OPTIMIZATION OF GAS METAL ARC WELD CLADDING PROCESS PARAMETERS USING AN INTELLIGENT TECHNIQUE

A PROJECT REPORT

Submitted By

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Bonafide Certificate

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BONAFIDE CERTIFICATE

Certified that this project report entitled "**Optimization of Gas Metal Arc Weld Cladding Process Parameters Using an Intelligent Technique**" is the bonafide work of

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who carried out the project work under my supervision.

Signature of the HOD **Signature of the Supervisor**

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This is to certify that Mr/Ms/Mrs J. YOGANANDH has participated and presented a paper titled Development of mathematical model to predict deposition area in austenitic stainless steel GMAW cladding in the 2nd National Conference on "ADVANCES IN MECHANICAL SCIENCES" during 27- 28, March 2008.

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Abstract

ABSTRACT

Weld cladding is a process of depositing a thick layer of metal surface to a carbon steel base metal for the purpose of providing a corrosion resistant surface when that surface is to be exposed to a corrosive environment. In weld cladding process, most of the engineers often face the problem of selecting optimum combination of input process parameters for achieving the desired bead geometry. Until recently trail and error methods were employed to determine the optimum process parameters, which result in wastage of cost and time. This project focuses on simulation and analysis of various input parameters and important clad bead parameters in austenitic stainless steel cladding of low carbon structural steel plates deposited by Gas Metal Arc Welding. Experiments were conducted based on four-factor five-level central composite rotatable design with full replication technique. Mathematical models relating gas metal arc welding process parameters to clad bead geometry were developed using multiple regression method. Developed mathematical models are helpful in predicting the clad bead geometry and in setting process parameters at optimum values to achieve the desirable clad quality at relatively low cost with a high degree of repeatability. The precision of the results was tested by conducting conformity tests using the same experimental set up. Further Genetic Algorithm was used to optimize the process parameters to achieve optimum range of dilution between 10 – 15%.

ஆய்வு சுருக்கம்

கார்பன் ஸ்டீல் என்ற உலோகத்தின் மீது பொதுவாக ஏற்படும் அரிப்பினை தடுக்க அதன் மீது தடினமான உலோக அடுக்குகளை படிய வைக்கும் செயலுக்கு வெல்டு க்ளேடிங் எனப்படுகிறது. மேற்கண்ட இச்செயல்முறையில் தேவையான பீடு வடிவியலை பெற தேவையான உகப்புநிலை உள்ளீடு அளபுருக்களை தேர்வு செய்வதில் பெரும்பாலான பொறியாளர்கள் பிரச்சனைகளை எதிர்கொள்கின்றனர். சமீபகாலமாக “சரிபார்த்தல் மற்றும் பிழை திருத்தல்” முறையின் மூலம் உகப்புநிலை அளபுருக்களை கண்டறிய முடியும். ஆனால் இதற்கான கால அளவும் மற்றும் பொருளின் விரயமும் அதிகம். குறைந்த கார்பன் அமைப்புள்ள இரும்பு உலோகங்களில் ஆஸ்டனடிக் ஸ்டைன்லஸ் ஸ்டீலினை படிய வைக்க “கேஸ் மெட்டல் ஆர்க் வெல்டிங்” முறைக்கு தேவையான பல்வேறு உள்ளீடு அளபுருக்களை பற்றி இவ்வாய்வு விவரிக்கிறது. “சென்ட்ரல் காம்போசடி ரொடேட்டபுள் டிசைன்” முறையில் ரிப்ளிகேஷன் முறையை பயன்படுத்தி நான்கு காரணிகள் ஐந்து நிலைகளில் இச்சோதனை செய்யப்படுகிறது. கேஸ் மெட்டல் ஆர்க் வெல்டிங் மற்றும் வெல்டு பீடு வடிவியலின் சமன்பாடை பல்சார்பலனாக்க முறையை பயன்படுத்தி கண்டறியப்பட்டது.

இவ்வாறு உருவாக்கப்பட்ட கணக்கு சமன்பாடு செயல் அளபுரு மற்றும் க்ளேடு பீடு வடிவியலின் உகப்புநிலை அளவுகளை கண்டறிய உதவுகிறது. அதே சமயம் அதன் பீடு வடிவியலை தொடர்ச்சியான முறையில் செயல்படும் போது மிகக்குறைந்த விலையில் விரும்பதக்க வகையில் பெறப்படுகிறடு. மேற்கண்ட முடிவுகளின் சரிநுட்பத்தை உறுதிசெய்ய அதே பரிசோதனை முறையை கொண்டு கையாளப்படுகிறது. மேலும் இந்த ஆய்வில் மரபு நெறிமுறையை பயன்படுத்தி அதன் செயல் அளபுருக்களில் உகப்புநிலை எல்லையான 10-15 சதவீதம் செய்து முடிக்கப்பட்டது.

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Words are inadequate in offering my thanks to **Dr. P. Palanisamy**, Associate Professor, our project coordinator and the **faculty members** of the Department of Mechanical Engineering, Kumaraguru College of Technology for their encouragement and cooperation in carrying out my project work. My sincere thanks also to all my **friends** for their help in all the matters during my project work.

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J. Yoganandh

Contents

CONTENTS

List of Tables

LIST OF TABLES

List of Figures

LIST OF FIGURES

List of Abbreviations

LIST OF ABBREVIATIONS

Abbreviation	Definition
GA	Genetic algorithm
SMAW, SAW,	Submerged Arc Welding
GTAW	Gas Tungsten Arc Welding
PAW	Plasma Arc Welding
GMAW	Gas Metal Arc Welding
FCAW	Flux Cored Arc Welding
ESW	Electroslag Welding
OAW	Oxy-Acetylene Welding
MAG	Metal Active Gas Welding
MIG	Metal Inert Gas Welding
F	Wire Feed Rate
S	Welding Speed
T	Gun Angle
N	Nozzle To Plate Distance
W	Bead Width
R	Reinforcement
P	Penetration
D	Dilution

Chapter 1

Introduction

CHAPTER 1

INTRODUCTION

1.1 WELD CLADDING

Weld Cladding is a process of depositing a thick layer of a metal surface to a carbon or low alloy steel base metal for the purpose of providing a corrosion resistant surface when that surface is to be exposed to a corrosive environment.

Cladding is an excellent way to impart corrosion resistance properties to the surface of a base metal, to conserve expensive or difficult to obtain materials by using a relatively thin surface layer on a less expensive base material. Typical metal components that are weld cladded include the internal surfaces of carbon and low-alloy steel pressure vessels used in chemical, fertilizer, food processing and petrochemical plants, paper digester, urea and nuclear reactor vessels, etc (Kannan et al. 2006). The biggest difference between welding a joint and cladding a surface is the dilution, which is illustrated in Figure 1.1. The real time experimental set up has been shown in the Figure 1.2 and a typical cross section sample of a GMAW cladding has been shown in the Figure 1.3. It is the amount of base metal melted (B) divided by the sum of the filler metal added and the base metal melted (A+B). The biggest difference between welding joint and cladding is the percentage of dilution. Dilution reduces the alloying elements and increases the carbon content in clad layer, which leads to a decrease in the corrosion resistance properties and other metallurgical problems. Control of dilution is essential in cladding process, where low dilution is typically desirable. With a low dilution value, the final deposit composition is close to that of the filler metal and the corrosion resistance of the clad is maintained.

Various welding processes employed for cladding are shielded metal arc welding (SMAW), submerged arc welding(SAW), gas tungsten arc welding (GTAW), plasma arc welding (PAW), gas metal arc welding (GMAW), flux cored arc welding (FCAW), electroslag welding (ESW), oxy-acetylene welding(OAW)and explosive welding (Kannan et al. 2006).Among the processes employed for weld cladding, All though presently SMAW, SAW and PAW are the most commonly used cladding processes, with the development of modern solid-state welding power sources it has become easy to control the mode of metal transfer, making it possible to use GMAW or MIG welding with high quality surfaced components. The chief advantages in using GMAW for surfacing are:

- High reliability
- All position capability
- Ease of use
- Low cost
- High productivity

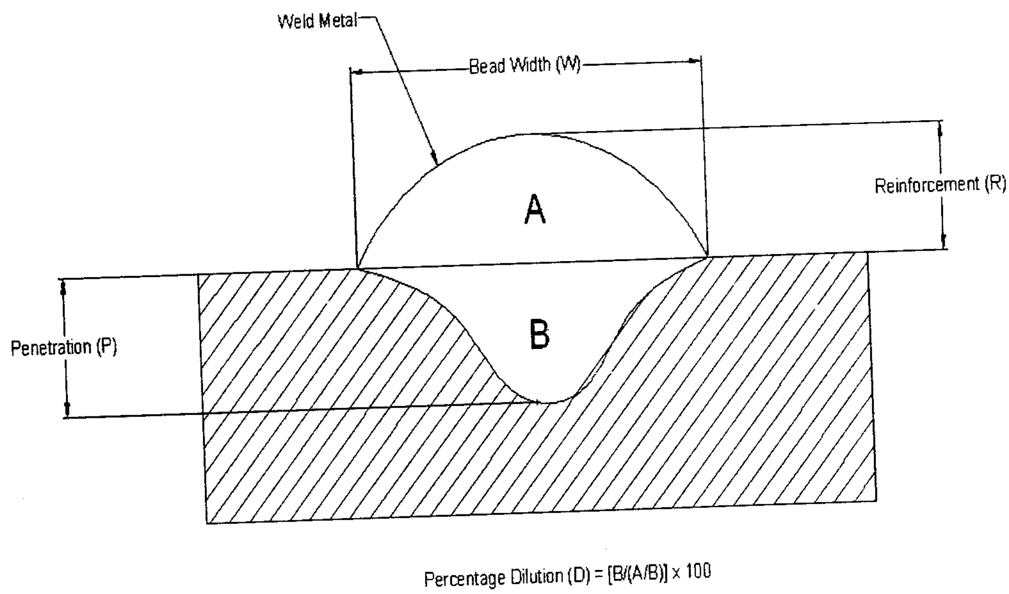

Figure 1.1 Weld bead geometry

In the cladding process, most engineers are often faced with problems of relating the process variables to the clad bead geometry and optimization of the bead parameters. Also, cladding is done with the aim of achieving minimum dilution. It is very difficult to achieve minimum dilution without optimizing the bead parameters. Optimization process is iterative, which requires repeated use of the same set of calculations. Until recently trail and error methods were used to determine the optimum process parameters for a required clad quality, which result in wastage of cost and time. In this work, optimization of dilution was carried out using intelligent techniques.

The optimum solution for any function lies in a boundary or zone and, hence, it is not a single constant value. This provides flexibility in fixing the limits for the constraints and there is a possibility for change in the value of the objective function as well as other constraints. Therefore, it is very important to know the impact of relaxing the limits of each constraint on the value of the objective function and other constraints before fixing the correct limits for the constraints to produce a sound and strong weld at the relatively lower cost with a high degree of repeatability.

Figure 1.2 Real time experimental set up

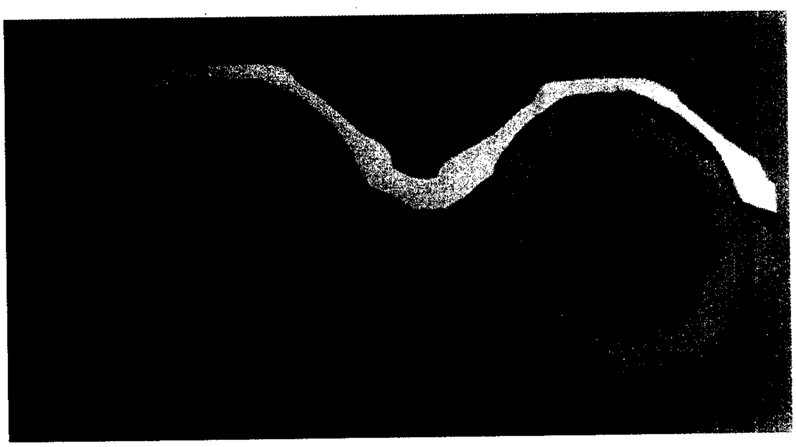

Figure 1.3 A typical cross section sample of a GMAW cladding

1.1.1 Cladding for Corrosion Resistance

Process industries are associated with handling, storing and processing various types of chemicals such as alkalis, hydrocarbons, inorganic chemicals and water with divergent qualities. In some of the process industries such as refineries and petrochemicals, both extremes in terms of temperature and pressure are likely to coexist, for example cryogenic and fired heaters and vacuum to high-pressure as high as 200 kg / Sq.cm. As a result the equipment handling these process chemicals demand materials of construction with good corrosion resistance and appropriate mechanical properties.

Stainless steel, nickel, copper, high nickel alloys and copper-nickel alloys are used to fabricate the components and accessories in large fabrication jobs, such as pressure vessels, chemical industries, power plants etc., where the corrosion was the major problem for failure.

If the components have been made with fully solid with the above metals then the cost would be very high. So a layer of noncorrosive metal is deposited by welding on the carbon steel to manufacture the above components to save from corrosion. The thickness of the cladded layer is usually small relative to that of the base metal, because it is the latter, which was designed to take the major proportion of the load. As a rule the strength of the cladding is not included in the design of the components.

1.1.2 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.

1.2 WELDING

Welding is a joining process that produces a local coalescence of materials by heating, by applying pressure, or both. In essence, the welding process fuses the surfaces of two distinct elements to form a single unit. It encompasses a broad range of joining techniques that include fusion welding, solid state welding, weld bonding, diffusion welding, brazing, and soldering. The Figure1.4 shows the classification of welding.

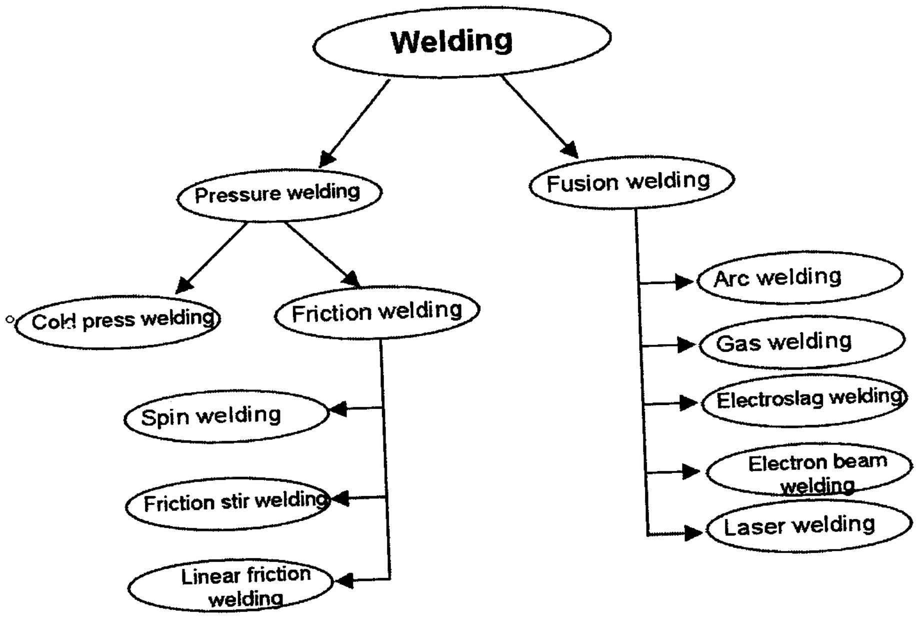

Figure 1.4 Classification of welding

1.3 SOLID-STATE WELDING

Like the forge welding, some modern welding methods do not involve the melting of the materials being joined. One of the most popular, ultrasonic welding is used to connect thin sheets or wires made of metal or thermoplastic by vibrating them at high frequency and under high pressure. The equipment and methods involved are similar to that of resistance welding, but instead of electric current, vibration provides energy input. Welding metals with this process does not involve melting the materials; instead, the weld is formed by introducing mechanical vibrations horizontally under pressure. When welding plastics, the materials should have similar melting temperatures, and the vibrations are introduced vertically. Ultrasonic welding is commonly used for making electrical connections out of aluminium or copper, and it is also a very common polymer welding process.

Another common process, explosion welding, involves the joining of materials by pushing them together under extremely high pressure. The energy from the impact plasticizes the materials, forming a weld, even though only a limited amount of heat is generated. The process is commonly used for welding dissimilar materials, such as the welding of aluminium with steel in ship hulls or compound plates. Other solid-state welding processes include co-extrusion welding, cold welding, diffusion welding, friction welding (including friction stir welding), high frequency welding, hot pressure welding, induction welding, and roll welding.

Friction welding (FW) is a class of solid-state welding processes that generates heat through mechanical friction between a moving workpiece and a stationary component, with the addition of an lateral force called "upset" to plastically displace and fuse the materials. Technically, because no melt occurs, friction welding is not actually a welding process in the traditional sense, but a forging technique. However, due to the similarities between these techniques and traditional welding, the term has become common. Friction welding is used with metals and thermoplastics in a wide variety of aviation and automotive applications.

1.3.1 Benefits

The combination of fast joining times of the order of a few seconds, and the direct heat input at the weld interface, gives rise to relatively small heat affected zones. Friction welding techniques are generally melt-free, which offers the advantage of avoiding grain growth in engineered materials such as high-strength heat-treated steels. Another advantage is that the motion tends to "clean" the surface between the materials being welded, which means they can be joined without as much prior preparation. During the welding process, depending on the method being used, small pieces of the "plastic" metal will be forced out of the working mass in rippled sheets of metal known as "flash". It is believed that the flash carries away debris and dirt.

Another advantage of friction welding is that it allows dissimilar materials to be joined. This is particularly useful in the aerospace field, where it is used to join lightweight aluminium stock to high-strength steels. Normally the wide difference in melting points of the two materials would make it impossible to weld using traditional techniques, and would require some sort of mechanical connection instead (bolts, etc.). Friction welding provides a "full strength" bond with no additional weight. Another common use for these sorts of bi-metal joins is in the nuclear industry, where copper-steel joints are common in the reactor cooling systems.

Friction welding is also used with thermoplastics, which act in a fashion analogous to metals under heat and pressure. The heats and pressures used on these materials are much lower than on metals, but the technique can be used to join metals to plastics with the metal interface being machined. For instance, the technique can be used to join eyeglass frames to the pins in their hinges. The lower energies and pressures used allows for a wider variety of techniques to be used.

1.4 FUSION WELDING

1.4.1 Arc Welding

These processes use a welding power supply to create and maintain an electric arc between an electrode and the base material to melt metals at the welding point. They can use either direct (DC) or alternating (AC) current, and consumable or non-consumable electrodes. The welding region is sometimes protected by some type of inert or semi-inert gas, known as a shielding gas, and filler material is sometimes used as well.

1.4.2 Shielded Metal Arc Welding

One of the most common types of arc welding is shielded metal arc welding (SMAW), which is also known as manual metal arc welding (MMA) or stick welding. Electric current is used to strike an arc between the base material and consumable electrode rod, which is made of steel and is covered with a flux that protects the weld area from oxidation and contamination by producing CO_2 gas during the welding process. The electrode core itself acts as filler material, making separate filler unnecessary.

The process is versatile and can be performed with relatively inexpensive equipment, making it well suited to shop jobs and field work. An operator can become reasonably proficient with a modest amount of training and can achieve mastery with experience. Weld times are rather slow, since the consumable electrodes must be frequently replaced and because slag, the residue from the flux, must be chipped away after welding. Furthermore, the process is generally limited to welding ferrous materials, though specialty electrodes have made possible the welding of cast iron, nickel, aluminium, copper, and other metals. Inexperienced operators may find it difficult to make good out-of-position welds with this process.

1.4.3 Gas Tungsten Arc Welding

Gas tungsten arc welding (GTAW), or tungsten inert gas (TIG) is a manual welding process that uses a non-consumable tungsten electrode, an inert or semi-inert gas mixture, and a separate filler material. Especially useful for welding thin materials, this method is characterized by a stable arc and high quality welds, but it requires significant operator skill and can only be accomplished at relatively low speeds.

1.4.4 Submerged Arc Welding

Submerged arc welding (SAW) is a high-productivity welding method in which the arc is struck beneath a covering layer of flux. This increases arc quality, since contaminants in the atmosphere are blocked by the flux. The slag that forms on the weld generally comes off by itself, and combined with the use of a continuous wire feed, the weld deposition rate is high. Working conditions are much improved over other arc welding processes, since the flux hides the arc and almost no smoke is produced. The process is commonly used in industry, especially for large products and in the manufacture of welded pressure vessels. Other arc welding processes include atomic hydrogen welding, carbon arc welding, electroslag welding, electrogas welding, and stud arc welding.

1.4.5 Gas Metal Arc Welding

Gas metal arc welding (GMAW), sometimes referred to by its subtypes metal inert gas (MIG) welding or metal active gas (MAG) welding, is a semi-automatic or automatic arc welding process in which a continuous and consumable wire electrode and a shielding gas are fed through a welding gun. A constant voltage, direct current power source is most commonly used with GMAW, but constant current systems, as well as alternating current, can be used. There are four primary methods of metal transfer in GMAW, called globular, short-circuiting, spray, and pulsed-spray, each of which has distinct properties and corresponding advantages and limitations.

Originally developed for welding aluminum and other non-ferrous materials in the 1940s, GMAW was soon applied to steels because it allowed for lower welding time compared to other welding processes. The cost of inert gas limited its use in steels until several years later, when the use of semi-inert gases such as carbon dioxide became common. Further developments during the 1950s and 1960s gave the process more versatility and as a result, it became a highly used industrial process. Today, GMAW is the most common industrial welding process, preferred for its versatility, speed and the relative ease of adapting the process to robotic automation. The automobile industry in particular uses GMAW welding almost exclusively. Unlike welding processes that do not employ a shielding gas, such as shielded metal arc welding, it is rarely used outdoors or in other areas of air volatility. A related process, flux cored arc welding, often does not utilize a shielding gas, instead employing a hollow electrode wire that is filled with flux on the inside.

1.4.5.1 Equipment

To perform gas metal arc welding, the basic necessary equipment as shown in the Figure 1.5 is a welding gun, a wire feed unit, a welding power supply, an electrode wire, and a shielding gas supply.The typical GMAW welding gun has a number of key parts—a control switch, a contact tip, a power cable, a gas nozzle, an electrode conduit and liner, and a gas hose. The control switch, or trigger, when pressed by the operator, initiates the wire feed, electric power, and the shielding gas flow, causing an electric arc to be struck. The contact tip, normally made of copper and sometimes chemically treated to reduce spatter, is connected to the welding power source through the power cable and transmits the electrical energy to the electrode while directing it to the weld area. It must be firmly secured and properly sized, since it must allow the passage of the electrode while maintaining an electrical contact. Before arriving at the contact tip, the wire is protected and guided by the electrode conduit and liner, which help prevent buckling and maintain an uninterrupted wire feed. The gas nozzle is used to evenly direct the shielding gas into the welding zone—if the flow is inconsistent, it may not provide adequate protection of the weld area. Larger nozzles provide greater shielding gas flow, which is useful for high current welding operations, in which the size of the molten weld pool is increased. The gas is supplied to the nozzle through a gas hose, which is connected to the tanks of shielding gas. Sometimes, a water hose is also built into the welding gun, cooling the gun in high heat operations.

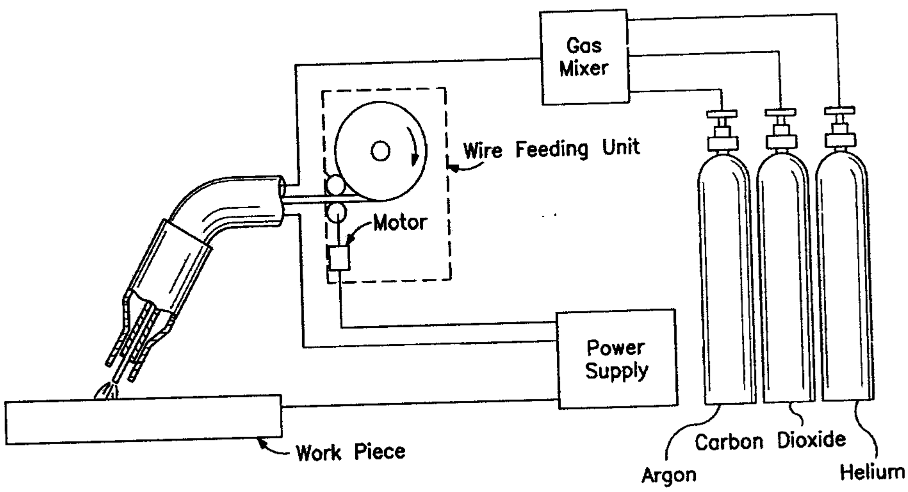

Figure 1.5 GMAW Circuit diagram

1.4.5.2 Power supply

Most applications of gas metal arc welding use a constant voltage power supply. As a result, any change in arc length results in a large change in heat input and current. A shorter arc length will cause a much greater heat input, which will make the wire electrode melt more quickly and thereby restore the original arc length. This helps operators keep the arc length consistent even when manually welding with hand-held welding guns. To achieve a similar effect, sometimes a constant current power source is used in combination with an arc voltage-controlled wire feed unit. In this case, a change in arc length makes the wire feed rate adjust in order to maintain a relatively constant arc length. In rare circumstances, a constant current power source and a constant wire feed rate unit might be coupled, especially for the welding of metals with high thermal conductivities, such as aluminum. This grants the operator additional control over the heat input into the weld, but requires significant skill to perform successfully.

Alternating current is rarely used with GMAW; instead, direct current is employed and the electrode is generally positively charged. Since the anode tends to have a greater heat concentration, this result in faster melting of the feed wire, which increases weld penetration and welding speed. The polarity can be reversed only when special emissive-coated electrode wires are used, but since these are not popular, a negatively charged electrode is rarely employed.

1.4.5.3 Electrode

Electrode selection is based primarily on the composition of the metal being welded, but also on the process variation being used, the joint design, and the material surface conditions. The choice of an electrode strongly influences the mechanical properties of the weld area, and is a key factor in weld quality. In general, the finished weld metal should have mechanical properties similar to those of the base material, with no defects such as discontinuities, entrained contaminants, or porosity, within the weld. To achieve these goals a wide variety of electrodes exist. All commercially available electrodes contain deoxidizing metals such as silicon, manganese, titanium, and aluminum in small percentages to help prevent oxygen porosity, and some contain denitriding metals such as titanium and zirconium to avoid nitrogen porosity. Depending on the process variation and base material being used, the diameters of the electrodes used in GMAW typically range from 0.7 to 2.4 mm, but can be as large as 4 mm. The smallest electrodes, generally up to 1.14 mm are associated with the short-circuiting metal transfer process, while the most common spray-transfer process mode electrodes are usually at least 0.9 mm.

1.4.5.4 Shielding gas

Shielding gases are necessary for gas metal arc welding to protect the welding area from atmospheric gases such as nitrogen and oxygen, which can cause fusion defects, porosity, and weld metal embrittlement if they come in contact with the electrode, the arc, or the welding metal. This problem is common to all arc welding processes, but instead of a shielding gas, many arc welding methods utilize a flux material which disintegrates into a protective gas when heated to welding temperatures. In GMAW, however, the electrode wire does not have a flux coating, and a separate shielding gas is employed to protect the weld. This eliminates slag, the hard residue from the flux that builds up after welding and must be chipped off to reveal the completed weld.

The choice of a shielding gas depends on several factors, most importantly the type of material being welded and the process variation being used. Pure inert gases such as argon and helium are only used for nonferrous welding; with steel they do not provide adequate weld penetration (argon) or cause an erratic arc and encourage spatter (with helium). Pure carbon dioxide, on the other hand, allows for deep penetration welds but encourages oxide formation, which adversely affect the mechanical properties of the weld. Its low cost makes it an attractive choice, but because of the violence of the arc, spatter is unavoidable and welding thin materials is difficult. As a result, argon and carbon dioxide are frequently mixed in a 75%/25% to 90%/10% mixture. Generally, in short circuit GMAW, higher carbon dioxide content increases the weld heat and energy when all other weld parameters (volts, current, electrode type and diameter) are held the same. As the carbon dioxide content increases over 20%, spray transfer GMAW becomes increasingly problematic with thinner electrodes.

1.4.5.5 Operation

In most of its applications, gas metal arc welding is a fairly simple welding process to learn, requiring no more than several days to master basic welding technique. Even when welding is performed by well-trained operators, however, weld quality can fluctuate, since it depends on a number of external factors.

Chapter 2

Literature Survey

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.

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.

Sathiya et al. (2005) have proposed a method to decide near optimal settings of the welding process parameters in friction welding of austenitic stainless steel by using a Genetic Algorithm. This method tries to find near optimal settings of the welding process parameters through experiments without a model between the inputs and output variable. It has an advantage of being able to carryout search without modifying the design space, which includes some irregular points. The method suggested in this study is used to determine the welding process parameters by which the desired tensile strength can be obtained in friction welding. The output variable is the tensile strength.

Correia et al. (2004) have done a work using GA as a method to decide near-optimal settings of a GMAW welding process. The problem was to choose the near-best values of three control variables (welding voltage, wire feed rate and welding speed) based on four quality responses (deposition efficiency, bead width, depth of penetration and reinforcement), inside a previous delimited experimental region. The search for the near-optimal was carried out step by step, with the GA predicting the next experimental based on the previous, and without the knowledge of the modelling equations between the inputs and outputs of the GWAW process. The Gas was able to locate the near-optimum conditions with a relatively small number of experiments.

Murugan et al. (2004) have used GA to optimize the process parameters to achieve minimum dilution, maximum reinforcement, minimum penetration and maximum bead width with the view of economizing on material.

Gunaraj et al. (1999) have developed models and the graphs showing the direct and interaction effects of process variables on the bead geometry are very useful in selecting the process parameters to achieve the desired weld bead quality. Also, the precision of the results obtained with the mathematical models were tested by using conformity test runs. The test runs were conducted nearly two years after the development of mathematical models with the same experimental setup, and it was found the accuracy of the predicted results is about 98%. Further, these mathematical models help to optimize SAW to make it a more cost-effective process.

Murugan et al. (1994) have developed mathematical equations using four factor 5 level factorial technique to predict the geometry of the weld bead in the deposition of 316L stainless steel onto structural steel IS 2062.the models developed have been checked for their adequacy and significance by using the F-test and t-test. Main and interaction effects of the control factors on dilution and bead geometry are presented in graphical form that helps in selecting quickly the process parameters to achieve the desired quality overlay.

Raveendra et al. (1987) used fractional factorial technique for the development of mathematical models for CO_2 shielded FCAW and showed the direct and interaction effects of process variables on the bead geometry are very useful in selecting the process parameters to achieve the desired weld bead quality

Oliveira Santos et al. examined the deposition and fusion characteristics of a rutile and a basic flux cored wire in pulsed MIG/MAG welding with controlled transfer. The deposition characteristics and the influence of the welding parameters on the geometric characteristics of the beads are also studied.

Chapter 3

Experimental Design Procedure

CHAPTER - 3

EXPERIMENTAL DESIGN PROCEDURE

The experimental design procedure used for this study is shown in the Figure 3.1 and important steps are briefly explained below.

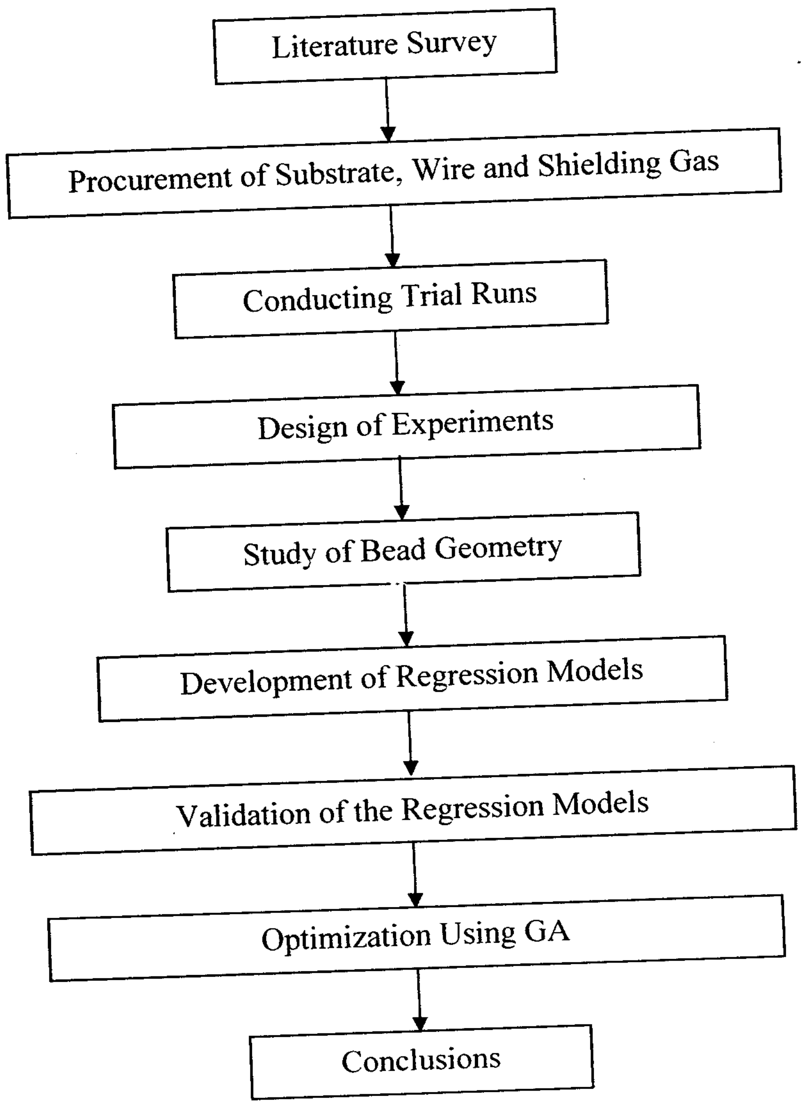

Figure 3.1 Experimental Design Procedure

The experiments were Conducted using THYRO μP 400 welding machine using DC electrode positive (DCEP). Test pieces of size 300mm×200mm×20 mm were cut from low carbon structural steel (IS: 2062) plate and its surfaces were ground to remove oxide scale and din before cladding. Stainless steel solid welding wire (ER 308L) of 1.2mm diameter was used for depositing the weld beads. Chemical composition of the base metal and welding wire is given in Table 3.1. 98% Argon and 2% of O_2 gas at a constant flow rate of 16.5 Litres/min was used for shielding. The experimental setup used consisted of a travelling carriage with a table for supporting the specimens. The carriage speed was continuously adjustable from 160 mm/min to 180 mm/min. The welding torch was held stationary in a frame mounted above the work table and it was provided with an attachment for both up and down movement with angular movement for setting the required nozzle-to-plate distance and welding torch angle respectively.

Table 3.1 Chemical composition of base metal and filler wire used (in %)

Material	C	Si	Mn	P	S	Al	Cr	Mo	Ni	FN
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	5-10

3.1 RESPONSE SURFACE DESIGNS

Apart from two level factorial designs, response surface designs are employed in the empirical study of relationships between one or more measured response variables and a number of independent or controllable variables of a process. This method has been successfully used since the year 1950, on a wide variety of problems, for example in agricultural, chemical and mechanical engineering.

Response surface designs are employed to investigate and predict the following important conditions of a process:

1. The effect on a particular response by a given set of input variables over some specified region of interest.
2. The required values of variables to obtain desirable or acceptable level of a response.
3. The required values of variables to achieve a minimum or a maximum response and the nature of response surface near this minimal or maximal value.

The relationship between response and control variables is almost always polynomial of second order designs were well devised. Besides, second order response surfaces lend themselves to detect optimum conditions with ease.

To describe the response surface by second order polynomials, the factors in experimental design should take at least three different values. A three level factorial experiments in which all possible combinations of 'k' factors at all levels of observations even when k is greater than 2, and the coefficients of the squared terms are estimated with relatively low precision.

Box and Wilson had developed new designs specifically for fitting second order response surfaces called central composite rotatable designs which are constructed by adding further treatments combinations to those obtained from a 2^k factorial. The total number of observations was reduced significantly by employing these designs. Each design consists of a two-level factorial matrix augmented by replicated experiments at the central points and symmetrically located 'star' points. For two to four factors, the central box is a full factorial design; for 5 or more factors it becomes a half-factorial design. The centre point is replicated to provide a measure of experimental errors and hence in using second order rotatable designs no replication is needed in order to find error mean square. Rotatable design means that the standard error of the estimated response at any point on the fitted surface is the same for all points that are at the same distance from the center of the region.

3.2 SELECTION OF DESIGN

One of the main objectives of present investigation was to study the main and interaction effects of process parameters on bead geometry with the help of mathematical models for predicting, controlling and optimizing weld bead quality parameters for GMAW cladding of structural steel plates. Therefore imperative to design the experiments based on factorial technique. As two level factorial techniques, either full or fractional type, have linear response surfaces and they do not estimate curvature, a five level factorial technique of response surface design (central composite rotatable design) was selected for this study.

3.3 DESIGN OF EXPERIMENTS

Experimental design is an important tool to aid the experimenter in coping with the complexities of technical investigation. This is an organized approach to the collection of data. The various steps involved in the design of experiments are given below.

1. Identifying the important process control variables.
2. Finding the upper and lower limits of the selected control variables.
3. Developing the design matrix
4. Conducting the experiments as per the design matrix
5. Recording the responses
6. Development of models and calculating the coefficients of the models
7. Checking the validity of the developed models
8. Conducting the conformity test

3.3.1 Identification of factors and responses

The chosen factors were Wire feed rate (F), Welding speed (S) Nozzle-to-plate distance (N), and Welding gun angle (T). The chosen responses were Bead Width (W), Reinforcement (R), Penetration (P), and Dilution (D) and they are show in the Figure 3.2

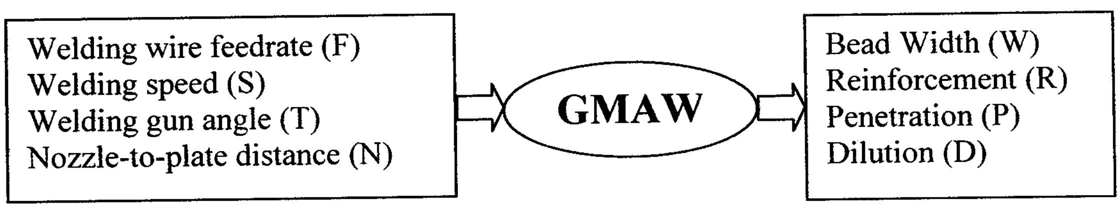

Figure 3.2 Chosen factors and responses for GMAW processes

3.3.2 Finding the limits of the process variables

The working ranges of all selected factors were fixed by conducting trial runs Murugan et al. (1994).This was carried out by varying one of the factors while keeping the rest of them at 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 factor was coded as +2 and the lower .limit was coded as -2. The coded values for intermediate values were calculated using the following equation 3.1

$$X_i = \frac{2[2X - (X_{max} + X_{min})]}{X_{max} - X_{min}} \qquad - (3.1)$$

where *Xi* is the required coded value of a variable *X*. *X* the any value of the variable from X_{min} to X_{max}, X_{min} the lower limit of the variable and X_{max} the upper limit of the variable. The chosen levels of the selected process parameters with their units and notations are given in Table 3.2.

Table 3.2 Welding parameters and their levels

PARAMETER	UNIT	NOTATION	FACTOR LEVELS				
			-2	-1	0	1	2
Wire feed rate	m/min	F	4	5	6	7	8
Welding speed	mm/min	S	160	165	170	175	180
Welding gun angle	deg	T	70	80	90	100	110
Nozzle-to-plate distance	mm	N	18	20	22	24	26

3.3.3 Development of design matrix

The design matrix chosen to conduct the experiment was a central composite rotatable design. This design matrix (Cochran 1987) comprised of a full replication of 2^4 (= 16) factorial design plus seven center points and eight star points which is shown in Table 3.3. All welding variables at the intermediate levels (0) constituted the center points and the combination of each welding variables at either its highest value (+2) or lowest value (-2) with other three variables of the intermediate levels (0), constituted the star points Murugan et al. (1994).Thus the 31 experimental runs allowed the estimation of the linear, quadratic and two-way interactive effects of the process parameters on deposition area.

3.3.4 Conducting the experiments as per the design matrix

The experiments were conducted at Kumaraguru College of Technology, Coimbatore. In this work 31 deposits as shown in Figures 3.3, 3.4, 3.5, and 3.6 were made using cladding condition corresponding to each treatment combination of parameters shown in Table 3.3 at random. At the end of each run settings for all four parameters were disturbed and reset for the next deposit. This was essential to introduce variability caused by errors in experimental settings (Harris 1983).

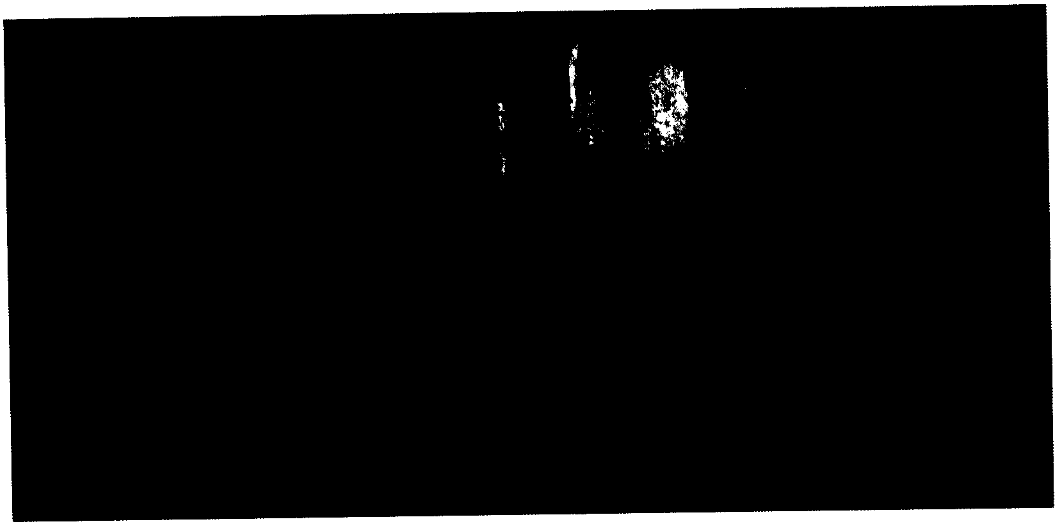

Figure 3.3 Cladded Specimens

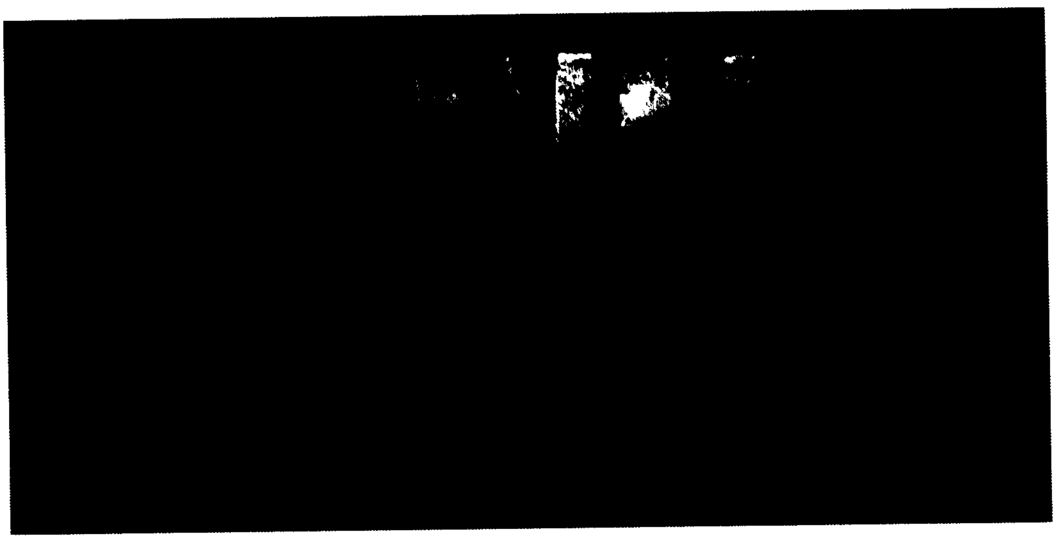

Figure 3.4 Cladded Specimens

3.3.5 Recording the responses

To measure the weld bead geometry transverse sections of each weld overlays were cut using power hacksaw from the mid-length position of the welds and the end faces were machined. Specimen end faces were polished and etched using a 2% nital solution and the bead profiles were traced for both sides of the specimen using a reflective type optical profile projector at a magnification of 10.A sample traced profile for Specimen No. 20 was shown in the Figure 3.7. The profile images were imported to AutoCAD 2004 as raster image and traced to a 2D form and then the clad bead parameters were observed for 31 trails as shown in the Table 3.3.

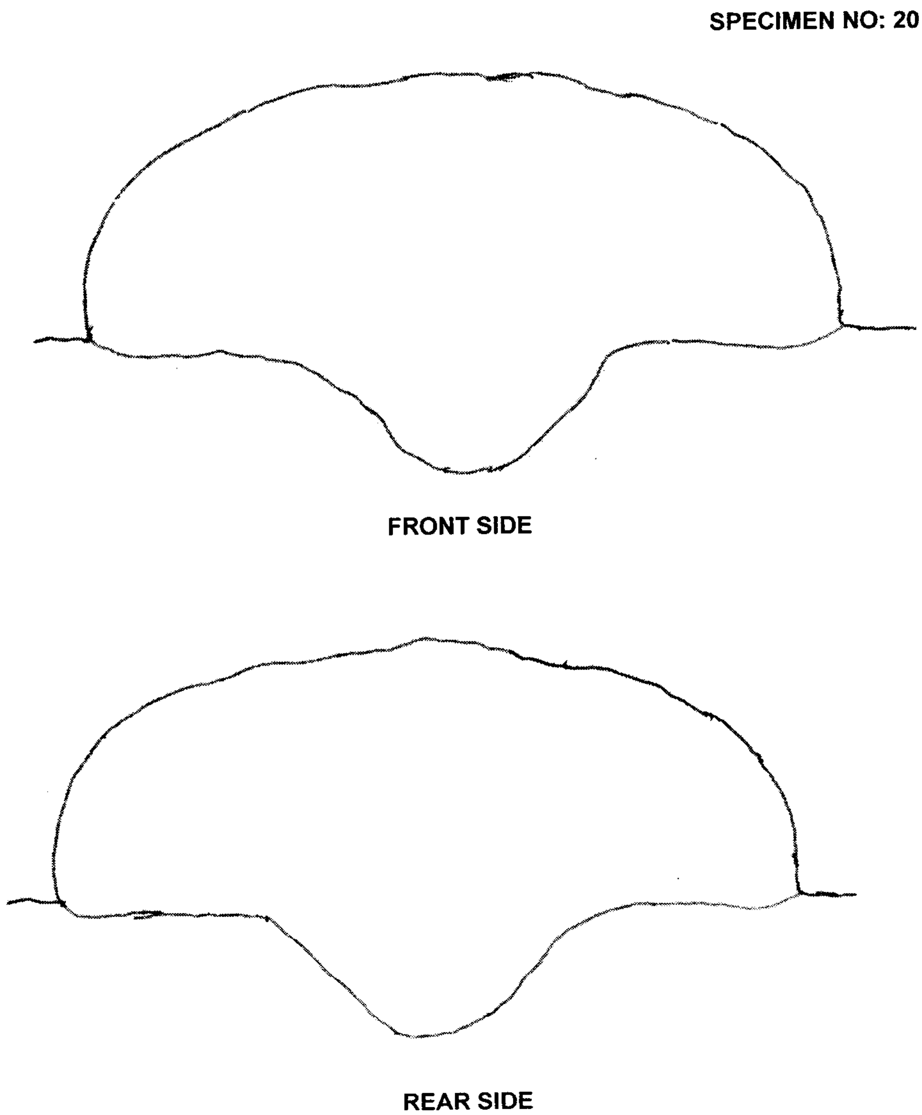

Figure 3.7 Clad bead Profiles traced using profile projector in 10 × Magnification

Figure 3.8 Band Saw Cutting

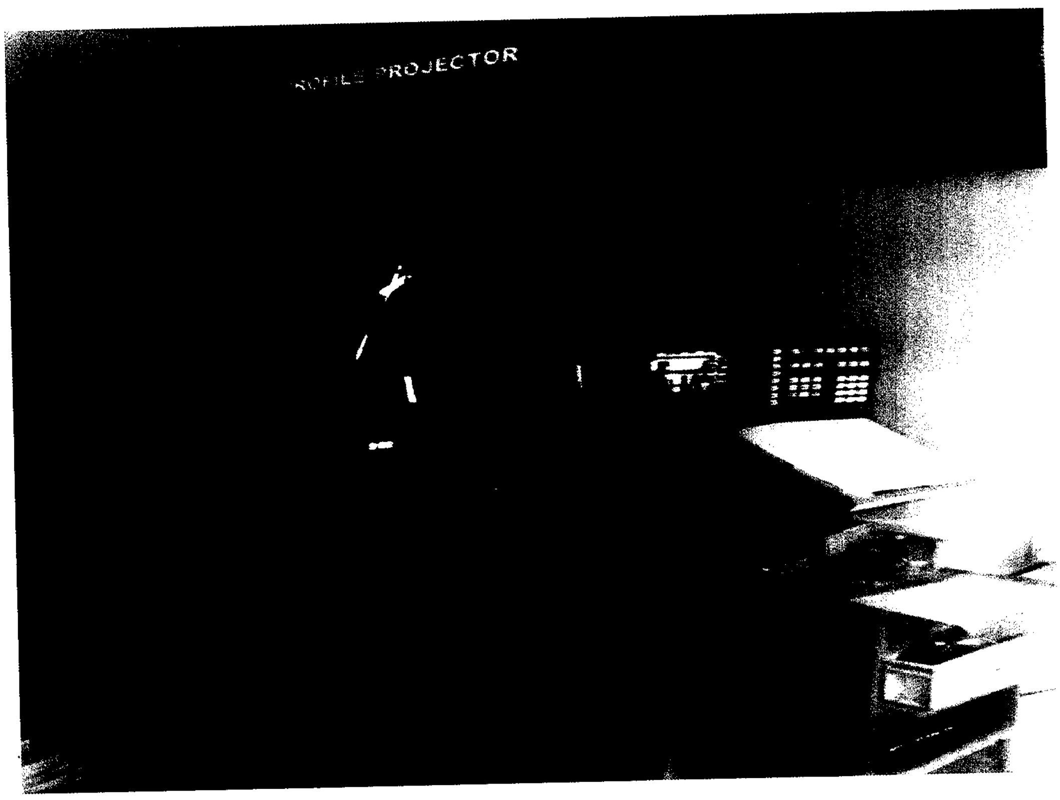

Figure 3.9 Profile Projector

Table 3.3 Design Matrix and the observed bead parameters

S. NO.	F	S	T	N	W mm	P mm	R mm	D %
1	-1	-1	-1	-1	13.59	5.37	2.98	21.69
2	+1	-1	-1	-1	16.31	6.21	3.22	18.14
3	-1	+1	-1	-1	13.21	5.29	3.13	23.35
4	+1	+1	-1	-1	14.35	6.19	3.13	17.35
5	-1	-1	+1	-1	16.58	4.85	1.61	16.92
6	+1	-1	+1	-1	17.09	5.82	1.34	9.20
7	-1	+1	+1	-1	16.06	4.68	1.63	18.63
8	+1	+1	+1	-1	17.07	5.43	1.68	12.58
9	-1	-1	-1	+1	13.33	5.45	2.77	22.09
10	+1	-1	-1	+1	13.72	6.64	2.56	12.94
11	-1	+1	-1	+1	13.15	5.39	3.00	22.24
12	+1	+1	-1	+1	12.94	6.30	2.79	15.10
13	-1	-1	+1	+1	14.54	5.02	1.53	15.12
14	+1	-1	+1	+1	14.83	6.20	0.65	5.70
15	-1	+1	+1	+1	13.54	4.92	1.20	13.84
16	+1	+1	+1	+1	15.86	5.72	0.87	7.50
17	-2	0	0	0	11.94	5.22	2.41	23.88
18	+2	0	0	0	17.05	6.32	3.01	15.11
19	0	-2	0	0	16.54	5.71	2.56	14.64
20	0	+2	0	0	14.85	5.24	2.84	18.54
21	0	0	-2	0	12.62	6.28	2.41	15.03
22	0	0	+2	0	13.52	5.50	0.80	8.67
23	0	0	0	-2	16.73	5.17	3.19	20.54
24	0	0	0	+2	13.94	5.67	1.94	12.40
25	0	0	0	0	15.74	5.35	2.99	17.74
26	0	0	0	0	14.92	5.83	1.92	13.41
27	0	0	0	0	16.16	5.55	2.55	15.98
28	0	0	0	0	16.70	5.17	2.62	17.57
29	0	0	0	0	16.28	5.31	2.48	15.78
30	0	0	0	0	15.80	5.36	2.28	16.27
31	0	0	0	0	15.60	5.34	2.62	16.88

3.3.6 Development models and calculating the coefficients of the models

The response function representing any of the bead geometry can be expressed (Cochran 1987) using Y = (F, S, T, and N) and the relationship selected being a second-degree response surface expressed as:

$$Y = b_0 + b_1 F + b_2 S + b_3 T + b_4 N + b_{11} F^2 + b_{22} S^2 + b_{33} T^2 + b_{44} N^2 + b_{12} FS + b_{13} FT + b_{14} FN + b_{23} ST + b_{24} SN + b_{34} TN$$

The values of the coefficients were calculated by regression analysis with the help of the following equation (Montgomery 2003):

$$b_0 = 0.142857\sum Y - 0.035714\sum\sum (X_{ii}Y)$$

$$b_i = 0.041778\sum (X_i Y)$$

$$b_{ii} = 0.03125\sum (X_{ii}Y) - 0.035714\sum\sum (X_{ii}Y) - 0.035714\sum Y$$

$$b_{ij} = 0.0625\sum (X_{ij}Y)$$

Table 3.4 Coefficients

S. No.	Coefficient	W	R	P	D
1	b_0	15.889	5.419	2.496	16.238
2	b_1	0.766	0.406	-0.017	-3.038
3	b_2	-0.3	-0.107	0.055	0.691
4	b_3	0.698	-0.24	-0.679	-2.755
5	b_4	-0.748	0.117	-0.244	-1.65
6	b_{11}	-0.329	0.081	0.01	0.761
7	b_{22}	-0.03	0.007	0.007	0.034
8	b_{33}	-0.685	0.11	-0.267	-1.151
9	b_{44}	-0.12	-0.007	-0.027	0.005
10	b_{12}	0.023	-0.051	0.04	0.269
11	b_{13}	0.005	-0.008	-0.078	-0.232
12	b_{14}	-0.162	0.04	-0.103	-0.544
13	b_{23}	0.174	-0.039	-0.017	0.152
14	b_{24}	0.122	-0.02	-0.004	-0.196
15	b_{34}	-0.232	0.023	-0.042	-0.437

The response coefficients were calculated using QA six sigma software (DOE-PCIV) and they shown in Table 3.4. After determining the coefficients the mathematical models were developed. The insignificant coefficients were eliminated without affecting the accuracy of the developed model by using t-test. This was done by back elimination technique, which is available in QA six sigma software (DOE-PCIV).The final mathematical models were constructed by using only significant coefficients. The developed final models with welding variables in coded form are given below.

Bead Width: $15.75+0.766\mathbf{F}-0.3\mathbf{S}+0.698\mathbf{T}-0.748\mathbf{N}-0.315\mathbf{F}^2-0.671\mathbf{T}^2-0.232\mathbf{TN}$

Reinforcement: $5.419+0.406\mathbf{F}-0.107\mathbf{S}-0.24\mathbf{T}+0.117\mathbf{N}+0.081\mathbf{F}^2+0.11\mathbf{T}^2-0.051\mathbf{FS}$

Penetration: $2.488-0.679\mathbf{T}-0.244\mathbf{N}-0.266\mathbf{T}^2-0.103\mathbf{FN}$

Dilution: $16.274-3.038\mathbf{F}+0.691\mathbf{S}-2.755\mathbf{T}-1.65\mathbf{N}+0.758\mathbf{F}^2-1.154\mathbf{T}^2-0.544\mathbf{FN}$

3.3.7 Checking the validation of the developed models

The validity of the developed models are shown in Figure 3.10, 3.11 and 3.12 which show the observed and predicted values of bead geometry parameters.

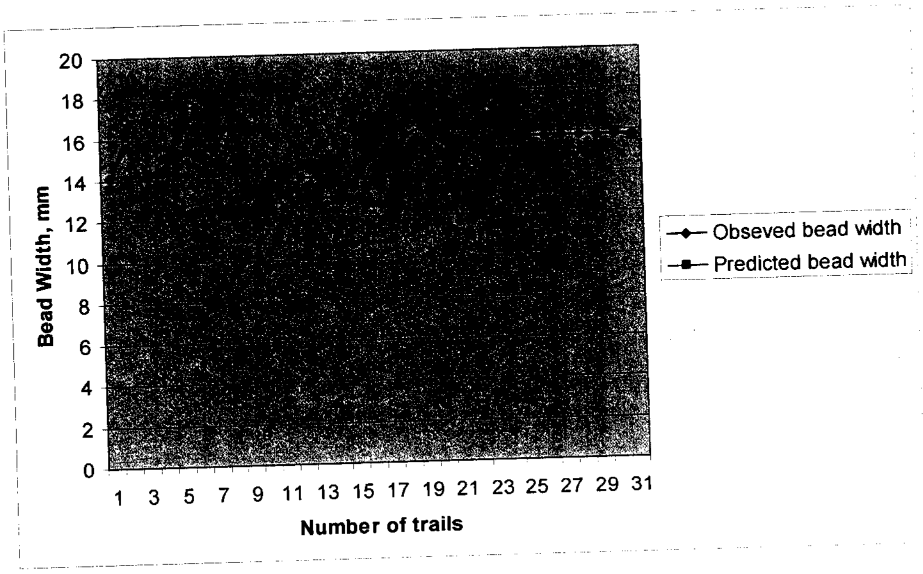

Figure 3.10 Observed and predicted weld bead width

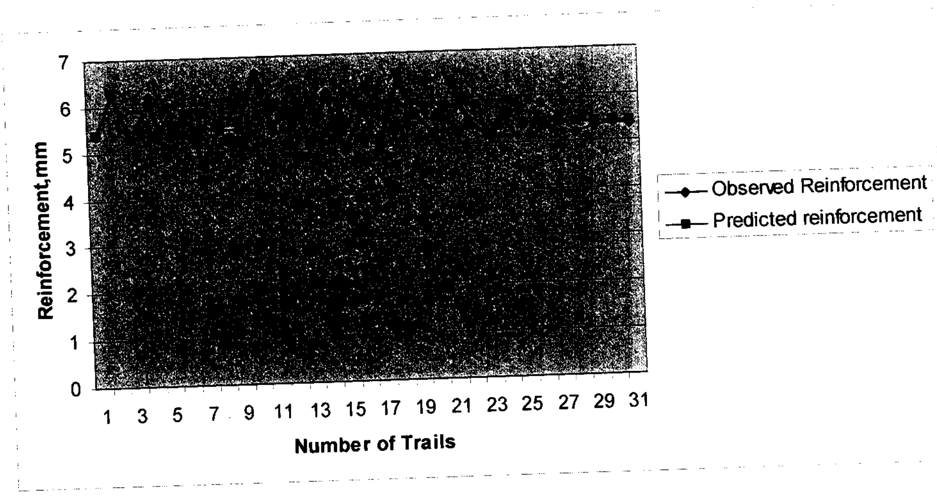

Figure 3.11 Observed and predicted Reinforcement

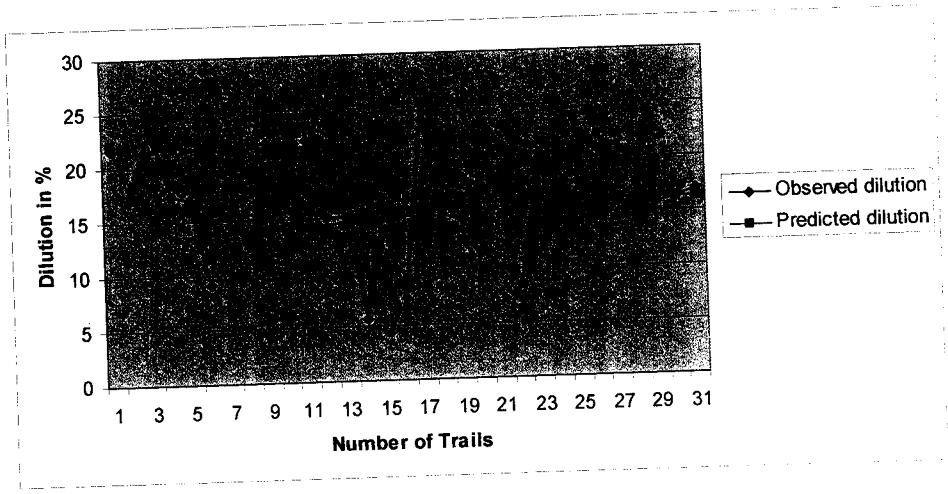

Figure 3.13 Observed and predicted Dilution

3.3.8 Conducting Conformity Test

Conformity tests were conducted using the same experimental setup to confirm the results of the experiment and demonstrate the reliability of the predicted values and the claddings deposited at optimum condition are shown in the Figure 3.14 and 3.15. The conformity test shows the accuracy of the developed models is above 96%. This is shown in table 3.5.

Table 3.5 Results of Conformity Tests

Process parameters in coded form				Predicted values of clad bead parameters				Actual values of clad bead parameters				Error, %			
I	S	N	T	W	P	R	D	W	P	R	D	W	P	R	D
-0.90	-1.81	1.34	1.94	13.03	5.33	0.80	10.33	12.95	5.22	0.78	10.47	-0.58	-2.12	-2.92	1.32
0.38	0.77	1.42	-0.67	16.11	5.29	1.17	10.74	16.21	5.37	1.21	10.98	0.61	1.51	3.41	2.24
0.27	-1.40	1.25	-0.45	16.64	5.52	1.35	10.11	16.42	5.43	1.37	10.27	-1.34	-1.70	1.47	1.53

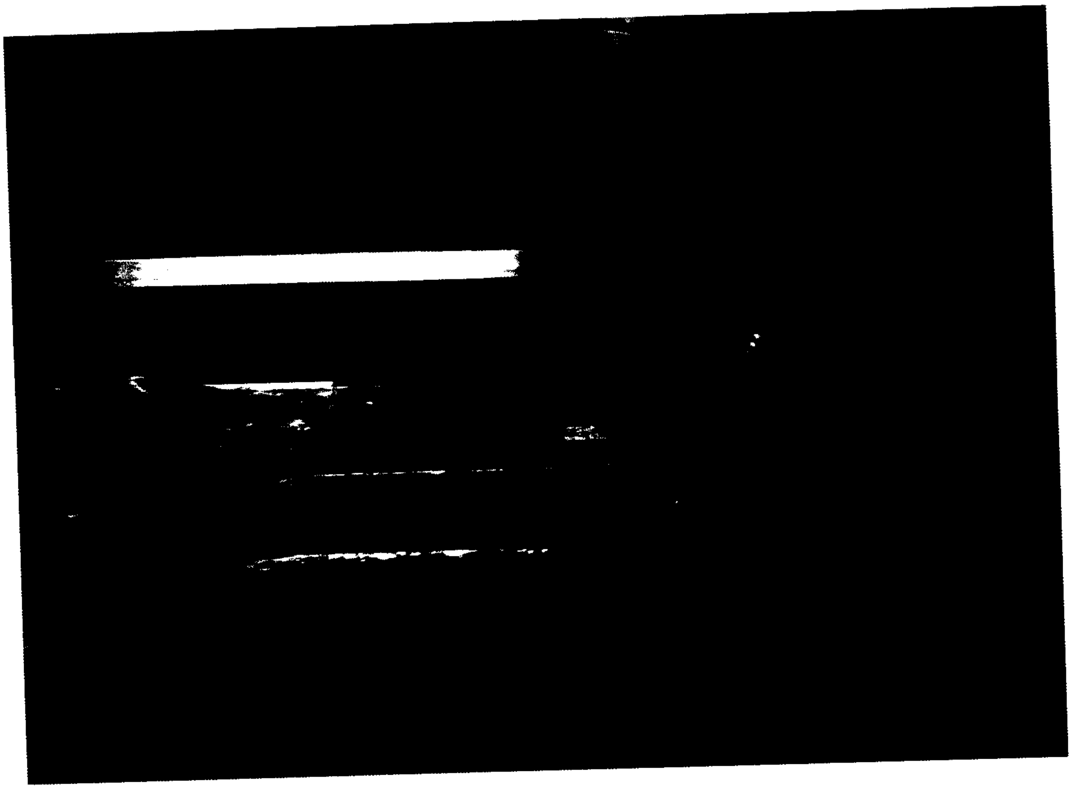

Figure 3.14 Claddings deposited at optimum condition

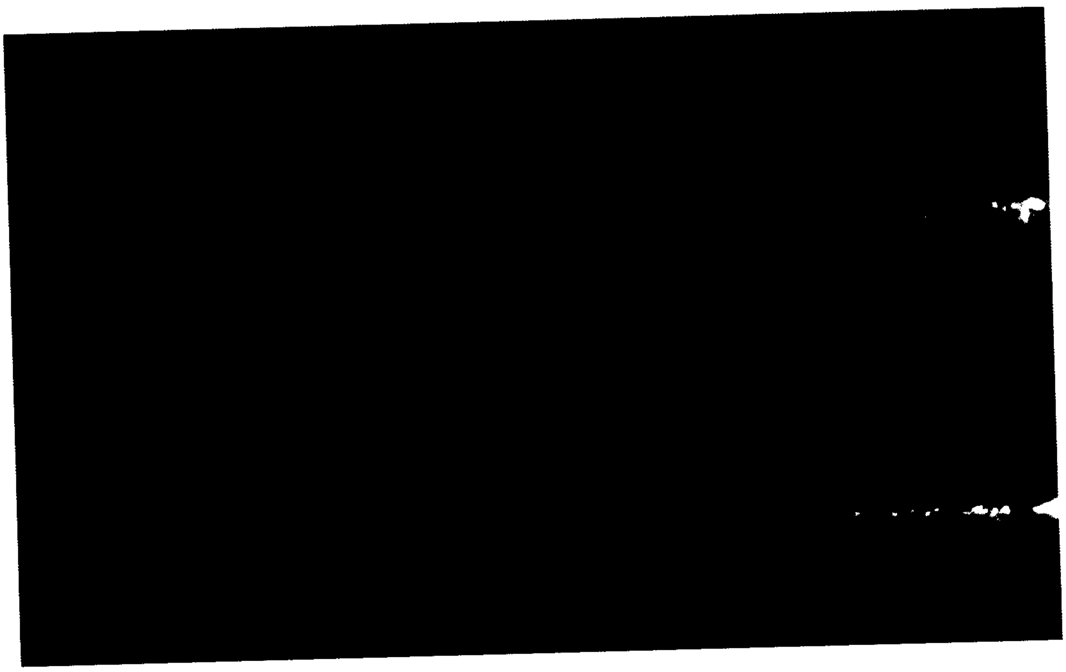

Figure 3.15 Claddings deposited at optimum condition

Chapter 4

Optimization Techniques – An Overview

CHAPTER 4

OPTIMIZATION TECHNIQUES – AN OVERVIEW

4.1 INTRODUCTION

Optimization analysis of any process is usually based on minimizing production cost, maximizing production rate, obtaining the accurate operating parameters and the best performance characteristics.

4.2 NECESSITY FOR OPTIMIZATION

Optimization algorithms are becoming increasingly popular in engineering design activities, primarily because of the availability and affordability of high-speed computer. They are extensively used in those engineering problems where the emphasis is on maximizing or minimizing a certain goal. For example, optimization is routinely used in aerospace deign activities to minimize the overall weight of the aircraft. Thus the minimization of the weight of the aircraft components is of major concern to aerospace designers. Chemical engineers, in the other hand, are interested in designing and operating a process plant for an optimum rate of production. Mechanical engineers design mechanical components for the purpose of achieving either a minimum manufacturing cost or a maximum component life.

Production engineers are interested in designing optimum schedule of the various machining operations to minimize the ideal time of machines and the overall job completion time. Civil engineers are involved in designing buildings, bridges, dams and other structures in order to achieve a minimum overall cost or maximizing safety or both. Electrical engineers are interested in designing communication networks so as to achieve minimum time for communication from one node to another.

All the above-mentioned task either minimization or maximization (collectively known as optimization) of an objective requires knowledge about the working principles of different optimization methods.

4.3 IMPORTANCE OF OPTIMIZATION

Following are the importance of optimization

- Reduces wastage of material, money and processing time.
- Decreases the fatigue of the worker who is on the shop floor.
- Productivity of the organization increases gradually.
- All the employees in the organization are very much satisfied with the type of work they are doing.
- Procurement of material will be very less because of the higher productivity.

4.4 TYPES OF SOLUTIONS

- A solution to an optimization problem specifies the values of the decision variables, and also the value of the objective function.
- A feasible solution satisfies all constraints.
- An optimal solution is feasible and provides the best objective function value. There may be multiple optimal solutions for a given problem.
- A near optimal solution is feasible and provides a superior objective function value, but not necessarily the best.

4.5 TYPES OF OPTIMIZATION TECHNIQUES

The types of optimization techniques are given below:

- Single or multi variable optimization
- Single or multi objective optimization
- Constrained or unconstrained optimization
- Linear or non-linear optimization
- Non-traditional optimization algorithms

- Genetic algorithm
- Particles swarm optimization
- Neural networks
- Simulated annealing
- Fuzzy logic

4.6 ADVANTAGES OF NON-TRADITIONAL TECHNIQUES

The advantages of Non-traditional techniques are

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

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

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

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

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

Chapter 5

Optimization of Gas Metal Arc Weld Cladding using Genetic Algorithm

CHAPTER – 5

OPTIMIZATION OF GAS METAL ARC WELD CLADDING USING GENETIC ALGORITHM

5.1 INTRODUCTION

Genetic Algorithms (GA) are adaptive methods which may be used to solve search and optimization problems. They are based on the genetic processes of biological organisms. Over many generations, natural populations evolve according to the principles of natural selection and "survival of the fittest", first clearly stated by Charles Darwin in The Origin of Species. By mimicking this process, genetic algorithms are able to "evolve" solutions to real world problems, if they have been suitably encoded. For example, GA can be used to design bridge structures, for maximum strength/weight ratio, or to determine the least wasteful layout for cutting shapes from cloth. They can also be used for online process control, such as in a chemical plant, or load balancing on a multi-processor computer system.

The basic principles of GA were first laid down rigorously by Holland (1975), and are well described in many texts. GA simulates those processes in natural populations which are essential to evolution. Exactly which biological processes are essential for evolution, and which processes have little or no role to play is still a matter for research; but the foundations are clear.

In nature, individuals in a population compete with each other for resources such as food, water and shelter. Also, members of the same species often compete to attract a mate. Those individuals which are most successful in surviving and attracting mates will have relatively larger numbers of offspring. Poorly performing individuals will produce few of even no offspring at all. This means that the genes from the highly adapted, or "fit" individuals will spread to an increasing number of individuals in each successive generation. The combination of good characteristics from different ancestors can sometimes produce "super fit" offspring, whose fitness is greater than that of either parent. In this way, species evolve to become more and better suited to their environment.

GA uses a direct analogy of natural behaviour. They work with a population of "individuals", each representing a possible solution to a given problem. Each individual is assigned a "fitness score" according to how good a solution to the problem it is. For example, the fitness score might be the strength/weight ratio for a given bridge design. (In nature this is equivalent to assessing how effective an organism is at competing for resources.) The highly fit individuals are given opportunities to "reproduce", by "cross breeding" with other individuals in the population. This produces new individuals as "offspring", which share some features taken from each "parent". The least fit members of the population are less likely to get selected for reproduction, and so "die out".

A whole new population of possible solutions is thus produced by selecting the best individuals from the current "generation", and mating them to produce a new set of individuals. This new generation contains a higher proportion of the characteristics possessed by the good members of the previous generation. In this way, over many generations, good characteristics are spread throughout the population, being mixed and exchanged with other good characteristics as they go. By favouring the mating of the more fit individuals, the most promising areas of the search space are explored. If the GA has been designed well, the population will converge to an optimal solution to the problem.

5.2 BASIC PRINCIPLES

The standard GA can be represented as shown in Figure 5.1

Before a GA can be run, a suitable coding (or representation) for the problem must be devised. We also require a fitness function, which assigns a figure of merit to each coded solution. During the run, parents must be selected for reproduction, and recombined to generate offspring. These aspects are described below.

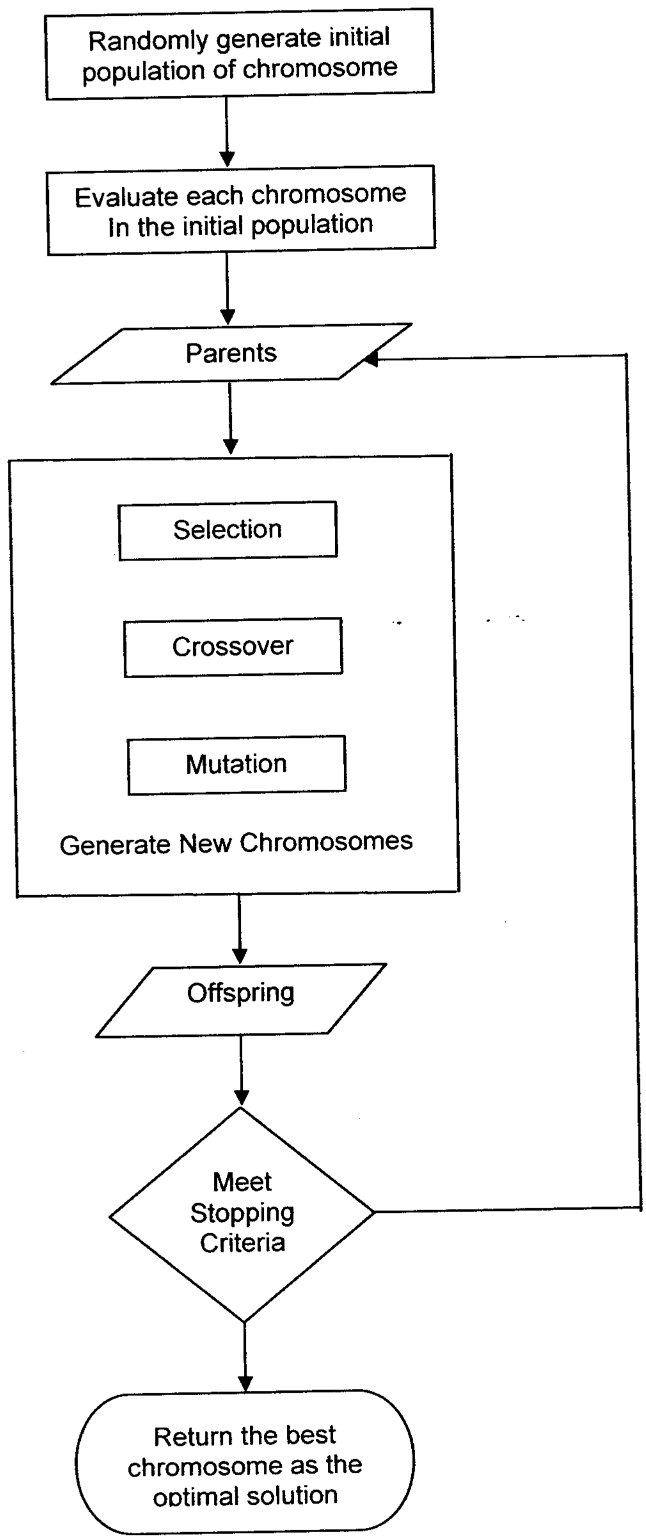

Figure 5.1 A Traditional Genetic Algorithm

5.2.1 Coding

It is assumed that a potential solution to a problem may be represented as a set of parameters (for example, the dimensions of the beams in a bridge design). These parameters (known as genes) are joined together to form a string of values (often referred to as a chromosome). Holland (1975) first showed, and many still believe, that the ideal is to use a binary alphabet for the string. For example, if our problem is to maximize a function of three variables, F(x; y; z), we might represent each variable by a 10-bit binary number (suitably scaled). Our chromosome would therefore contain three genes, and consist of 30 binary digits. In genetics terms, the set of parameters represented by a particular chromosome is referred to as a genotype. The genotype contains the information required to construct an organism - which is referred to as the phenotype. The same terms are used in GAs. For example, in a bridge design task, the set of parameters specifying a particular design is the genotype, while the finished construction is the phenotype. The fitness of an individual depends on the performance of the phenotype. This can be inferred from the genotype - i.e. it can be computed from the chromosome, using the fitness function.

5.2.2 Fitness function

A fitness function must be devised for each problem to be solved. Given a particular chromosome, the fitness function returns a single numerical "fitness," or "figure of merit," which is supposed to be proportional to the "utility" or "ability" of the individual which that chromosome represents. For many problems, particularly function optimization, it is obvious what the fitness function should measure - it should just be the value of the function. But this is not always the case, for example with combinatorial optimization. In a realistic bridge design task, there are many performance measures we may want to optimize: strength/weight ratio, span, width, maximum load, cost, construction time - or, more likely, some combination of all these.

5.2.3 Reproduction

During the reproductive phase of the GA, individuals are selected from the population and recombined, producing offspring which will comprise the next generation. Parents are selected randomly from the population using a scheme which favours the more fit individuals. Good individuals will probably be selected several times in a generation; poor ones may not be at all.

Having selected two parents, their chromosomes are recombined, typically using the mechanisms of crossover and mutation. The most basic forms of these operators are as follows:

5.2.3.1 Crossover

It takes two individuals, and cuts their chromosome strings at some randomly chosen position, to produce two "head" segments and two "tail" segments. The tail segments are then swapped over to produce two new full length chromosomes as shown in Figure 5.2. The two offspring each inherit some genes from each parent. This is known as single point crossover. Crossover is not usually applied to all pairs of individuals selected for mating. A random choice is made, where the likelihood of crossover being applied is typically between 0.6 and 1.0. If crossover is not applied, offspring are produced simply by duplicating the parents. This gives each individual a chance of passing on its genes without the disruption of crossover.

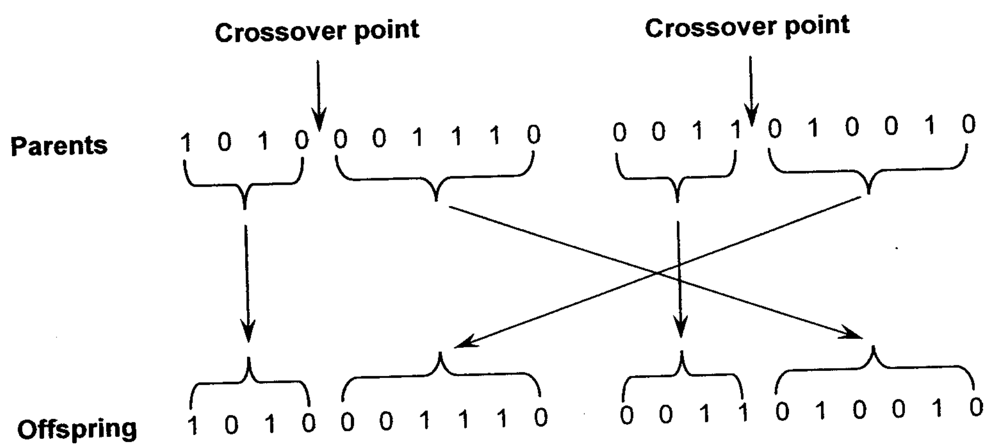

Figure 5.2 Single – Point Crossover

5.2.3.2 Mutation

It is applied to each child individually after crossover. It randomly alters each gene with a small probability (typically 0.001). Figure 5.3 shows the fifth gene of the chromosome being mutated. The traditional view is that crossover is the more important of the two techniques for rapidly exploring a search space. Mutation provides a small amount of random search, and helps ensure that no point in the search space has a zero probability of being examined. An example of two individuals reproducing to give two offspring is shown in Figure 5.4. The fitness function is an exponential function of one variable, with a maximum at x = 0:2. It is coded as a 10-bit binary number Table 5.1 shows two parents and the offspring they produce when crossed over after the second bit (for clarity, no mutation is applied). This illustrates how it is possible for crossover to recombine parts of the chromosomes of two individuals and give rise to offspring of higher fitness. (Of course, crossover can also produce offspring of low fitness, but these will not be likely to get selected for reproduction in the next generation.)

MUTATION POINT

↓

Offspring	1	0	1	0	**0**	1	0	0	1	0
Mutated Offspring	1	0	1	0	**1**	1	0	0	1	0

Figure 5.3 A Single Mutation

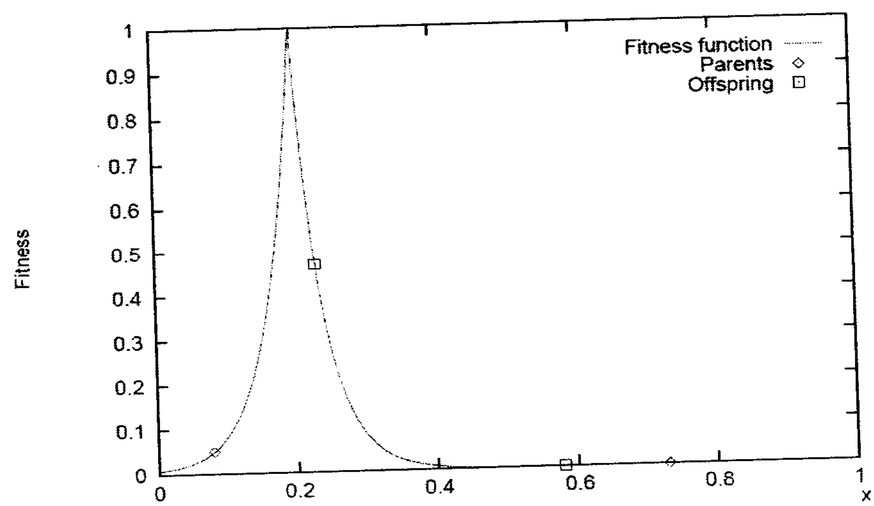

Figure 5.4 Illustration of Crossover

Table 5.1 Details of Individual

Individual	x	Fitness	Chromosome
Parent 1	0.08	0.05	00 01010010
Parent 2	0.73	0.000002	10 11101011
Offspring 1	0.23	0.47	00 11101011
Offspring 2	0.58	0.00007	10 01010010

5.2.4 Convergence

If the GA has been correctly implemented, the population will evolve over successive generations so that the fitness of the best and the average individual in each generation increases towards the global optimum. Convergence is the progression towards increasing uniformity. A gene is said to have converged when 95% of the population share the same value (DeJong 1975).The population is said to have converged when all of the genes have converged.

Figure 5.5 shows how fitness varies in a typical GA. As the population converges, the average fitness will approach that of the best individual.

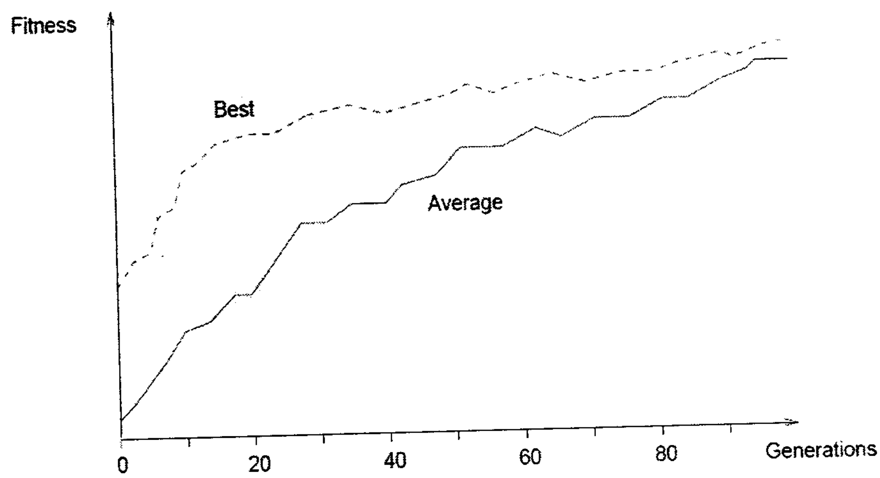

Figure 5.5 Typical GA Run

5.3 SIMULATION PROCEDURE

The aim of this study is to find the optimum adjusts for the Wire Feed rate (F), welding speed (S), welding gun angle (T) and nozzle-to-plate distance (N) 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 5.2.

Table 5.2 GA search ranges

PARAMETERS	RANGE
Wire Feed rate (F)	4-8 m/min
Welding speed (S)	160-180 mm/min
Welding gun angle (T)	70-110°
Nozzle-to-plate distance (N)	18-26 mm

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 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 5.3 show the options used for the study.

Table 5.3 Options of GA computation

Population type	Double Vector
Population size	30
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.

5.4. 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 Feedrate (F)

X (2) = Welding speed (S)

X (3) = Welding gun angle (T)

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

5.5 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…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)=16.274-3.038*x(1)+0.691*x(2)-2.755*x(3)-1.65*x(4)+0.758*x(1)^2-1.154*x(3)^2-0.544*x(1)*x(4); Percentage dilution.

g(1)=15.75+0.766*x(1)-0.3*x(2)+0.698*x(3)-0.748*x(4)-0.315*x(1)^2-0.671*x(3)^2-0.232*x(3)*x(4)-17.09; Bead Width and its upper limit.

g(2)=11.94-15.75+0.766*x(1)-0.3*x(2)+0.698*x(3)-0.748*x(4)-0.315*x(1)^2-0.671*x(3)^2-0.232*x(3)*x(4); Bead Width and lower limit.

g(3)=5.419+0.406*x(1)-0.107*x(2)-0.24*x(3)+0.117*x(4)+0.081*x(1)^2+0.11*x(3)^2-0.051*x(1)*x(2)-6.645; Penetration and its upper limit.

g(4)=4.68-5.419+0.406*x(1)-0.107*x(2)-0.24*x(3)+0.117*x(4)+0.081*x(1)^2+0.11*x(3)^2-0.051*x(1)*x(2);Penetration and its lower limit.

g(5)=2.488-0.679*x(3)-0.244*x(4)-0.266*x(3)^2-0.103*x(1)*x(4)-3.22; Reinforcement and its upper limit.

g(6)=2.488-0.679*x(3)-0.244*x(4)-0.266*x(3)^2-0.103*x(1)*x(4); Reinforcement and its lower limit.

g(7)=f-23.88; upper limit of percentage dilution.

g(8)=5.70-f; lower limit of percentage dilution.

Step 2: invoke an optimization routine

Select and type the corresponding boxes as per the requirement as shown in the Table 5.2.

Step 3: Running the M-file.

After evaluations, this produces the following optimum values of process parameters in coded form

X (1) = Wire Feed rate (F) = 0.27306
X (2) = Welding speed (S) = -1.39529
X (3) = Welding torch angle (T) = 1.24662
X (4) = Nozzle-to-plate distance (N) = 0.44806

Chapter 6

Results and Discussions

CHAPTER - 6

RESULTS AND DISCUSSION

6.1. GENETIC ALGORITHMIC APPROACH

After running the M-file in MATLAB 7.0 simulation software for the optional setting parameters that has been shown on Table 5.3, following various optimum results have been obtained from different number of trials.

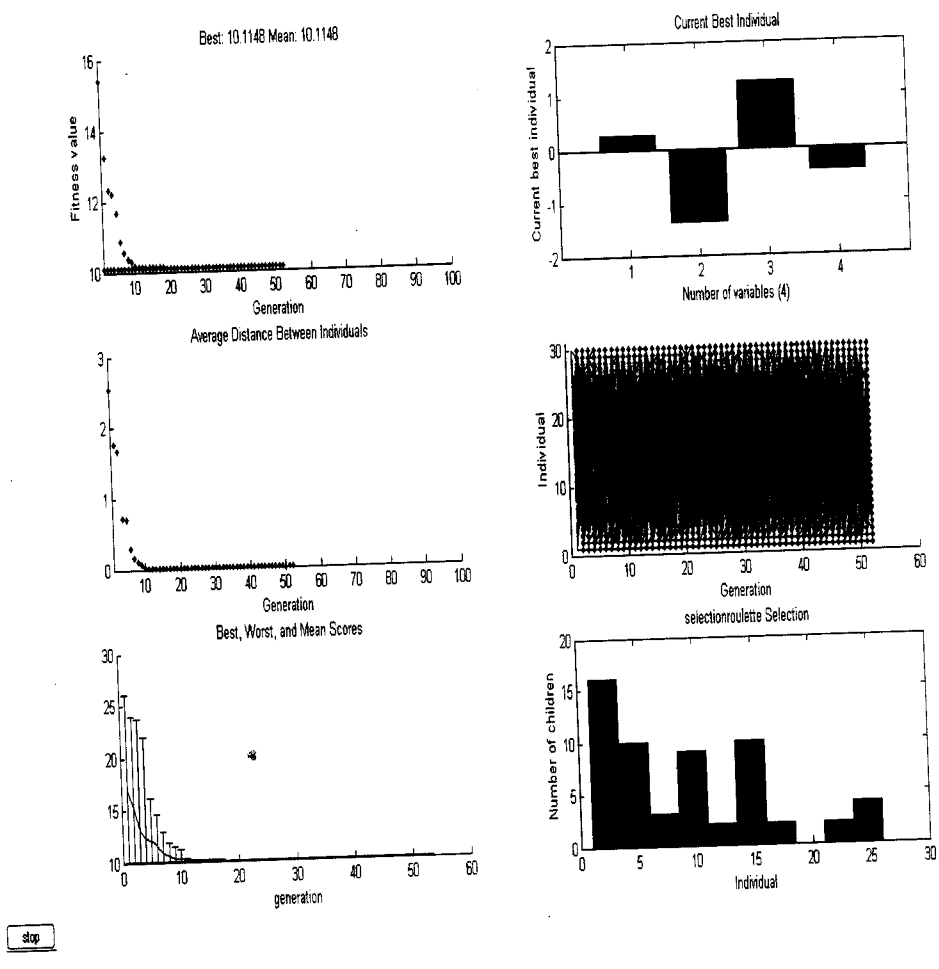

Figure 6.1 Percentage Dilution 10.11%

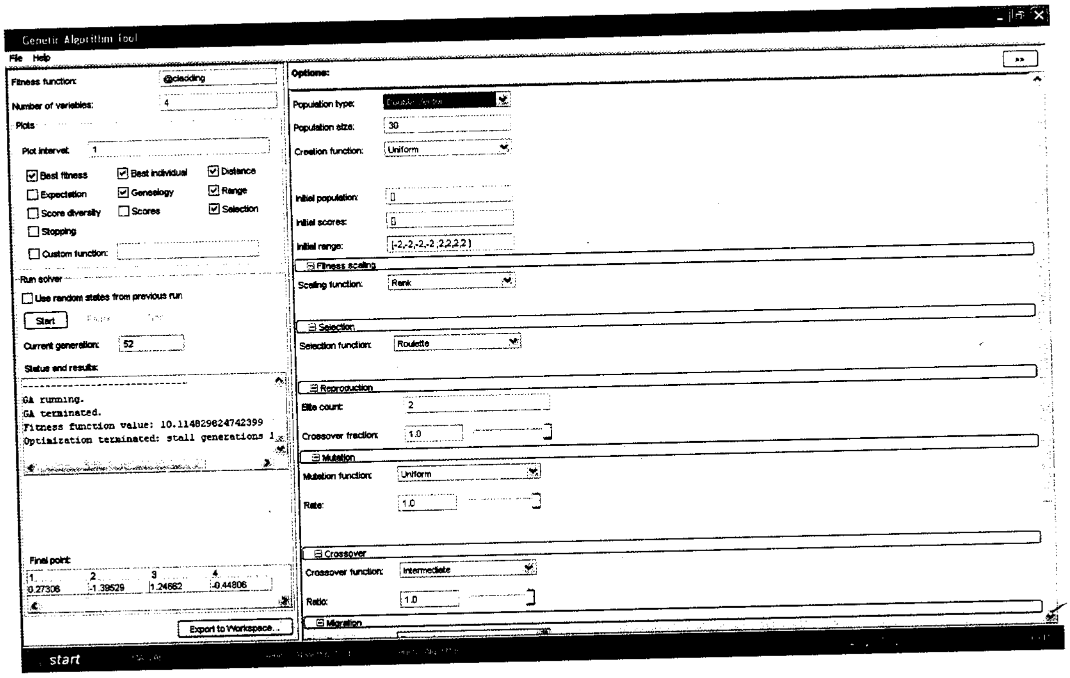

Figure 6.2 Genetic Algorithm Tool Box Setting

Among the above results optimum values of the process parameters obtained are shown in the Figure 6.1, at 52nd iteration is found to be the best. The genetic algorithm tool box setting has been shown in Figure 6.2.

Corresponding input parameters are as follows.

X (1) = Wire Feed rate (F) = 6.27306 m/min

X (2) = Welding speed (S) = 163.02355 mm/min

X (3) = Welding gun angle (T) = 102.4662 degree

X (4) = Nozzle-to-plate distance (N) 21.10388 mm

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

Bead Width (W) = 16.64 mm

Reinforcement (R) = 5.5239 mm

Penetration (P) = 1.3500 mm

Percentage Dilution (D) = 10.11%

Chapter 7

Conclusions

CHAPTER 7

CONCLUSIONS

- A five level four factor full factorial design matrix based on the central composite rotatable design technique was used for the development of mathematical models to predict the clad bead geometry for austenitic steel cladding using GMAW.
- 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.
- In cladding by a welding process, weld bead geometry and dilution are important to economise on material. This study used a genetic algorithm to determine the welding process parameters such as Wire feed rate, Welding speed, Welding gun angle 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.
- However, the optimization by GA technique requires a good setting of its own parameters, such as population size, number of generations, etc. otherwise there is a risk of an insufficient sweeping of the search space.
- 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

SCOPE FOR FUTURE WORK

- Mathematical model for other parameters like Wetting angle and Fusion angle can be developed.
- Various other non-traditional optimization techniques can employed to obtain optimum process parameters for weld cladding.
- A `C` program for genetic 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% .
- Hybridization of various non-traditional optimization techniques can be developed and programmed to find the most accurate process parameters
- Development of mathematical model and optimization of heat input in cladding by GMAW can be done.
- Weld bead geometry and dilution in GMAW can be modelled and predicted using artificial neural network.
- Prediction and control of weld bead geometry and shape relationships in GMAW cladding of Austenitic Stainless Steel can be determined.

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