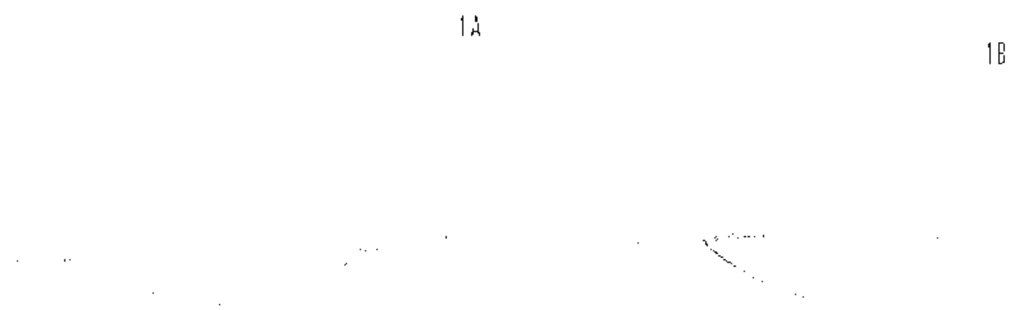


FIG. 4.11 BEAD PROFILE

TABLE 4.4 DESIGN MATRIX AND THE OBSERVED VALUES OF WELD BEAD GEOMETRY:

TRIAL No.	DESIGN MATRIX				BEAD PARAMETERS		
	I	S	F	T	Depth D	Width W	D/W
1	-1	-1	-1	-1	0.7006	2.2338	0.3136
2	+1	-1	-1	-1	1.1993	3.2461	0.3694
3	-1	+1	-1	-1	1.1023	4.8894	0.2254
4	+1	+1	-1	-1	1.2076	3.32	0.3637
5	-1	-1	+1	-1	1.1231	3.3144	0.3388
6	+1	-1	+1	-1	1.0033	3.2497	0.3087
7	-1	+1	+1	-1	1.1096	2.4593	0.4511
8	+1	+1	+1	-1	0.9574	2.2845	0.419
9	-1	-1	-1	+1	1.3687	3.1387	0.436
10	+1	-1	-1	+1	1.0262	3.9151	0.2621
11	-1	+1	-1	+1	1.329	3.5384	0.3755
12	+1	+1	-1	+1	1.31	4.8879	0.268
13	-1	-1	+1	+1	1.3947	3.4434	0.405
14	+1	-1	+1	+1	1.1932	3.3218	0.3592
15	-1	+1	+1	+1	1.3594	3.4701	0.3917
16	+1	+1	+1	+1	1.0489	4.0312	0.2602
17	-2	0	0	0	0.7832	3.7917	0.2066
18	+2	0	0	0	1.8874	3.9711	0.4753
19	0	-2	0	0	0.6599	2.8376	0.2326
20	0	+2	0	0	1.7251	4.2366	0.4072
21	0	0	-2	0	1.9874	4.1124	0.4833
22	0	0	+2	0	0.4659	2.1211	0.2196
23	0	0	0	-2	0.4511	2.0007	0.2255
24	0	0	0	+2	1.6874	4.6083	0.3662
25	0	0	0	0	1.2434	4.1378	0.3005
26	0	0	0	0	0.4552	3.9935	0.114
27	0	0	0	0	0.4678	3.5325	0.1325
28	0	0	0	0	0.4237	3.2125	0.1319
29	0	0	0	0	0.4326	3.2488	0.1332
30	0	0	0	0	0.4457	3.3186	0.1343
31	0	0	0	0	0.4369	3.2945	0.1326

CHAPTER 5

DEVELOPMENT OF MATHEMATICAL MODELS

5.1 DEVELOPMENT OF MATHEMATICAL MODELS

Using observed values as obtained from the Table 4.4, mathematical models were developed. The response function representing any of the clad bead geometry can be expressed using the equation (5.1)

$$Y = f\,(A, B, C, D) \qquad \text{------- (5.1)}$$

Where Y = Response variable (E.g. bead width)

A = Welding Current	(I) in Amperes
B = Welding speed	(S) in mm/min
C = Shielding Gas Flow rate	(F) in Litres/min
D = Torch Angle	(T) in Degrees

The second order surface response model for the four selected factors is given by the equation (5.2):

$$Y = \beta_0 + \sum_{i=1}^{4} \beta_i X_i + \sum_{i=1, i=j}^{4} \beta_{ii} X_i^2 + \sum_{i=1}^{4} \beta_{ij} X_i X_j \qquad \text{.......... (5.2)}$$

The second order surface response model [equation (5.3)] could be expressed as follows:

$$Y = \beta_0 + \beta_1 A + \beta_2 B + \beta_3 C + \beta_4 D + \beta_{11} A^2 + \beta_{22} B^2 + \beta_{33} C^2 + \beta_{44} D^2 + \beta_{12} AB + \beta_{13} AC + \beta_{14} AD + \beta_{23} BC + \beta_{24} BD + \beta_{34} CD \qquad \text{.......... (5.3)}$$

Where β_0 is the free term of the regression equation, the coefficients β_1, β_2, β_3 and β_4 are linear terms, the coefficients β_{11}, β_{22}, β_{33} and β_{44} quadratic terms, and the coefficients β_{12}, β_{13}, β_{14} etc....are the interaction terms. The coefficients were calculated using QA six sigma software (DOE-PC IV). After determining the coefficients, the mathematical models were developed. The developed mathematical models are given as follows:

Bead Width (W), mm =

$$0.558 + 0.069A + 0.106B - 0.129C + 0.171D + 0.185A^2 + 0.150B^2 + 0.158C^2 + 0.119D^2 - 0.013AB - 0.064AC - 0.075AD - 0.056BC - 0.018BD - 0.001CD \quad \text{------ (5.4)}$$

Depth of Penetration (P), mm =

$$3.534 + 0.089A + 0.242B - 0.316C + 0.415D + 0.080A^2 - 0.006B^2 - 0.111C^2 - 0.064D^2 - 0.090AB - 0.086AC + 0.210AD - 0.324BC + 0.0758BD + 0.073CD \quad \text{------- (5.5)}$$

Depth to Width Ratio =

$$0.154 + 0.009A + 0.013B - 0.009C + 0.010D + 0.050A^2 + 0.045B^2 + 0.053C^2 + 0.039D^2 + 0.004AB - 0.010AC - 0.037AD + 0.016BC - 0.018BD - 0.011CD \quad \text{-------- (5.6)}$$

5.2 Checking the adequacy of the developed models

The adequacy of the developed model was tested using the analysis of variance (ANOVA) technique. As per this technique, if the F - ratio values of the developed models do not exceed the standard tabulated values for a desired level of confidence (95%) and the calculated R - ratio values of the developed model exceed the standard values for a desired level of confidence (95%), then the models are said to be adequate within the confidence limit. These conditions were satisfied for the developed models. The values are shown in table 5.1.

TABLE 5.1 ANALYSIS OF VARIANCE FOR TESTING ADEQUACY OF THE MODELS

PARAMETER	1st Order terms		2nd Order terms		Lack of Fit		Error terms		F-ratio	R-ratio	Whether model is adequate
	SS	DF	SS	DF	SS	DF	SS	DF			
D	3.8031	14	2.471	16	1.921	10	0.550	6	2.098	2.966	Adequate
W	1.6410	14	5.051	16	4.187	10	0.864	6	2.907	5.773	Adequate
D/W	0.236	14	0.148	16	0.122	10	0.025	6	2.902	4.005	Adequate

F RATIO (10, 6, 0.05) = 2.93693

R RATIO (14, 6, 0.05) = 2.87122

CHAPTER 6

DEVELOPMENT OF MATHEMATICAL MODEL USING QUALITY AMERICA SOFTWARE

6.1. SOFTWARE USED FOR THE DEVELOPMENT OF THE REGRESSION MODEL

Some of the softwares used in the determination of the regression coefficients are as follows:

1. Quality America (DOE - PC IV)
2. Systat
3. Minitab
4. Design Expert
5. MATLAB
6. SPSS

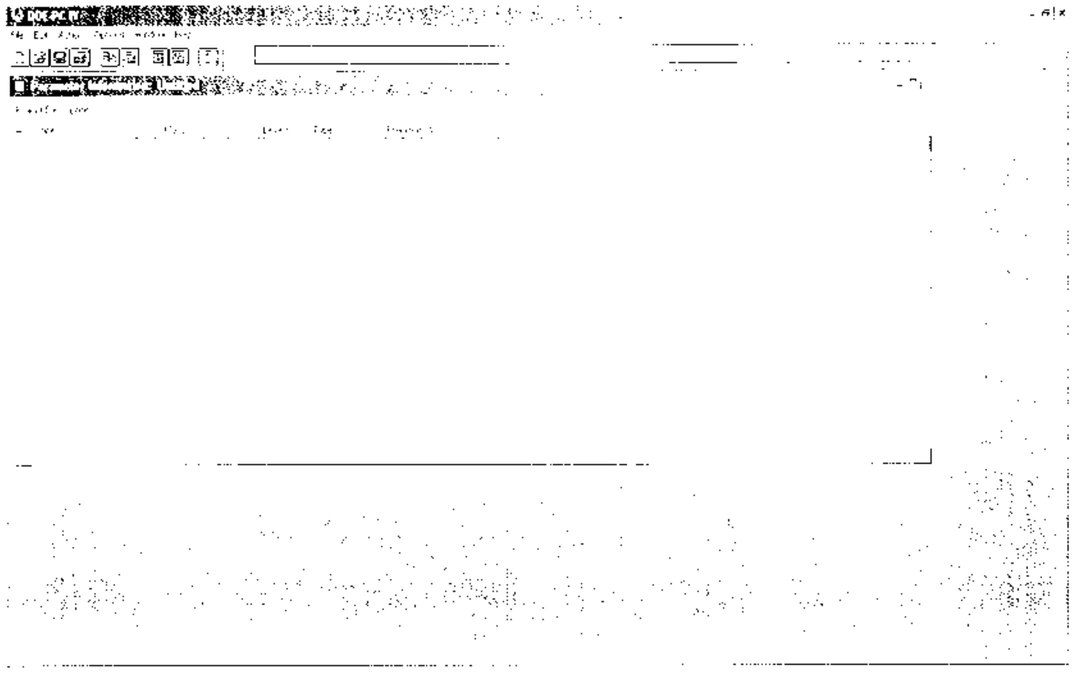
Among the softwares, Quality America Six Sigma Software (DOE – PC IV) has been found to be easier to calculate the regression coefficients. Hence, this software is used for the experimental study purpose.

6.2. STEPS IN FINDING RERESSION COEFFICIENTS

The steps used in finding the regression coefficients are explained as follows:

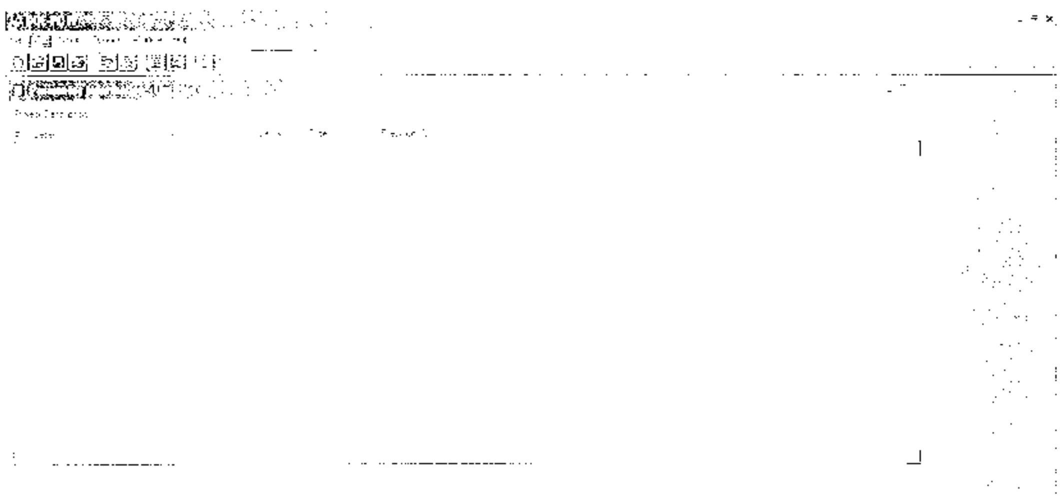
STEP 1:

A new file of DOE - PC IV software is opened.



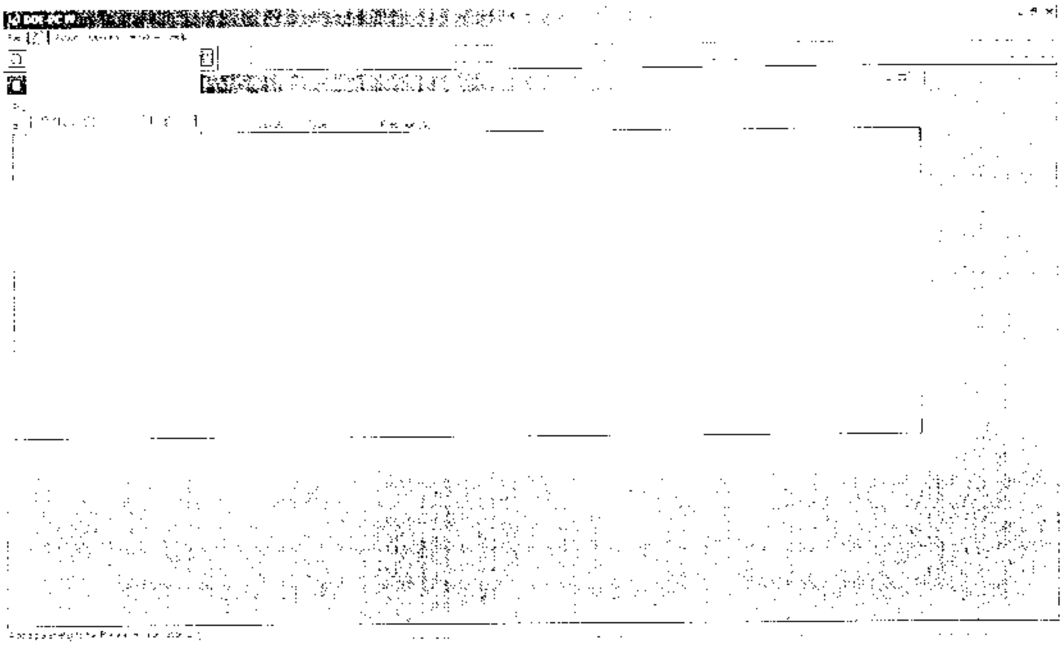
STEP 2:

'EDIT' option is chosen from the standard tool bar.



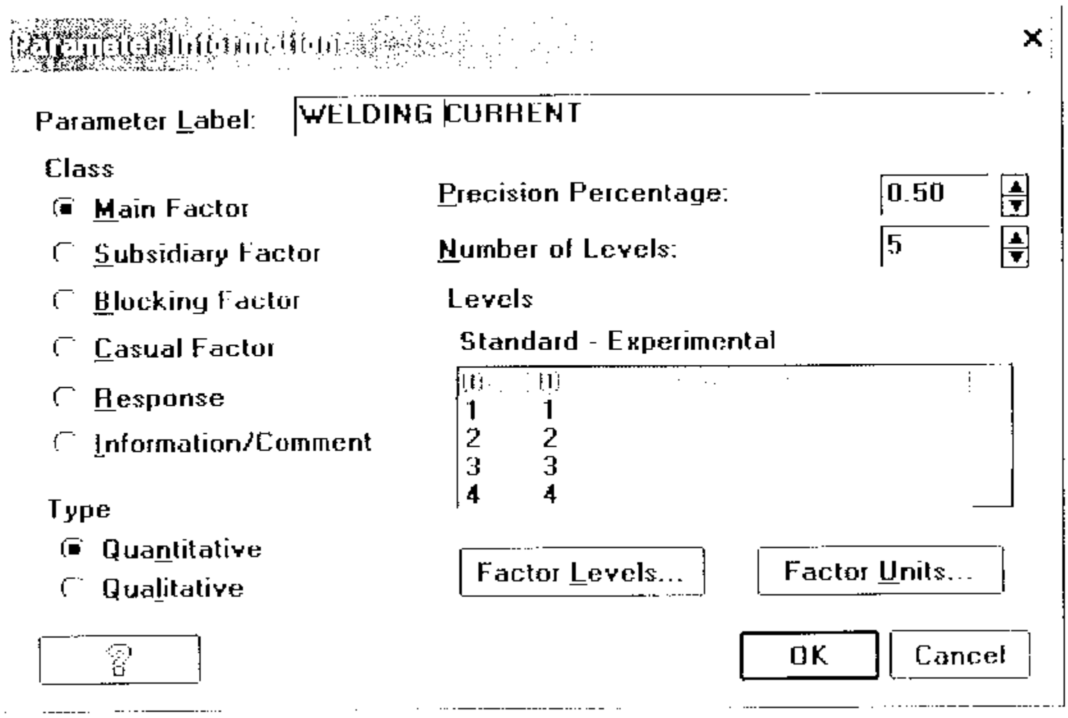
STEP 3:

Now the 'ADD PARAMETER' option is chosen the drop down menu.



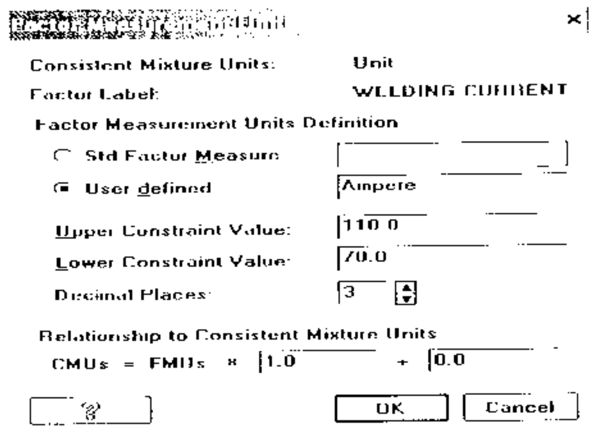
STEP 4:

Then the name of the input parameter is given in the 'PARAMETER LABEL'.



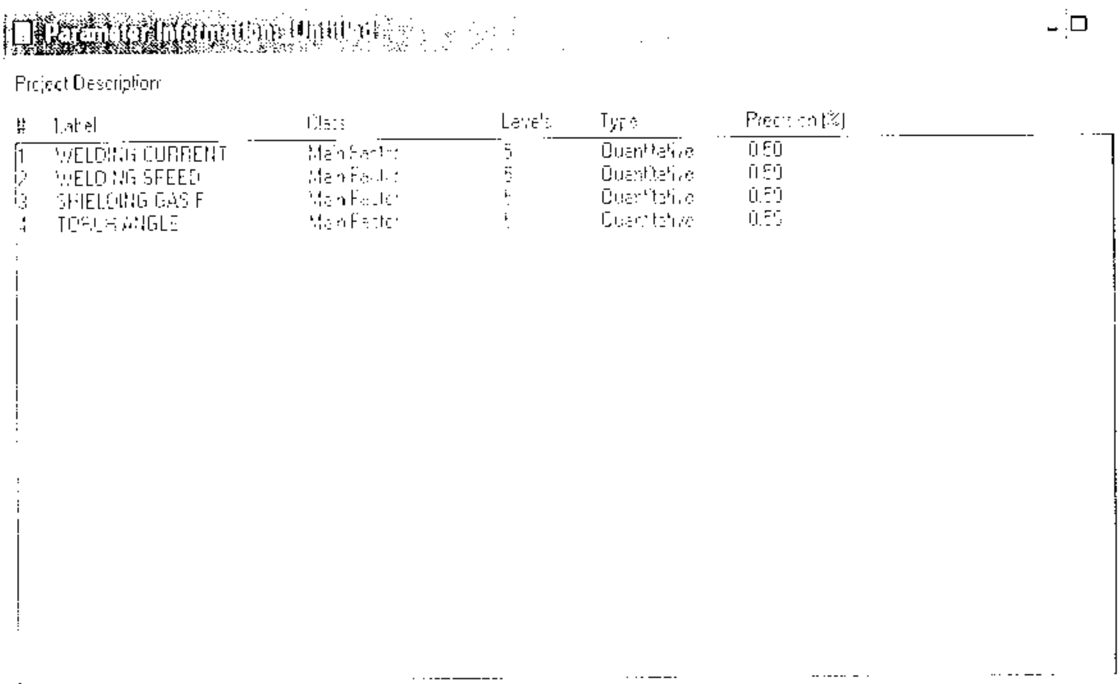
STEP 5:

Now the level of the input Parameter is taken as five and the user defined unit is given. Then the upper and lower constraint values are given.



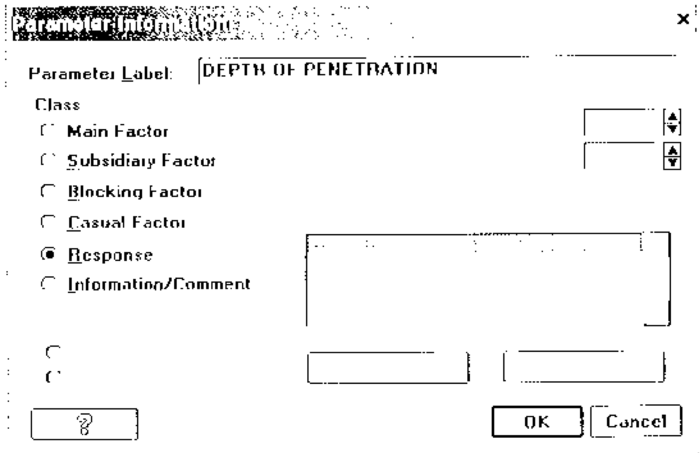
STEP 6:

Similarly, steps 3 to 5 are followed to enter all the input parameters along with their respective units and limit values.



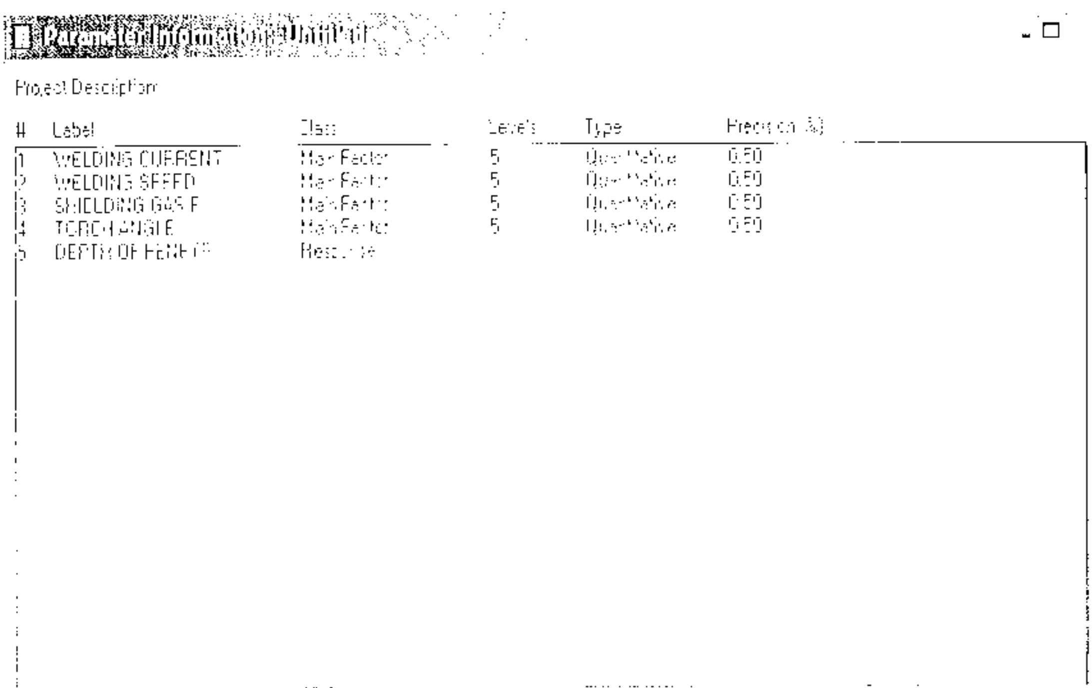
STEP 7:

After choosing the 'RESPONSE' class the name of the output parameter is given in the 'PARAMETER LABEL'.



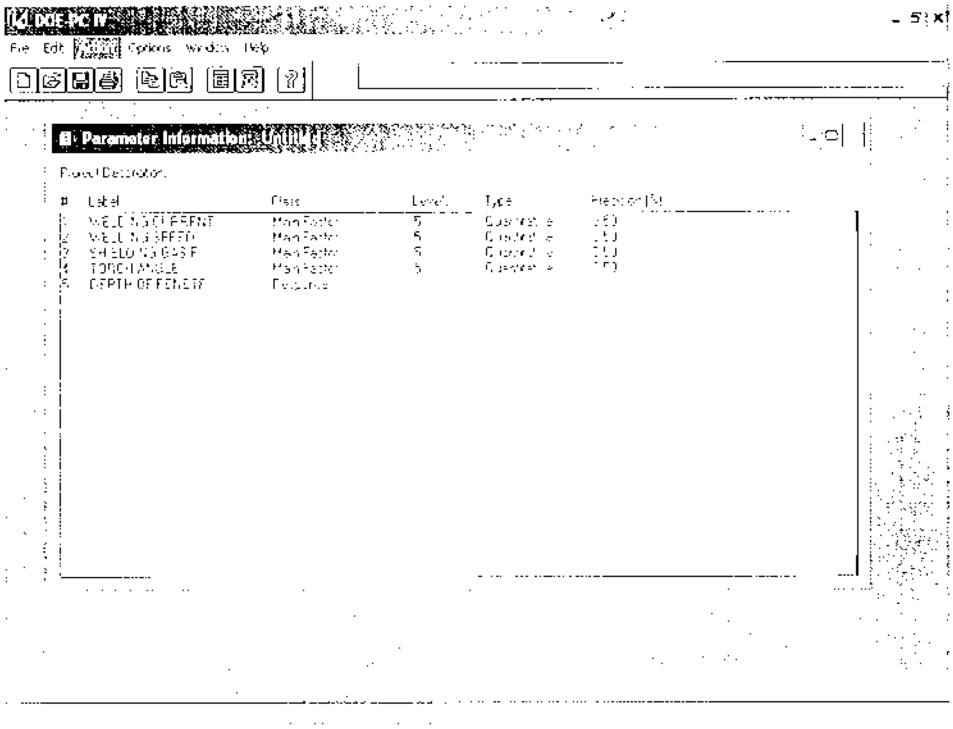
STEP 8:

Finally, a dialogue box is obtained showing all the input and output parameters.



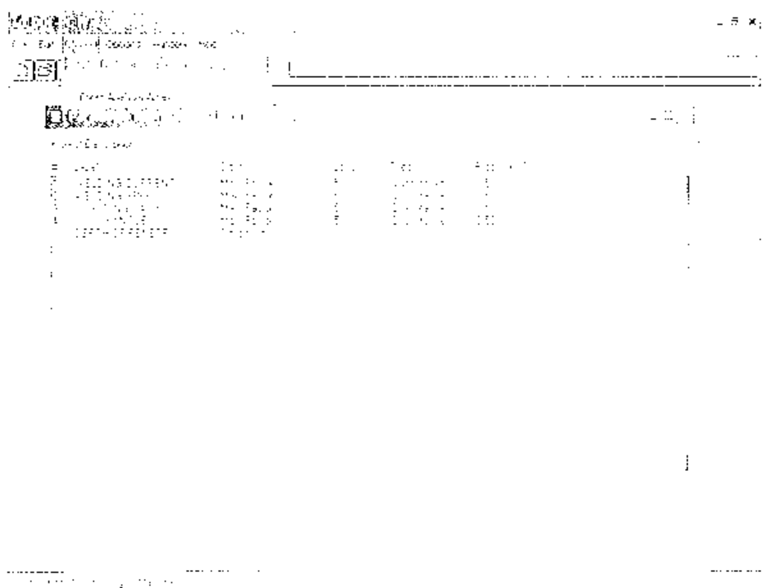
STEP 9:

'ACTION' option is chosen from the standard tool bar.



STEP 10:

Now the 'MAIN FACTOR INTERACTION ARRAY' option is chosen the drop down menu.

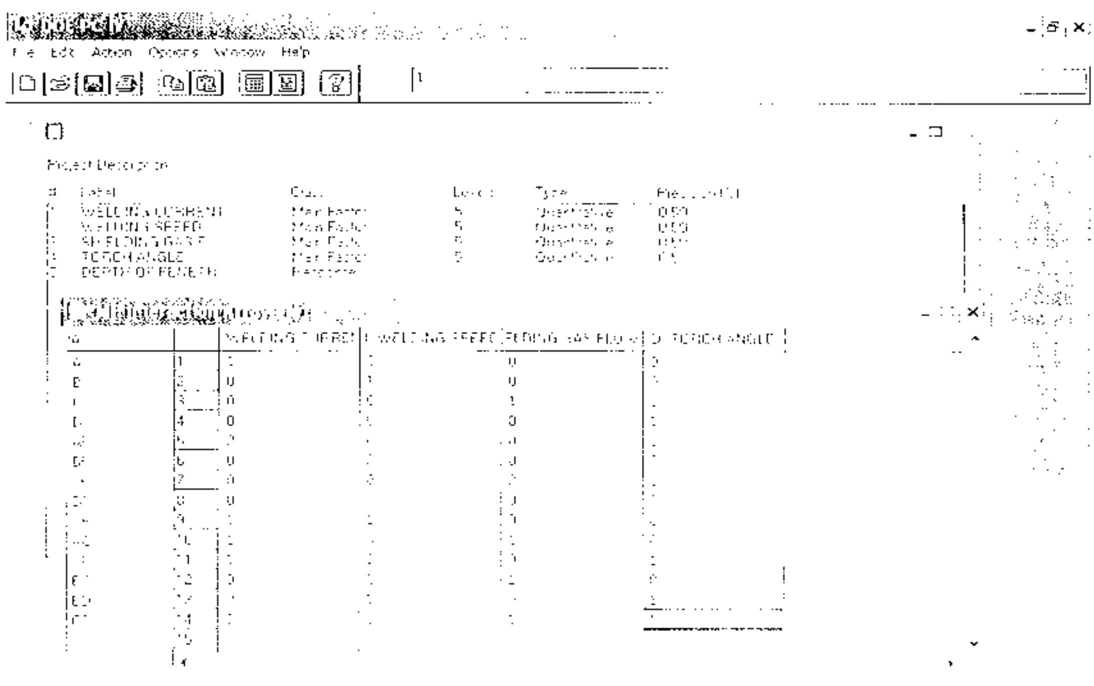


STEP 11:

Then the 'RESPONSE SURFACE' option is chosen from the given options.

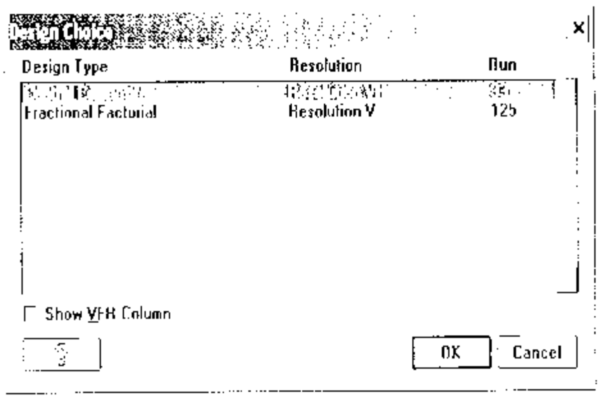
STEP 12:

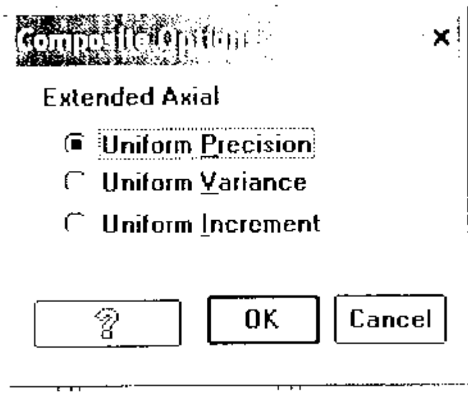
Now the 'CHOOSE DESIGN ARRAY' option is chosen from the drop down menu.



STEP 13:

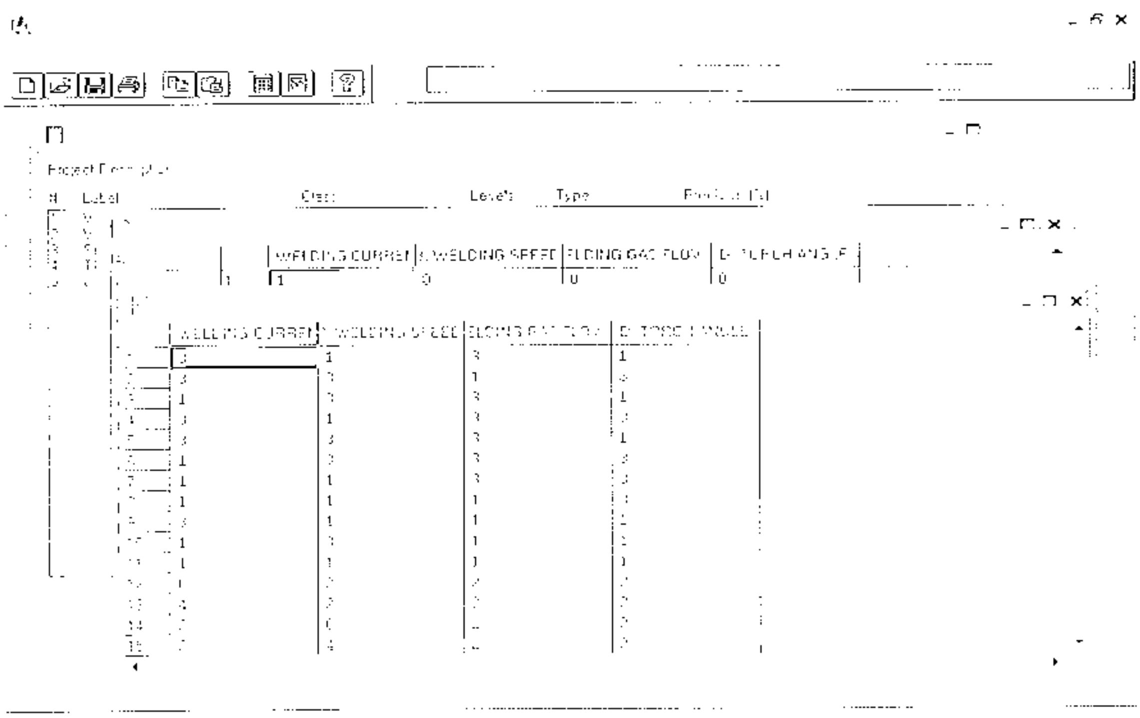
After this, the 'CENTRAL COMPOSITE' design type is chosen along with 'UNIFORM PRECISION' type.





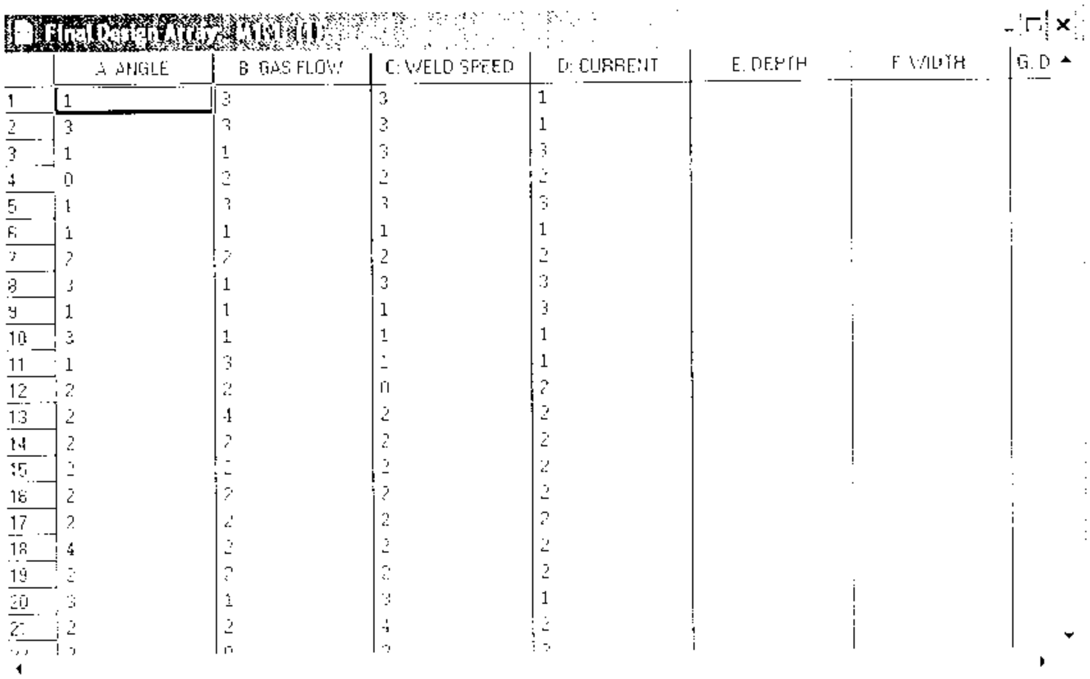
STEP 14:

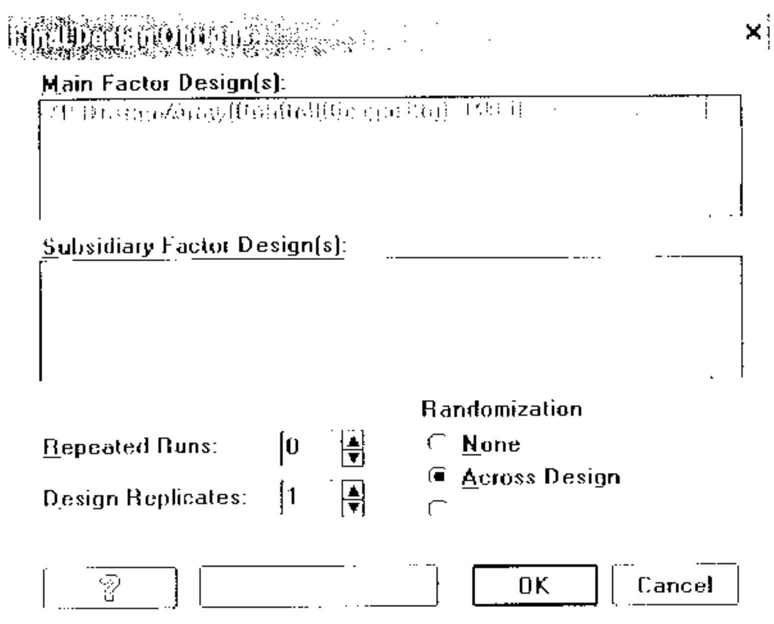
After this, the 'CENTRAL DESIGN ARRAY' option is chosen from the drop down menu and the design matrix from the excel sheet is copied and pasted.



STEP 15:

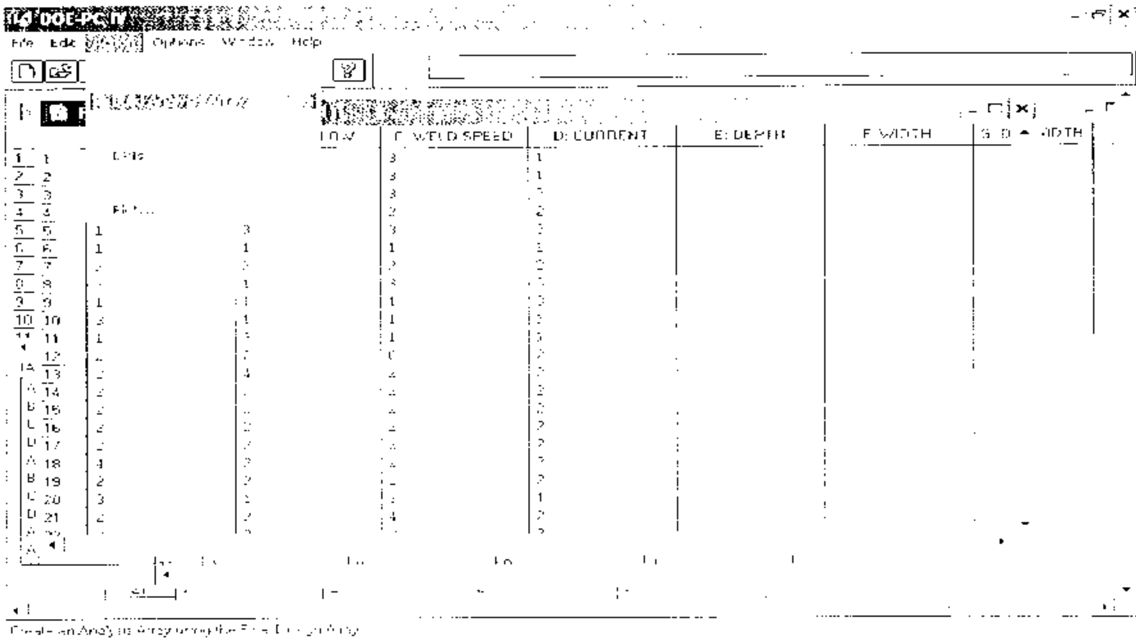
After copying the design matrix, the 'FINAL DESIGN MATRIX' option is chosen from the drop down menu after which 'NONE' randomization option is selected.





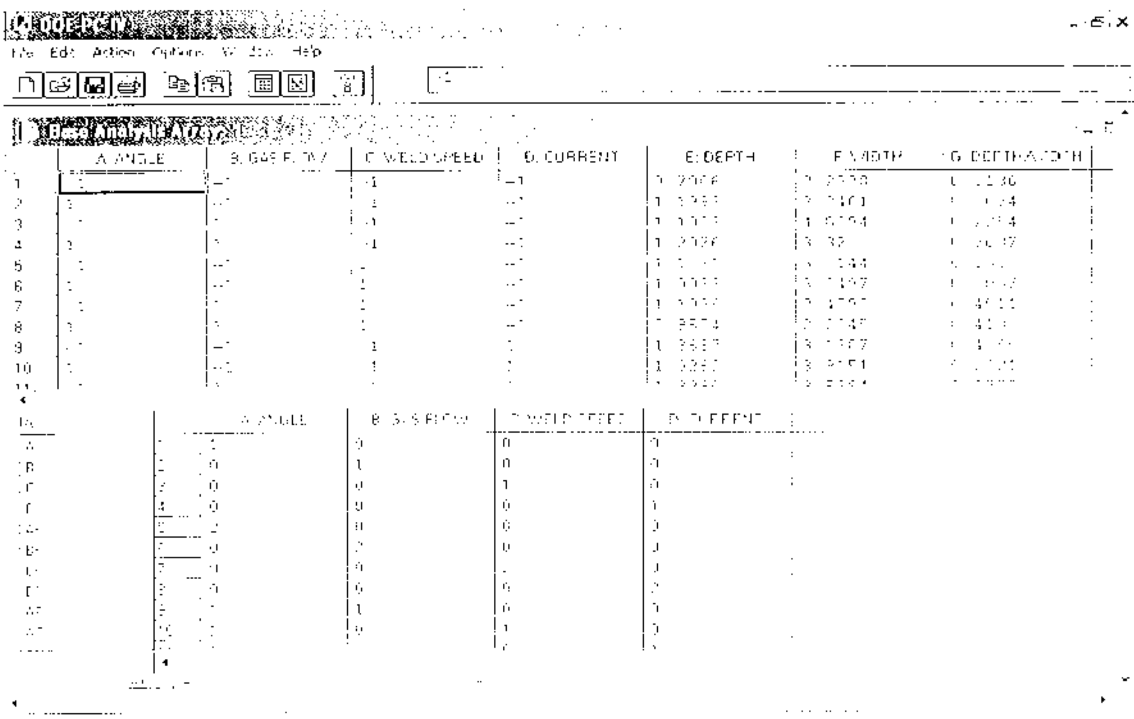
STEP 16:

Then the 'BUILD ANALYSIS ARRAY' option is chosen.



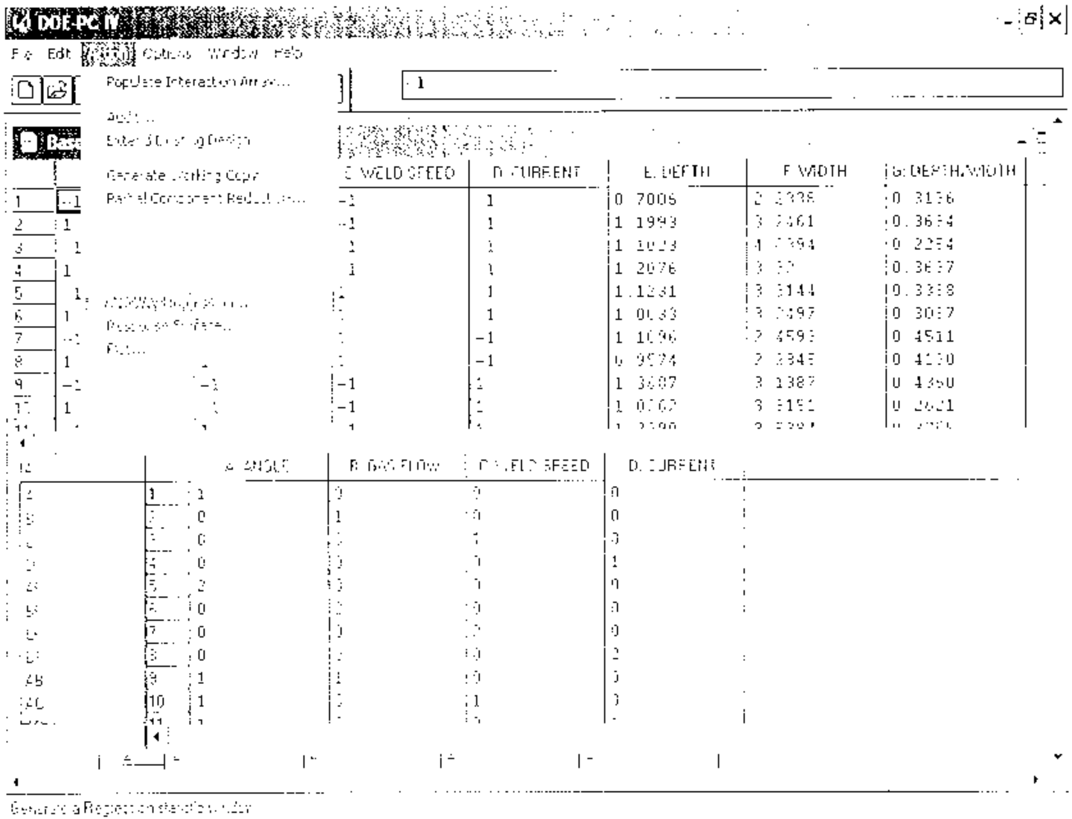
STEP 17:

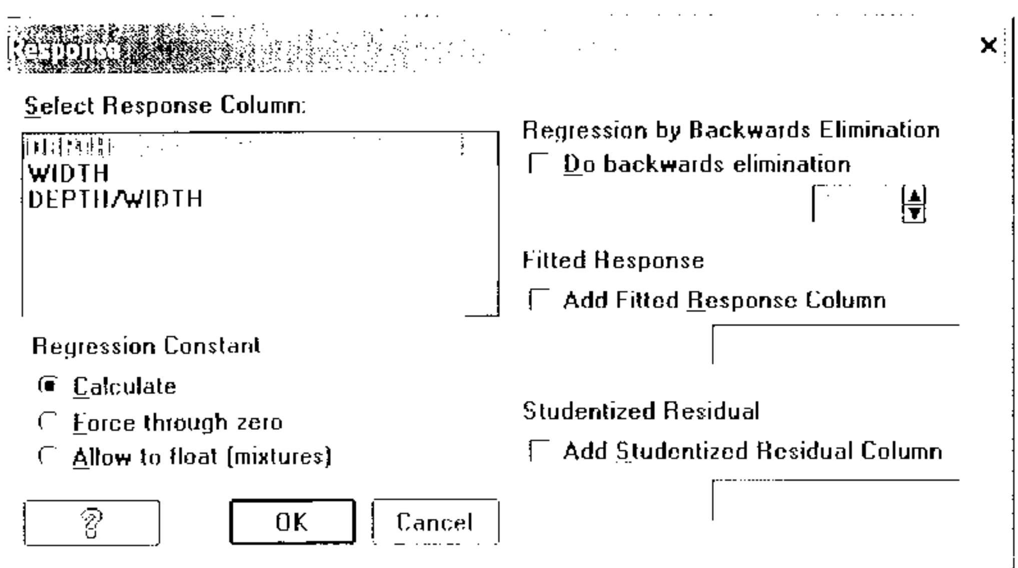
Now the value of the output is pasted from the excel sheet.



STEP 18:

After this, the 'ANOVA / REGRESSION' option is chosen from the drop down menu in order to find the values of regression coefficients.





STEP 19:

Finally, the values of the regression coefficients are obtained from which the mathematical model is developed. Also, the value of F-ratio and R-ratio are obtained to check the adequacy.

DOE-PC IV - [ANOVA/Regression Results]

File Edit Action Options Window Help

Source / Parameter	Level of Significance	Levels	Coefficient	Standard Error	Transmitted Variance
Mean	0.000	0	0.559	0.000	0.000
A ANGLE	0.599	5	0.069	0.080	0.067
B GAS FLOW	0.794	5	0.106	0.080	0.067
C WELD SPEED	0.872	5	-0.129	0.080	0.067
D CURRENT	0.950	5	0.171	0.080	0.067
A²	0.977	25	0.185	0.074	0.061
B²	0.940	25	0.149	0.074	0.061
C²	0.952	25	0.158	0.074	0.061
D²	0.872	25	0.110	0.074	0.061
AB	0.105	25	-0.013	0.099	0.082
AC	0.476	25	-0.064	0.099	0.082
AD	0.544	25	-0.075	0.099	0.082
BC	0.421	25	-0.056	0.099	0.082
BD	0.141	25	0.012	0.099	0.082
CD	0.011	25	-0.001	0.099	0.082

CORRELATION TABLE

	A	B	C	D	A²	B²	C²	D²	AB	AC	AD
A	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
B		1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C			1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
D				1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
A²					1.000	-0.099	0.088	-0.088	0.000	0.000	0.000
B²						1.000	-0.088	0.088	0.000	0.000	0.000
C²							1.000	-0.088	0.000	0.000	0.000
D²								1.000	0.000	0.000	0.000
AB									1.000	0.000	0.000
AC										1.000	0.000
AD											1.000
BC											

CHAPTER 7

OPTIMIZATION

7.1 INTRODUCTION

Optimization is the process of obtaining the best results under given circumstances. In design, construction and maintenance of any engineering system, engineers/managers have to take many technological and managerial decisions at several stages. Fig 7.1 shows the steps involved in the optimization process.

The ultimate goal of all such decisions is to either minimize the effort required or maximize the desired benefits.

Mechanical engineers design mechanical equipments like pumps, turbines and heat transfer equipments for maximum efficiency and mechanical components like linkages, cams, and gears, machine tools for the purpose of achieving either a minimum manufacturing cost or a maximum component life.

Production engineers are interested in designing optimum schedules of various machining operations to minimize the idle time of machines and the overall job completion time.

7.1.1 TYPES OF OPTIMIZATION TECHNIQUES

The following are the types of optimization.

i. traditional optimization technique and

ii. non-traditional optimization technique

7.1.2 TRADITIONAL AND NON - TRADITIONAL OPTIMIZATION TECHNIQUES

Traditional techniques for optimization include linear programming, random search method, geometric programming, dynamic programming and integer programming.

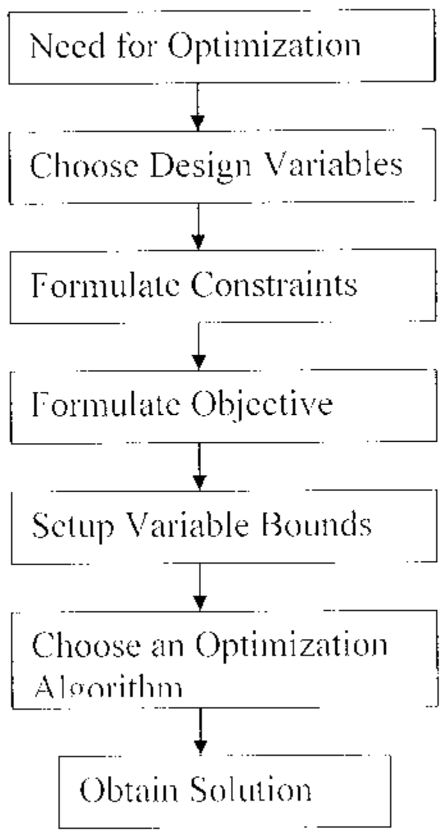


FIG. 7.1 STEPS INVOLVED IN THE OPTIMIZATION PROCESS

7.2 ADVANTAGES OF NON-TRADITIONAL OPTIMIZATION TECHNIQUES:

The advantages of non-traditional optimization techniques are as follows:

1. A population of points is used for starting the procedure instead of a single design point.

2. GA uses only the values of the objective function. The derivatives are not used in the search procedure.

3. Search method is naturally applicable for solving discrete and integer programming problems. For continuous design variables, the string length can be varied to achieve any desired resolution.

4. The objective function value corresponding to a design vector plays the role of fitness in natural genetics.

5. In every new generation, a new set of strings is produced by using randomized parents selection and crossover from the old generation.

7.3 PROCESS OPTIMIZATION

When optimization is based on the process that the product undergoes is called Process Optimization.

The ability to control a process does not guarantee optimal control. Optimal process control can be a difficult task due to several reasons.

1. Complex correlations between process variables might make it necessary to consider many parameters simultaneously during process adjustments.

2. Several process levels might exist, all with different optimal variable settings.

3. Changes in raw materials and process conditions require continuous adjustments of variable settings.

4. Several quality parameters might need to be optimized simultaneously.

This project work is mainly concerned with process parameters such as welding current (I), welding speed (S), welding torch angle (T) and shielding gas flow rate (F) of Gas Tungsten Arc Welding (GTAW). Hence it comes under process optimization.

7.4 OBJECTIVES OF OPTIMIZATION

Following are the objectives of optimization

1. To reduce wastage of material, money and processing time.

2. To decrease the fatigue of the worker who is on the shop floor.

3. To increase productivity of the organization gradually.

4. To satisfy the employees in the organization.

5. Procurement of material will be very less because of the higher productivity.

7.5 TYPES OF SOLUTION

1. A solution to an optimization problem specifies the values of the decision variables, and also the value of the objective function.

2. A feasible solution satisfies all constraints.

3. An optimal solution is feasible and provides the best objective function value. There may be multiple optimal solutions for a given problem.

4. A near optimal solution is feasible and provides a superior objective function value, but not necessarily the best.

7.6 THE GENERAL PROCEDURE USED TO FORMULATE AND SOLVE OPTIMIZATION PROBLEMS

Many of the optimization techniques are adaptable to parallel computing. Much of the current research is focused on methods of decreasing the computation time.

The following steps summarize the general procedure used to formulate and solve optimization problems. Some problems may not require that the engineer follow the steps in the exact order, but each of the steps should be considered in the process.

1) Analyze the process itself to identify the process variables and specific characteristics of interest, i.e., make a list of all the variables.

2) Determine the criterion for optimization and specify the objective function in terms of the above variables together with coefficients.

3) Develop via mathematical expressions a valid process model that relates the input-output variables of the process and associated coefficients. Include both equality and inequality constraints. Use well known physical principles such as mass balances, energy balance, empirical relations, implicit concepts and external restrictions. Identify the independent and dependent variables to get the number of degrees of freedom.

4) If the problem formulation is too large in scope:

   - break it up into manageable parts, or
   - simplify the objective function and the model

5) Apply a suitable optimization technique for mathematical statement of the problem.

6) Examine the sensitivity of the result, to changes in the values of the parameters in the problem and the assumptions.

In this thesis optimization of Gas Tungsten Arc Welding (GTAW) is attempted using an optimization technique called Genetic Algorithm (GA).

CHAPTER 8

GENETIC ALGORITHM

8.1 INTRODUCTION

Definition: A genetic algorithm (GA) is a search technique used in computing to find exact or approximate solutions to optimization and search problems. Genetic algorithms are categorized as global search heuristics. Genetic algorithms are a particular class of evolutionary algorithms (also known as evolutionary computation) that use techniques inspired by evolutionary biology such as inheritance, mutation, selection, and crossover (also called recombination).

The idea of applying the biological principles of natural evolution to artificial systems, introduced more than three decades ago, has seen impressive growth in the past few years. The basic concept of Genetic Algorithm is to encode a potential solution to a problem as a series of parameters. A single set of parameters value is treated as the genome of an individual solution. An initial population of individuals is generated at random or statistically.

Every evolutionary step, known as a generation, the individuals in the current population are decoded (evaluated) according to some predefined quality criterion, referred to as fitness function. The chromosomes with the highest population fitness function. The chromosomes with the highest population fitness score are selected for mating. The genes of the two parents are allowed to exchange to produce offsprings. These children then replace their parents in the next generation. Thus, the old population is discarded and the new population becomes the current population. The current population is checked for acceptability of solution. The iteration is stopped after the completion of maximal number of generations or on the attainment of the best result.

8.1.1 BASIC DESCRIPTION OF GENETIC ALGORITHM

The Genetic Algorithms are inspired by Darwin's theory about evolution. Algorithm is started with a set solutions from one population are taken and used to form a new population. This is motivated by a hope, that the new population will be better than the old one. Solutions which are selected to form new solutions (offsprings) are selected according to their fitness. The more suitable they are, the more chances they have to reproduce. This is repeated until some conditions (for example, number of population or improvement of the best solution) are satisfied.

8.1.2 OUTLINE OF BASIC GENETIC ALGORITHM CYCLE

The genetic algorithm cycle used in this study is illustrated in Fig.8.1. The various steps involved are briefly described as given below.

8.1.2.1 Start

Random populations of 'n' chromosomes (suitable solutions for the problem) are generated.

8.1.2.2 Fitness

The fitness function of each chromosome in the population is evaluated.

8.1.2.3 New Population

A new population is created by repeating following steps.

8.1.2.4 Selection

Two parent chromosomes are selected from the population according to their fitness, better the fitness, bigger the chance to be selected.

8.1.2.5 Cross-over

The parents are crossed over to form a new offspring with a cross-over probability.

8.1.2.6 Childless

If no cross-over is performed, offspring is an exact copy of parents.

8.1.2.7 Mutation

New offsprings are mutated with a mutation probability.

8.1.2.8 Accepting

New offsprings are placed in a new population.

8.1.2.9 Replace

Newly generated population is used for a further run of algorithm, that is, individuals from old population are killed and replaced by the new ones.

8.1.2.10 Test

The generation is stopped, if the condition is satisfied and returns the best solution in current population.

8.1.2.11 Loop

If the termination criteria are not met, the loop is repeated from the fitness step again as reported above.

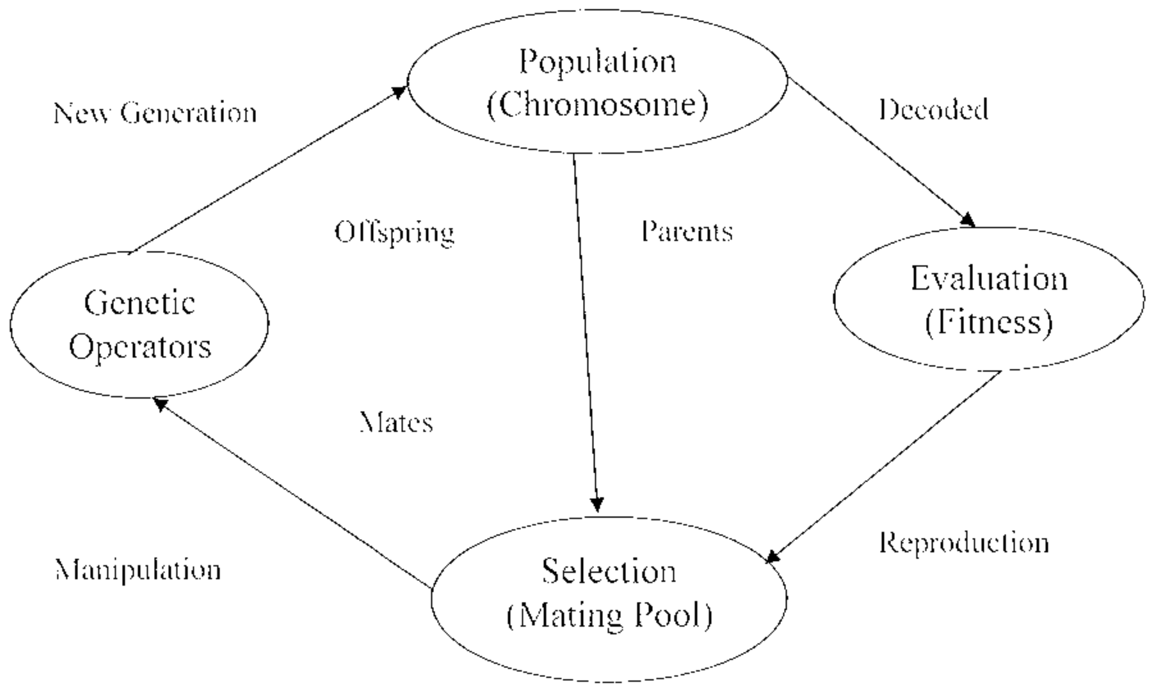


FIG. 8.1 GENETIC ALGORITHM CYCLE

8.2 OPTIMIZATION PROCEDURE:

The GTAW optimization procedure using genetic algorithm shown in figure 16 is used in this study. Her, initial population means the lower bounds of the optimization problems, and each possible solution is called an individual. In this work, a possible solution is formed by values of the welding current, welding speed, torch angle and shielding gas flow rate. The following section will give the clear cut procedure of using the MATLAB genetic algorithm tool options for that has chosen.

8.2.1 Fitness Function

Fitness function is the objective function that is to minimize. Specify the function as a function handle of the form @objfun, where objfun.m is an M-file that returns a scalar. In this study depth-to-width ratio is taken as objective function.

8.2.2 Number of variables

The number of independent variables for the fitness functions. Here four numbers of variables were taken for simulation.

8.2.3 Plot Functions

Plot functions enable to plot various aspects of the genetic algorithm as it is expecting. Each one will draw in a separate axis on the display window. The stop button on the window is used to interrupt a running process. The following section shows the options in the GA tool command window.

8.2.4 Plot interval

Plot interval specifies the number of generations between successive updates of the plot. One is taken for the study.

8.2.5 Best Fitness Plot

Best fitness plot. plots the best function value in each generation versus iteration number. The best fitness value will show the optimized value of the objective function. In this work it shows the optimized value of depth-to-width ratio.

8.2.6 Expectation Plot

Expectation plot will plot the expected number of children versus the raw scores at each generation.

8.2.7 Score Diversity Plot

Score diversity plot will plot a histogram of the scores at each generation.

8.2.8 Stopping Plot

Stopping plot will plot the stopping criteria levels.

8.2.9 Best Individual Plot

Best individual plot, plots the vector entries of the individual with the best fitness function value in each generation. Here it plots the histogram of welding current, welding speed, nozzle-to-plate distance and shielding gas flow rate which is indicated as 1, 2, 3 and 4 respectively.

8.2.10 Genealogy Plot

Genealogy plot plots the genealogy of individuals. Lines from one generation to the next are colour-coded as follows:

1. Red lines indicate mutation children.
2. Blue lines indicate crossover children.
3. Black lines indicate elite individuals.

8.2.11 Scores Plot

Scores plot will plot the scores of the individuals at each generation.

8.2.12 Distance Plot

Distance plot will plot the average distance between individuals at each generation.

8.2.13 Range Plot

Range plot will plot the minimum, maximum and mean fitness function values in each generation.

8.2.14 Selection Plot

Selection plot will plot a histogram of the parents. This shows you which parents are contributing to each generation.

8.2.15 Custom function

Custom function enables to use own plot function.

8.2.16 Population Options

Population options specify options for the population of the genetic algorithm as shown.

8.2.17 Population type

Population type specifies the type of the input to the fitness function. Double vector is taken as the population type.

8.2.18 Population Size

Population size specifies how many individuals there are in each generation. If population size to be a vector of length greater than 1, the algorithm creates multiple subpopulations. Each entry of the vector specifies the size of a subpopulation. For this work population size is set as 31.

8.2.19 Creation Function

Creation function specifies the function that creates the initial population. The default creation function uniform creates a random initial population with a uniform distribution.

8.2.20 Initial population

Initial population enables to specify an initial population for the genetic algorithm. An initial population not specified, for this work the algorithm will create one using the creation function.

8.2.21 Initial Scores

Initial scores enable to specify scores for initial population. If initial scores not specified, the algorithm will compute the scores using the fitness function. For this work initial score was not specified.

8.2.22 Initial Range

Initial range specifies lower and upper bounds for the entries of the vectors in the initial population. Initial range can be specified as a matrix with 2 rows and initial length columns. The first row contains lower bounds for the entries of the vectors in the initial population, while the second row contains upper bounds. If initial range is specified as a 2-by-1 matrix, the two scalars are expanded to constant vectors of length initial length. Here the initial range is specified as [-2, -2, -2, -2, 2, 2, 2, 2] which is the coded values of the input.

8.2.23 Fitness Scaling Options

The scaling function converts raw fitness scores returned by the fitness function to values in a range that is suitable for the selection function.

8.2.24 Scaling Function

Scaling function specifies the function that performs the scaling. The following are the various options:

1. Rank will scale the raw scores based on the rank of each individual, rather than its score. The rank of an individual is its position in the sorted scores. The rank of the fittest individual is 1, the next fittest is 2 and so on. Rank fitness scaling removes the effect of the spread of the raw scores.

2. Proportional will make the expectation proportional to the raw fitness score. This strategy has weakness when raw scores are not in a "good" range.

3. Top will scale the individuals with the highest fitness values equally. If this option selected, then specify as quantity, the number of fittest individuals that produce offspring. Quality must be an integer between 1 and population size or s fraction between 0 and 1 specifying a fraction of the population size. Each of these individuals has an equal probability of reproducing. The rest have probability 0 of reproducing. The expectation has the form [0 1/n 1/n 0 0 1/n 0 0 1/n......]

4. Shift linear – The function will scale the raw scores so that the expectation of the fittest individual is equal to a constant, which should be specified as maximum survival rate, multiplied by the average score.

5. Custom will enable to write own scaling function.

Among these options rank is chosen as the scaling function for this work.

8.2.25 Selection Options

The selection function will choose parents for the next generation based on their scaled values from the fitness scaling function.

Selection option is chosen from the following selection functions:

1. Stochastic uniform will layout a line which each parent corresponds to a section of the line of length proportional to its expectation. The algorithm will move along the line in steps of equal size, one step for each parent. At each step, the algorithm will allocate a parent from the section it lands on. The first step is a uniform random number less than the step size.

2. Remainder will assign parents deterministically from the integer part of each individual's scaled value and then uses roulette selection on the remaining fractional part.

3. Uniform will select parents at random from a uniform distribution using the expectations and number of parents. This results in an undirected search. Uniform selection is not a useful search strategy, but can used to test the genetic algorithm.

4. Roulette simulates a roulette wheel with the area of each segment proportional to the expectation. The algorithm then uses a random number to select one of the sections with a probability equal to its area.

5. Tournament - The function will select each parent by choosing individuals at random, and then choosing the best individual out of that set to be a parent.

6. Custom will enables to write own selection function.

Hence roulette is chosen for the study.

8.2.26 Reproduction Options

Reproduction options will determine how the genetic algorithm creates children at each new generation.

8.2.27 Elite Count

Elite count will specify the number of individuals that are guaranteed to survive to the next generation. Hence elite count must be a positive integer less than or equal to population size.

8.2.28 Crossover Fraction

Crossover fraction will specify the fraction of the next generation, other than elite individuals, that are produced by crossover. The remaining individuals, other than elite individuals, in the next generation are produced by mutation. So crossover fraction should be a fraction between 0 and 1, either by entering the fraction in the text box or moving the slider.

8.2.29 Mutation Options

Mutation function will make small random changes in the individuals in the population, which provides genetic diversity and enable the GA to search a broader space. Specify the function that performs the mutation in the mutation function field. The option is chosen from the following functions:

1. Uniform is a two-step process. First, the algorithm will select a fraction of the vector entries of an individual for mutation, where each entry has a probability of mutation rate of being mutated. In the second step, the algorithm will replace each selected entry by a random number selected uniformly from that entry.

2. Gaussian will add a random number to each vector entry of an individual. This random number is taken from Gaussian distribution centered on zero. The variance of this distribution can be controlled with two parameters. The scale parameter determines the variance at the first generation. The shrink parameters control how variance shrinks as generations go by. If the shrink parameter is 0, the variance shrinks as generations go by. If the shrink parameter is 0, the variance is constant. If the shrink parameters is 1. The variance shrinks to 0 linearly as the last generation is reached.

3. Custom will enables to write own mutation function.

Uniform is the option for the study.

8.2.30 Crossover Options

Crossover combines two individuals, or parents, to form a new individual, or child, for the next generation.

It specifies the function that performs the crossover in the crossover function field. From the following functions the crossover option is chosen:

1. Single point will choose a random integer n between 1 and number of variables, and selects the vector entries numbered less than or equal to n from the first parent, selects genes numbered greater than n from the second parent and concatenates these entries to form the child.

2. Two point will select two random integers m and n between 1 and number of variables. The algorithm selects genes numbered less than or equal to m from the first parent, will select genes numbered from m+1 to n from the second parent, and selects genes numbered greater than n from the first parent. The algorithm then concatenates these genes to form a single gene.

3. Scattered will create a random binary vector. It then selects the genes where the vector is a 1 from the first parent, and the genes where the vector is a 0 from the second parent and combines the genes to form the child.

4. Intermediate creates children by a weighted average of the parents. Intermediate crossover is controlled by a single parameter ratio:

   Child = parent + rand * ratio * (parent2 - parent1)

If ratio is in the range [0, 1] then the children produced are within the hypercube defined by the parent's locations at opposite vertices.

If ratio is in a larger range, say 1.1 then children can be generated outside the hypercube. Ratio can be a scalar or a vector of length number of variables. If ratio is a scalar, then all of the children will lie on the line between the parents. If ratio is a vector then children can be any point within the hypercube.

5. Heuristic will create children that lie on the line containing the two parents, a small distance away from the parent with the better fitness value in the direction away from the parent with the worse fitness value.

6. Custom will enable to write own crossover function.

So intermediate is used for this work.

8.2.31 Migration Options

Migration is the movement of individuals between subpopulations, which the algorithm creates if population size is to be a vector of length greater than 1. Every so often, the best individuals from one subpopulation replace the worst individuals in another subpopulation. Controlling migration occurs by the following three parameters.

8.2.32 Direction

Migration can take in one direction or two.

1. If direction is set as forward, migration takes place toward the last subpopulation. That is the nth subpopulation migrates into the $(n-1)^{th}$ subpopulation.

2. If direction is set as both, the nth subpopulation migrates into both the $(n-1)^{th}$ and the $(n+1)^{th}$ subpopulation.

3. Migration wraps at the ends of the subpopulations. That is, the last subpopulation migrates into the first, and the first may migrate into the last. To prevent wrapping, a subpopulation of size zero is specified.

Forward direction of migration is taken for the work.

8.2.33 Fraction

Fraction controls how many individuals move between subpopulations. Fraction is the fraction of the smaller of the two subpopulations that moves. If individuals migrate from a subpopulation of 50 individuals into a population of 100 individuals and fraction is 0.1, 5 individuals (0.1 * 50) migrate. Individuals that migrate from one subpopulation to another are copied. They are not removed from the source subpopulation.

Default migration fraction 0.2 is taken for the work.

8.2.34 Interval

Interval controls how many generations pass between migrations. For this work migration interval is set as 20, hence migration between subpopulations takes place every 20 generations.

8.2.35 Hybrid Function Options

Hybrid function enables to specify another minimization function that runs after the genetic algorithm terminates. The choices are

1. None
2. fminsearch
3. patternsearch
4. fminunc

None is set as hybrid function option. Because no other function will run after GA terminates.

8.2.36 Stopping Criteria Options

Stopping criteria will determine what causes the algorithm to terminate.

8.2.37 Generation

Generation specify the maximum number of iterations the genetic algorithm performs.

8.2.38 Time Limit

Time limit will specify the maximum time in seconds the genetic algorithm runs before stopping.

8.2.39 Fitness Limit

If the best fitness value is less than or equal to the value of fitness limit, the algorithm stops.

8.2.40 Stall Generations

If there is no improvement in the best fitness value for the number of generations specified by stall generations, the algorithm stops.

8.2.41 Stall Time Limit

If there is no improvement in the best fitness value for an interval of time in seconds specified by stall time limit, the algorithm stops.

8.3 Output Function Options

8.3.1 History to New Window

The iterative history of the algorithm outputs to a separate window.

8.3.2 Interval

Interval specifies the number of generations between successive outputs.

8.3.3 Custom

Custom enables to write own output function.

8.4 Display to Command Window Options

8.4.1 Level of Display

Level of displays specifies the amount of information displayed in the MATLAB command window while running the genetic algorithm. Option is chosen from the following options:

1. Off – Only the final answer is displayed.
2. Iterative – Information is displayed for each iteration.
3. Diagnose – Information is displayed if the algorithm fails to converge. In addition, options that are changed from the defaults are listed.
4. Final – The outcome of the pattern search (successful or unsuccessful), the reason for stopping, and the final point are displayed.

Off is chosen for the work.

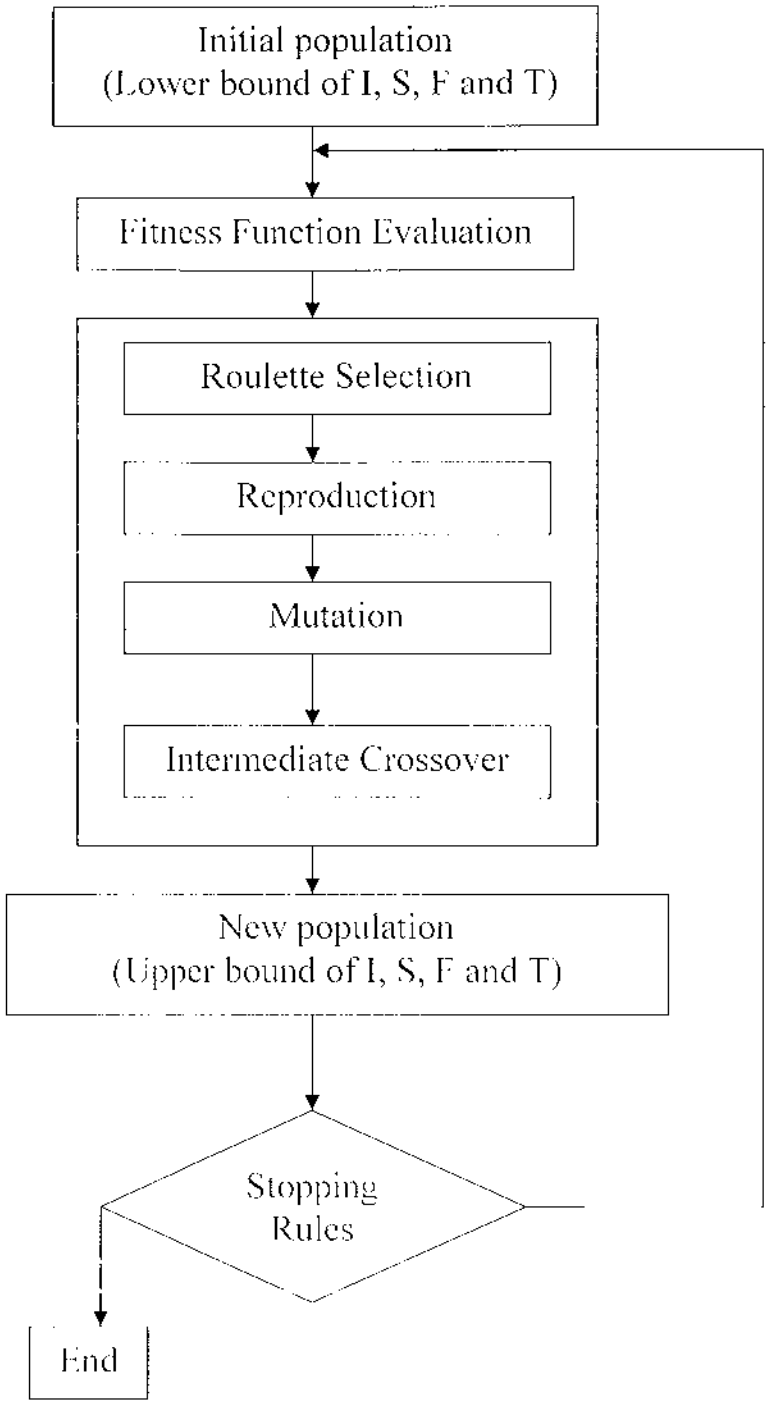


FIG. 8.2 FLOW CHART FOR GENETIC ALGORITHM

8.5 SIMULATION PROCEDURE

The aim of this study is to find the optimum adjusts for the welding current, welding speed, gas flow rate and welding gun angle in GTA welding process. The optimum parameters are those that deliver responses closest possible to the cited values. And it is assumed that the near optimal point is within the following experimental region proposed by Shanping Lu and is shown in the Table 8.1

TABLE 8.1 GA SEARCH RANGES

Parameters	Range
Welding current	70 to 110
Welding speed	170 to 210
Gas flow rate	5 to 25
Welding gun angle	50 to 90

When the MATLAB command window is opened, an M-file has been created and saved as the file name dot m (.m). Then, in the MATLAB command window to open GA tool, type gatool and press enter. When GA toolbox is opened, enter the fitness function as @file name (same file name where the M-file has been saved), number of variables that is used for the fitness function and select the plots required. The table 8 shows the options used for the study.

In GA, the population size, crossover rate and mutation rate are important factors in the performance of the algorithms. A large population size or a higher crossover rate allows exploration of the solution space and reduces the chances of settling for poor solution. However, if they are too large or high it results in wasted computation time exploring unpromising regions of the solution space.

About mutation rate, if it is too high, there will be much random perturbation, and the offspring will loose the good information of the parents. The 1% value is within the typical range for the mutation rate. The crossover rate is 90%, i.e. 90% of the pairs are crossed, whereas the remaining 10% are added to the next generation without crossover. The chosen type of the crossover was single, which means that a new individual is formed when the parent genes are swapped over at some random single point along their chromosome. Accuracy is the bit quantity for each variable.

TABLE 8.2 OPTIONS OF GA COMPUTATION

Population Type	Double Vector
Population size	31
Creation Function	Uniform
Initial range	[-2,-2,-2,-2;2,2,2,2]
Fitness Scaling function	Rank
Selection function	Roulette
Reproduction elite count	2
Crossover fraction	0.9
Mutation function	Uniform
Mutation rate	0.01
Crossover function	Intermediate
Migration Direction	Forward
Migration Fraction	0.2
Migration Interval	20
Hybrid Function	None
Number of generations	100
Stall generations	50
Stall time limit	20

8.6 SELECTION OF OBJECTIVE FUNCTIONS AND CONSTRAINTS

The objective function selected for optimization was Depth/Width ratio. The response variables bead width, depth of penetration were given as constraints in the equation.. In optimization, generally the constraints with their upper bounds should be given in such a way that their value will be less than of equal to zero. Also, the objective function will usually be minimized. To obtain good depth/width ratio in any application, it is always desirable to have maximum weld bead width. The process parameters and their notations used in writing the M-file using MATLAB software are given below.

A = Welding current (I)

B = Welding speed (S)

C = Gas flow rate (F)

D = Welding torch angle (T)

8.7 OPTIMIZATION OF THE FUNCTION

The purpose is optimization of weld bead geometry parameters with their limits as constraints. The model is a non-linear model with constraints. The constrained minimum of a scalar function of several functions of several variables at an initial estimate, which is referred as "constrained non-linear optimization" is mathematically stated as follows:

Minimize $f(x)$

Subject to $g(x1, x2, x3....xn) \leq 0$

The limits of the constraints bead width and depth of penetration were established by data obtained from past experience with a view that they should provide a sound and defect-free weld bead along with a feasible solution to objective function.

Several numerical methods are available for optimization of non linear equation with constraints. A Genetic Algorithm method is efficient and quickest one, and this method is used to determine the optimal Depth/Width ratio. The step by step procedure of minimization of Depth/Width ratio using the GA optimization tool box available in MATLAB software is as follows.

Step 1: Writing M-file function [f, g] = f(x)

[f,g] = beadonplate(x)

f(1)=0.154+0.009*x(1)+0.013*x(2)-0.009*x(3)+0.010*x(4)+
0.050*x(1)^2+0.045*x(2)^2+0.053*x(3)^2+0.039*x(4)^2+
0.004*x(1)*x(2)-0.010*x(1)*x(3)-0.037*x(1)*x(4)+0.016*x(2)*x(3)-
0.018*x(2)*x(4)-0.011*x(3)*x(4); Depth to width ratio.

g(1)=0.558+0.069*x(1)+0.106*x(2)-0.129*x(3)+0.171*x(4)
+0.185*x(1)^2+0.150*x(2)^2+0.158*x(3)^2+0.119*x(4)^2-
0.013*x(1)*x(2)-0.064*x(1)*x(3)-0.075*x(1)*x(4)-0.056*x(2)*x(3)-
0.018*x(2)*x(4)-0.001*x(3)*x(4)-1.9874; upper limit of depth of penetration

g(2)=0.4237-0.558+0.069*x(1)+0.106*x(2)-0.129*x(3)+0.171*x(4)
+0.185*x(1)^2+0.150*x(2)^2+0.158*x(3)^2+0.119*x(4)^2-
0.013*x(1)*x(2)-0.064*x(1)*x(3)-0.075*x(1)*x(4)-0.056*x(2)*x(3)-
0.018*x(2)*x(4)-0.001*x(3)*x(4); lower limit of depth of penetration.

CHAPTER 9

RESULTS AND DISCUSION

After running the M-file in MATLAB 7.0 simulation software for the optional setting parameters that has been shown on Table 8.2.

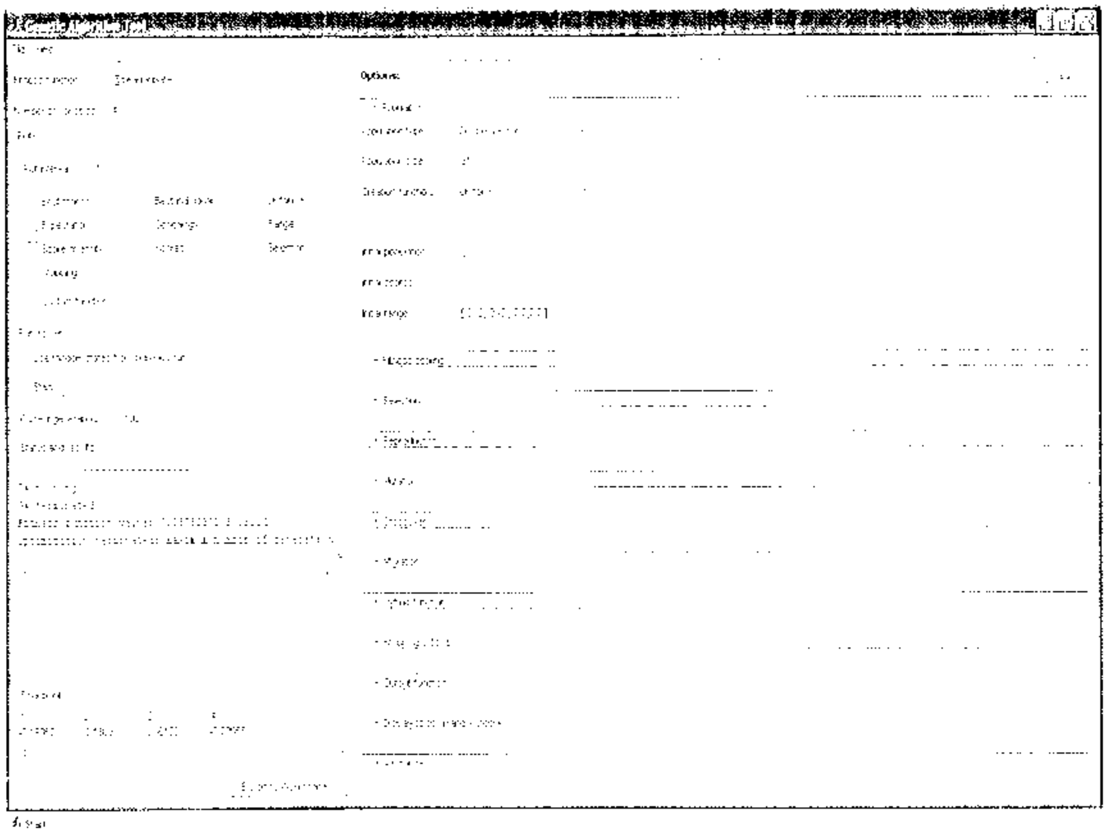


FIG. 9.1 GA INPUT OPTIONS

The execution and output from GA is shown below. Among the above results optimum values of the process parameters obtained are shown below. at 100th iteration is found to be the best. The genetic algorithm tool box setting has been shown below.

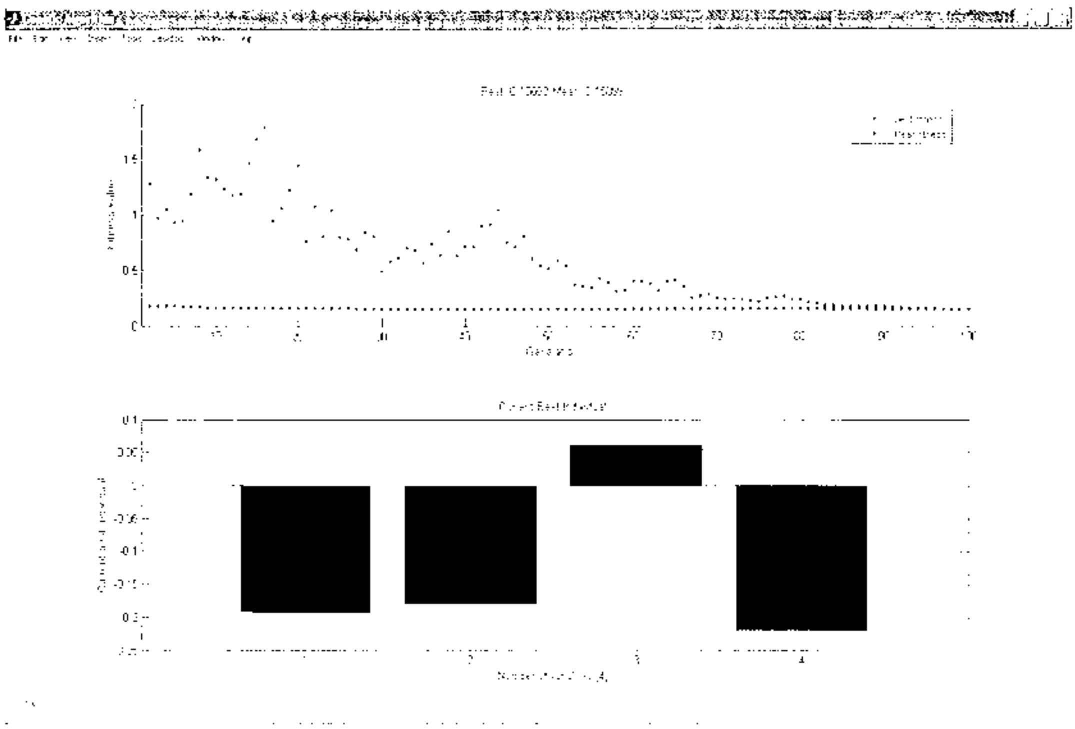


FIG. 9.2 GA OUTPUT GRAPH

Corresponding optimal input parameters are as follows.

X (1) = Welding Current (I) = 88.0618 Amps

X (2) = Welding speed (S) = 188.197 mm/min

X (3) = Shielding gas flow rate (F) = 10.4617 litres/min

X (4) = Welding torch angle (T) = 67.7905 degree

For these optimized process parameters, the values of the weld parameters are:

Bead Width (W) = 8.4663 mm

Depth of Penetration (D) = 2.1949 mm

Depth to width ratio (D/W) = 0.1549

CHAPTER 10

CONCLUSIONS

- A five level four factor full factorial design matrix based on the central composite rotatable design technique was used for the development of mathematical models to predict the depth/width ratio of the bead geometry for austenitic steel bead on plate welding using GTAW.

- The models developed can be employed easily in automated or robotic welding in the form of a program, for obtaining the desired weld bead dimensions.

- The prediction results using response surface methodology are very close to the experimental results.

- The Genetic Algorithm tool available in MATLAB 7.0 software was effectively employed for the optimization of weld bead geometry.

- This study used a Genetic algorithm to determine the welding process parameters such as Welding Current, Welding speed, Welding gun angle and Gas flow rate to obtain optimum weld bead geometry. The process parameters for obtaining optimal bead depth/width ratio were determined using Genetic Algorithm.

- The proposed method can find the near optimal setting of the welding process parameters to achieve material stability.

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