OPTIMIZATION OF PULSED GMAW PROCESS PARAMETERS IN STAINLESS STEEL CLADDING USING HYBRID TECHNIQUE

A Project Report

Submitted by

V.R. Hariram - 71205114016

B. Pradeep Manoj - 71205114031

S. Shyam Kirthi - 71205114046

in partial fulfillment for the award of the degree

of

BACHELOR OF ENGINEERING

in

MECHANICAL ENGINEERING

KUMARAGURU COLLEGE OF TECHNOLOGY

COIMBATORE – 641 006

ANNA UNIVERSITY :: CHENNAI 600 025

APRIL 2009

ANNA UNIVERSITY: CHENNAI 600 025

BONAFIDE CERTIFICATE

Certified that this project report entitled "**OPTIMIZATION OF PULSED GMAW PROCESS PARAMETERS IN STAINLESS STEEL CLADDING USING HYBRID TECHNIQUE**" is the bonafide work of

V.R. Hariram	-	**71205114016**
B. Pradeep Manoj	-	**71205114031**
S. Shyam Kirthi	-	**71205114046**

Who carried out the project work under my supervision.

SIGNATURE 24/4/2009

Dr.T.Kannan

HEAD OF THE DEPARTMENT

Dept. of Mechanical Engineering

Kumaraguru College of Technology

Coimbatore 641 006

SIGNATURE

Dr.T.Kannan

SUPERVISOR

PROFFESOR

Dept. of Mechanical Engineering

Kumaraguru College of Technology

Coimbatore 641 006

INTERNAL EXAMINER

EXTERNAL EXAMINER

DEPARTMENT OF MECHANICAL ENGINEERING

KUMARAGURU COLLEGE OF TECHNOLOGY

COIMBATORE – 641 006

ABSTRACT

Weld cladding is a process of depositing a thick layer of a corrosion resistance material over carbon steel plate to improve corrosion resistance properties. Some metals cannot be directly welded to each other as they form brittle phases or suffer other cracking problems such as liquation cracking in the weld zone. In such cases a strip of the cladding metal is fillet welded over the completed internal weld seam to give a continuous corrosion-resistant alloy surface. In recent years, weld cladding processes have been developed rapidly and are now applied in numerous industries such as chemical, fertilizer, nuclear, petrochemical and steam power plants. The main problem faced in cladding is the selection of optimum combination of process parameters for achieving the required weld bead width. Our objective in this project is to optimize the various input process parameters like welding current, welding speed, contact tip to work distance, pinch to get minimal dilution in stainless steel cladding of low carbon structural steel plates using pulsed gas metal arc welding. The experiments were conducted based on central composite rotatable design with full replications technique and mathematical models were developed using multiple regression method. The developed mathematical models have been checked for its adequacy and significance. These mathematical models are very useful for predicting the weld bead width. The parameters are then optimized using Hybrid Technique to find the optimal dilution. In Hybrid Technique, a PSOGA i.e. Particle Swarm Genetic Algorithm Optimization is used. In this technique, Particle Swarm Optimization is first used to find the initial population then Genetic Algorithm is used to find the optimal value.

ACKNOWLEDGEMENT

We wish to express our sincere gratitude to our project guide **Dr.T.Kannan**, Professor and Head of Department, Mechanical Engineering, Kumaraguru College of Technology, Coimbatore, for his encouragement, guidance and moral support throughout the work, for providing valuable suggestions, fruitful discussions for improvement and the successful completion of the project.

We thank our beloved Vice-Principal **Prof.R.Annamalai**, Kumaraguru College of Technology, Coimbatore, for providing such an opportunity and the necessary facilities to carry out this project work successfully.

We thank our Project Co-Ordinator **Mr.K.G.Mahesvaran,** Senior Lecturer, Department of Mechanical Engineering, Kumaraguru College of Technology, Coimbatore, for his encouragement, guidance and moral support throughout the work

We would like to express our gratitude for the financial support of this project by the All India Council for Technical Education (AICTE).

We wish to thank the Management of Kumaraguru College of Technology, for having provided all the necessary facilities for the completion of project work.

We would like to express our sincere thanks to lab technicians **Mr.J.Vincent**, **Mr.S.Belpin** and **Mr.Suburaj**, for rendering their guidance continuous in doing the project.

Last but not the least we would like to thank all the faculty members whose valuable guidance, inspiration and continuous encouragement throughout the course made it possible to complete this project.

TABLE OF CONTENT

LIST OF TABLE

LIST OF FIGURE

List of Abbreviation

Ac	Arc Control
AWS	American welding society
CTWD	Contact tip to Work piece Distance
DF	Degree of Freedom
DOE	Design of Experiments
FCAW	Flux-Cored Arc Welding
GA	Genetic Algorithm
GMAW	Gas Metal Arc Welding
GMAW-P	Pulsed Gas Metal Arc Welding
GTAW	Gas Tungsten Arc Welding
IS	Indian Standard
MIG	Metal Inert Gas welding
N	Nozzle to Plate Distance
PSO	Particle Swarm Optimization
RSM	Response Surface Methodology
S	Welding Speed
SAW	Submerged Arc Welding
SMAW	Submerged Metal Arc Welding
SS	Sum of Square
T	Welding gun
W	Clad Bead Width
R	Height of Reinforcement
P	Depth of Penetration

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".

Welding is used for making permanent joints. Application of welding involves the manufacturing of automobiles bodies, structural works, aircraft frames, machine bodies, railway wagons, tanks, furnaces, boilers, furniture, ship building, etc. Role of welding process has now almost become inevitable. Recent developments in the area of welding are robotic welding, space welding, under water welding, etc. there are various methods of welding.

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 as shown in the Figure 1.1:

1.3 Fusion Welding

1.3.1 Arc Welding

Arc welding is the process of joining two metal pieces by melting their edges by an electric arc. The arc type is further classified into several classes.

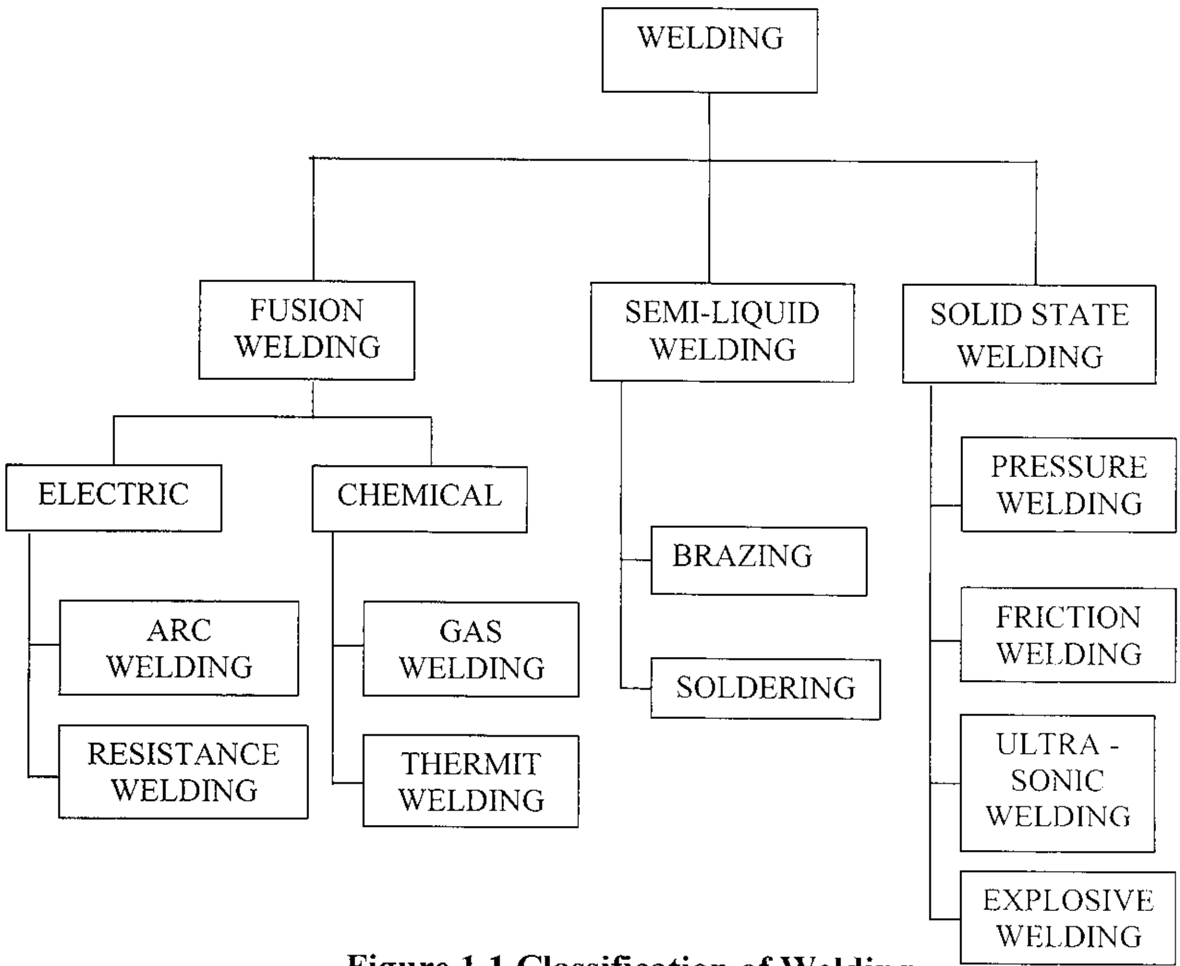


Figure 1.1 Classification of Welding

1.3.1.1 Shielded Metal Arc Welding

In this type of arc welding, the electric arc is produced between two conductors. The electrode is one conductor and the work piece is another conductor. The electrode and work piece is another conductor. The electrode and work piece are brought nearer with a small air gap. The electrode also supplies additional filler metal into the joint. A transformer or generator is used for supplying the current. Electrodes used in arc welding are generally coated with a flux which in turn produces a gaseous shield preventing the reaction of the molten metal with oxygen and nitrogen in the atmosphere. This removes the impurities from the molten metal in the form a slag, which gets deposited over the weld metal protects the weld seam from rapid cooling.

1.3.1.2 Gas Tungsten Arc Welding

In this welding, an electric arc is produced between a non-consumable tungsten electrode and the work piece. When the arc is produced, the inert gas from the cylinder passes through the welding head around the electrode, which surrounds the arc and protects the weld from atmospheric effects.

1.3.1.3 Gas Metal Arc Welding

In this welding, the electrode arc is produced between a consumable metal electrode and the work. During welding, the arc and welding zone are surrounded by an inert gas. This inert gas covers and protects the weld from atmospheric effects. Argon or helium is used as inert gas. This welding can be done manually or automatically. MIG welding is used for welding aluminium, stainless steel and magnesium without weld defects.

1.3.1.4 Plasma Arc Welding

In this process, the heat generated by an ionized gas jet called plasma is used for joining metal pieces together. Inert gas is ionized by an electric arc. The arc is produced between the tungsten electrode and the copper nozzle. Argon is gas is supplied through the arc. The gas gets ionized due to the arc. The ionized gas is called the plasma. This plasma arc is directed on the work piece to be welded. Due to the high heat, the metal at the joint gets melted and welds together. Another steam of inert gas say helium is supplied around the nozzle on the weld zone through the outer shell of the nozzle. This acts as shielding gas for the weld. This welding can be applied to almost all metals.

1.3.1.5 Submerged Arc Welding

In this welding, an electric arc is produced between the electrode and the work plate. But the arc is completely submerged (hidden) under the flux powder. The arc is not visible outside. The electrode is a continuous bare wire electrode. When the arc is produced in the welding zone, the end of electrode and the arc are completely covered by flux powder. So there will not be any defect in the weld due to atmospheric effects. The electrode is contained in a hopper. The flux powder is supplied over the work in front of the welding area continuously. The flux covers the arc and molten metal. Some of the flux melts and forms slag on the weld. The unused flux is sucked by a pipe. The electrode is fed down automatically. The welder need not wear the protective glass. SAW is specially used for welding carbon steels and alloys steels.

1.3.2 Gas Welding

In this welding process, a gas flame is used to melt the edges of metal to be joined. The flame is produced at the tip of welding torch. The combination of Oxygen and Acetylene, Air and Acetylene or Oxygen and hydrogen is used to produce the welding flame. The flame will melt only the metal. So, additional metal to the weld is supplied by the filler rod. A flux is used during welding to prevent oxidations and to remove impurities.

1.3.3 Resistance Welding

In resistance welding, the two metal parts to be joined arc heated to plastic state by electric resistance. At this state the metal parts are pressed together and welding takes place. In this process, there are two copper electrodes in a circuit which are if low resistance. The metal parts to be welded are placed between the electrodes. When the current is passed, the electrical resistance at the metal joint becomes very high. So the metals are brought to red hot plastic condition. Now mechanical, air or hydraulic pressure is applied to complete the weld. Resistance welding is used in mass production for welding sheet metal, wire and tubes.

1.3.4 Thermit Welding

This is a fusion welding process in which, welding is done by pouring superheated liquid steel around the parts to be welded. Thermit steel is a mixture of fine aluminium powder and iron oxide. Barium peroxide powder is also added to the mixture and is added to the crucible and ignited thermit reaction takes place and superheated liquid steel is produced. The temperature is around 3000°C. The ends of the parts to be joined are kept parallel with a uniform gap between them. This gap is filled with wax which becomes pattern. Aflame is used to melt wax and the wax goes out leaving the ends of the work to preheated condition. Then heating is stopped and the liquid thermit steel is poured into mould between the ends of work pieces. The molten metal solidifies and the weld is completed.

1.4 Solid State Welding

1.4.1 Friction Welding

In this process, welding is done by the heat developed by mechanical friction. In friction welding, the parts to be joined (normally cylindrical) are axially aligned. One part is held stationary by a fixture. The other part is held in a chuck and rotated at high speed say 12000 rpm. Then the parts are brought into contact by moving the rotating part axially. An axial thrust is given to the rotating unit. Because of the rubbing action or friction between contacting surfaces of the work pieces, high heat is generated. Welding takes place. Now the rotation is stopped. The pressure is maintained until the welding is completed. This type of welding is applied for welding similar as well as dissimilar metal.

1.4.2 Ultrasonic Welding

In this process, high pressure and high frequency vibrations are combined to produce the weld. A frequency converter converts 50 cps electric power into high frequency (say 20000 to 60000 cps) power. A transducer converts the high frequency into vibratory energy. This high frequency vibration is known as ultrasonic vibration. This vibration is transmitted to coupling system which has welding tip. The components to be joined are clamped between welding tip and the supporting anvil. A light pressure is sufficient to keep the components in close contact. Because of high frequency vibrations the contact surfaces get heated, reach plastic stage and get welded together. The welding takes place due to inter atomic bonding.

1.4.3 Explosive Welding

In this process, two metal surfaces are brought together with high relative velocity under a heavy pressure. The pressure and velocity are developed by igniting an explosive. The explosion causes very high impact and forces the metal surfaces to join at a high velocity. Metallurgical bond takes place between the surfaces. The strength of the weld increases due to interlocking action.

1.5 Semi Liquid Welding

1.5.1 Brazing

Brazing is the process of joining two similar or dissimilar metals by a fusible alloy called spelter. The melting temperature of the filler metal is higher. It is also known as filler rod. The spelter has its melting point (at about 600°C) below the melting point of work piece. The work metals are heated to a temperature below their melting point. The filler metal is allowed to flow in the gap between the work pieces allowing it to join the work pieces. The spelter is made of copper and zinc alloy or silver alloy.

1.5.2 Soldering

Soldering is the process of joining two similar or dissimilar metals by adding a low melting alloy called solder. The work metals are not melted in soldering. Solder is an alloy of tin and lead. The solder melts at low temperatures. First, the work pieces are cleaned well and arranged in a proper position. Zinc chloride is used as flux to prevent atmospheric effects. The flux is spread on the joint by a soldering iron. Then the solder joins the two wok pieces and solidifies. For heating the work pieces and to melt the solder and flux, an electric soldering iron or a welding torch is used. Soldering is used in repairing radiators, fitting covers to containers, etc.

1.6 Cladding

Cladding is the process of applying a thick layer of weld metal over a base material to improve the corrosion resistance properties. Corrosion is one of the main problems in the chemical industries. A huge quantity of metal is lost by corrosion. The development of new chemical process requiring storing facility for more corrosive substances, call for new materials for the fabrication of storage and pressure vessels. The cost is however, an important criterion. The fabrication of a vessel entirely from corrosion resistant material becomes an extremely uneconomical solution in many solutions. The composite materials solved problems, using a base material of carbon or low alloy steel for the strength of the structure and a clad layer of corrosion resistant material in contact with the chemical corrosive atmosphere. The desirable characteristics of such a cladding alloy are reasonable strength, weldability to the steel, resistance to general and localized corrosion attack, and good corrosion fatigue properties.

1.7 Welding Processes Used for Cladding

1.7.1 Submerged Arc Welding

Submerged arc welding is a fusion welding process in which the heat is produced from an arc between the work and a continuously fed filler metal electrode. This can be used for the purpose for weld cladding.

1.7.2 Flux Cored Arc Welding

Flux cored arc welding (FCAW) is a fusion welding process in which heating is produced from an arc between the work and a continuously fed filler metal electrode. Atmospheric shielding is provided completely or in part by the flux sealed within the tubular electrode. FCAW process can be used for the purpose of weld cladding.

1.7.3 Laser Beam Welding

In laser cladding, additives materials and a thin layer of substrate are melted by a laser beam, and the latter ensures metallurgical binding between layers and substrate. In addition to improving wear or corrosion resistance properties of a surface, the technique can also be used to repair a component that has damaged by rebuilding the entire area. Eg. The laser cladding of piston rings.

1.7.4 Gas Metal Arc Welding

In this welding, the electric arc is produced between a consumable metal electrode and the work. During welding, the arc and welding zone are surrounded by an inert gas. This inert gas protects the weld from atmospheric effects. Weld cladding can be made by this method.

1.8 Advantages of Weld Cladding

Weld cladding has several advantages while manufacturing a product. Some of its advantages are discussed below:

1. Corrosion resistance is improved by means of cladding a layer of corrosion resistant material over base carbon metal.
2. The cost of the product when made entirely of a single corrosion resistance material (like, stainless steel) becomes very high. So, in order to reduce the cost of the material, cladding is preferred.
3. The strength of a material cannot be compromised for the purpose of corrosion resistance, pitting resistance, etc. But, cladding helps in providing strength to a material as well as improves the corrosion resistance properties.
4. Laser cladding can be used to repair a component that has suffered damage by rebuilding the entire area.

1.9 Application of Weld Cladding

Some of the applications of weld cladding are in the industries such as chemical and fertilizer plants, nuclear and steam power plants, food processing and petrochemical industries and many others.

1.9.1 Boiler Tubes

Heat exchangers tubes in power boilers and waste recovery systems are typically made up of ferritic steels. Ferritic steels provide strength and structural integrity for the system as well as excellent resistance to high temperature, pressure water or steam; however, the fireside of the ferritic steel tube components in these system can suffer significantly higher metal wastage rates on the tube wall due to high temperature corrosion and corrosion attack from the hot flue gas steam. Without adequate protection, the plant may experience frequent shutdowns and excessive maintenance costs. Hence a bimetallic approach using the cladding technology employing GMAW process can reduce corrosion. A typical example is shown in Figure 1.2 and a typical example for application of welding is shown in Figure 1.3

1.9.2 Spent Nuclear Fuel Shipping Flasks

Spent Nuclear Fuel Shipping Flasks are used for shipping spent Nuclear Fuel from various Atomic Power Plants to recharging plants. The equipments are manufactured from 45mm thick IS: 2062 Grade plates and Stainless Steel. 304L plates of various thickness. The equipment is shielded by lead. The entire equipment is cladded with 6mm thick Stainless Steel 304L plates.

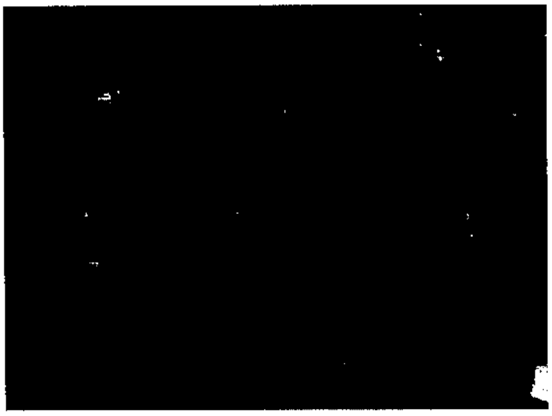
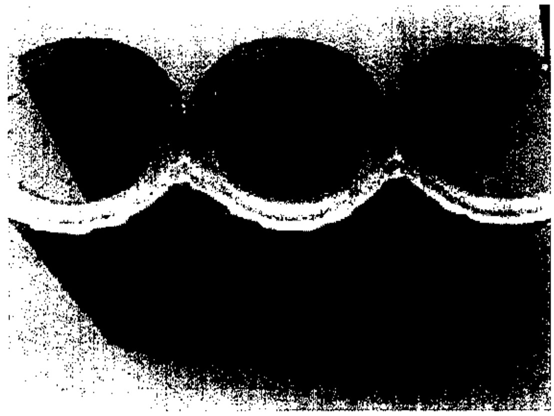
 

Figure 1.2 Typical Example for Cladded Object

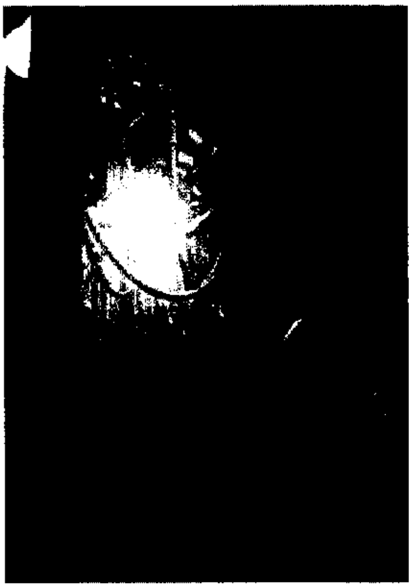
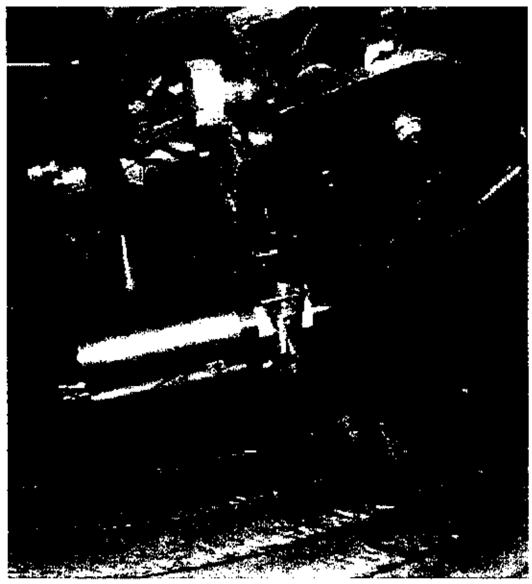
 

Figure 1.3 Applications of Cladding Process

1.9.3 Nuclear Fuel Charging Casks

Nuclear fuel charging casks are used for charging of Nuclear Fuel into the reactors. These are manufactured from IS: 2062 Grade plates and cladded with Stainless Steel 304L plates. They are also provided with lead shielding.

1.9.4 Refinery Industry

In the refinery industry, pressure vessels used in high temperature, high pressure "hydrogen service" such as hydro-cracking and hydro-treating are usually constructed of Chromium, Molybdenum or vanadium steels. To overcome corrosion areas with these vessels, clad welds of ER 347 alloy are typically applied to plate on pressure vessels.

1.10 Differences between Welding And Cladding

Basically, cladding is the applying of thick layer of weld metal (filler) over the base metal to improve corrosion resistance properties. But, in welding, the filler material is used for the purpose of joining two different work pieces.

The primary difference between welding and cladding is the dilution. Dilution is defined as the amount of base metal melted (B) divided by the sum of the filler metal added and base metal melted (A+B). In cladding, the dilution percentage should be very low in order to retain the characteristics of the clad metal in the final composite material. As shown in Figure 1.4

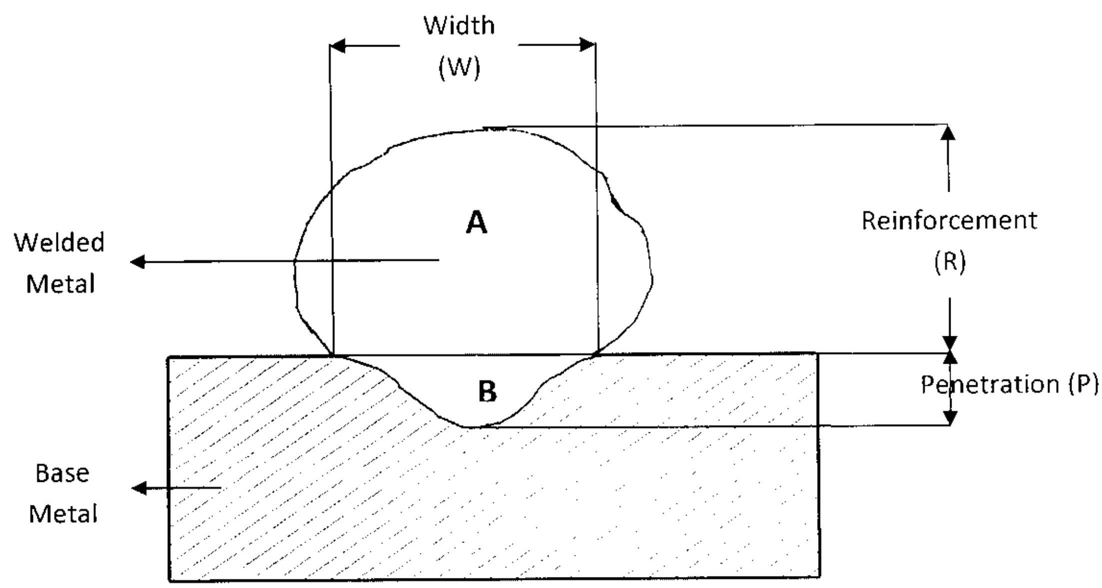


Figure 1.4 Weld Bead Geometry

Percentage Dilution (D) = [B / (A+B)] * 100

1.11 Stainless Steel Cladding

Cladding is mainly done using stainless steel or nickel base alloys. Stainless steels having a minimum twelve percentage of chromium render them stainless. Together with chromium, several alloying additions are made to suit them to different service conditions by enhancing specific properties. Based on the room temperature structure of the matrix, stainless steels can be grouped into three main types are martensitic, ferritic, and austenitic.

Among these austenitic grades are widely used because it has excellent oxidation and corrosion resistance and good high and low temperature properties. It also posses excellent strength and ductility.

CHAPTER - 2

LITERATURE SURVEY

Nouri et al. (2007) gave the effect of pulsed gas metal arc welding variables on the dilution and weld bead geometry in cladding X65 pipeline steel with 316L stainless steel. Using a full factorial method, a series of experiments were carried out to know the effect of wire feed rate, welding speed, distance between gas nozzle and plate, and the vertical angle of welding on dilution and weld bead geometry. The findings indicated that the dilution of weld metal and its dimension i.e. width, height and depth increase with the feed rate, but the contact angle of the bead decreases first and then increases. Meantime, welding speed has an opposite effect except for dilution. There is an interaction effect between welding parameters at the contact angle. The results also show forehand welding or decreasing electrode extension decrease the angle of contact. Finally, a mathematical model is contrived to highlight the relationship between welding variables with dilution and weld bead geometry.

Benyounis et al. (2007) have made Optimization of different welding processes using statistical and numerical approaches. Welding input parameters play a very significant role in determining the quality of a weld joint. The joint quality can be defined in terms of properties such as weld-bead geometry, mechanical properties, and distortion. Generally, all welding processes are used with the aim of obtaining a welded joint with the desired weld-bead parameters, excellent mechanical properties with minimum distortion. Nowadays, application of design of experiment (DoE), evolutionary algorithms and computational network are widely used to develop a mathematical relationship between the welding process input parameters and the output variables of the weld joint in order to determine the welding input parameters that lead to the desired weld quality. A comprehensive literature review of the application of these methods in the area of welding has been introduced herein. This review was classified according to the output features of the weld, i.e. bead geometry and mechanical properties of the welds.

Palani et al. (2006) have Modeled and simulated the wire feed rate for steady current and pulsed current gas metal arc welding using 317L flux cored wire by changing frequency, peak current, base current and duration of peak and base currents. The effects of pulse parameters on the burnoff factor and burnoff rates were also analysed. The investigation was carried out using AWS 5.22–95 filler wire of size 1.2 mm diameter and the base metal used was IS:2062 structural steel plate of 20 mm thickness. An argon and 5% CO_2 gas mixture at a flow rate of 16 l/min was used for shielding throughout the welding. The values of arc resistance heating constant (α) and wire resistance heating constant (β) for 317L austenitic stainless steel wire are found to be 0.2998 mm /A/sec and 0.000138 A^{-2} sec^{-1}, respectively. It was observed that the pulse parameters have significant influence on wire feed rate. Among the pulse parameters, the peak parameters have more influence on the wire feed rate; however, the effect of base parameters can not be neglected. Also, it was observed that the higher the excess current is, the higher the feed rate is.

Kannan et al. (2006) have conducted an experimental study to analyze the effects of various FCAW process parameters on important clad quality parameters in duplex stainless steel cladding of low carbon structural steel plates. The experiments were conducted using the four-factor five level central composite rotatable designs with full replications technique and having mathematical models developed using multiple regression method. The effects of the input process parameters on clad quality parameters on clad quality parameters have been presented in graphical form, which helps in selecting welding process parameters to achieve the desired clad quality quickly

Kannan et al. (2006) gave the application of response surface methodology to develop mathematical models and to analyze various effects of flux cored arc welding process parameters on the FN of duplex stainless steel clad metals. The experiments were conducted based on four factor, five-level, central composite rotatable design with full replications technique and mathematical models developed using multiple regression technique. The developed mathematical models are very useful for predicting and controlling the FN in duplex stainless steel cladding. The main and interaction effects of input process parameters on calculated FN (by WRC-1992 diagram) and measured FN have been presented in graphic form, which helps in selecting FCAW process parameters to achieve the required FN.

Subramaniam et al. (1999) gave an Experimental Approach to Selection of Pulsing Parameters in Pulsed GMAW. An efficient method of identifying power supply pulsing parameters for pulsed gas metal arc welding based on statistical experimental design is presented. Fractional factorial screening experiments are combined with D-optimal experimental designs to allow the user to develop an accurate wire feed rate model for varying pulsing conditions and to characterize the desirable one droplet per pulse (ODPP) operating region for a given wire type and diameter. Equations defining the wire feed rates and time at a given peak current required for ODPP transfer are presented. Compared to conventional techniques, a very small number of experiments are required. Joints produced using this approach are evaluated and found to meet applicable bead geometry standards.

Robinson et al. have made optimization of a profiled corrugated horn antenna using Particle swarm, genetic algorithm, and their hybrids. Genetic algorithms (GA) have proven to be a useful method of optimization for difficult and discontinuous multidimensional engineering problems. A new method of optimization, particle swarm optimization (PSO), is able to accomplish the same goal as GA optimization in a new and faster way. Also investigated is the possibility of hybridizing the two algorithms. The result shows that PSGAO that is Particle Swarm Genetic Algorithm Optimization gives the most optimal value

CHAPTER 3
PULSED GAS METAL ARC WELDING

3.1 Introduction

Gas Metal Arc Welding (GMAW), by definition, is an arc welding process which produces the coalescence of metals by heating them with an arc between a continuously fed filler metal electrode and the work. The process uses shielding from an externally supplied gas to protect the molten weld pool. The application of GMAW generally requires DC+ (reverse) polarity to the electrode. In non-standard terminology, GMAW is commonly known as MIG (Metal Inert Gas) welding and it is less commonly known as MAG (Metal Active Gas) welding. In either case, the GMAW process lends itself to weld a wide range of both solid carbon steel and tubular metal-cored electrodes. The alloy material range for GMAW includes: carbon steel, stainless steel, aluminum, magnesium, copper, nickel, silicon bronze and tubular metal-cored surfacing alloys. The GMAW process lends itself to semiautomatic, robotic automation and hard automation welding applications.

The history of GMAW had its industrial introduction in the late 1940's. The site was the Battelle Memorial Institute, and it was there that Hobart and Devers, sponsored by the Air Reduction Company, researched and developed the first use of a continuously fed aluminum wire electrode, shielded with 100% argon gas.

Axial spray transfer for aluminum was the earliest metal transfer mode for the process. This eventually led to the use of argon plus small additions of oxygen. The oxygen improved arc stability and finally permitted the use of axial spray transfer on ferrous materials. The process was limited because of the high energy level of axial spray transfer to plate thickness material.

In the early 1950's, the work of Lyubavshkii and Novoshilov initiated the development of the GMAW process to include the use of large diameters of steel electrode shielded with carbon dioxide, a reactive gas. The process development at this stage was high in weld spatter, and the level of heat generated by the arc made the process uninviting to welders.

In the late 1950's improvements in power source technology and the interface of small diameter electrodes, in the 0.035" -0.062" (0.9 - 1.6 mm) diameter range, permitted the implementation of the discrete mode known as short-circuiting transfer. This development permitted the use of lower heat input welding on thin sections of base material, and it provided the opportunity for all-position welding.

In the early 1960's, power source research and development led to the introduction of pulsed spray in the GMAW mode. The idea for pulsed spray transfer, GMAW-P, occurred in the 1950's and it conceptually involved the use of a high-speed transition between a high-energy peak current to a low background current. The motivation behind the idea was the need to decrease spatter and eliminate incomplete fusion defects. The pulsed arc process incorporated the benefits of axial spray transfer clean, spatter-free welds having excellent fusion, with lower heat input. The lower average current provided by GMAW-P allowed for out-of-position welding capability with improved weld quality, when compared with short-circuit transfer.

The 1970's introduced power source technology, which further enhanced the development of the GMAW process and GMAW-P in particular. This period saw the incorporation of the earliest thyristor power sources for pulsed GMAW. The Welding Institute of the United Kingdom is largely responsible for determining the linear relationship between pulsed frequency and wire feed speed. The algorithm for this mathematical relationship permitted a fundamental base for subsequent synergic transistor controlled power sources. The new high speed electronic controls improved the interface between welding sophistication and the welding shop floor. The new descriptor for this development was the word "Synergic." As it relates, synergy means: one knob control – as the welder increases or decreases wire feed speed, a predetermined pulsed energy is automatically applied to the arc. Synergic power sources made it easier to use GMAW-P.

Pulsed spray metal transfer, known by the acronym GMAW-P, is a highly controlled variant of axial spray transfer, in which the welding current is cycled between a high peak current level to a low background current level. Metal transfer occurs during the high energy peak level in the form of a single molten droplet.

GMAW-P was developed for two demanding reasons: control of weld spatter and the elimination of incomplete fusion defects common to globular and short-circuiting transfer. Its earliest application included the welding of high strength low alloy base material for out-of-position ship hull fabrication. The advantages that it brought to the shipbuilding industry included: higher efficiency electrodes than FCAW, and the ability to deliver lower hydrogen weld deposits. The mode employs electrode diameters from 0.8 – 1.6 mm solid wire electrodes and metal-cored electrodes from 1.1 –

2.0 mm diameter. It is used for welding a wide range of material types. Argon based shielding gas selection with a maximum of 18% CO_2 supports the use of pulsed spray metal transfer with carbon steels.

The welding current alternates between a peak current and a lower background current, and this controlled dynamic of the current results in a lower average current than is found with axial spray transfer.

The time, which includes the peak current and the background current, is a period, and the period is known as a cycle (Hz). The high current excursion exceeds the globular to spray transition current, and the low current is reduced to a value lower than is seen with short-circuiting transfer. Ideally, during the peak current, the high point of the period, a single droplet of molten metal is detached and transferred across the arc. The descent to the lower current, known as the background current, provides arc stability and is largely responsible for the overall heat input into the weld. The frequency is the number of times the period occurs per second, or cycles per second. The frequency of the period increases in proportion to the wire feed speed. Taken together they produce an average current, which leverages its use in a wide material thickness range.

3.2 Advantages of Pulsed Spray Transfer

- Absent or very low levels of spatter.
- More resistant to lack of fusion defects than other modes of GMAW metal transfer.
- Excellent weld bead appearance.
- High operator appeal.
- Offers an engineered solution for the control of weld fume

generation.

- Reduced levels of heat induced distortion.
- Ability to weld out-of-position.
- Lower hydrogen deposit.
- Reduces the tendency for arc blow.
- Handles poor fit-up.
- When compared to FCAW, SMAW, and GMAW-S, pulsed spray transfer provides a low cost high-electrode efficiency of 98%.
- Lends itself to robotic and hard automation applications.
- Capable of arc travel speeds greater than 50 inches per minute (1.2 m/min.).

3.3 Limitations of Pulsed Spray Transfer

- Equipment to support the process is more expensive than traditional systems.
- Blends of argon based shielding gas are more expensive than carbon dioxide.
- Higher arc energy requires the use of additional safety protection for welders and bystanders.
- Adds complexity to welding.
- Requires the use of windscreens outdoors.

3.4 Comparison between GMAW and Pulsed GMAW

In GMAW the drops of molten metal transfers continuously. Since the metal transfer occurs continuously, there will not be any sufficient for the metal to dissipate the heat. So the weldment and the base material may be affected by heat. But in Pulsed GMAW, the metal transfer occurs drop by drop (i.e.) only after the molten droplet reaches the base metal the next drop leaves the nozzle. Pulsing reduces overall heat input. So there is sufficient time for the droplet to dissipate the heat before the next molten droplet reaches the weldment area. So the base metal will not get affected by the heat.

GMAW can often be too hot for thin gauge metals however; creating burn through or warping and the thinner metals commonly used for appliances may create problems for GMAW. If such problems occur during operations, the pulsed GMAW welding procedure may offer a resolution. In the right applications, pulsed GMAW can:

- Reduce spatter to nearly non-existent levels.
- Minimize distortion, yet provide good fusion.
- Create weld beads with an appearance alike a TIG weld.
- Weld thin or thick metals.
- Permit using a larger diameter (i.e., less expensive) electrode.
- Permit all-position welding.
- Increase travel speeds up to 35 percent or more (over short circuit transfer).

In GMAW the molten droplet is forced to pinch off from the nozzle with more velocity also the next droplet also smashes the weldpool with such a speed spatter will be more and due to this the bead shape appearance may not to uniform. In Pulsed GMAW the peak current pinches off a spray - transfer droplet and propels it toward the weldment for good fusion. The background current maintains the arc but is too low for metal transfer to happen. But in GMAW the current is constant, and therefore the spray transfer occurs continuously and fastly.

Pulsed GMAW produces good fusion, little spatter and beads with better appearances since the molten metal drop is transferred one at a time, the bead will be more even and the droplet is transferred smoothly and there will be minimum spatter. GMAW is a Constant Voltage Variable Current process. But Pulsed GMAW is a Constant Current Variable Voltage Process. In Pulsed GMAW the amperage level is lower than the amperage level required for spray welding, which is how pulsing can eliminate problems with warping and burn through.

In Pulsed GMAW despite its lower heat input, pulsing provides the good fusion associated with spray transfer. Because the weld puddle cools in between pulses and freezes faster, operators have better directional control over the weld bead. Compared to short circuit or spray transfer, Pulsed GMAW often permits using a larger diameter wire and/or faster wire feed speeds without adding excess heat. This increases travel speed and/or deposition rates.

3.5 GMAW-P Waveform Components

Front Flank Ramp-up Rate (1)

The ramp-up rate determines how rapidly the current will increase from the background current to the peak current. The ramp-up rate assists in the formation of the molten droplet at the end of the electrode. The rate is measured in terms of amps/millisecond. The rate of rise can reach 1000 amps/millisecond. As the slope of the ramp-up rate increases, the stiffness of the arc also increases. A fast ramp-up rate is associated with arc stiffness and louder arc noise. Decreasing the rate of rise contributes to a softer sounding arc. As shown in Figure 3.1

Overshoot (2)

Overshoot describes the condition where the front flank increases to a predetermined level beyond the level of the peak current. It is expressed in units of percent. Increasing overshoot is associated with a more rigid arc that is less prone to deflection. Overshoot adds to the pinch current and it increases the electromagnetic pinch force applied to the molten droplet.

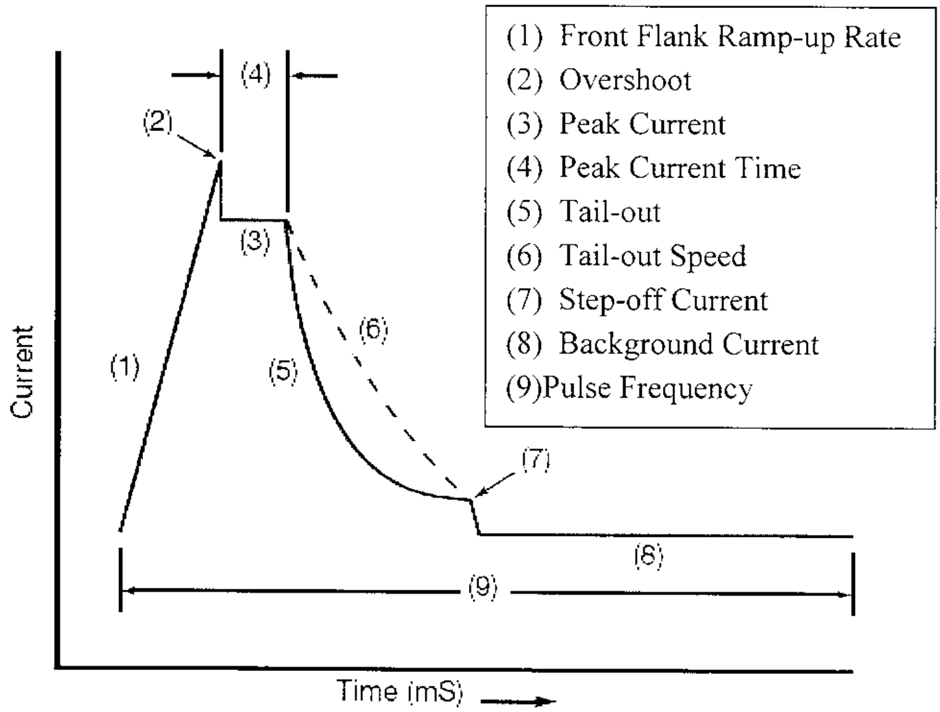


Figure 3.1 Current Waveform

Peak Current (3)

Peak current is the nominal current for the high energy pulse. It is adjusted to a level that is set consistently above the globular to spray transition current. Peak current is expressed in units of ampere. During the time when the peak current is delivered, the molten droplet detaches from the electrode. An increase in peak current increases the average welding current and the weld penetration.

Peak Current Time (4)

Peak current time describes the length of time that the current is at its peak. It is associated with droplet size. Peak time is expressed in terms of milliseconds. As the peak time increases, the droplets decrease in size. As the peak time decreases, the droplet size increases. The traditional expectation is that a single molten droplet is transferred with each pulse peak. The effective time at peak can range from less than 1 millisecond to 3 or more milliseconds. An increase in peak time increases average current, and it also increases weld penetration.

Tail-out (5)

Tail-out is associated with current decay from the peak to the background current. It generally follows an exponential path to the background current. The increase in tail-out time increases the average current and marginally increases penetration. Tail-out time is increased to provide an increase in droplet fluidity. This results in improved toe wetting, a softer arc sound, and increased puddle fluidity.

Tail-out Speed (6)

Tail-out speed defines the rate at which the waveform moves from the peak current to either the step-off current or the background current. Manipulation of this portion of the waveform increases or decreases the exponential fall to the background current.

Step-off Current (7)

Step-off current defines the current level at the portion of the waveform where tail-out ends. It can add to, or take away from, the area under the waveform. It is associated with stabilizing the arc with stainless or nickel alloy filler metals.

Background Current (8)

Background current refers to the lower nominal current of the output. The unit of measure for the background current is ampere. Increases in background current will increase penetration.

Pulse Frequency (9)

Pulse frequency is responsible for how often the pulse cycle occurs in one second. As the frequency increases, the arc narrows, the average current increases, and the molten droplets become smaller. As the frequency decreases, the weld bead and the arc become wider. Frequency is generally proportional to the wire feed speed.

3.6 Components of Pulsed GMAW:

Power source

The power source for equipment requires a 3 phase input. Combination power sources and wire drives, which range in current capacity from 5 – 425 amps. The wide output range power source/wire feeder combinations are intended for wide sheet metal applications.

Inverter

The inverter used is from Lincoln Electric and the model is Invertec V350-PRO Adv Process. The wide variable option provides to vary the current, pinch etc…

Wire feeder

The wire feeder is from Lincoln Electric model LF-74 can operate for a wide range of diameters.Solid Wire Size Range is (0.025 - 0.045 inches) or (0.6 - 1.2 mm). The Wire Speed Range is (30 - 800 inches/min) or (0.8 - 20.3 m/min). The controls options such as cold feed, Gas purge, Burn back range is (0 to 0.25 secs) and the Post flow range is (0 to 10 secs) which makes a complete control over the wire feed and the operation.

Welding torch

The welding torch has a trigger to switch on and switch off the wire feed and welding. The shielding gas flows through the cable and comes out through the Gas Diffuser which is located in the nozzle. The wire comes out through the nozzle or contact tip.

Shielding gas

Argon and Helium are the two inert shielding gases used for protecting the molten weld pool. Argon promotes arc starting, increased droplet pinch rate, and deep finger-like penetration profile. Argon is also a poor thermal conductor. Oxygen acts as an arc stabilizer in Argon rich blends. It reacts with the weld pool, but to a lesser extent than CO_2. Oxygen is a good choice of shielding gas for the sheet metal pulsed spray metal transfer.

Composition: 98% Argon + 2% Oxygen.

Automation:

The welding can be done by fixing the torch in the manipulator and the adjustments such as angle, contact tip to work distance and direction of weld. The direction and the speed control can be achieved by the X axis and

Y axis controls in desired speed which can be controlled by a knob. The table speed ranges between (0 to 200 mm / minute).

When the manipulator is interfaced with a computer, and the parameters such as Table speed direction and path of weld are given, the welding takes place in the specified way without any manual interruption.

CHAPTER 4
EXPERIMENTAL DESIGN PROCEDURE

4.1 Steps in Experimental Design Procedure

The various steps in the experimental design procedure are as follows:

a) Identification of factors and responses
b) Finding the limits of the process variables
c) Development of design matrix
d) Conducting experiment as per the design matrix
e) Recording the response
f) Development of the mathematical models
g) Checking the adequacy of the developed models
h) Conducting conformity tests

4.1.1 Identification of factors and responses

The input parameters were identified based on the literature survey. Wire feed rate (W), Welding speed (S), Welding gun angle (T), Nozzle to plate distance (N), and Pinch (P) were found to be the vital independently controllable process parameters affecting the output parameters. The responses chosen were clad bead (W), Height of reinforcement (R), Depth of penetration (P) and Percent dilution (D). The responses were chosen based on the impact these parameters have on the final composite material.

4.1.2 Finding the Limits of the Process Variables

The working ranges of all selected factors are fixed by conducting trail 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 parameters was decided upon by inspecting 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. The coded values for intermediate values were calculated using the equation (4.1):

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

Where X_i is the required coded value of a parameter X; X is any value of the parameter from X_{min} to X_{max} ; X_{min} is the lower limit of the parameter and X_{max} is the upper limit of the parameter. The chosen levels of the selected parameters with their units and notations are given in table 4.1.

4.1.3 Development of Design Matrix

The design matrix chosen to conduct the experiments was a central composite rotatable design. This design matrix comprises a full replication of 2^5 = 32 factorial designs. 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 (-2) with other four parameters of the intermediate levels (0) constitute the star points. The design matrix is shown in table 4.2

4.1.4. Conducting Experiments as Per the Design Matrix

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

Table 4.1 Welding Parameters and Their Levels

Parameter	Unit	Notation	Levels				
			-2	-1	0	1	2
Welding current	A	I	200	225	250	275	300
Welding speed	mm/min	S	150	158	166	174	182
CTWD	mm	N	10	14	18	22	26
Welding gun Angle	Degree	T	70	80	90	100	110
Pinch	-	Ac	-10	-5	0	5	10

Table 4.2 Design Matrix

Trial Number	Design Matrix				
	I	S	N	T	Ac
1	-1	-1	-1	-1	+1
2	+1	-1	-1	-1	-1
3	-1	+1	-1	-1	-1
4	+1	+1	-1	-1	+1
5	-1	-1	+1	-1	-1
6	+1	-1	+1	-1	+1
7	-1	+1	+1	-1	+1
8	+1	+1	+1	-1	-1
9	-1	-1	-1	+1	-1
10	+1	-1	-1	+1	+1
11	-1	+1	-1	+1	+1
12	+1	+1	-1	+1	-1
13	-1	-1	+1	+1	+1
14	+1	-1	+1	+1	-1
15	-1	+1	+1	+1	-1
16	+1	+1	+1	+1	+1
17	-2	0	0	0	0
18	+2	0	0	0	0
19	0	-2	0	0	0
20	0	+2	0	0	0
21	0	0	-2	0	0
22	0	0	+2	0	0
23	0	0	0	-2	0
24	0	0	0	+2	0
25	0	0	0	0	-2
26	0	0	0	0	+2
27	0	0	0	0	0
28	0	0	0	0	0
29	0	0	0	0	0
30	0	0	0	0	0
31	0	0	0	0	0
32	0	0	0	0	0

4.1.4.1 Experimental Setup

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

1. A constant current gas metal arc welding machine (Invertec V350-PRO Advanced Process with 5-425 amp output range) (Figure. 4.2).
2. The Welding Manipulator (Figure. 4.3).
3. Wire Feeder LF-74 Model (Figure. 4.2).
4. The Filler Material – ER308L stainless steel wire of 1.2mm diameter.
5. Gas cylinder constituting a mixture of 98% argon and 2% oxygen (Figure. 4.4).
6. Mild steel plate of grade IS2062

The main experimental setup used consists of a travelling carriage with a table for supporting the specimens. A power source is present (Figure 4.2). The welding torch (Figure. 4.3) is held stationary in a frame above the table, and it is provided with an attachment in a frame above nozzle to plate distance and welding gun angle respectively.

The experiments were conducted using the constant current welding machine (Figure. 4.2). Test plates of size 300 x 200 x 20 mm were cut from Mild steel plate of grade IS2062 GRB, and one surface was cleaned to remove the oxide scale and dirt before cladding. ER308L stainless steel welding wire of 1.2mm diameter (table 4.3) was used for depositing the weld beads through the wire feeder (Figure. 4.2). Argon gas at a constant flow rate of 16 liters per minute was used for shielding. The important and most difficult parameter found from trial run is wire feed rate. Wire feed rate is proportional to Current. Wire feed rate must be greater than Critical

Wire feed rate to achieve pulsed metal transfer. Relationship found from trial run shown in equation 4.2. The formula derived based on the graph drawn for trial run shown in Figure 4.1

$$\text{Wire feed rate} = 0.96742857*\text{current}+ 79.1 \qquad \text{......... (4.2)}$$

Table 4.3 Properties of Base metal and Filler Wire

Material	C	Si	Mn	P	S	Al	Cr	Mo	Ni
IS 2062	0.150	0.160	0.870	0.015	0.016	0.031	-	-	-
ER 308L	0.03	0.57	1.76	0.021	0.008	-	19.52	0.75	10.02

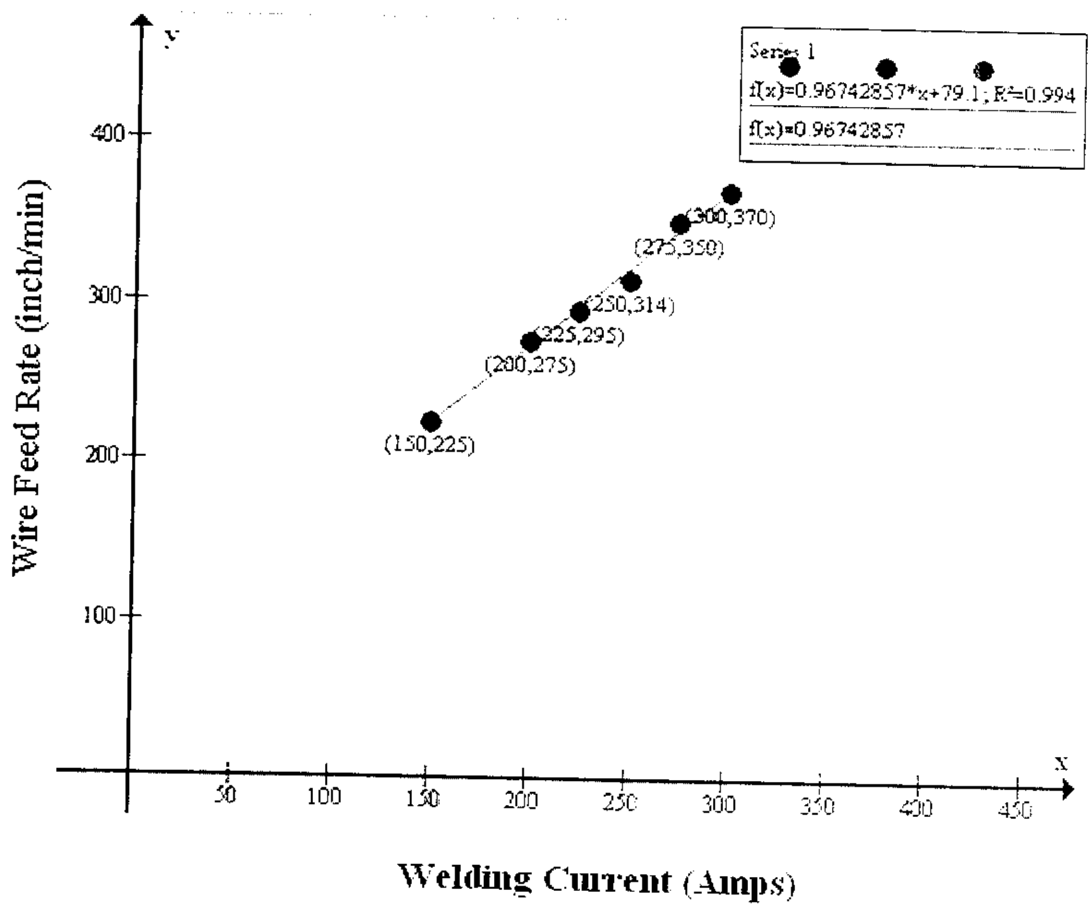


Figure 4.1 Relationship between Pulsed Current and Wire Feed Rate

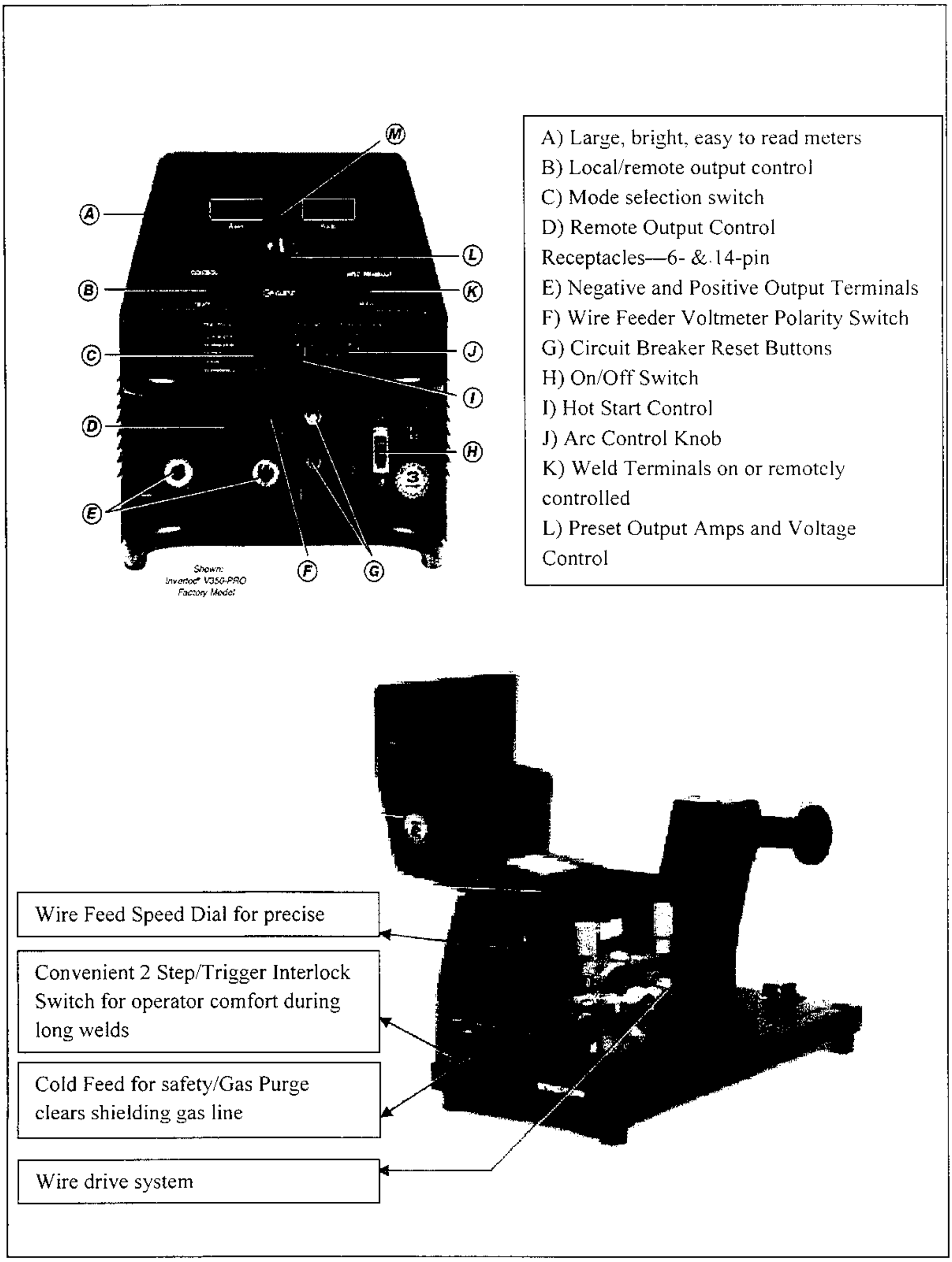


Figure 4.2 Inverter and Wire Feeder

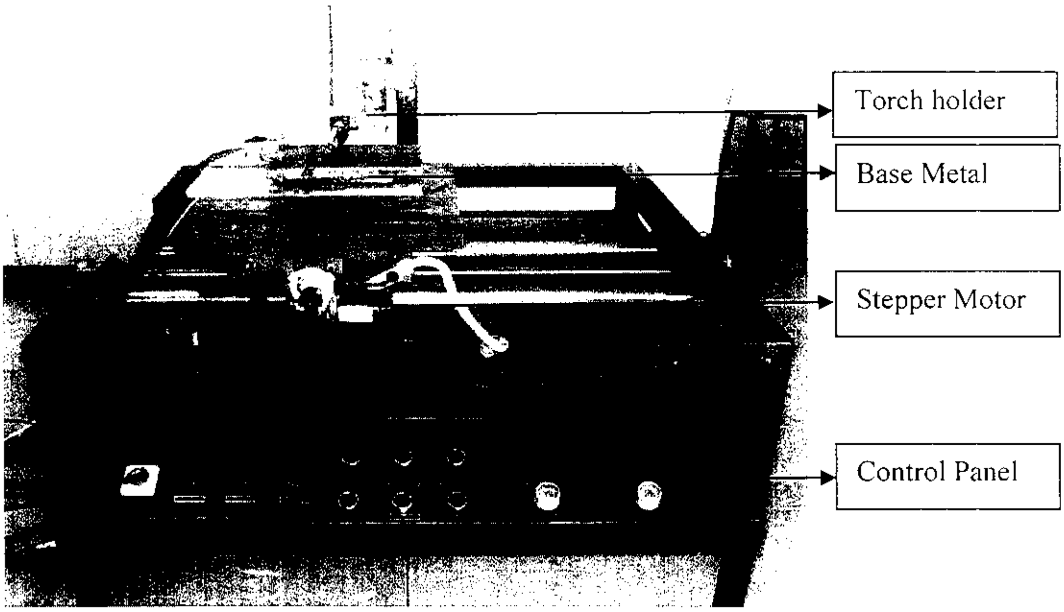


Figure 4.3 Manipulator

Figure 4.4 Shielding Gas

Figure 4.5 Cladding Process

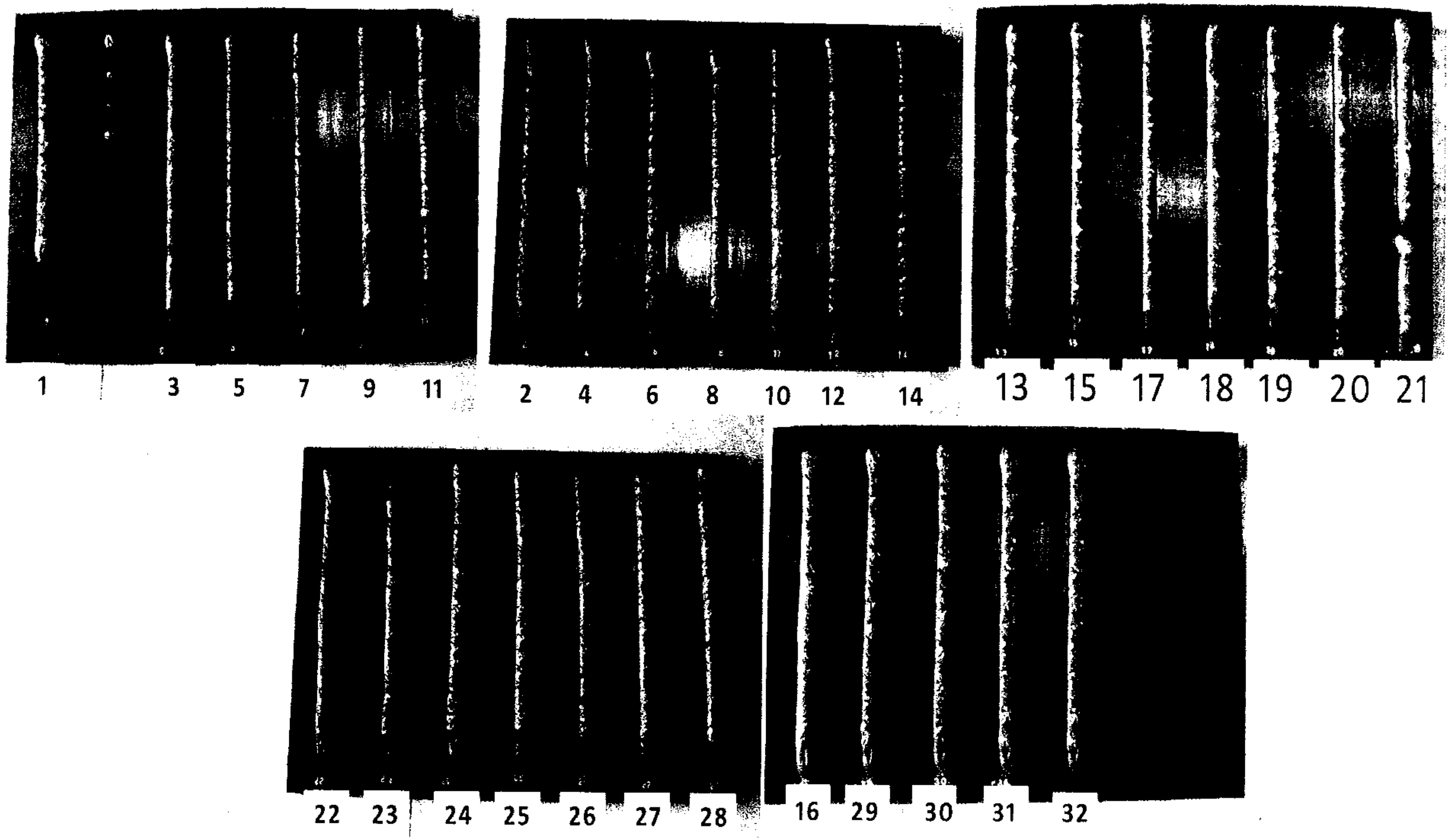


Figure 4.6 Cladded Specimens

4.1.5 Recording the Responses

To measure the clad bead geometry, transverse sections of each weld overlays were cut using band saw (Figure 4.7) from the mid-length position of the welds, and the end faces were machined and Grinded (Figure 4.7). Specimen end faces were polished and etched using a 5% natal solution display bead dimensions.

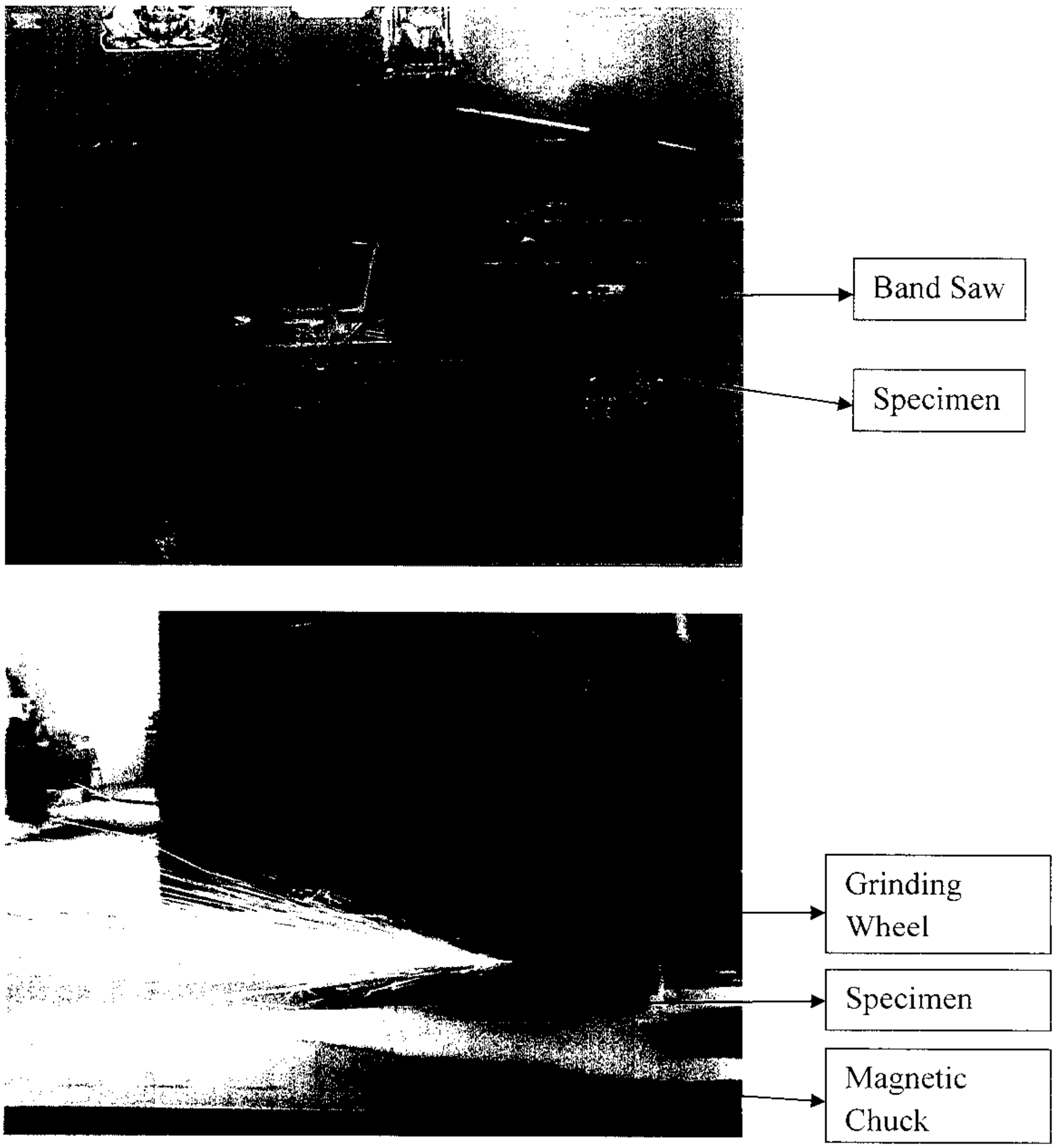


Figure 4.7 Band Saw Cutting and Grinding of Cladded Specimens

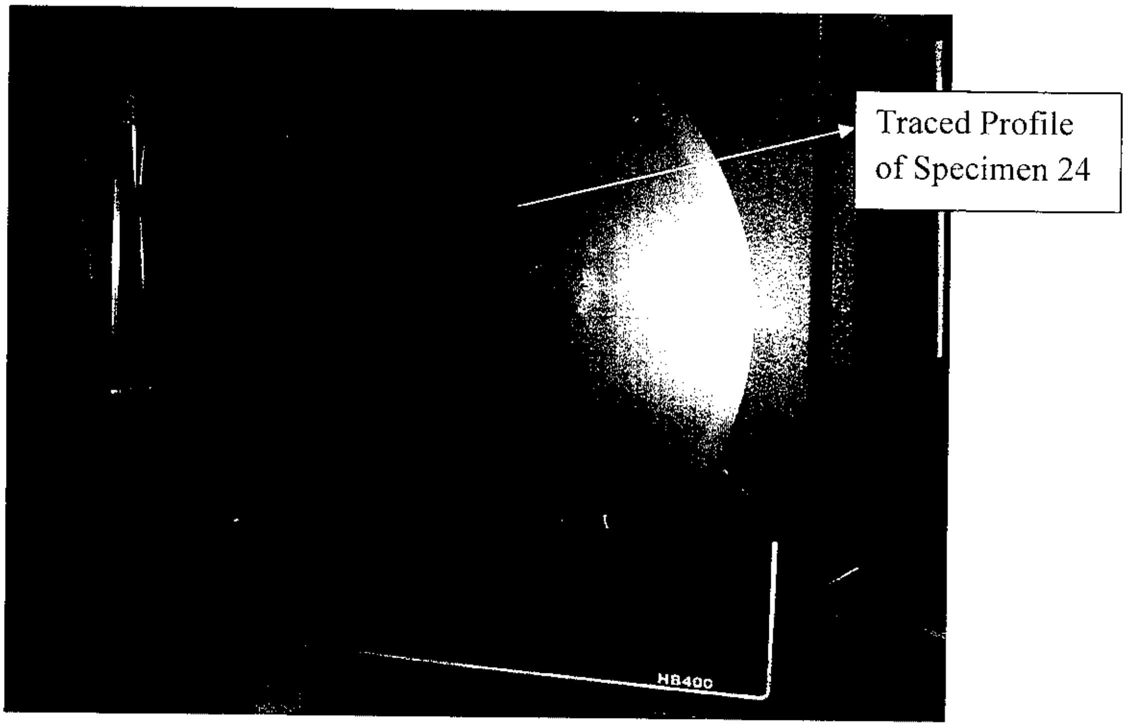


Figure 4.8 Profile Projector

The clad bead profiles were traced using a reflective type optical profile projector (Figure 4.8) at a magnification of X10, in M/S Roots Industries Ltd, Coimbatore. Then the bead dimensions such as depth of penetration, height of reinforcement and clad bead width were measured. The traced bead profiles (Figure 4.9) were scanned in order to find the various clad parameters and the percentage dilution with the help of AUTOCAD software. The measured clad bead dimensions and percentage dilution are shown in table 4.4.

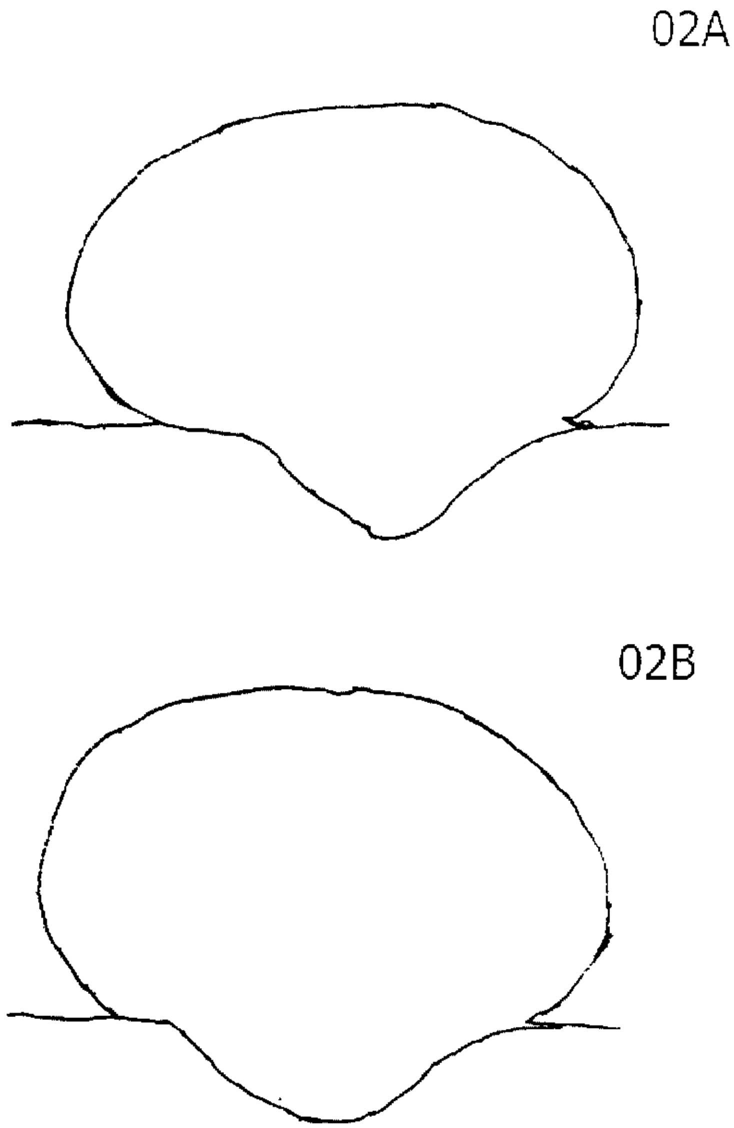


Figure 2.9 Traced Profiles (Specimen No. 2)

Where, A represent the profile of specimen's front side and B represent the profile of specimen's back side.

Table 4.4 Design Matrix and the Observed Values of Clad Bead Geometry

Trial No.	Design Matrix					Bead Parameters			
	I	S	N	T	Ac	W (mm)	P (mm)	R (mm)	D (%)
1	-1	-1	-1	-1	+1	6.9743	1.6735	6.0262	10.720
2	+1	-1	-1	-1	-1	7.6549	1.9715	5.8874	12.167
3	-1	+1	-1	-1	-1	6.3456	1.6986	5.4519	12.745
4	+1	+1	-1	-1	+1	7.7635	1.7396	6.0684	10.610
5	-1	-1	+1	-1	-1	7.2683	2.443	5.7206	16.673
6	+1	-1	+1	-1	+1	9.4383	2.4905	5.9169	15.966
7	-1	+1	+1	-1	+1	6.0823	2.4672	5.4921	16.589
8	+1	+1	+1	-1	-1	8.4666	2.0737	5.9467	14.984
9	-1	-1	-1	+1	-1	6.3029	1.5809	5.9059	10.274
10	+1	-1	-1	+1	+1	7.0136	1.5662	5.9833	9.7072
11	-1	+1	-1	+1	+1	6.2956	1.5861	5.5105	11.116
12	+1	+1	-1	+1	-1	7.741	1.8466	5.8752	11.427
13	-1	-1	+1	+1	+1	7.3231	2.1648	5.721	15.290
14	+1	-1	+1	+1	-1	9.6171	2.695	6.3745	18.540
15	-1	+1	+1	+1	-1	6.6335	2.3089	5.554	17.231
16	+1	+1	+1	+1	+1	10.514	2.7298	5.4645	20.875
17	-2	0	0	0	0	6.5557	1.9905	5.8059	13.657
18	+2	0	0	0	0	7.4772	2.5737	6.6551	15.741
19	0	-2	0	0	0	7.5886	2.5046	6.4069	15.778
20	0	+2	0	0	0	7.5014	2.1842	5.6782	16.823
21	0	0	-2	0	0	6.1421	1.3752	6.0976	8.9417
22	0	0	+2	0	0	8.5647	3.1854	5.6366	22.947
23	0	0	0	-2	0	7.9575	2.2018	5.8281	15.749
24	0	0	0	+2	0	7.7085	1.8589	6.0752	13.272
25	0	0	0	0	-2	7.8365	2.3577	5.7492	16.632
26	0	0	0	0	+2	8.2082	2.3658	5.9901	16.380
27	0	0	0	0	0	7.9371	2.1362	6.0153	15.183
28	0	0	0	0	0	8.4371	2.1715	5.699	14.827
29	0	0	0	0	0	9.323	3.1425	5.576	22.843
30	0	0	0	0	0	9.2205	3.2872	5.6149	23.633
31	0	0	0	0	0	10.059	2.8661	5.621	21.552
32	0	0	0	0	0	8.9953	2.7207	5.7052	19.608

4.1.6 Development of Mathematical Models

Using observed values as obtained from the Table 4, mathematical models were developed. The response function representing any of the clad bead geometry can be expressed using the equation (4.3)

$$\mathbf{Y = f\,(A, B, C, D, E)} \qquad \text{------- } \mathbf{(4.3)}$$

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

A =	Welding Current	(I) in Amperes
B =	Welding speed	(S) in mm/min
C =	Nozzle to plate distance	(N) in mm
D =	Welding torch Angle	(T) in Degrees
E =	Pinch	(Ac)

The second order surface response model for the four selected factors is given by the equation (4.4):

$$Y = \beta_O + \sum_{i=0}^{5} \beta_i X_i + \sum_{i=0, i<j}^{5} \beta_{ij} X_i^2 + \sum_{i=0}^{5} \beta_{ij} X_i X_j \qquad \text{------- (4.4)}$$

The second order surface response model [equation (4.4)] could be expressed as follows:

$$Y = \beta_0 + \beta_1 A + \beta_2 B + \beta_3 C + \beta_4 D + \beta_5 E + \beta_{11} A^2 + \beta_{22} B^2 + \beta_{33} C^2 + \beta_{44} D^2 + \beta_{55} E^2 + \beta_{12} AB + \beta_{13} AC + \beta_{014} AD + \beta_{15} AE + \beta_{23} BC + \beta_{24} BD + \beta_{25} BE + \beta_{34} CD + \beta_{35} CE + \beta_{45} DE \qquad \text{------- (4.5)}$$

Where β_0 is the free term of the regression equation, the coefficients β_1, β_2. β_3 , β_4 and β_5 are linear terms, the coefficients β_{11}. β_{22}. β_{33}. β_{44} and β_{55} quadratic terms, and the coefficients β_{12}, β_{13}, β_{14}, β_{15} 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:

Clad Bead Width (W), mm $=8.923+0.701A-0.08B+0.587C+0.040D+0.088E-0.423A^2-0.291B^2-0.338C^2-0.219D^2-0.171E^2+0.205AB+0.405AC+0.105AD+0.070AE-0.134BC+0.225BD+0.098BE+0.26CD+0.086CE+0.021DE$ ------- (4.6)

Depth of Penetration (P), mm $=2.942+0.098A-0.032B+0.389C-0.032D-0.008E-0.168A^2-0.153B^2-0.169C^2-0.231D^2-0.149E^2-0.033AB+0.001AC+0.075AD+0.005AE-0.018BC+0.066BD+0.087BE+0.058CD+0.054CE-0.036DE$ ------- (4.7)

Height of Reinforcement (R), mm $=5.752+0.160A-0.151B-0.060C+0.016D-0.002E+0.084A^2+0.037B^2-0.006C^2+0.015D^2-0.006E^2+0.035AB+0.018AC-0.008AD-0.048AE-0.024BC-0.062BD-0.003BE+0.012CD-0.092CE-0.095DE$ ------- (4.8)

Percentage Dilution (D), % $=21.296+0.325A+0.347B+3.141C-0.039D-0.153E-1.665A^2-1.264B^2-1.353C^2-1.712D^2-1.213E^2-0.200AB+0.346AC+0.602AD+0.203AE+0.011BC+0.465BD+0.548BE+0.715CD+0.360CE+0.137DE$ ------- (4.9)

4.1.7 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 4.5.

Table 4.5 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			
W	36.89	20	6.233	11	3.513	6	2.721	5	1.076	3.390	Adequate
P	7.81	20	0.404	11	0.142	6	0.261	5	0.454	7.472	Adequate
R	1.92	20	0.572	11	0.444	6	0.128	5	2.885	3.747	Adequate
D	506.07	20	21.739	11	6.289	6	15.45	5	0.339	8.189	Adequate

F ratio (6, 5, 0.05) = 3.40451

R ratio (20, 5, 0.05) = 3.20665

CHAPTER 5

DEVELOPMENT OF MATHEMATICAL MODELS USING QUALITY AMERICA SOFTWARE

5.1. Software Used For the Development of The Regression Model

Some of the software's 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

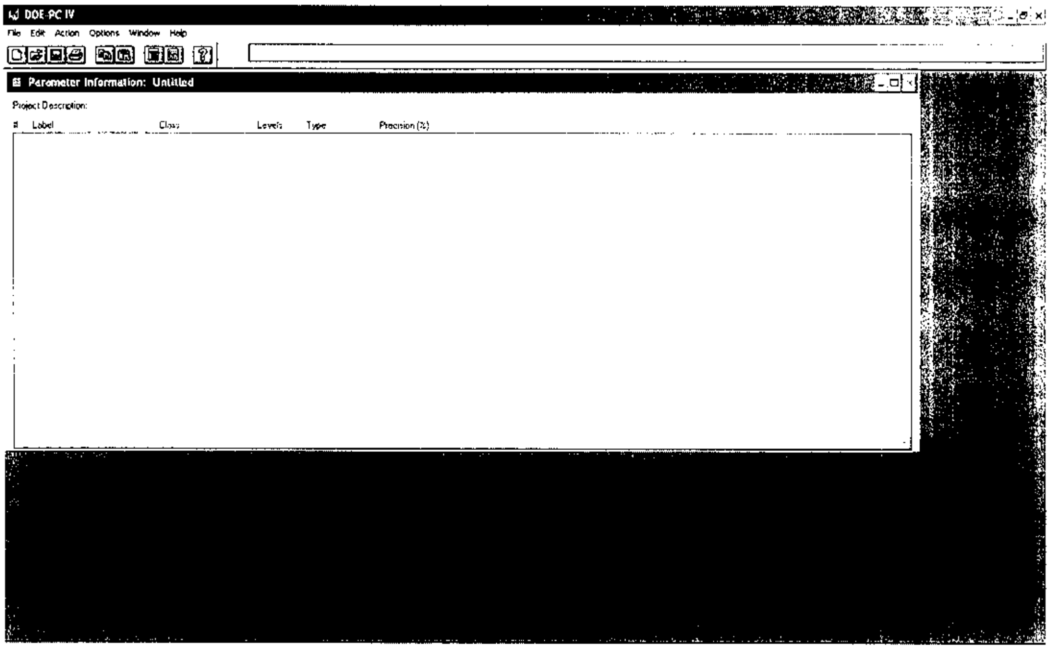
Among the software's, Quality America Six Sigma Software (DOE – PC IV) has been found to be easier to calculate the regression coefficients. Hence, this software is used for the experimental study purpose.

5.2. Steps In Finding Regression Coefficients

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

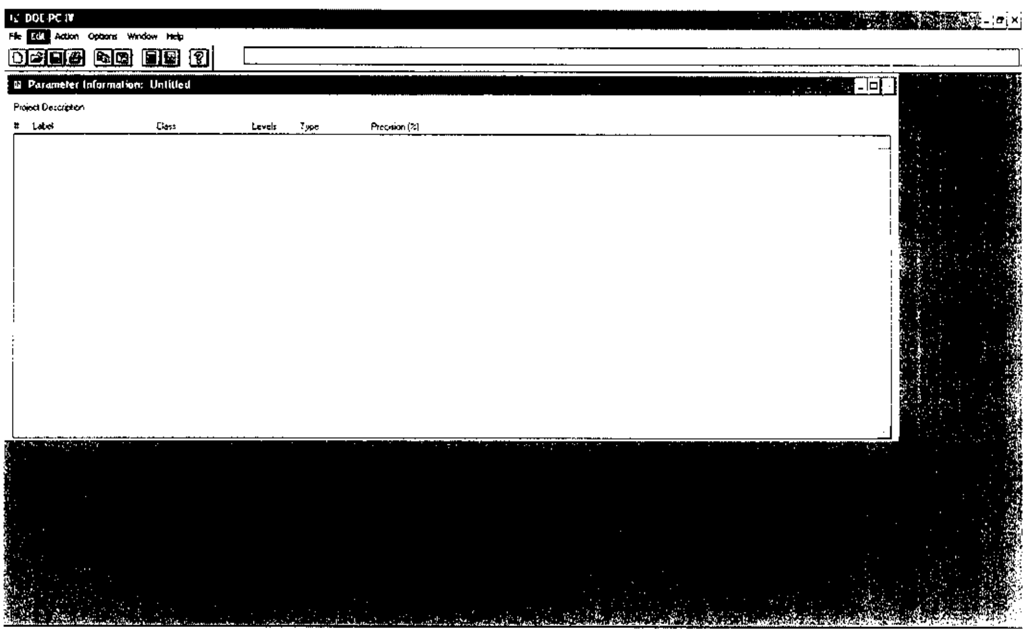
STEP 1:

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



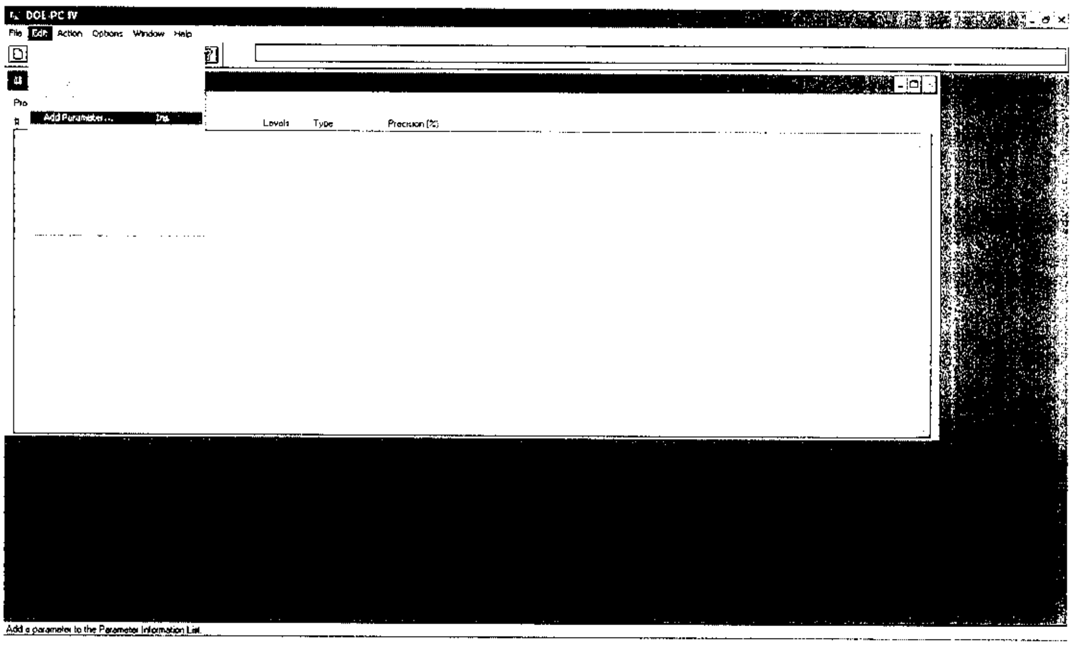
STEP 2:

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



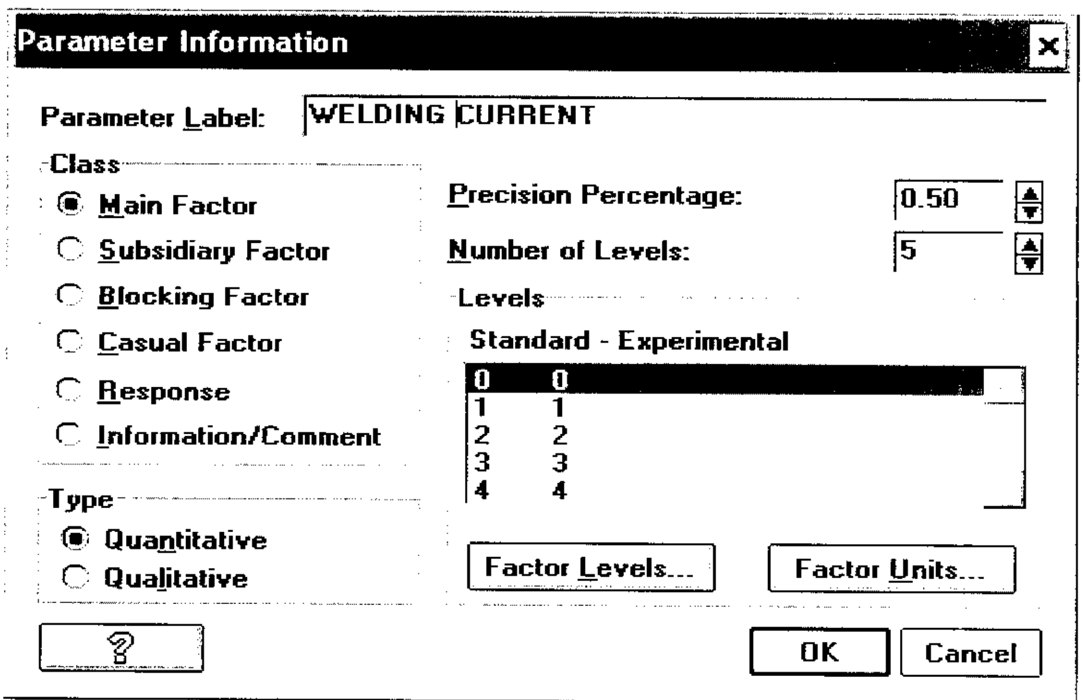
STEP 3:

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



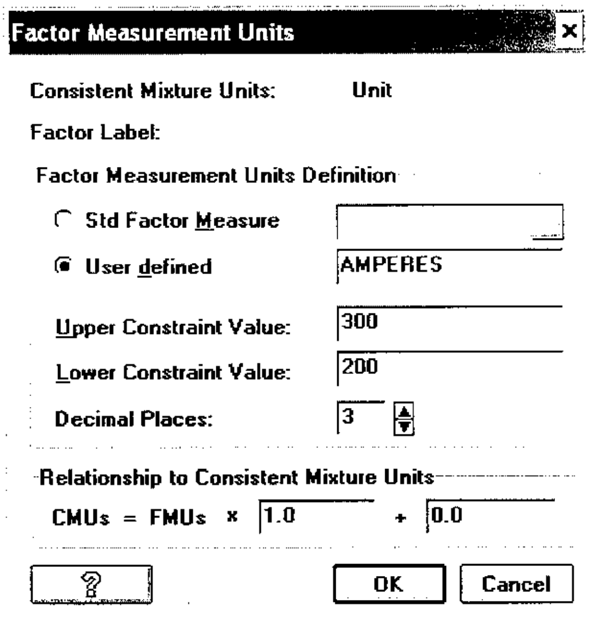
STEP 4:

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



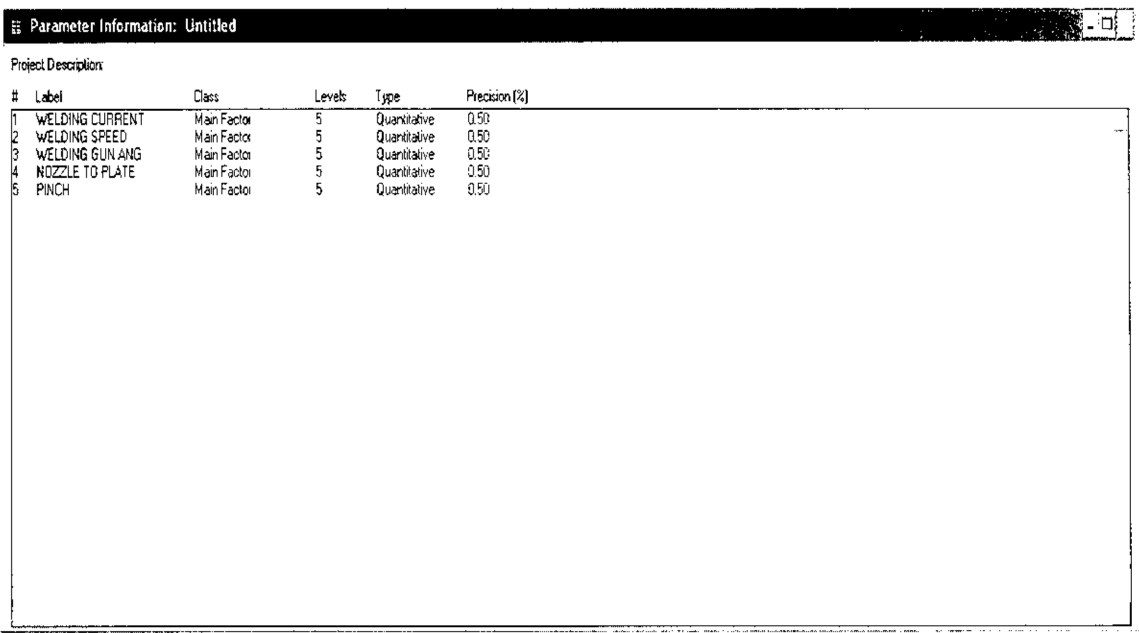
STEP 5:

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:

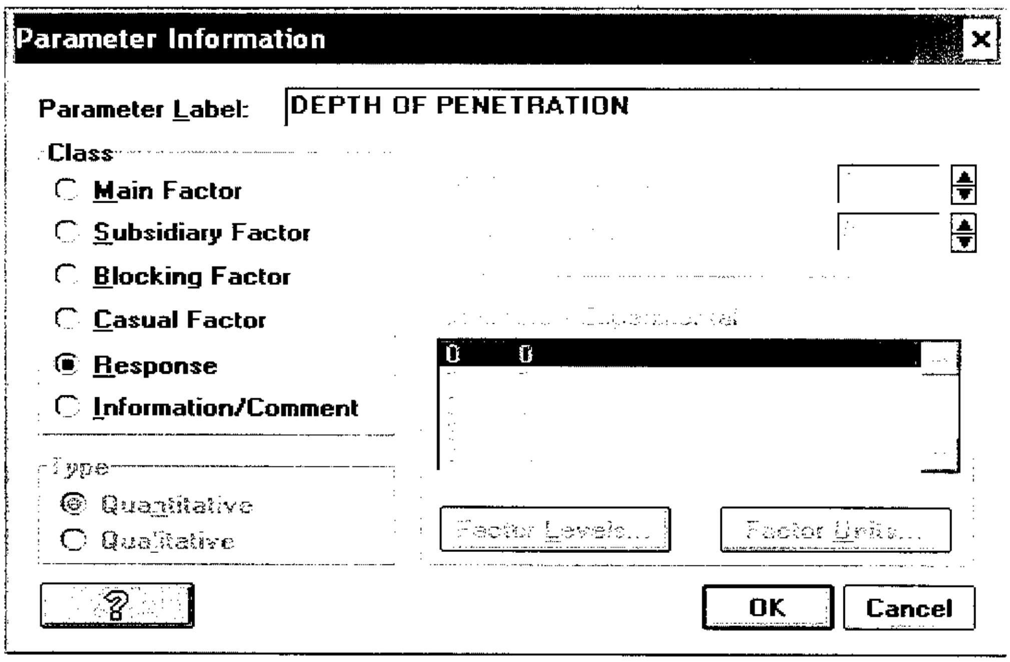
Similarly, steps 3 to 5 are followed to enter all the input parameters along with their respective units and limit values.



#	Label	Class	Levels	Type	Precision (%)
1	WELDING CURRENT	Main Factor	5	Quantitative	0.50
2	WELDING SPEED	Main Factor	5	Quantitative	0.50
3	WELDING GUN ANG	Main Factor	5	Quantitative	0.50
4	NOZZLE TO PLATE	Main Factor	5	Quantitative	0.50
5	PINCH	Main Factor	5	Quantitative	0.50

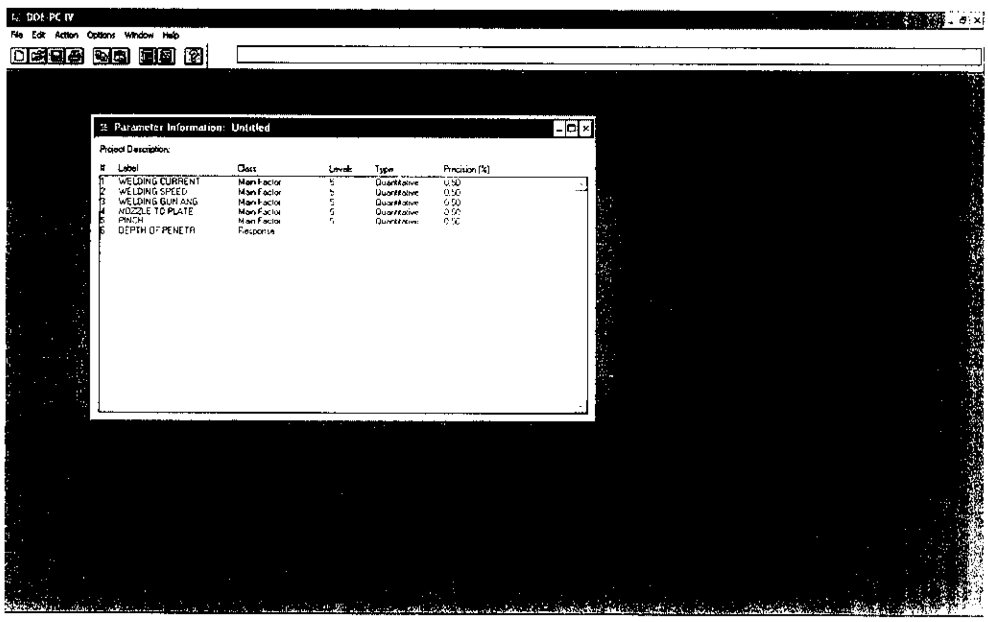
STEP 7:

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



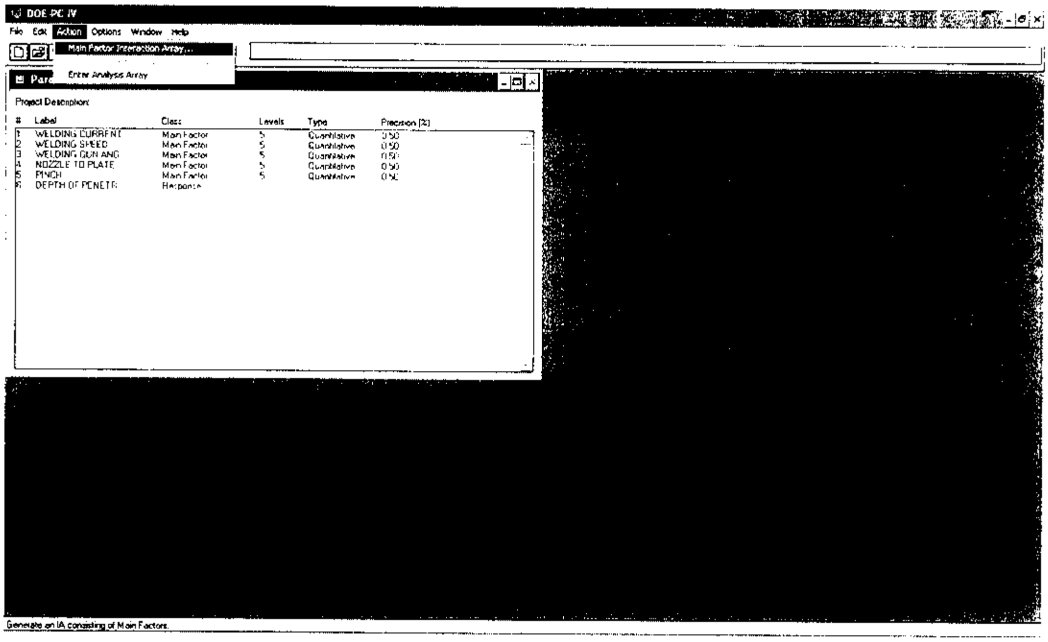
STEP 8:

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



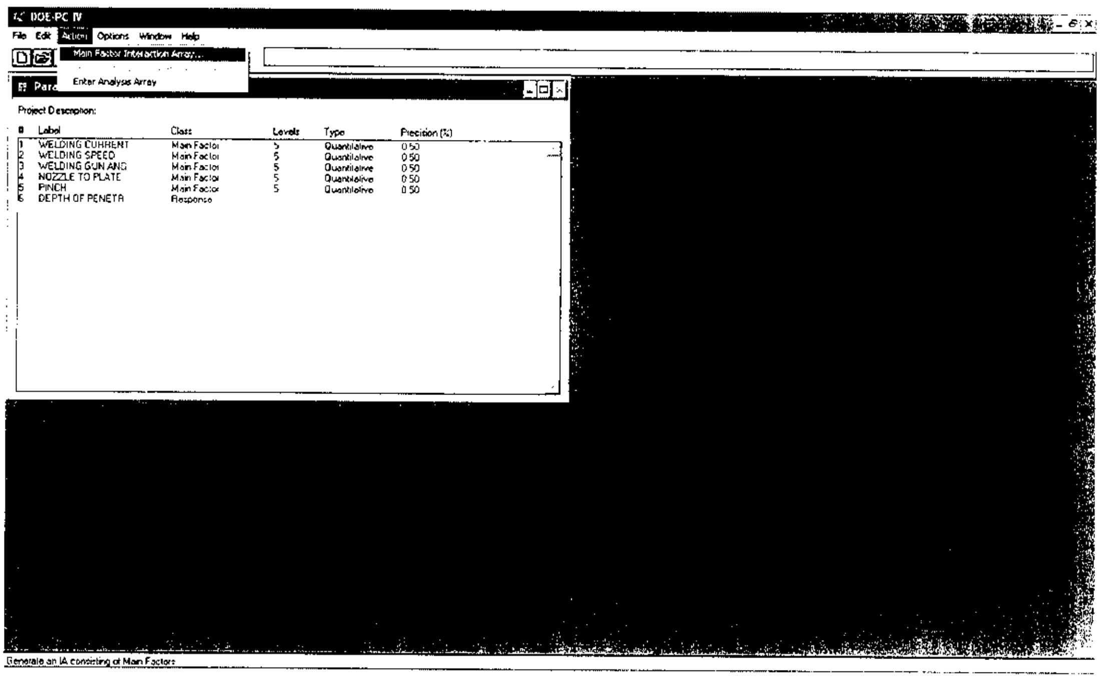
STEP 9:

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



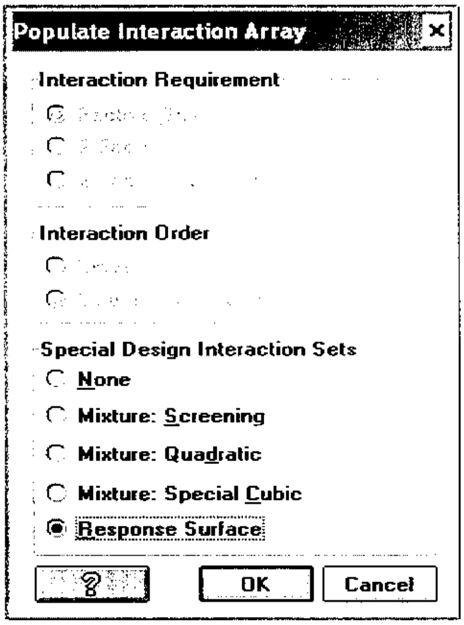
STEP 10:

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



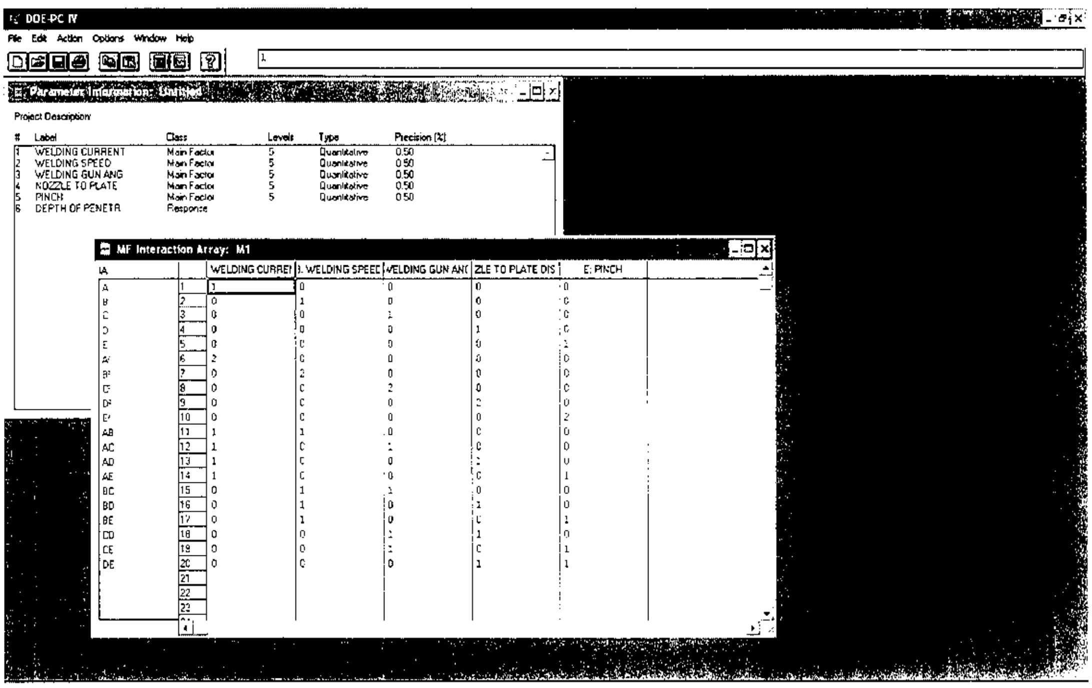
STEP 11:

Then the ‘RESPONSE SURFACE’ option is chosen from the given options.



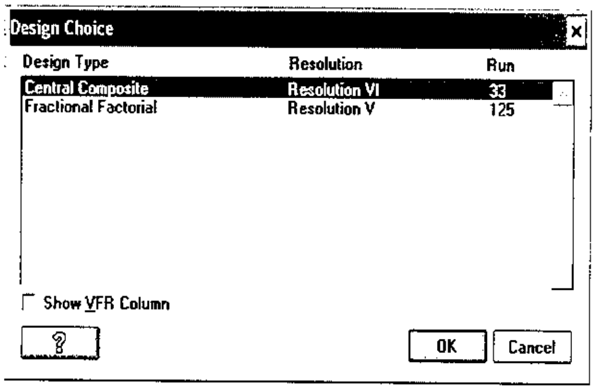
STEP 12:

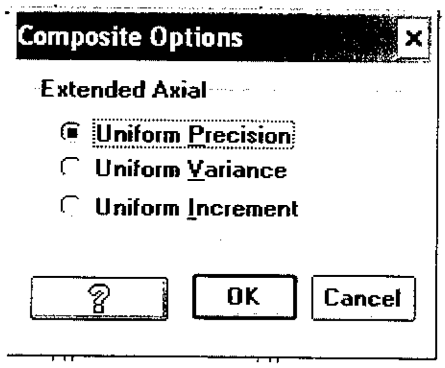
Now the ‘CHOOSE DESIGN ARRAY’ option is chosen from the drop down menu.



STEP 13:

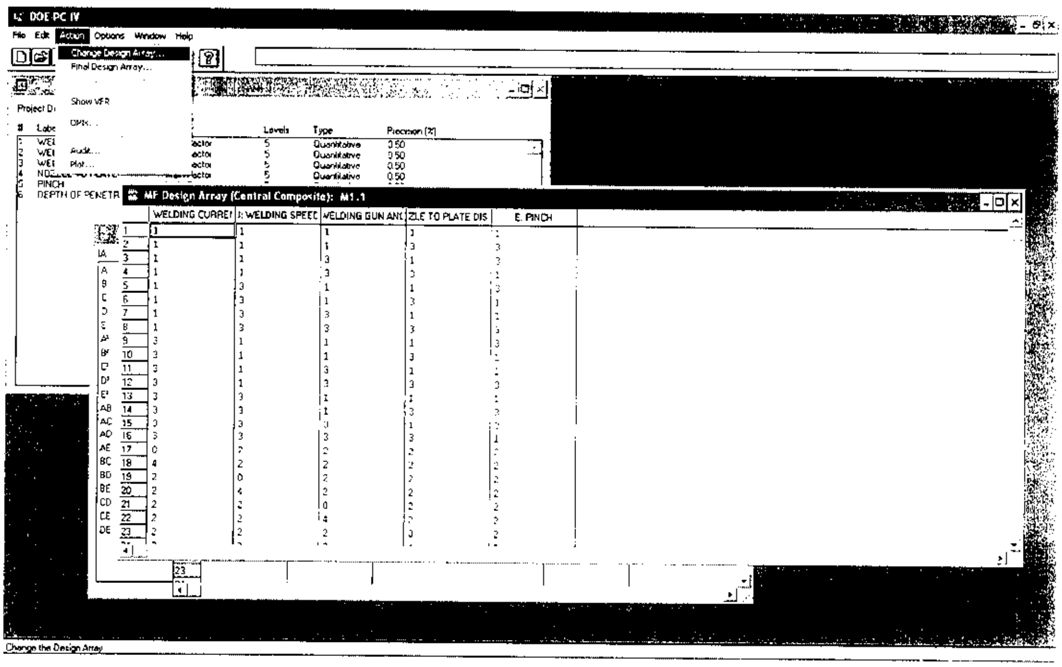
After this, the 'CENTRAL COMPOSITE' design type is chosen along with 'UNIFORM PRECISION' type.





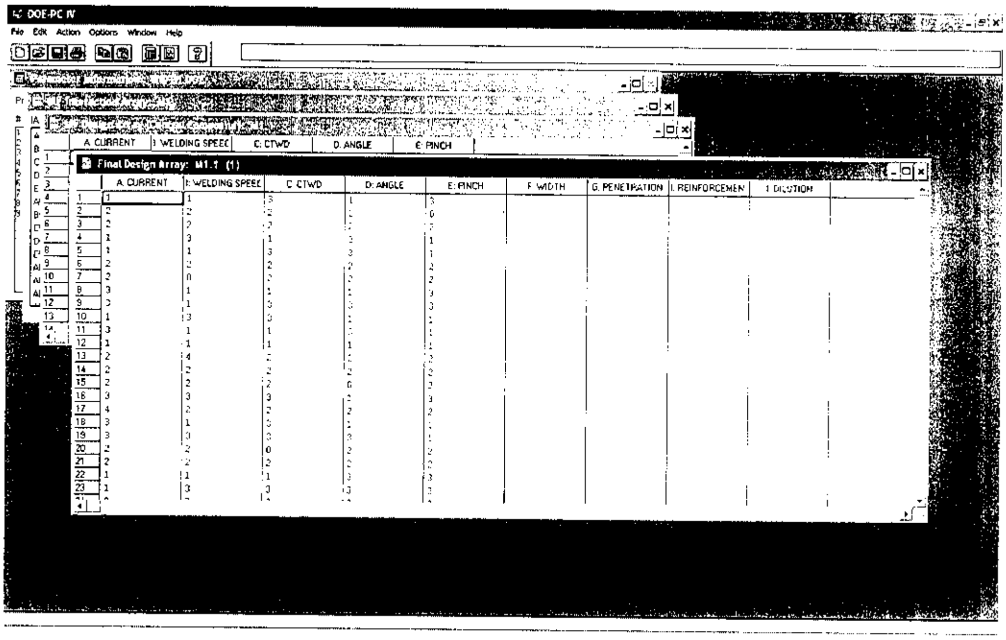
STEP 14:

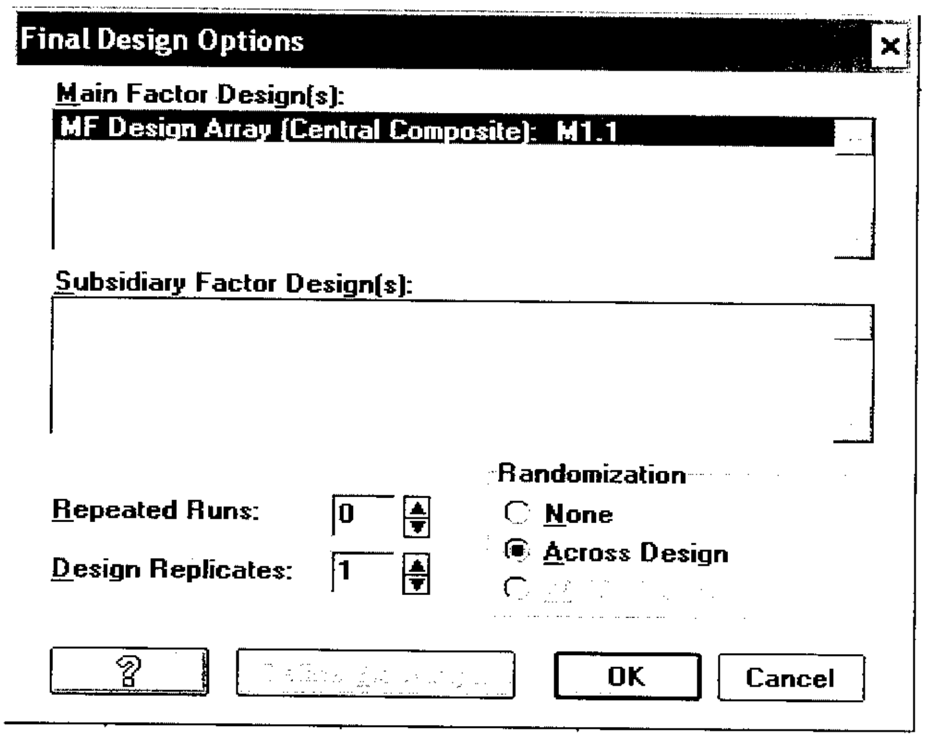
After this, the 'CENTRAL DESIGN ARRAY' option is chosen from the drop down menu and the design matrix from the excel sheet is copied and pasted.



STEP 15:

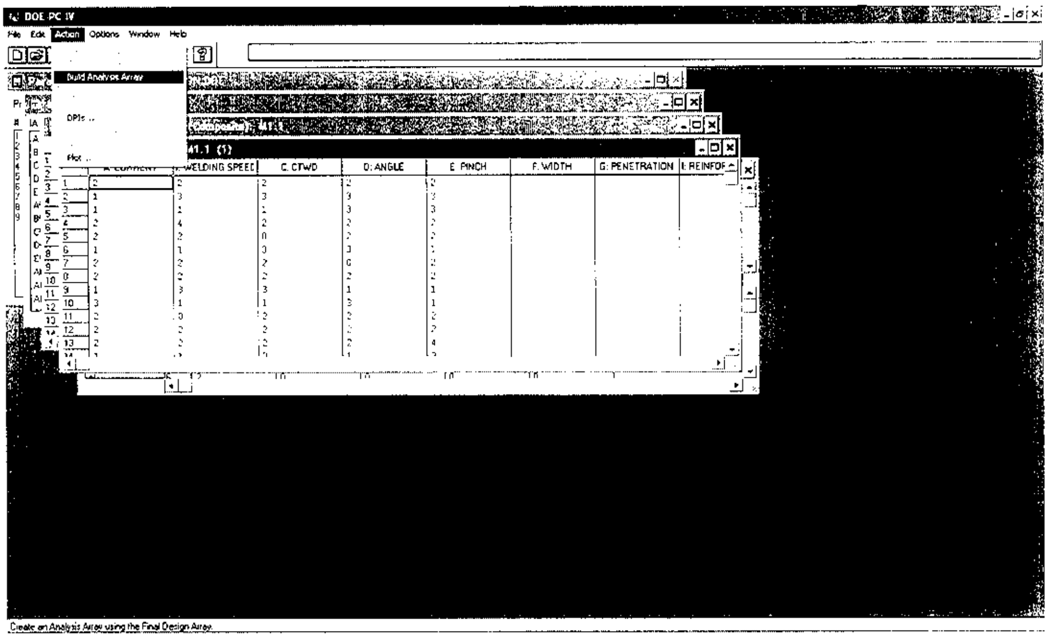
After copying the design matrix, the 'FINAL DESIGN MATRIX' option is chosen from the drop down menu after which 'NONE' randomization option is selected.





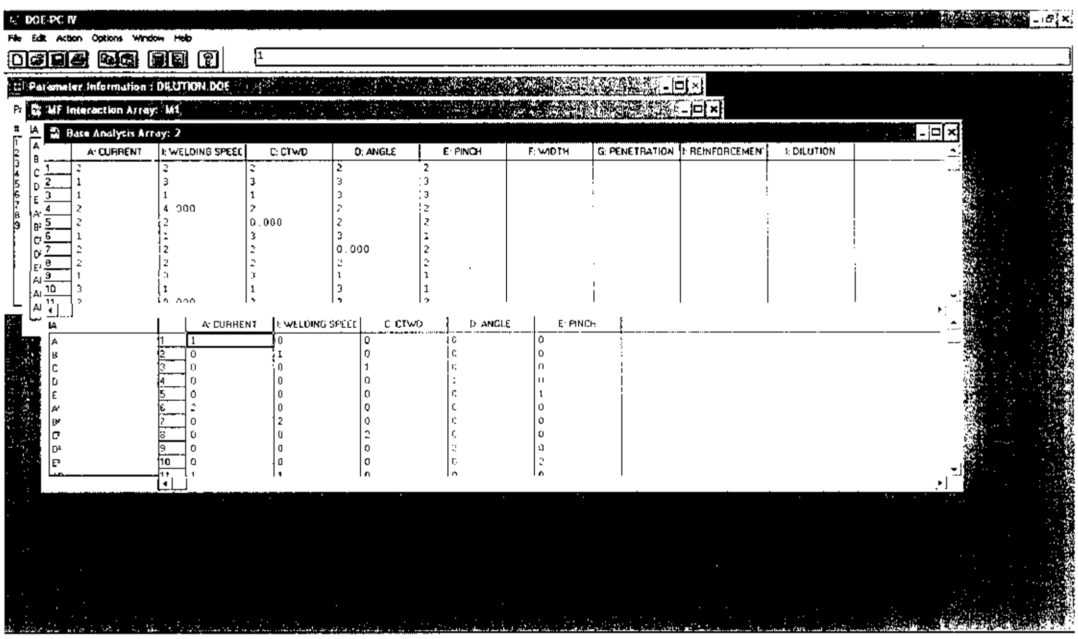
STEP 16:

Then the 'BUILD ANALYSIS ARRAY' option is chosen.



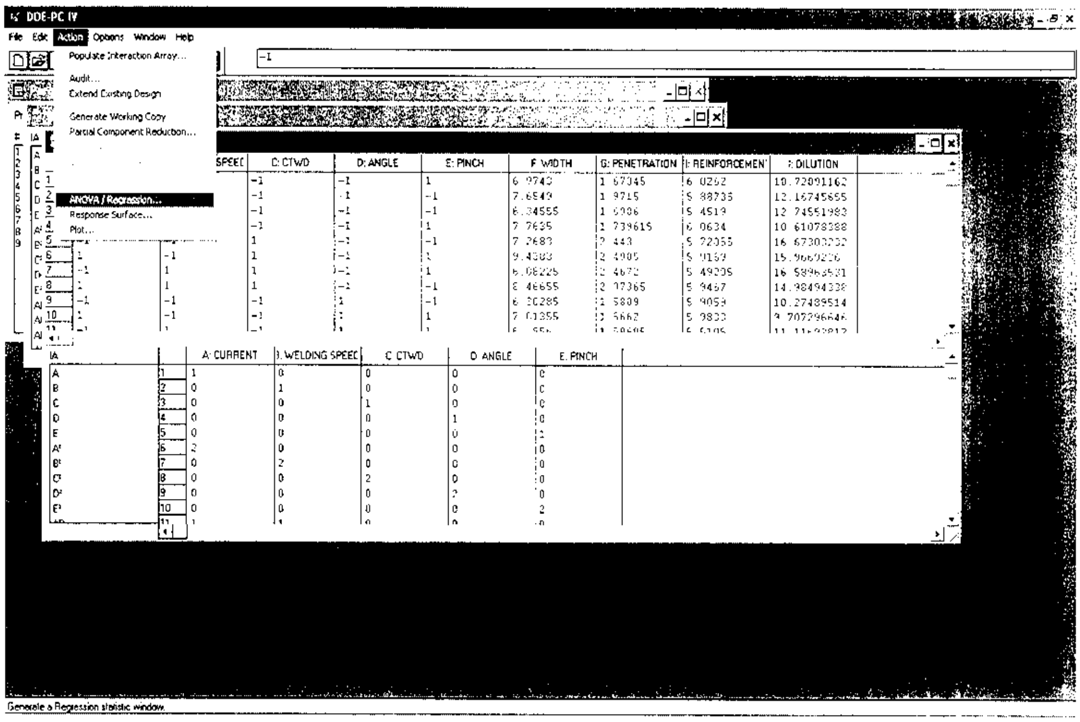
STEP 17:

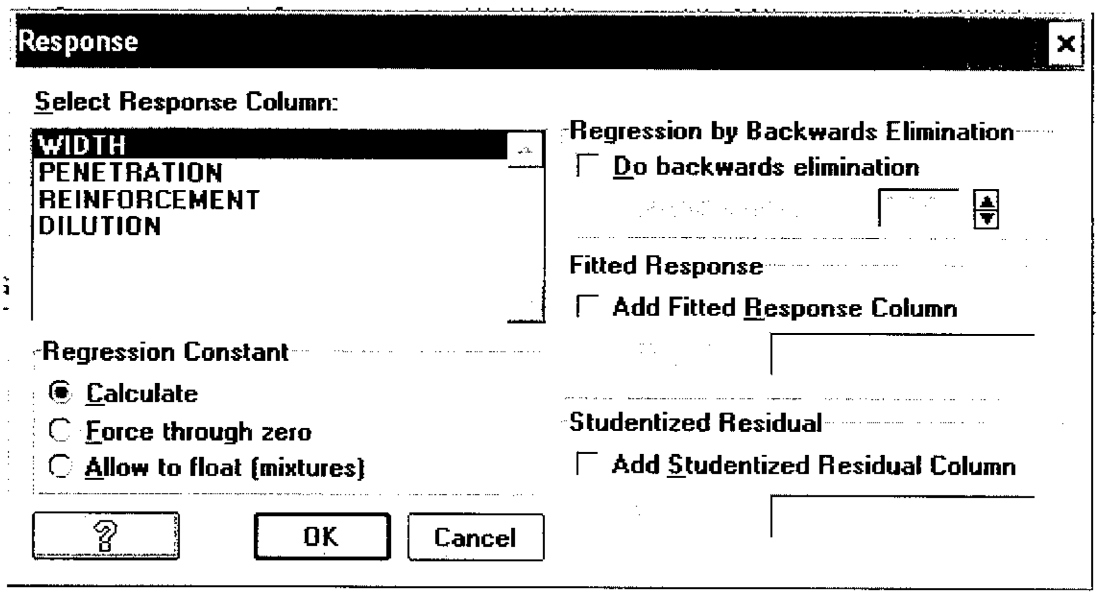
Now the value of the output is pasted from the excel sheet.



STEP 18:

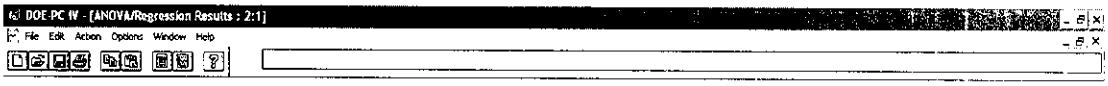
After this, the 'ANOVA / REGRESSION' option is chosen from the drop down menu in order to find the values of regression coefficients.





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.



FITTED PARAMETERS.

Source / Parameter	Level of Significance	Levels	Coefficient	Standard Error	Transmitted Variance	Sum of Squares (Partial SS)	t-Ratio
Mean	0.000	0	8.923	0.000	0.000	0.000	0.000
A CURRENT	0.999	5	0.701	0.154	0.046	11.797	4.563
B WELDING SPEED	0.388	5	-0.080	0.154	0.046	0.154	-0.522
C CTWD	0.997	5	0.587	0.154	0.046	8.281	3.823
D ANGLE	0.198	5	0.040	0.154	0.046	0.038	0.257
E PINCH	0.423	5	0.088	0.154	0.046	0.187	0.574
A²	0.989	25	-0.423	0.139	0.042	5.242	-3.041
B²	0.939	25	-0.291	0.139	0.042	2.477	-2.091
C²	0.967	25	-0.338	0.139	0.042	3.361	-2.435
D²	0.856	25	-0.219	0.139	0.042	1.401	-1.573
E²	0.756	25	-0.171	0.139	0.042	0.860	-1.232
AB	0.700	25	0.205	0.188	0.056	0.670	1.087
AC	0.945	25	0.405	0.188	0.056	2.620	2.150
AD	0.411	25	0.105	0.188	0.056	0.176	0.557
AE	0.284	25	0.070	0.188	0.056	0.079	0.374
BC	0.510	25	-0.134	0.188	0.056	0.289	-0.714
BD	0.744	25	0.225	0.188	0.056	0.812	1.197
BE	0.386	25	0.098	0.188	0.056	0.153	0.519
CD	0.811	25	0.264	0.188	0.056	1.112	1.401
CE	0.342	25	0.086	0.188	0.056	0.117	0.455
DE	0.085	25	0.021	0.188	0.056	0.007	0.109

CORRELATION TABLE

	A	B	C	D	E	A²	B²	C²	D²	E²	AB	AC	AD	AE	BC	BD	BE	CD	CE
A	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00
B		1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00
C			1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00
D				1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00
E					1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00
A²						1.000	-0.067	-0.067	-0.067	-0.067	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00
B²							1.000	-0.067	-0.067	-0.067	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00
C²								1.000	-0.067	-0.067	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00
D²									1.000	-0.067	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00
E²										1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00
AB											1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00
AC												1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00
AD													1.000	0.000	0.000	0.000	0.000	0.000	0.00
AE														1.000	0.000	0.000	0.000	0.000	0.00
BC															1.000	0.000	0.000	0.000	0.00
BD																1.000	0.000	0.000	0.00
BE																	1.000	0.000	0.00
CD																		1.000	0.00
CE																			1.00

CHAPTER 6

OPTIMIZATION TECHNIQUES – AN OVERVIEW

6.1 Introduction

One of the most fundamental principles in our world is the search for an optimal state. It begins in the microcosm where atoms in physics try to form bonds in order to minimize the energy of their electrons. When molecules form solid bodies during the process of freezing, they try to assume energy-optimal crystal structures. These processes, of course, are not driven by any higher intention but purely result from the laws of physics. The same goes for the biological principle of survival of the fittest which, together with the biological evolution, leads to better adaptation of the species to their environment. Here, a local optimum is a well-adapted species that dominates all other animals in its surroundings. Homo sapiens have reached this level, sharing it with ants, bacteria, flies, cockroaches, and all sorts of other creepy creatures.

As long as humankind exists, we strive for perfection in many areas. We want to reach a maximum degree of happiness with the least amount of effort. In our economy, profit and sales must be maximized and costs should be as low as possible. Therefore, optimization is one of the oldest of sciences which even extends into daily life. If something is important, general, and abstract enough, there is always a mathematical discipline dealing with it. Global optimization is the branch of applied mathematics and numerical analysis that focuses on, well, optimization. The goal of global optimization is to find the best possible elements $x\star$ from a set X according to a set of criteria F = {f1, f2... fn}. These criteria are expressed as mathematical functions, the so-called objective functions.

An objective function $f : X \rightarrow Y$ with $Y \subseteq R$ is a mathematical function which is subject to optimization.

6.2 Classification of Optimization Algorithms

Generally, optimization algorithms can be divided in two basic classes: deterministic and probabilistic algorithms. Deterministic algorithms are most often used if a clear relation between the characteristics of the possible solutions and their utility for a given problem exists. Then, the search space can efficiently be explored using for example a divide and conquer scheme. If the relation between a solution candidate and its "fitness"are not so obvious or too complicated, or the dimensionality of the search space is very high, it becomes harder to solve a problem deterministically. Trying it would possible result in exhaustive enumeration of the search space, which is not feasible even for relatively small problems. Then, probabilistic algorithms come into play. The initial work in this area which now has become one of most important research fields in optimization was started about 55 years ago. An especially relevant family of probabilistic algorithms are the Monte Carlo based approaches. They trade in guaranteed correctness of the solution for a shorter runtime. This does not mean that the results obtained using them are incorrect – they may just not be the global optima. Heuristics used in global optimization are functions that help decide which one of a set of possible solutions is to be examined next. On one hand, deterministic algorithms usually employ heuristics in order to define the processing order of the solution candidates. An example for such a strategy is informed search. Probabilistic methods, on the other hand, may only consider those elements of the search space in further computations that have been selected by the heuristic. Classification is shown in Figure 6 .1

A heuristic is a part of an optimization algorithm that uses the information currently gathered by the algorithm to help to decide which solution candidate should be tested next or how the next individual can be produced.

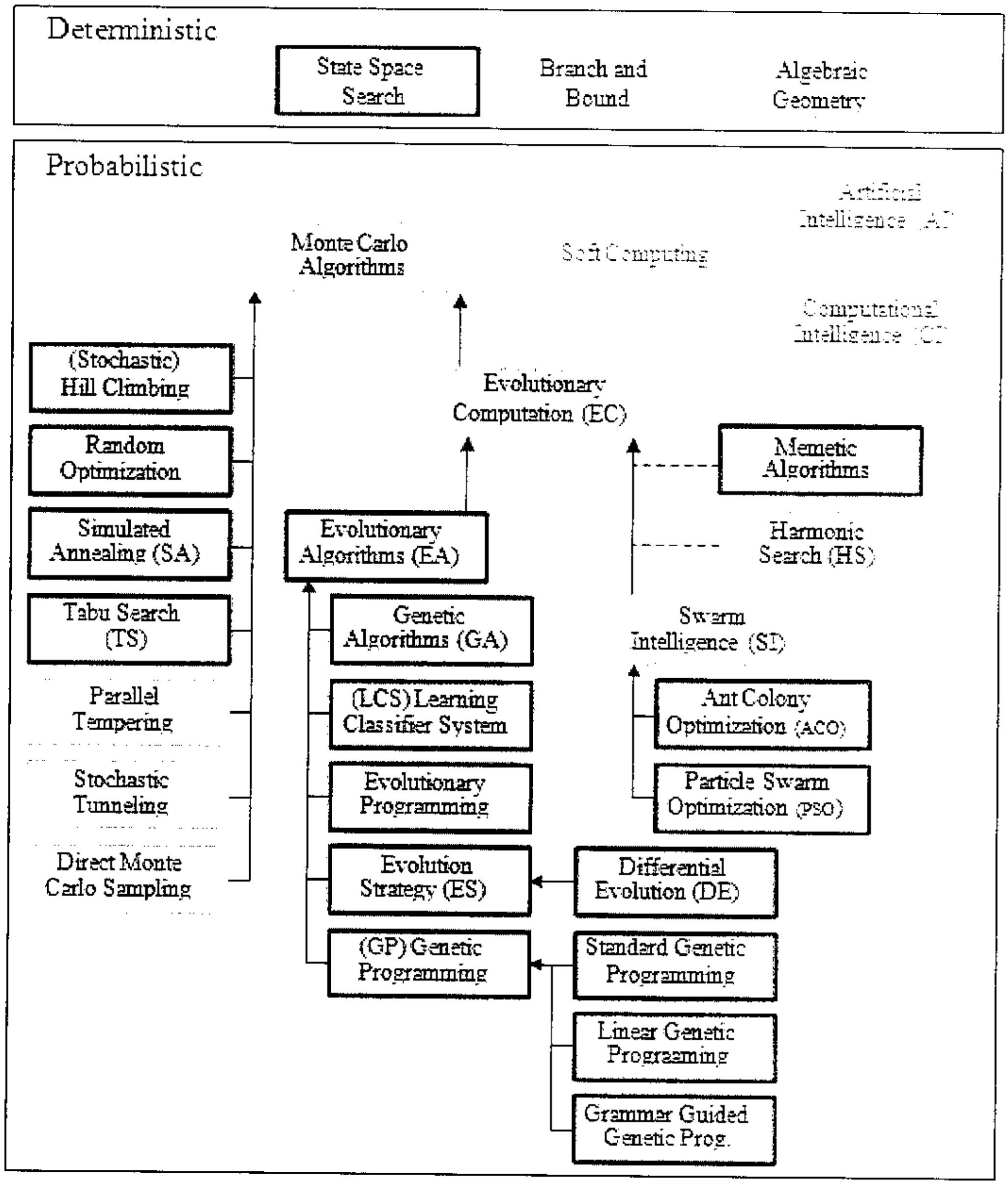


Figure 6.1 A Classification of Optimization Algorithms

6.3 Advantages of Non-Traditional Optimization Techniques

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

- A population of points is used for starting the procedure instead of a single design point.
- GA uses only the values of the objective function. The derivatives are not used in the search procedure.
- 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.
- The objective function value corresponding to a design vector plays the role of fitness in natural genetics.
- In every new generation, a new set of strings is produced by using randomized parents selection and crossover from the old generation.

6.4 Objectives of Optimization

Following are the objectives of optimization

- To reduce wastage of material, money and processing time.
- To decrease the fatigue of the worker who is on the shop floor.
- To increase productivity of the organization gradually.
- To satisfy the employees in the organization.
- Procurement of material will be very less because of the higher productivity.

CHAPTER 7

OPTIMIZATION OF PULSED GAS METAL ARC WELD CLADDING USING HYBRID TECHNIQUE

7.1 Introduction

Compiler writers constantly invent new optimization algorithms to improve the state of the art. They frequently arrive at significantly different algorithms for a particular compiler optimization. Often, however, there is no clear winner among the different algorithms. Each algorithm has situations in which it is preferable to the other algorithms. For example, many different register allocation algorithms have been invented that achieve either a good running time performance, possibly at the expense of increased allocation time, or a reduction in allocation time at the expense of performance. Two register allocation algorithms that differ in these seemingly mutually exclusive goals are graph coloring and linear scan.

Graph coloring is an aggressive technique for allocating registers, but is computationally expensive due to its use of the interference graph, which can have a worst-case size that is quadratic in the number of live ranges. Linear scan (LS), on the other hand, does not build an interference graph, but instead allocates registers to variables in a greedy fashion by scanning all the live ranges in a single pass. It is simple, efficient, and produces a relative good packing of all the variables of a method into the available physical registers. Graph coloring can sometimes lead to more effective packing of the registers, but it can be much more expensive than linear scan.

A new class of optimization heuristics, hybrid optimizations. Hybrid optimizations assume that one has implemented two or more algorithms for the same optimization. A hybrid optimization uses a heuristic to choose the best of these algorithms to apply in a given situation. Here we construct a hybrid register allocator that chooses between two different register allocation algorithms, graph coloring and linear scan. The goal is to create an allocator that achieves a good balance between two factors: trying to find a good packing of the variables to registers (and thereby achieving good running time performance) and trying to reduce the overhead of the allocator. We discuss how we use supervised learning to construct a hybrid allocator.

7.2 PSGAO Technique

Heuristic optimization provides a robust and efficient approach for solving complex real-world problems. The focus of this research is on a hybrid method combining two heuristic optimization techniques, genetic algorithms (GA) and particle swarm optimization (PSO), for the global optimization of multimodal functions. Denoted as PS-GAO, this hybrid technique incorporates concepts from GA and PSO and creates individuals in a new generation not only by crossover and mutation operations as found in GA but also by mechanisms of PSO.

In technique, PSO is used to create the initial population and then GA is used to find optimal value. Initially around 100 iteration is done using PSO then the Gbest value is taken. Then this value is give to GA and around 100 iteration is performed in GA to get the Gbest value.

7.3 Genetic Algorithm

7.3.1 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.

7.3.2 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.

7.3.3 Outline of Basic Genetic Algorithm Cycle

The genetic algorithm cycle used in this study is illustrated in Figure 7.1. The various steps involved are briefly described as given below.

Start

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

Fitness

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

New Population

A new population is created by repeating following steps.

Selection

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

Cross-over

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

Childless

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

Mutation

New offsprings are mutated with a mutation probability.

Accepting

New offsprings are placed in a new population.

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.

Test

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

Loop

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

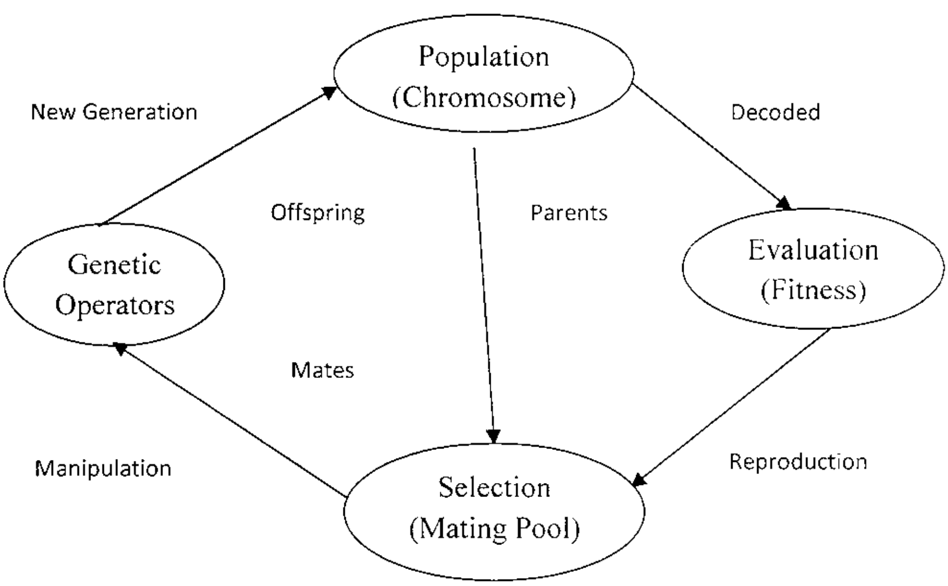


Figure 7.1 Genetic Algorithm Cycle

7.4 Particle Swarm Optimization

7.4.1 Introduction

Particle Swarm Optimization (PSO), developed by Eberhart and Kennedy in 1995, is a form of swarm intelligence in which the behavior of a biological social system like a flock of birds or a school of fish is simulated. When a swarm looks for food, its individuals will spread in the environment and move around independently. Each individual has a degree of freedom or randomness in its movements which enables it to find food accu-mulations. So, sooner or later, one of them will find something digestible and, being social, announces this to its neighbors. These can then approach the source of food, too. Particle Swarm Optimization has been discussed, improved, and refined by many researchers such as Venter and Sobieszczanski-Sobieski, Cai et al., Gao and Duan, and Gao and Ren. Comparisons with other evolutionary approaches have been provided by Eberhart and Shi and Angeline. With Particle Swarm Optimization, a swarm of particles (individuals) in a n-dimensional search space G is simulated, where each particle p has a position p.g ∈ G ⊆ Rn and a velocity p.v ∈ Rn. The position p.g corresponds to the genotypes, and, in most cases, also to the solution candidates, i. e., p.x = p.g, since most often the problem space X is also the Rn and X = G. However, this is not necessarily the case and generally, we can introduce any form of genotype-phenotype mapping in Particle Swarm Optimization. The velocity vector p.v of an individual p determines in which direction the search will continue and if it has an explorative (high velocity) or an exploitive (low velocity) character. In the initialization phase of Particle Swarm Optimization, the positions and velocities of all individuals are randomly initialized. In each step, first the velocity of a particle is updated and then its position. Therefore, each particle p has a memory holding its best position best(p) ∈ G. In order to realize the social component, the particle furthermore knows a set of topological neighbors N(p). This set could be defined to contain adjacent particles within a specific perimeter, i. e., all individuals which are no further away from p.g than a given distance δ according to a certain distance measure dist. using the Euclidian distance measure disteucl we get:

$$\forall\, p, q \in Pop : q \in N(p) \Leftrightarrow disteucl(p.g, q.g) \leq \delta$$

Each particle can communicate with its neighbors, so the best position found so far by anyelement in N(p) is known to all of them as best(N(p)). The best position ever visited by any individual in the population (which the optimization algorithm always keeps track of) is best(Pop).

The PSO algorithm may make use of either best(N(p)) or best(Pop) for adjusting the velocity of the particle p. If it relies on the global best position, the algorithm will converge fast but may find the global optimum less probably. If, on the other hand, neighborhood communication is used, the convergence speed drops but the global optimum is found morelikely.

PSOUpdate: The search operation q = psoUpdate(p,Pop) applied in Particle Swarm Optimization creates a new particles q to replace an existing one (p) by incor- porating its genotype p.g, its velocity p.v. We distinguish local updating and global updating which additionally uses the data from the whole population Pop. psoUpdate thus fulfills one of these two equations and third Equation, showing how the ith components of the corresponding vectors are computed.v_i

$$q.v_i = p.v_i + (randomu(0, c_i) * (best(p) .g_i - p.g_i))+(randomu(0, d_i) * (best(Pop) .g_i - p.g_i))$$

$q.v_i = p.vi + (randomu(0, c_i) * (best(p) .g_i - p.g_i)) + (randomu(0, d_i) * (best(N(p)) .g_i - p.g_i))$

$q.g_i = p.g_i + p.v_i$

The learning rate vectors c and d have strong influence of the convergence speed of Particle Swarm Optimization. The search space G (and thus, also the values of p.g) is normally confined by minimum and maximum boundaries. For the absolute values of the velocity, normally maximum thresholds also exist. Thus, real implementations of "psoUpdate" have to check and refine their results before the utility of the solution candidates is evaluated.

7.4.2 Algorithm: Illustrates the native form of the Particle Swarm Optimization using the update procedure. This algorithm can easily be generalized for multi-objective optimization and for returning sets of optimal solutions

Algorithm:

x⋆ ← psoOptimizerfps

Input: f: the function to optimize

Input: ps: the population size

Data: Pop: the particle population

Data: i: a counter variable

Output: x⋆: the best value found

```
begin
    Pop ←− createPop(ps)
    while terminationCriterion() do
        for i ←− 0 up to len(Pop) − 1 do
            Pop[i] ←− psoUpdate(Pop[i],Pop)
    return best(Pop) .x
end
```

7.5 Simulation Procedure

The aim of this study is to find the optimum adjusts for the Welding Current (I), welding speed (S), welding gun angle (T), nozzle-to-plate distance (N) and pinch (Ac) in a GMAW Cladding process. The optimum parameters are those who deliver responses the closest possible of the cited values and is shown in the table 7.1 & 7.2.

Table 7.1 PSO search ranges

PARAMETERS	RANGE
Welding Current (I)	200-300 amps
Welding speed (S)	150-182 mm/min
Nozzle-to-plate distance (N)	10-26 mm
Welding gun angle (T)	70-110 degree
Pinch (Ac)	-10 to 10

The input range for GA is the output of PSO. So the input range for GA is got from the output of PSO.

Table 7.2 GA search ranges

PARAMETERS	RANGE
Welding Current (I)	280.64-282.64 amps
Welding speed (S)	168.31-170.30 mm/min
Nozzle-to-plate distance (N)	19.52-21.52 mm
Welding gun angle (T)	77.39-79.39 degree
Pinch (Ac)	-6.029 to -4.029

When the MATLAB command window is opened, M-file has been created and saved as the file name dot m. Then, in the MATLAB command window to perfume PSO, the PSO program is written and saved as a M-file in MATlab. To executive the program, first the input range is coded form should be stored in a variable. Then the PSO parameters have to be specified while calling the PSO function. The PSO parameters are given in table 6.

Usage:

```
  [optOUT]=PSO(functname,D)
 or:
  [optOUT,tr,te]=...

PSO(functname,D,mv,VarRange,minmax,PSOparams,plotfcn,PSOseedVal
ue)
```

Inputs:

functname - string of matlab function to optimize

D - # of inputs to the function (dimension of problem)

Optional Inputs:

mv - max particle velocity, either a scalar or a vector of length D

(this allows each component to have it's own max velocity),

default = 4, set if not input or input as NaN

VarRange - matrix of ranges for each input variable,

default -100 to 100, of form:

[min1 max1

min2 max2

...

minD maxD]

minmax = 0, funct minimized (default)

= 1, funct maximized

= 2, funct is targeted to P(12) (minimizes distance to errgoal)

PSOparams - PSO parameters

P(1) - Epochs between updating display, default = 100. if 0,

no display

P(2) - Maximum number of iterations (epochs) to train, default = 2000.

P(3) - population size, default = 24

P(4) - acceleration const 1 (local best influence), default = 2

P(5) - acceleration const 2 (global best influence), default = 2

P(6) - Initial inertia weight, default = 0.9

P(7) - Final inertia weight, default = 0.4

P(8) - Epoch when inertial weight at final value, default = 1500

P(9)- minimum global error gradient,

if abs(Gbest(i+1)-Gbest(i)) < gradient over

certain length of epochs, terminate run, default = 1e-25

P(10)- epochs before error gradient criterion terminates run,

default = 150, if the SSE does not change over 250 epochs

then exit

P(11)- error goal, if NaN then unconstrained min or max, default=NaN

P(12)- type flag (which kind of PSO to use)

0 = Common PSO w/intertia (default)

1,2 = Trelea types 1,2

3 = Clerc's Constricted PSO, Type 1"

P(13)- PSOseed, default=0

= 0 for initial positions all random

= 1 for initial particles as user input

plotfcn - optional name of plotting function, default 'goplotpso',

make your own and put here

PSOseedValue - initial particle position, depends on P(13), must be

set if P(13) is 1 or 2, not used for P(13)=0, needs to

be nXm where n<=ps, and m<=D

If n<ps and/or m<D then remaining values are set random

on Varrange

Outputs:

optOUT - optimal inputs and associated min/max output of function, of form:

[bestin1
bestin2
...
bestinD
bestOUT]

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. Following table 7.3 show the options used for the study.

Table 7.3 Options of GA computation

Population type	Double Vector
Population size	32
Fitness scaling function	Rank
Selection function	Roulette
Reproduction elite count	2
Crossover rate	100%
Crossover function	Intermediate
Mutation function	Uniform
Mutation rate	1%
Number generations	52
Migration	Forward

In the 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 100% i.e., 100% of the pairs as crossed, whereas the remaining 10% are added to the next generation without crossover. The chosen type of the crossover was Intermediate. Accuracy is the bit quantity for each variable.

7.5.1. Selection of Objective Functions and Constraints

The objective function selected for optimization was percentage dilution (D). The response variables bead width (W), penetration (P) and reinforcement (R) were given as constraints in their equation form. In optimization, generally the constraints with their upper bounds should be given in such a way that their value will be less than or equal to zero. Also, the objective function will usually be minimized. To obtain good quality of claddings in any application, it is always desirable to have maximum weld bead width and reinforcement with minimum penetration. The process parameters and their notations used in writing the M-file using MATLAB 7.0 software are given below.

X (1) = Wire Feed rate (F)

X (2) = Welding speed (S)

X (3) = Welding gun angle (T)

X (4) = Nozzle-to-plate distance (N)

X (5) = Pinch (Ac)

7.5.2 Optimization of the Function

The main purpose of this paper using other important clad quality parameters with their limits as constraints. The model is a nonlinear equation with constraints. The constrained minimum of a scalar function of several functions of several variables at an initial estimate, which is referred as "constrained nonlinear optimization" is mathematically stated as follows

Minimize f(x)

Subject to $g(x1, x2, x3 \ldots xn) < 0$

The limits of the constraints bead width; penetration and reinforcement were established by data obtained from past experience with a view that they should provide a sound and defect-free clad quality along with a feasible solution to the 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 was used to determine the optimum percentage dilution. The step by step procedure of minimization of percentage dilution using the GA optimization tool box available in MATLAB 7 software is given below.

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

f(1)= 21.296+0.325*x(1)+0.347*x(2)+3.141*x(3)-0.039*x(4)-0.153*x(5)-1.665*x(1)^2- 1.264*x(2)^2- 1.353*x(3)^2-1.712*x(4)^2-1.213*x(5)^2-0.200*x(1)*x(2)+0.346*x(1)*x(3)+0.602*x(1)*x(4)+0.203*x(1)*x(5)+0.01 1*x(2)*x(3)+0.465*x(2)*x(4)+0.548*x(2)*x(5)+0.715*x(3)*x(4)+0.360*x(3)*x(5)+0.137*x(4)*x(5); Percentage dilution.

g(1)=8.923+0.701*x(1)- 0.08*x(2)+ 0.587*x(3)+0.040*x(4)+0.088*x(5)-0.423*x(1)^2- 0.291*x(2)^2-0.338*x(3)^2- 0.219*x(4)^2-0.171*x(5)^2+ 0.205*x(1)*x(2)+ 0.405*x(1)*x(3)+ 0.105*x(1)*x(4)+ .070*x(1)*x(5)-0.134*x(2)*x(3)+ 0.225*x(2)*x(4)+ 0.098*x(2)*x(5)+ 0.26*x(3)*x(4)+ 0.086*x(3)*x(5)+ 0.021*x(4)*x(5)- 10.514; Bead Width and its upper limit.

g(2)=6.0823- 8.923+ 0.701*x(1)- 0.08*x(2)+ 0.587*x(3)+ 0.040*x(4)+ 0.088*x(5)- 0.423*x(1)^2- 0.291*x(2)^2- 0.338*x(3)^2- 0.219*x(4)^2-0.171*x(5)^2+0.205*x(1)*x(2)+0.405*x(1)*x(3)+0.105*x(1)*x(4)+0.070* x(1)*x(5)- 0.134*x(2)*x(3)+ 0.225*x(2)*x(4)+ 0.098*x(2)*x(5)+ 0.26*x(3)*x(4)+ 0.086*x(3)*x(5)+0.021*x(4)*x(5); Bead Width and lower limit.

g(3)=2.942+ 0.098*x(1)- 0.032*x(2)+ 0.389*x(3)-0.032*x(4)-0.008*x(5)-0.168*x(1)^2- 0.153*x(2)^2- 0.169*x(3)^2- 0.231*x(4)^2-0.149*x(5)^2-0.033*x(1)*x(2)+ 0.001*x(1)*x(3)+ 0.075*x(1)*x(4)+ 0.005*x(1)*x(5)-0.018*x(2)*x(3)+0.066*x(2)*x(4)+0.087*x(2)*x(5)+0.058*x(3)*x(4)+0.05 4*x(3)*x(5)-0.036*x(4)*x(5)- 3.2872; Penetration and its upper limit.

g(4)= 1.3752-2.942+ 0.098*x(1)- 0.032*x(2)+ 0.389*x(3)- 0.032*x(4)- 0.008*x(5)- 0.168*x(1)^2- 0.153*x(2)^2- 0.169*x(3)^2- 0.231*x(4)^2- 0.149*x(5)^2- 0.033*x(1)*x(2)+ 0.001*x(1)*x(3)+ 0.075*x(1)*x(4) +0.005*x(1)*x(5)- 0.018*x(2)*x(3)+ 0.066*x(2)*x(4)+ 0.087*x(2)*x(5)+ 0.058*x(3)*x(4)+0.054*x(3)*x(5)-0.036*x(4)*x(5); Penetration and its lower limit.

g(5)=5.752+ 0.160*x(1)- 0.151*x(2)- 0.060*x(3)+0.016*x(4)-0.002*x(5) +0.084*x(1)^2+ 0.037*x(2)^2- 0.006*x(3)^2+0.015*x(4)^2-0.006*x(5)^2+ 0.035*x(1)*x(2)+ 0.018*x(1)*x(3)- 0.008*x(1)*x(4)- 0.048*x(1)*x(5)- 0.024*x(2)*x(3)- 0.062*x(2)*x(4)- 0.003*x(2)*x(5)+0.012*x(3)*x(4)- 0.092*x(3)*x(5)-0.095*x(4)*x(5)- 6.65505; Reinforcement and its upper limit.

g(6)=5.4519- 5.752+ 0.160*x(1)- 0.151*x(2)- 0.060*x(3)+ 0.016*x(4)- 0.002*x(5)+ 0.084*x(1)^2+ 0.037*x(2)^2- 0.006*x(3)^2+0.015*x(4)^2- 0.006*x(5)^2+ 0.035*x(1)*x(2)+ 0.018*x(1)*x(3)- 0.008*x(1)*x(4)- 0.048*x(1)*x(5)- 0.024*x(2)*x(3)- 0.062*x(2)*x(4)- 0.003*x(2)*x(5)+ 0.012*x(3)*x(4)-0.092*x(3)*x(5)-0.095*x(4)*x(5); Reinforcement and its lower limit.

g(7)= f-23.6334; upper limit of percentage dilution.

g(8)= 8.941799-f; lower limit of percentage dilution.

Step 2: Invoke PSO function

Input range is defined and the PSO function is called with all its parameters as given is in the table 7.1.

Step 4: Running the M-file.

After evaluating using PSO the following optimum values of process parameters in coded form was obtained

X (1) = Welding Current (I) = 1.2656

X (2) = Welding speed (S) = 0.4132

X (3) = Welding torch angle (T) = 0.6312

X (4) = Nozzle-to-plate distance (N) = -1.1604

X (5) = Pinch (Ac) = -1.0058

Step 3: Invoke GA function

Select and type the corresponding boxes as per the requirement as shown in the table 7.2.

Step 4: Running the M-file.

After evaluating using GA i.e. the final Hybrid, the following optimum values of process parameters in coded form was obtained

X (1) = Welding Current (I) = 1.26568

X (2) = Welding speed (S) = 0.41329

X (3) = Welding torch angle (T) = 0.63112

X (4) = Nozzle-to-plate distance (N) = -1.16029

X (5) = Pinch (Ac) = -1.00589

CHAPTER 8
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 7.1 & 7.2, following various optimum results have been obtained from different number of trials. The execution and output from PSO is shown in Figure.8.1

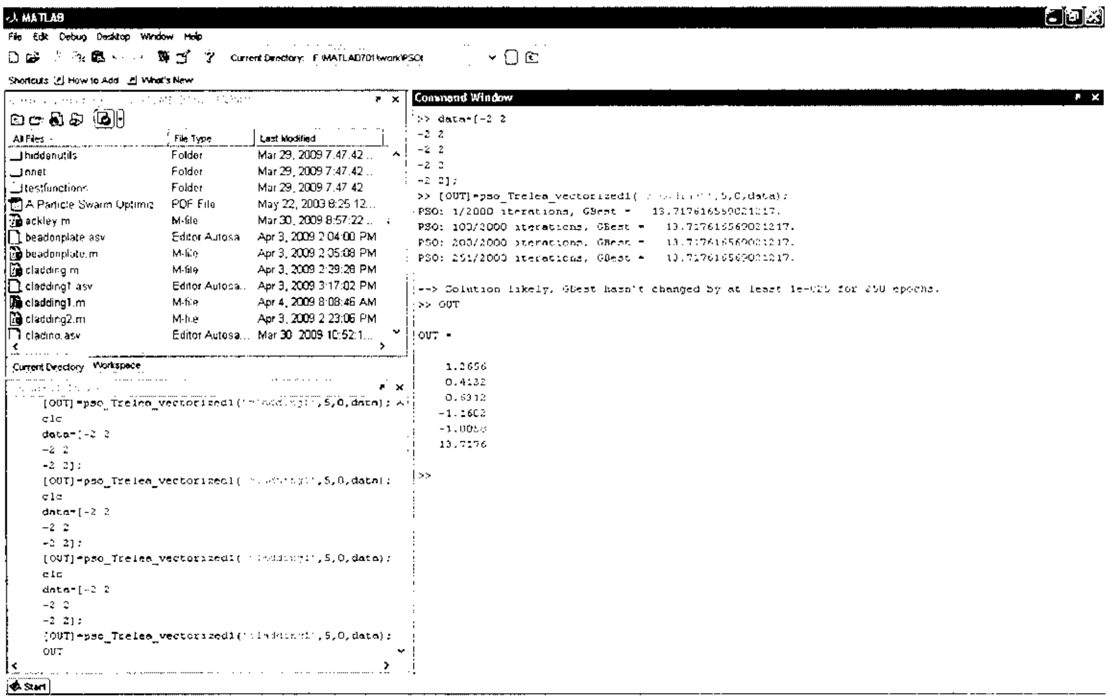


Figure 8.1 Particle Swarm Optimization Execution in Matlab

The execution and output from GA is shown in Figure.8.2 Among the above results optimum values of the process parameters obtained are shown in the Figure 8.3, at 100th iteration is found to be the best. The genetic algorithm tool box setting has been shown in Figure 8.2.

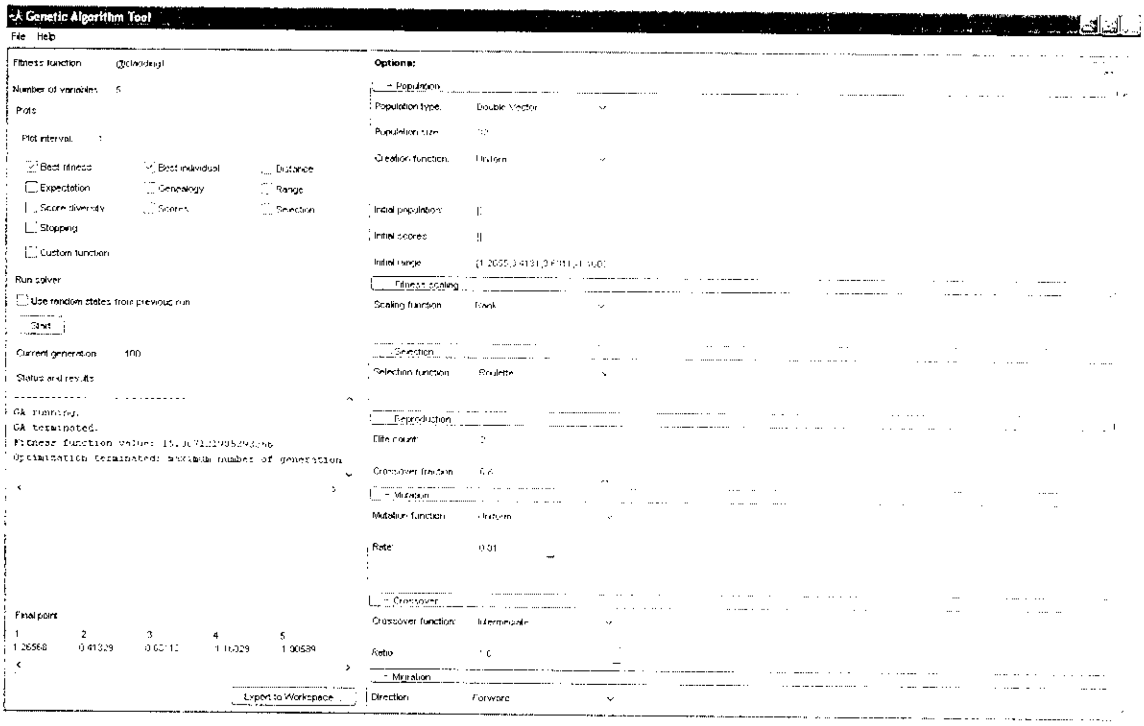


Figure 8.2 Genetic Algorithm Tool Box

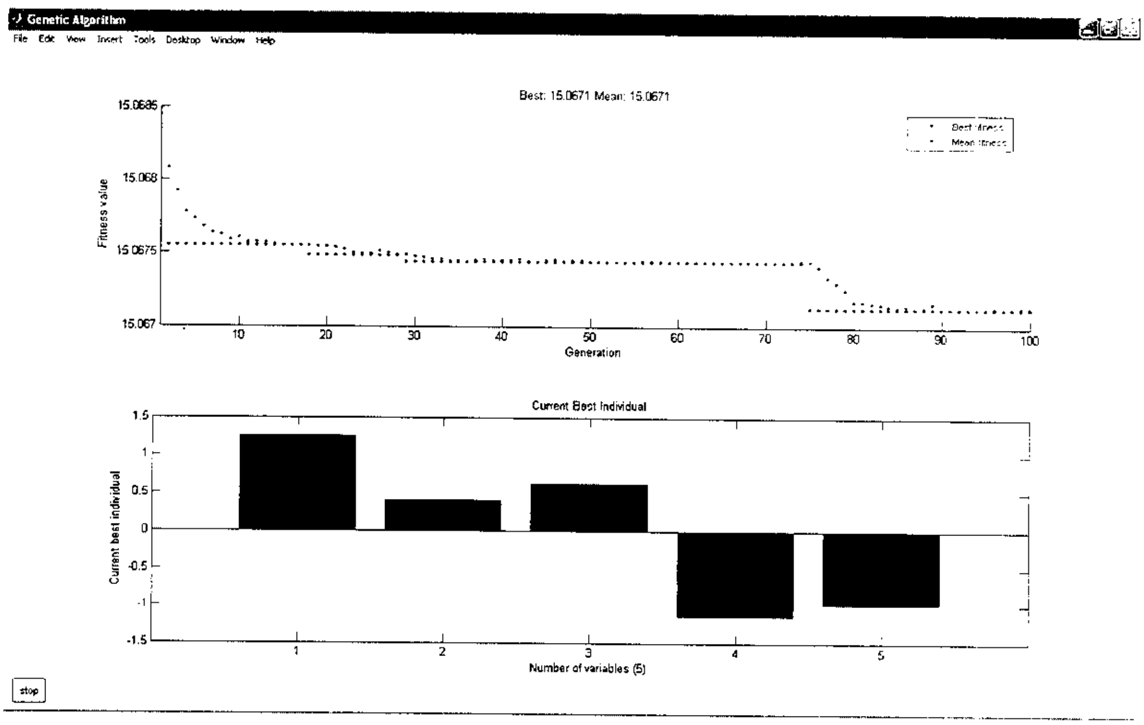


Figure 8.3 Genetic Algorithm Output

Corresponding optimal input parameters are as follows.

X (1) = Welding Current (I) = 281.642 Amps

X (2) = Welding speed (S) = 169.3063 mm/min

X (3) = Welding torch angle (T) = 20.52448 degree

X (4) = Nozzle-to-plate distance (N) = 78.3971 mm

X (5) = Pinch (Ac) = -5.02945

Wire Feed Rate found substituting current in equation (4.1) is 351.56 inch/min.

For these optimized process parameters, the values of the clad quality parameters are

Bead Width (W) = 8.4663 mm

Reinforcement (R) = 6.0593 mm

Penetration (P) = 2.1949 mm

Percentage Dilution (D) = 15.0671%

CHAPTER 8
CONCLUSIONS

- In cladding by a five level five factor full factorial design matrix based on the central composite rotatable design technique was used for the development of mathematical models to predict the clad bead geometry for austenitic steel cladding using GMAW.-P

- 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 clad bead geometry.

- Welding process, weld bead geometry and dilution are important to economise on material. This study used a hybrid algorithm to determine the welding process parameters such as Welding Current, Welding speed, Welding gun angle, pinch and Nozzle-to-plate distance to obtain optimum weld bead geometry. In the optimization of welding process using genetic algorithm, the objective function of obtaining a value between 10 and 15 % was achieved.

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

SCOPE FOR FUTURE WORK

- Mathematical model for other parameters like Wetting angle and Fusion angle can be developed.
- External devices like Laptop can be connected to inverter to make analysis of current waveform.
- Various other non-traditional optimization techniques can employed to obtain optimum process parameters for weld cladding.
- A `C` program for hybrid algorithm can be developed which should have the objective function such as Maximizing Bead Width, Reinforcement, Minimising Penetration, Maximizing Reinforcement and dilution should be maintained in the range between 10 – 15% .
- Development of mathematical model and optimization of heat input in cladding by GMAW-P can be done.
- Weld bead geometry and dilution in GMAW-P can be modelled and predicted using artificial neural network.
- Prediction and control of weld bead geometry and shape relationships in GMAW–P cladding of Austenitic Stainless Steel can be determined.

REFERENCES

1 Cochran W. G. and Cox G. M. (1987). `Experimental Designs` pp. 370, New York, John Wiley & Sons.

2 Ghosh P.K. Gupta P.C. and Goyal V.K. (1998) `Stainless steel cladding of structural steel plate using the pulsed current GMAW process` Welding Journal 77(7) pp. 307-s - 314-s.

3 Gunaraj V. and Murugan N. (1999). `Prediction and comparison of the area of the heat affected zone for the bead on plate and bead on joint in submerged arc welding of pipes` - Journal of Material Processing Technology Vol. 95, pp. 246 to 261.

4 Gunaraj V. and Murugan N. (2005) `Prediction and control of weld bead geometry and shape relationships in submerged arc welding of pipes` - Journal of Material Processing Technology Vol. 168, pp. 478 - 487.

5 Kannan T. and Murugan N. (2005) `Optimization of FCAW process parameters in Duplex Stainless Steel Weld Cladding` - Journal of Manufacturing Technology Today, Vol. 4, No. 4 pp. 3-7.

6 Kannan T. and Murugan N. (2006) `Effect of flux cored welding process parameters on duplex stainless steel clad quality` - Journal of Material Processing Technology Vol.176, pp. 230 - 239.

7 Kannan T. and Murugan N. (2006) `Sensitivity analysis of flux cored arc cladding parameters using Response Surface Methodology` - International Journal of Manufacturing Science & Production Vol. 7, pp. 3-4.

8 Montgomery DC (2003) `Design and analysis of Experiments` – John Wiley &Sons (ASIA) Pvt.Ltd.

9 Murugan N. and Palani P.K. (2004) `Optimization of Bead Geometry in Automatic Stainless Steel Cladding by MIG Welding using a Genetic Algorithm` - IE(I) Journal-PR Vol. 84, pp. 49-54.

10 Murugan N. and Parmer S. (1995) `Effects of MIG process parameters on the geometry of the bead in the automatic surfacing of stainless steel` - International Journal for the Joining of Materials Vol. 7(2), pp. 71 to 80.

11 Murugan N. and Parmer S. (1994) `Mathematical Model for Prediction of Dilution and Bead Geometry in Single Wire Submerged Arc Surfacing` - Indian Welding Journal pp. 22 to 27.

12 Nouri M, Abdollah-zadehy A. and Malek F. (2007) `Effect of Welding parameters on Dilution and Weld Bead Geometry in Cladding` - Journal of Material Science and Technology Vol. 23, No. 6.

13 Raveedra, J. and Parmar R.S. (1987). `Mathematical models to predict weld bead geometry for flux cored arc welding` - Metal Construction Vol. 189, (1) pp. 31R - 35R.

14 S. Subramaniam, D. R. White, J. E. Jones And D. W. Lyons (1999) 'Experimental Approach to Selection of Pulsing Parameters in Pulsed GMAW 'Welding Journal, AWS Publication Services Division.

15 Robinson, Sinton,S. Rahmat-Samii,Y. 'Particle swarm, genetic algorithm, and their hybrids: optimization of a profiled corrugated horn antenna'.

16 Welding, brazing, and soldering. (1993) ASM Handbook, Volume 6, ASM Handbook, USA.

17 GMAW Welding Guide. (1995) C4200, Lincoln Electrical.

18 Thomas Weise (2009) 'Global Optimization Algorithms Theory and Application '

19 R.Saravanan. (2006) 'Manufacturing Optimization through Intelligent Techniques'- Taylor & francis group.

20 Maurice Clerc. (2006) 'Particle Swarm Optimization '- New Age Publication.

21 www.americanweldingsociety.com

22 www.linconelectric.com

23 www.weldreality.com

24 www.particleswarm.info

25 www.indianweldingsociety.com