Optimization of Flux Cored Arc Welding Process Parameters Using Intelligent Techniques

A Project Report

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BONAFIDE CERTIFICATE

Certified that this project report entitled "**Optimization of Flux Cored Arc Welding Process Parameters Using Intelligent Techniques**" is the bonafide work of

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Who carried out the project work under my supervision.

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ABSTRACT

Arc welding process is used in most of the manufacturing industries. In arc welding process, it is very essential to optimize the process parameters to achieve the desired weld bead characteristics. In this project work, objective function of maximizing bead width and height of reinforcement and minimizing the dilution and penetration were considered. Four process parameters (welding current, welding speed, nozzle-to-plate distance, and torch angle) were identified for optimization subjected to realistic process constraints. This optimization problem formulated as a multi objective, multivariable, non linear programming problem.

In order to overcome the difficulties with conventional techniques a new techniques called particle swarm optimization and ant colony optimization are implemented in this work. PSO is a simple and powerful technique based on the concept of social interaction to problem solving. In PSO a swarm search of n individuals communicate either directly or indirectly with one another for getting the search direction. The proposed PSO algorithm starts with five particles (solutions) and search for new ones by updating the velocities

Ant colony algorithms use the pheromone trial used by real ants as a medium for communication and feed-back among ants. It is a population based cooperative search procedure that is derived from the behavior of real ants. The solution generation is guided by artificial pheromone trials and problem-specific heuristic information. The ACO algorithm starts with twenty solutions and search for new ones based on pheromone trials.

Maximum of hundred iterations were performed and the solutions were obtained for ACO and PSO algorithms. Program has been written using C language. The solutions obtained by these procedures were found to be superior. The computational effort is very less and easy to implement.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBERVIATIONS

PSO	-	Particle Swarm Optimization
ACO	-	Ant Colony Optimization
GA	-	Genetic Algorithm
SAW	-	Submerged Arc Welding
GMAW	-	Gas Metal Arc Welding
FCAW	-	Flux Cored Arc Welding
SMAW	-	Shielded Metal Arc Welding
GTAW	-	Gas Tungsten Arc Welding
HAZ	-	Heat Affected Zone
RSM	-	Response Surface Methodology
I	-	Welding Current
S	-	Welding Speed
N	-	Nozzle-to-Plate Distance
T	-	Torch Angle
P	-	Depth of Penetration
D	-	Percentage Dilution
W	-	Weld Bead Width
R	-	Height of Reinforcement
V_{id}	-	Particle Velocity
X_{id}	-	Particle Position
P_{id}	-	Local Best
P_{gd}	-	Global Best
ω	-	Inertia Weight
C1	-	Social Coefficient
C2	-	Cognitive Coefficient
T	-	Current Iteration Number/Maximum Iteration
R	-	Maximum Step Size
r	-	Random Number
x_i	-	Parent Solution
X	-	Parent Solution
α	-	Uniform Random Number

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Most of the engineering applications require both high strength and corrosion resistant materials for long term reliability and performance. Often the performance can best be achieved by the use of steels which do not possess the required corrosion resistance. A possible materials solution to providing structural components which combine the attributes of high strength and corrosion resistance is to clad the surface of the steel with a metallurgically compatible corrosion resistant alloy. The characteristics desirable in such a cladding alloy are reasonable strength, weldability in duplex stainless steel. The have chlorine stress corrosion cracking resistance and strength significantly greater than that of the 300-series austenitics.

In recent years, weld cladding processes have been developed rapidly and are now applied in numerous industries such as chemical and fertilizer plants, nuclear and steam power plants, food processing and petrochemical industries etc.,the biggest difference between welding a joint and cladding is the percentage dilution . The composition and properties of cladding are strongly influenced by the dilution obtained. Control of dilution is very important in cladding, where typically low dilution is desirable. When the dilution is low, the final deposit composition will be closer to that of the filler metal and the corrosion resistance of the cladding will also be maintained.

Among the various processes used for cladding, FCAW process has become an optimum choice for cladding due to its high reliability. all position capability, ease of use, low cost and high productivity. Also, with the increased emphasize on the use of automated and robotic system, FCAW has been employed increasingly in mechanized cladding in industry.

1.2 CLASSIFICATION OF WELDING PROCESSES

Welding techniques are employed mainly to join engineering materials and to increase the strength. In recent years, welding processes have been developed rapidly and are now applied in numerous industries like nuclear and steam power plants, pressure vessels, train bodies, aircraft and missile components and in many automobiles.

The American Welding Society (AWS) has made each welding process definition as complete as possible so that it will suffice without reference to another definition. They define process as a distinctive action or series of actions involved in the course of producing a basic type of result.

The AWS definition for a welding process is a materials joining process which produces coalescence of materials by heating them to suitable temperatures with or without the application of pressure or by the application of pressure alone and with or without the use of filler materials.

AWS has grouped the processes together according to the "mode of energy transfer" as the primary consideration. A secondary factor is the "influence of capillary attraction in effecting distribution of filler metal" in the joint. Capillary attraction distinguishes the welding processes grouped under "Brazing" and "Soldering" from "Arc Welding", "Gas Welding". "Resistance Welding", "Solid State Welding" and "Other Processess".

Classification of Arc Welding

The arc welding group includes eight specific processes, each separate and different from the others but in many aspects similar.

1.2.1 Carbon Arc Welding

The carbon arc welding process is the oldest of all the arc welding processes and is considered to be the beginning of arc welding. The welding Society defines carbon arc welding as an arc welding process which produces coalescence of metals by heating them with an arc between a carbon electrode and the work-piece. No shielding is used. Pressure and filler metal may or may not be used. It has limited application today, but a variation of twin carbon arc welding is more popular. Another variation uses compressed air for cutting.

1.2.2 Shielded Metal Arc Welding

The development of the metal arc welding process soon followed the carbon arc. This developed into the currently popular shielded metal arc welding (SMAW) process defined as an arc welding process which produces coalescence of metals by heating them with an arc between a covered metal electrode and the workpiece. Shielding is obtained from decomposition of the electrode covering. Pressure is not used and filler metal is obtained from the electrode.

1.2.3 Submerged Arc Welding

Automatic welding utilizing bare electrode wires was used in the 1920s, but it was the submerged arc welding (SAW) process that made automatic welding popular. Submerged arc welding is defined as "an arc welding process which produces coalescence of metals by heating them with an arc between a bare metal electrode or electrodes and the workpiece. Pressure is not used and filler metal is obtained from the electrode and sometimes for a supplementary welding rod." It is normally limited to the

1.2.7 Flux-Cored Arc Welding

A variation of metal arc welding has become a distinct welding process and is known as flux-cored arc welding (FCAW). It is defined as "an arc welding process which produces coalescence of metals by heating them with an arc between a continuous filler metal (consumable) electrode and the workpiece. Shielding is provided by a flux contained within the tubular electrode." Additional shielding may or may not be obtained from an externally supplied gas or gas mixture.

1.2.8 Stud Arc Welding

The final process within the arc welding group of processes is known as stud arc welding . This process is defined as "an arc welding group of process which produces coalescence of metals by heating them with an arc between a metal stud or similar part and the workpiece". When the surfaces to be joined are properly heated they are brought together under pressure. Partial shielding may be obtained by the use of ceramic ferrule surrounding the stud.

1.2.9 Brazing

Brazing is "a group of welding processes which produces coalescence of materials by heating them to a suitable temperature and by using a filter metal, having liquids above 450^0c and below the solids of the base materials. The filler metal is distributed between the closely fitted surfaces of the joint by capillary attraction."

A braze is a very special form of weld, the base metal is theoretically not melted. There are seven popular different processes within the brazing group. The source of heat differs among the processes. Braze welding relates to welding processes using brass or bronze filler metal, where the filler metal is not distributed by capillary action.

1.2.10 Oxy Fuel Gas Welding

Oxy fuel gas welding is "a group of welding processes which produces coalescence by heating materials with an oxy fuel gas flame or flames with or without the application of pressure and with or without the use of filler metal."

There are four distinct processes within this group and in the case of two of them, oxy-acetylene welding and oxy-hydrogen welding; the classification is based on the fuel gas used. The heat of the flame is created by the chemical reaction or the burning of the gases. In the third process, air acetylene welding, air is used instead of oxygen, and in fourth category, pressure gas welding; pressure is applied in addition to the heat from the burning of the gases. This welding process normally utilizes acetylene as the fuel gas. The oxygen thermal cutting processes have much in common with this welding process.

1.2.11 Resistance Welding

Resistance welding is "a group of welding processes which produces coalescence of metals with the heat obtained from resistance of the work to electric current in a circuit of which the work is a part, and by the application of pressure". In general, the difference among the resistance welding processes has to be with the design of the weld and the type of machine necessary to produce the weld. In almost all cases the processes are applied automatically since the welding machines incorporate both electrical and mechanical functions.

1.3 OPTIMIZATION

Optimization is the act of obtaining the best result under given circumstances. In design, constructing, and maintenance of any engineering system, engineers/managers have to take many technological and managerial decisions at several stages, Figure 1.1 shows the steps involved in the optimization process.

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

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

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

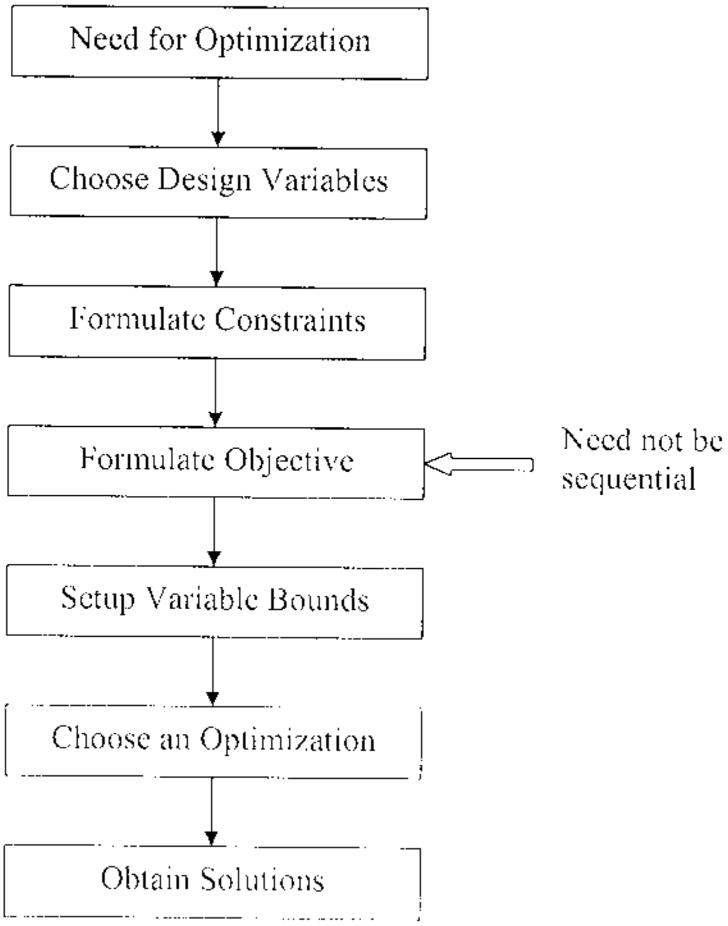

FIGURE 1.1 STEPS INVOLVED IN AN OPTIMIZATION PROCESS

1.3.1 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.

1.3.2 Classification of Optimization Problems

Existence of constraints: An optimization problem can be classified as a constrained or an unconstrained one, depending upon the presence or not of constraints.

Nature of the equations: Optimization problems can be classified as linear, quadratic, polynomial. non-linear depending upon the nature of the objective functions and the constraints. This classification is important, because computational methods are usually selected on the basis of such a classification, i.e. the nature of the involved functions dictates the type of solution procedure.

Admissible values of the design variables: Depending upon the values permitted for the design variables, optimization problems can be classified as integer or real valued. and deterministic or stochastic.

In this project work Optimization of flux cored arc welding is attempted using an optimization technique called Particle swarm optimization and ant colony optimization. The details of these techniques are given in the chapter 5 and chapter 6 respectively.

CHAPTER 2

FLUX CORED ARC WELDING

2.1 INTRODUCTION

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

FCAW was first developed in the early 1950's as an alternative to shielded metal arc welding . The advantage of FCAW vs. SMAW is that the use of stick electrodes (like those used in SMAW) was unnecessary. This helped FCAW to overcome many of the restrictions associated with SMAW.

Flux Cored Arc Welding is frequently referred to as flux cored welding. Flux cored welding is a commonly used high deposition rate welding process that adds the benefits of flux to the welding simplicity of MIG welding. As in MIG welding wire is continuously fed from a spool. Flux cored welding is therefore referred to as a semiautomatic welding process.

Self shielding flux cored arc welding wires are available or gas shielded welding wires may be used. Flux cored welding is generally more forgiving than MIG welding. Less precleaning may be necessary than MIG welding. However, the condition of the base metal can affect weld quality. Excessive contamination must be eliminated.

Flux cored welding produces a flux that must be removed. Flux cored welding has good weld appearance (smooth, uniform welds having good contour).

2.2 TWO TYPES OF FCAW

The first type of FCAW is the type that requires no shielding gas. This is made possible by the flux core in the tubular consumable electrode. However, this core contains more than just flux; it also contains various ingredients that when exposed to the high temperatures of welding generate a shielding gas for protecting the arc. This type of FCAW is preferable because it is portable and has excellent penetration into the base metal. Also, the conditions of air flow do not need to be considered.

The second type of FCAW actually uses a shielding gas that must be supplied by an external supply. This type of FCAW was developed primarily for welding steels. In fact, since it uses both a flux cored electrode and an external shielding gas, one might say that it is a combination of gas metal (GMAW) and flux-cored arc welding. This particular style of FCAW is preferable for welding thicker and out-of-position metals. The slag created by the flux is also easier to remove. However, it cannot be used in a windy environment as the loss of the shielding gas from air flow will produce visible porosity (small craters) on the surface of the weld.

2.3 ADVANTAGES OF FCAW

- All position capability.
- Good quality weld metal deposit.
- Higher deposition rates than SMAW.
- Low operator skill required.
- Metallurgical benefits that can be gained from a flux.
- No shielding gas needed making it suitable for outdoor welding and/or windy conditions.

2.4 APPLICATIONS OF FCAW

- Earth moving equipment fabrication.
- Long and C-seam welding of boiler drum.
- Structural fabrication of boilers.
- "High-speed" automotive applications.
- Fabrication of components of chemical plant.
- Fabrication of components of fertilizer plant.
- Fabrication of components of nuclear and steam power plant.
- Fabrication of components of food processing and petrochemical industries.

2.5 DISADVANTAGES OF FCAW

All of the usual issues that occur in welding can occur in FCAW such as incomplete fusion between base metals, slag inclusion (non-metallic inclusions), and cracks in the welds, etc

- Porosity -- the gases (specifically those from the flux-core) don't escape the welded area before the metal hardens, leaving holes in the welded metal.
- More costly filler material/wire as compared to GMAW.
- Less suitable for applications that require painting, such as automotive body work.

2.6 FCAW PROCESS

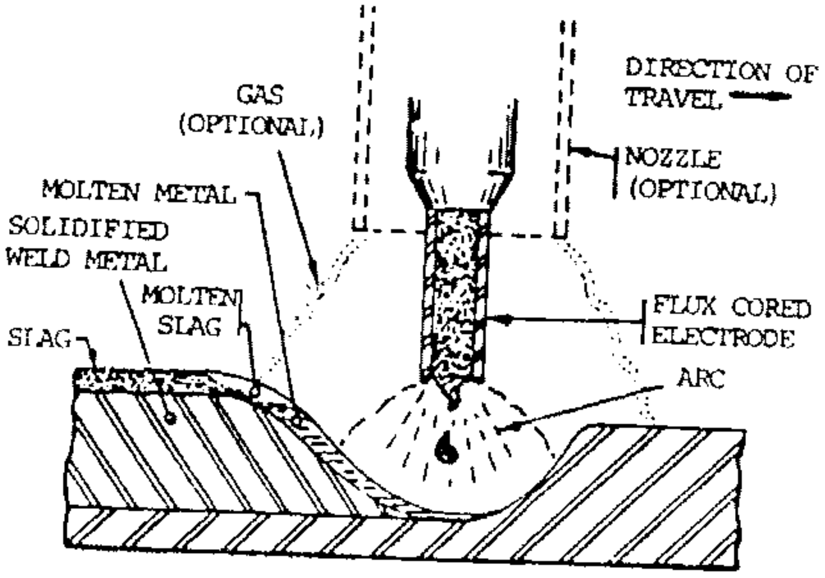

FIGURE 2.1 FLUX CORED ARC WELDING

Some of the important points of FCAW process are presented below.

1. Flux Core equipment used for flux-cored arc welding is similar to that used for gas metal arc welding which is shown in Figure 2.1. The basic arc welding equipment consists of a power source, controls, wire feeder, welding gun, and welding cables. A major difference between the gas shielded electrodes and the self-shielded electrodes

is that the gas shielded wires also require a gas shielding system. This may also have an effect on the type of welding gun used. Fume extractors are often used with this process. For machines and automatic welding, several items, such as seam followers and motion devices, are added to the basic equipment as shown in Figure 2.2.

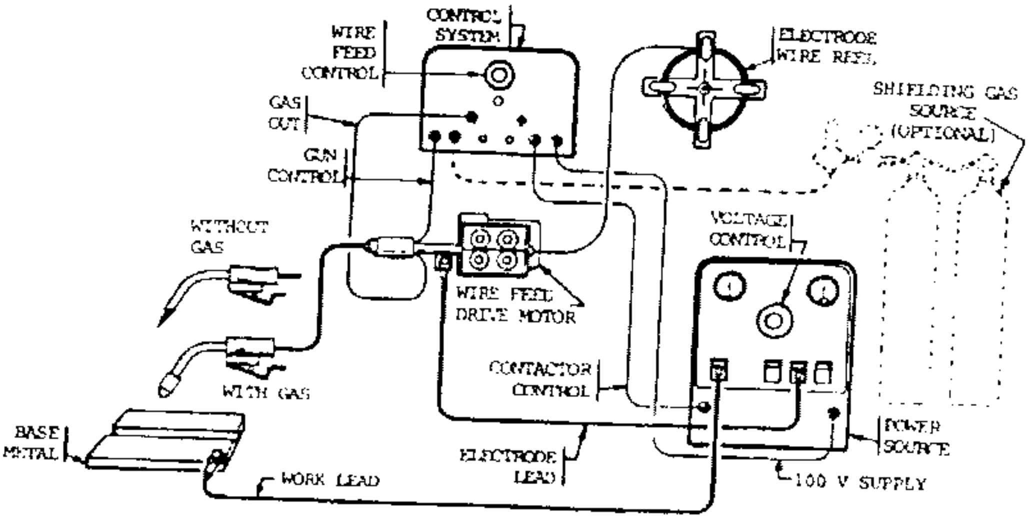

FIGURE 2.2 EQUIPMENT USED FOR SEMIAUTOMATIC FLUX-CORED ARC WELDING

2. Flux Core power source, or welding machine, provides the electric power of the proper voltage and amperage to maintain a welding arc. Most power sources operate on 230 or 460 volt input power, but machines that operate on 200 or 575 volt input are also available. Power sources may operate on either single phase or three-phase input with a frequency of 50 to 60 hertz. Most power sources used for flux-cored arc welding have a duty cycle of 100 percent, which indicates they can be used to weld continuously. Some machines used for this process have duty cycles of 60 percent, which means that they can be used to weld 6 of every 10 minutes. The power sources generally recommended for flux-cored arc welding are direct current constant voltage type. Both rotating (generator) and static (single or three-phase transformer-rectifiers) are used. The same power sources used with gas metal arc welding are used with flux-cored arc welding. Flux-cored arc welding generally uses higher welding currents than gas metal arc welding, which sometimes requires a larger power source. It is important to use a power source that is capable of producing the maximum current level required for an application.

3. Flux Core Flux-cored arc welding uses direct current. Direct current can be either reverse or straight polarity. Flux-cored electrode wires are designed to operate on either DCEP or DCEN. The wires designed for use with an external gas shielding system are generally designed for use with DCEP.Some self-shielding flux-cored ties are used with DCEP while others are developed for use with DCEN. Electrode positive current gives better penetration into the weld joint. Electrode negative current gives lighter penetration and is used for welding thinner metal or metals where there is poor fit-up. The weld created by DCEN is wider and shallower than the weld produced by DCEP.

4. Flux Core generator welding machines used for this process can be powered by an electric rotor for shop use, or by an internal combustion engine for field applications. The gasoline or diesel engine-driven welding machines have either liquid or air-cooled engines. Motor-driven generators produce a very stable arc, but are noisier, more expensive, consume more power, and require more maintenance than transformer-rectifier machines.

5. A wire feed motor provides power for driving the electrode through the cable and gun to the work. There are several different wire feeding systems available. FCAW, Flux Core System selection depends upon the application. Most of the wire feed systems used for flux-cored arc welding are the constant speed type, which are used with constant voltage power sources. With a variable speed wire feeder, a voltage sensing circuit is used to maintain the desired arc length by varying the wire feed speed. Variations in the arc length increase or decrease the wire feed speed. A wire feeder consists of an electrical rotor connected to a gear box containing drive rolls. The gear box and wire feed motor have form feed rolls in the gear box.

6. Both air-cooled FCAW, Flux Core and water-cooled FCAW, Flux Core guns are used for flux-cored arc welding. Air-cooled guns are cooled primarily by the surrounding air, but a shielding gas, when used, provides additional cooling effects .A water-cooled gun has ducts to permit water to circulate around the contact tube and nozzle. Water-cooled guns permit more efficient cooling of the gun. Water-cooled guns are recommended for use with welding currents greater than 600 amperes, and are preferred for many applications using 500 amperes. Welding guns are rated at the maximum current capacity for continuous operation. Air-cooled guns are preferred for

most applications less than 500 amperes, although water-cooled guns may also be used. Air-cooled guns are lighter and easier to manipulate.

7. Flux Core Shielding gas equipment and electrodes.

a. Flux Core Shielding gas equipment used for gas shielded flux-cored wires consists of a gas supply hose, a gas regulator, control valves, and supply hose to the welding gun.

b. Flux Core shielding gases are supplied in liquid form when they are in storage tanks with vaporizers, or in a gas form in high pressure cylinders. An exception to this is carbon dioxide. When put in high pressure cylinders, it exists in both liquid and gas forms.

c. The primary purpose of the FCAW, Flux Core shielding gas is to protect the arc and weld puddle from contaminating effects of the atmosphere. The nitrogen and oxygen of the atmosphere, if allowed to come in contact with the molten weld metal, cause porosity and brittleness. In flux-cored arc welding, shielding is accomplished by the decomposition of the electrode core or by a combination of this and surrounding the arc with a shielding gas supplied from an external source. A shielding gas displaces air in the arc area. Welding is accomplished under a blanket of shielding gas. Inert and active gases may both be used for flux-cored arc welding. Active gases such as carbon dioxide, argon-oxygen mixture, and argon-carbon dioxide mixtures are used for almost all applications. Carbon dioxide is the most common. The choice of the proper shielding gas for a specific application is based on the type of metal to be welded, arc characteristics and metal transfer, availability, cost of the gas, mechanical property requirements, and penetration and weld bead shape. The various shielding gases are summarized below.

i. Carbon dioxide.

Carbon dioxide is manufactured from fuel gases which are given off by the burning of natural gas, fuel oil, or coke. It is also obtained as a by-product of calcining operation in lime kilns, from the manufacturing of ammonia and from the fermentation of alcohol, which is almost 100 percent pure. Carbon dioxide is made available to the user in either cylinder or bulk containers. The cylinder is more common. With the bulk system, carbon dioxide is usually drawn off as a liquid and heated to the gas state before going to the welding torch. The bulk system is normally only used when supplying a large number of welding stations. In the cylinder, the carbon dioxide is in both a liquid and a vapor form with the liquid carbon dioxide occupying approximately two thirds of the space in the cylinder. By weight, this is approximately 90 percent of the content of the cylinder. Above the liquid, it exists as a vapor gas. As carbon dioxide is drawn from the cylinder, it is replaced with carbon dioxide that vaporizes from the liquid in the cylinder and therefore the overall pressure will be indicated by the pressure gauge. When the pressure in the cylinder has dropped to 1379 kPa, the cylinder should be replaced with a new cylinder. A positive pressure should always be left in the cylinder in order to prevent moisture and other contaminants from backing up into the cylinder. The normal discharge rate of the CO_2 cylinder is about 4.7 to 24 liters per min. However, a maximum discharge rate of 12 liters per min is recommended when welding using a single cylinder. As the vapor pressure drops from the cylinder pressure to discharge pressure through the CO_2 regulator, it absorbs a great deal of heat. If flow rates are set too high, this absorption of heat can lead to freezing of the regulator and flowmeter which interrupts the shielding gas flow. When flow rate higher than 12 liters per min is required, normal practice is to manifold two CO_2 cylinders in parallel or to place a heater between the cylinder and gas regulator, pressure regulator, and flowmeter. Excessive flow rates can also result in drawing liquid from the cylinder. Carbon dioxide is the most widely used shielding gas for flux-cored arc welding. Most active gases cannot be used for shielding, but carbon dioxide provides several advantages for use in welding steel. These are deep penetration and low cost. Carbon dioxide promotes a globular transfer. The carbon dioxide shielding gas breaks down into components such as carbon monoxide and oxygen. Because carbon dioxide is an oxidizing gas, deoxidizing elements are added to the core of the electrode wire to remove oxygen. The oxides formed by the deoxidizing elements float to the surface of the weld and become part of the slag covering. Some of the carbon dioxide gas will break down to carbon and oxygen. If the carbon content of the weld pool is below about 0.05 percent, carbon dioxide shielding will tend to increase the carbon content of the weld metal. Carbon, which can reduce the corrosion resistance of some stainless steels, is a problem for critical corrosion application. Extra carbon can also reduce the toughness and ductility of some low alloy steels. If the carbon content in the weld metal is greater than about 0.10 percent, carbon dioxide shielding will tend to reduce the carbon content. This loss of carbon can be attributed to the formation of carbon monoxide, which can be trapped in the weld as porosity deoxidizing elements in the flux core reducing the effects of carbon monoxide formation.

ii. Argon-carbon dioxide mixtures. Argon and carbon dioxide are sometimes mixed for use with flux-cored arc welding. A high percentage of argon gas in the mixture tends to promote a higher deposition efficiency due to the creation of less spatter. The most commonly used gas mixture in flux-cored arc welding is a 75 percent argon-25 percent carbon dioxide mixture. The gas mixture produces a fine globular metal transfer that approaches a spray. It also reduces the amount of oxidation that occurs, compared to pure carbon dioxide. The weld deposited in an argon-carbon dioxide shield generally has higher tensile and yield strengths. Argon-carbon dioxide mixtures are often used for out-of-position welding, achieving better arc characteristics. These mixtures are often used on low alloy steels and stainless steels. Electrodes that are designed for use with CO_2 may cause an excessive buildup of manganese, silicon, and other deoxidizing elements if they are used with shielding gas mixtures containing a high percentage of argon. This will have an effect on the mechanical properties of the weld.

iii. Argon-oxygen mixtures. Argon-oxygen mixtures containing 1 or 2 percent oxygen are used for some applications. Argon-oxygen mixtures tend to promote a spray transfer which reduces the amount of spatter produced. A major application of these mixtures is the welding of stainless steel where carbon dioxide can cause corrosion problems.

d. The electrodes used for flux-cored arc welding provide the filler metal to the weld puddle and shielding for the arc. Shielding is required for sane electrode types. The purpose of the shielding gas is to provide protection from the atmosphere to the arc and molten weld puddle. The chemical composition of the electrode wire and flux core, in combination with the shielding gas, will determine the weld metal composition and mechanical properties of the weld. The electrodes for flux-cored arc welding consist of a metal shield surrounding a core of fluxing and/or alloying compounds. The cores of carbon steel and low alloy electrodes contain primarily fluxing compounds. Some of the low alloy steel electrode cores contain high amounts of alloying compounds with a low flux content. Most low alloy steel electrodes require gas shielding. The sheath comprises approximately 75 to 90 percent of the weight of the electrode. Self-shielded electrodes contain more fluxing compounds than gas shielded electrodes. The compounds contained in the electrode perform basically the same functions as the coating of a covered electrode used in shielded metal arc welding. These functions are:

- To form a slag coating that floats on the surface of the weld metal and protects it during solidification.
- To provide deoxidizers and scavengers which help purify and produce solid weld-metal.
- To provide arc stabilizers which produce a smooth welding arc and keep spatter to a minimum.
- To add alloying elements to the weld metal which will increase the strength and improve other properties in the weld metal.
- To provide shielding gas. Gas shielded wires require an external supply of shielding gas to supplement that produced by the core of the electrode.

e. The classification system used for tubular wire electrodes was devised by the American Welding Society. Carbon and low alloy steels are classified on the basis of the following items:

1. Mechanical properties of the weld metal.

2. Welding position.

3. Chemical composition of the weld metal.

4. Type of welding current.

5. Whether or not a CO_2 shielding gas is used.

An example of a carbon steel electrode classification is E70T-4 where:

1. The "E" indicates an electrode.

2. The second digit or "7" indicates the minimum tensile strength in units of 69 MPa.

3. The third digit or "0" indicates the welding positions. A "0" indicates flat and horizontal positions and a "1" indicates all positions.

4. The "T" stands for a tubular or flux cored wire classification.

5. The suffix "4" gives the performance and usability capabilities as shown in When a "G" classification is used, no specific performance and usability requirements are indicated. This classification is intended for electrodes not covered by another classification. The chemical composition requirements of the deposited weld metal for carbon steel electrodes Single pass electrodes do not have chemical composition requirements because checking the chemistry of undiluted weld metal does not give the true results of normal single pass weld chemistry.

The classification of low alloy steel electrodes is similar to the classification of carbon steel electrodes. An example of a low alloy steel classification is E81T1-NI2 where:

1. The "E" indicates electrode.

2. The second digit or "8" indicates the minimum tensile in strength in units of 69 MPa. In this case it is 552 MPa.

3. The third digit or "1" indicates the welding position capabilities of the electrode. A "1" indicates all positions and an "0" flat and horizontal position only.

4. The "T" indicates a tubular or flux-cored electrode used in flux cored arc welding.

5. The fifth digit or "1" describes the usability and performance characteristics of the electrode. These digits are the same as used in carbon steel electrode classification but only EXXT1-X, EXXT4-X, EXXT5-X and EXXT8-X are used with low alloy steel flux-cored electrode classifications.

6. The suffix or "Ni_2" tells the chemical composition of the deposited weld metal

The classification system for stainless steel electrodes is based on the chemical composition of the weld metal and the type of shielding to be employed during welding. An example of a stainless steel electrode classification is E308T-1 where:

1. The "E" indicates the electrode.

2. The digits between the "E" and the "T" indicates the chemical composition of the weld..

3. The "T" designates a tubular or flux cored electrode wire.

4. The suffix of "1" indicates the type of shielding to be used

8. Welding Cables.

a. The welding cables and connectors are used to connect the power source to the welding gun and to the work. These cables are normally made of copper. The cable consists of hundreds of wires that are enclosed in an insulated casing of natural or synthetic rubber. The cable that connects the power source to the welding gun is called the electrode lead. In semiautomatic welding, this cable is often part of the cable assembly, which also includes the shielding gas hose and the conduit that the electrode wire is fed through. For machine or automatic welding, the electrode lead is normally separate. The cable that connects the work to the power source is called the work lead. The work leads are usually connected to the work by pinchers, clamps, or a bolt.

b. The size of the welding cables used depends on the output capacity of the welding machine, the duty cycle of the machine, and the distance between the welding machine and the work. Cable sizes range from the smallest AWG. No 8 to AWG. No 4/0 with amperage ratings of 75 amperes on up.. A cable that is too small may become too hot during welding.

c. Advantages. The major advantages of flux-cored welding are reduced cost and higher deposition rates than either SMAW or solid wire GMAW. The cost is less for flux-cored electrodes because the alloying agents are in the flux, not in the steel filler wire as they are with solid electrodes. Flux-cored welding is ideal where bead appearance is important and no machining of the weld is required. Flux-cored welding without carbon dioxide shielding can be used for most mild steel construction applications. The resulting welds have higher strength but less ductility than those for which carbon dioxide shielding is used. There is less porosity and greater penetration of the weld with carbon dioxide shielding. The flux-cored process has increased tolerances for scale and dirt. There is less weld spatter than with solid-wire MIG welding. It has a high deposition rate, and faster travel speeds are often used. Using small diameter electrode wires, welding can be done in all positions. Some flux-cored wires do not need an external supply of shielding gas, which simplifies the equipment. The electrode wire is fed continuously so there is very little time spent on changing electrodes. A higher percentage of the filler metal is deposited when compared to shield metal arc welding. Finally, better penetration is obtained than from shielded metal arc welding.

d. Disadvantages. Most low-alloy or mild-steel electrodes of the flux-cored type are more sensitive to changes in welding conditions than are SMAW electrodes. This sensitivity, called voltage tolerance, can be decreased if a shielding gas is used, or if the slag-forming components of the core material are increased. A constant-potential power source and constant-speed electrode feeder is needed to maintain a constant arc voltage.

e. Process Principles. The flux-cored welding wire, or electrode, is a hollow tube filled with a mixture of deoxidizers, fluxing agents, metal powders, and ferro-alloys. The closure seam, which appears as a fine line, is the only visible difference between flux-cored wires and solid cold-drawn wire. Flux-cored electrode welding can be done in two ways: carbon dioxide gas can be used with the flux to provide additional shielding, or the flux core alone can provide all the shielding gas and slagging materials. The carbon dioxide gas shield produces a deeply penetrating arc and usually provides better weld than is possible without an external gas shield. Although flux-cored arc welding may be applied semi automatically, by machine, or automatically, the process is usually applied semi automatically. In semiautomatic welding, the wire feeder feeds the electrode wire and the power source maintains the arc length. The welder manipulates the welding gun and adjusts the welding parameters. Flux-cored arc welding is also used in machine welding where, in addition to feeding the wire and maintaining the arc length, the machinery also provides the joint travel. The welding operator continuously monitors the welding and makes adjustments in the welding parameters. Automatic welding is used in high production applications.

2.7 PROCESS VARIABLES

- Wire feed speed (and current)
- Arc voltage
- Electrode extension
- Travel speed
- Electrode angles
- Electrode wire type
- Shielding gas composition (if required) Note: FCAW wires that don't require a shielding gas commonly emit fumes that are extremely toxic: these require adequate ventilation or the use of a sealed mask that will provide the welder with fresh air.

2.7.1 Welding Current

All the welding parameters bead width, depth of penetration, height of reinforcement and percentage dilution increase with increase in welding current. This is due to the increase in welding current density and the weight of wire fused per unit of time. Also with increase in welding current the arc becomes stiffer and hotter which penetrates more deeply and melting more base metal.

2.7.2 Welding Speed

It is obvious that the welding parameters height of reinforcement and bead width decrease with increase in welding speed but depth of penetration and percentage dilution increases with increase in welding speed. Decrease in R and W can be obviously attributed to the reduced heat input per unit length of weld bead as welding speed is increased and lesser filler metal is applied per unit length of the weld. The percentage dilution of the base metal in the pool increases with the increase in welding speed, since the weight of the deposited metal per unit of length decreases with the cross section of the bead decreases very little. With low welding speed the arc is almost vertical and in this instance the weld pool cushions the effect of arc and prevents deeper penetration.

2.7.3 Nozzle-To-Plate Distance

It is obvious that depth of penetration and percentage dilution decrease slightly with increase in nozzle-to-plate distance but bead width and height of reinforcement increases with increase in nozzle-to-plate distance. Increase in nozzle-to-plate distance increases the circuit resistance, which reduces the welding current. The decrease of welding current reduces the penetration of the arc and hence reduces the dilution. With increase in nozzle-to-plate distance the arc length is increased and hence the bead width is increased due to wider arc area at the weld surface and this consequently increases the reinforcement height because the same volume of filler metal is added.

2.7.4 Torch Angle

Height of reinforcement, depth of penetration and percentage dilution decrease with increase in welding torch angle but bead width increases with increase in welding torch angle. The reason is when the torch angle is increased in forehand welding the arc force pushes the weld metal forward, i.e., towards the cold metal, which reduces the penetration, reinforcement and percentage dilution but width of the weld increases.

The term welding gun angle refers to the angle between the FCAW gun and the work as it relates to the direction of travel. Backhand welding are dragging angle produces a weld with deep penetration and higher buildups. Forehand welding produces a weld width shallow penetration and little buildups.

Slight changes in gun angle can be used to control the yield as the grooves spacing changes. The narrow gaps may require more penetration, but as the gap spacing increases a yield with less penetration may be required. Changing the electrode extension and yielding gun angle at the same time can result in a quality weld spacing made with less than ideal conditions.

2.8 NEED FOR FCAW OPTIMIZATION

Several works had been done for optimizing welding parameters using conventional technique. The conventional technique employed for optimization involves more computational effort and lot of time. In this project work, new approaches in non traditional optimization techniques named 'Particle swarm optimization' and 'Ant colony optimization 'has been used. The results produced by these two optimization techniques were superior, when compared to other conventional techniques. And more over the time to perform the above analysis is less compared to other techniques.

CHAPTER 3

LITERATURE SURVEY

3.1 INTRODUCTION

Literature survey is a background work that is made for the project work. It is based on books and academic publications. The topics of literature surveys are selected so that they support the project. The main goal of a literature survey is to gather a basis for the practical work. It is not smart to re-invent the wheel, i.e., one has to know what has already been done

3.1. LITERATURE SURVEY WITH CRITICAL COMMENTS

Raveendra and Parmar (1987) presented mathematical models developed for predicting the weld bead geometry and shape relations for CO_2 shielded flux cored arc welding which can be used not only for automated systems but also equally effectively for semi automatic welding. A fractional factorial technique was used to design the experiments. Regression analysis was used to develop the mathematical models and the variance method was used to test the adequacies of the models. The experiments were designed with a view to developing mathematical models to correlate independently controllable welding parameters.

The first ACO system was introduced by Marco Dorigo in his Ph.D. thesis (1992), and was called Ant System (AS). AS is the result of a research on computational intelligence approaches to combinatorial optimization that Dorigo conducted at Politecnico di Milano in collaboration with Alberto Colorni and Vittorio Maniezzo. AS was initially applied to the travelling salesman problem, and to the quadratic assignment problem .

Kennedy and Eberhart (1995) introduced a method for optimization of nonlinear functions. It also explained that particle swarm optimization concept in terms of its precursors, briefly reviewing the stages of its development from social simulation to optimizer. Benchmark testing of the paradigm is described, and applications, including nonlinear function optimization and neural network training, are proposed. Particle swarm optimization as developed by authors comprises a very simple concept, and paradigms can be implemented in a few lines of computer code. It requires only primitive mathematical operators, and is computationally inexpensive in terms of both memory requirements and speed. The author discussed the application of the algorithm to the training of artificial neural network weights. The adjustment toward pbest and gbest by the particle swarm optimizer is conceptually similar to the crossover operation utilized by genetic algorithms.

Since 1995 Dorigo, Gambardella and Stützle have been working on various extended versions of the AS paradigm. Dorigo and Gambardella have proposed Ant Colony System (ACS), while Stützle and Hoos have proposed MAX-MIN Ant System (MMAS). They have both have been applied to the symmetric and asymmetric travelling salesman problem, with excellent results. Dorigo, Gambardella and Stützle have also proposed new hybrid versions of ant colony optimization with local search. In problems like the quadratic assignment problem and the sequential ordering problem these ACO algorithms outperform all known algorithms on vast classes of benchmark problems.

Pherson (1997) demonstrated that the Taguchi methods can be used in the welding process to affect improved levels of technology and advance the state of the art. The author concluded that optimization of welding parameters using Taguchi methods produced good results.

Gunaraj and Murugan (1998) studied the effect of controllable process variables on the heat input and the area of the heat —affected zone (HAZ) for bead-on-plate and bead-on-joint welding was calculated and analyzed using mathematical models developed for the submerged arc welding of pipes. The final mathematical models furnished can be employed to predict the area of the heat-affected zone of the weld bead for the range of parameters used in the investigation by substituting their respective values in coded form.

Shi and Eberhart, (1998) analyzed the impact of the inertia weight and maximum velocity on the performance of the particle swarm optimizer, and then provide guidelines for selecting these two parameters. A number of experiments had done with different inertia weights and different values of maximum velocity. It was concluded that when V_{max} is small (≤2) an inertia weight of approximately W= 1 is a good choice, while when V_{max} is not small (≥3) an inertia weight of W=0.8 is a good choice. The selection of inertia parameter and maximum velocity allowed may be problem dependent.

Shunmugam et al. (1999) considered a face milling operation for optimization. The machining parameters such as number of passes, depth of cut, speed and feed are obtained using a genetic algorithm, to yield minimum total production cost while considering technological constraints such as allowable speed and feed, dimensional accuracy, surface finish, tool wear and machine tool capabilities. The method proposed in the present work based on the genetic algorithm always yields production cost values less than or equal to the values obtained by other methods. The author described the application of Genetic Algorithm GA in face-milling to determine the optimal parameters such as speed, feed and depth of cut in each pass. The proposed method yielded a minimum total production cost compare to conventional techniques.

Ant Colony Optimization (ACO) studies artificial systems that take inspiration from the behavior of real ant colonies and which are used to solve discrete optimization problems. In 1999, the Ant Colony Optimization metaheuristic was defined by Dorigo, Di Caro and Gambardella

Tusek (2001) described the procedure to elaborate mathematical models for basic welding parameters (current and welding velocity), and incorporate them into an algorithm for manual and robotic TIG welding of austenitic stainless steel sheet.

Murthy et al. (2002) described a procedure to calculate the machining conditions namely number of passes, depth of cut in each pass, feed and speed for face milling operation by considering minimum production cost as the objective function. Optimum values of machining conditions for each pass are determined based on the objective function criteria by particle swarm optimization technique, which was specifically developed for this purpose. These optimum values were obtained by considering technological constraints such as allowable speed and feed, dimensional accuracy of the product, surface finish of the product, tool wear and machine tool capabilities. The proposed approach can be easily modified for other machining operations like turning, grinding, welding.

Eswin (2002) described how to improve the performance of the fuzzy reasoning model through fitting fuzzy membership functions using particle swarm optimization algorithm and Genetic algorithm. The paper discussed the use of fuzzy on particle swarm optimization and genetic algorithms with a case study. The author finally concluded that the implementation of PSO is easier than GA training, because the needs of communication between the particles (agents) after each iteration.

Xie et al. (2002) introduced a new technique called adaptive PSO, which automatically tracks various changes in a dynamic system. As a evolutionary algorithm, particle swarm optimization had been successfully applied to many applications. In this paper the author focused on the locations varying in the problem space where the optimum value occurs and analyzed the performance on the bench mark functions with various severities. Both standard and dissipative versions were compared on two multimode optimization problems typically used in evolutionary optimization research.

Carlisle (2002) proposed a method for adapting the particle swarm optimizer for dynamic environments. Two methods for initiating this process were examined periodic setting, based on the iteration count, and triggered resetting, based on the magnitude of the change in environment. The results suggested that these two modifications allow PS0 to search in both static and dynamic environments. The author concluded that it is necessary to evaluate the effect of the changing environment on the choice of the inertia parameter.

Trelea (2003) analyzed the Particle swarm optimization algorithm using standard results from the dynamic system theory. The described PSO algorithm includes some tuning parameters that greatly influence the algorithm performance, often stated as the exploration-exploitation tradeoff. The dynamic behavior and the convergence of the simplified PSO algorithm were analyzed using tools from the discrete-time dynamic system theory. Best results were usually obtained with a medium number of particles. The trade off between exploration-exploitation is discussed.

Dorigo and Stützle, (2004) presented a full overview of the many successful applications of Ant Colony Optimization in their recent book "Ant Colony Optimization"

Murugan and Palani (2004) proposed the genetic algorithm to find the optimum values of input process parameters for cladding operation. In cladding, the most important aspect is the dilution of the base metal by the weld metal which has to be controlled effectively within the optimum range for better economy and to ensure the desired mechanical and corrosion resistant properties of the overlay. Development of mathematical equations by using four factor five level factorial techniques to predict weld bead geometry is presented. The proposed method can find the near-optimal setting of the welding process parameters to achieve economy of material in cladding.

Mistry and Pandey (2005) highlighted the prediction. of weld dilution through advanced gas metal arc welding. Dilution is the most important factors governing the success of any surfacing operation and is expressed in percentage. The paper reports mathematical model developed using fractional factorial technique to predict the dilution by Advanced GMAW process. The response factor dilution as affected by Wire feed rate, Arc voltage, Nozzle to plate distance, and welding speed was investigated and analyzed.

Kannan and Murugan(2006) developed mathematical models to predict the clad quality parameters in duplex stainless steel cladding. The author described the procedure to develop the models using Response surface methodology (RSM). This work highlighted the use of RSM by designing a four-factor five-level central composite rotatable design matrix with full replication of planning, conduction, execution and development of mathematical models. These are useful not only for predicting the weld bead quality but also for selecting optimum process parameters for achieving the desired quality and process optimization.

Kim et al. Presented new algorithms to establish mathematical models for predicting bead width for multi-pass welding by both neural network and multiple regression methods. The models were based on relationships between process parameters and bead width, and can be used to predict the effect of process parameters on bead width. Using GMA welding, multi-pass butt welds were carried out in order to verify the performance of the neural network estimator and multiple regression methods as well as to select the most suitable model.

Parsopolous proposed a new technique, named function "stretching" for the alleviation of the local minima problem. The main feature of this technique is the usage of a two-stage transformation of the objective function to eliminate local minima, while preserving the global ones. Experiments indicate that combined with the particle swarm optimizer method, the new algorithm is capable of escaping from local minima and respectively local the global ones. This modified algorithm behaves predictably and reliably and the results were quite satisfactory.

Rylander Presented a method to employ particle swarm optimization in a split architecture injected with a plain attracted configuration. The author described the results of experimental attempts to improve the performance of the basic PSO by splitting the input vectors into two sub-vectors. The key advantage of PSO over other optimization algorithms in training neural networks is its comparative simplicity.

CHAPTER 4

DATA COLLECTION

4.1 EXPERIMENTAL DATA

The data used for optimizing FCAW process parameters were collected from the research paper titled "Effect of Flux Cored Arc Welding Process Parameters on Duplex Stainless Steel Clad Quality" published in the Journal of Materials Processing Technology 176 (2006) Page.No:230-239 by T.Kannan and N.Murugan. The experimental data are given in the Table 4.1 and Table 4.2

4.2 CLADDING PROCESSES

In metallurgy, cladding is the bonding together of dissimilar metals. It is distinct from welding or gluing as a method to fasten the metals together. Cladding is often achieved by extruding two metals through a die or pressing sheets together under high pressure

Various welding processes employed for cladding are Flux-Cored Arc Welding, Gas Metal Arc Welding, Plasma Arc Welding , Gas Tungsten Arc Welding, Submerged Arc Welding ,Shielded Metal Arc Welding ,electroslag welding , oxy acetylene welding and explosive welding. Among the processes employed for weld cladding FCAW is readily accepted by the industries due to the following features

- High deposition rates, especially for out-of-position welding
- More tolerant of rust and mill scale than GMAW
- Simpler and more adaptable than SAW
- Less operator skill required than GMAW
- High productivity than SMAW
- Good surface appearance
- Good radiographic standard quality
- Minimum electrode wastage

TABLE 4.1 WELDING PARAMETERS AND THEIR LEVELS

PARAMETERS	UNITS	NOTATION	LIMITS				
			-2	-1	0	+1	+2
Welding Current	A	I	200	225	250	275	300
Welding Speed	cm/min	S	20	30	40	50	60
Nozzle-To-Plate Distance	mm	N	22	24	26	28	30
Torch Angle	deg	T	20	15	10	5	0

Design matrix and observed values of clad quality parameters in natural form are shown in Table 4.2.

TABLE 4.2 DESIGN MATRIX AND OBSERVED VALUES OF CLAD QUALITY PARAMETERS

S.No.	Design matrix				W(mm)	P(mm)	R(mm)	D (%)
	I	S	N	T				
1	225	30	24	15	29.05	0.61	4.97	07.86
2	275	30	24	15	36.62	0.73	5.00	12.10
3	225	50	24	15	24.20	0.63	4.23	11.35
4	275	50	24	15	28.00	0.77	4.27	11.98
5	225	30	28	15	30.00	0.57	5.00	06.54
6	275	30	28	15	34.98	0.67	5.29	08.82
7	225	50	28	15	25.59	0.58	4.18	09.69
8	275	50	28	15	29.51	0.70	4.20	11.16
9	225	30	24	05	28.34	0.73	5.00	08.97
10	275	30	24	05	34.50	0.97	5.10	13.75
11	225	50	24	05	24.00	1.00	4.00	18.52
12	275	50	24	05	27.80	1.20	4.34	20.58
13	225	30	28	05	29.26	0.60	5.08	07.46
14	275	30	28	05	34.80	0.80	5.28	09.14
15	225	50	28	05	25.30	0.97	4.00	18.00
16	275	50	28	05	27.70	1.00	4.20	14.80
17	200	40	26	10	20.15	0.40	3.98	05.86
18	300	40	26	10	31.00	1.07	4.90	16.48
19	250	20	26	10	39.53	0.70	5.68	05.31
20	250	60	26	10	23.10	1.00	3.63	17.35
21	250	40	22	10	25.10	0.83	4.32	11.71
22	250	40	30	10	28.00	0.63	4.81	09.01
23	250	40	26	20	30.20	0.56	4.17	10.54
24	250	40	26	0	26.00	0.87	4.87	13.98
25	250	40	26	10	27.88	0.70	4.55	10.33
26	250	40	26	10	29.42	0.83	4.34	13.60
27	250	40	26	10	28.00	0.77	4.50	10.73
28	250	40	26	10	27.90	0.87	4.50	11.71
29	250	40	26	10	29.20	0.83	4.32	13.76
30	250	40	26	10	27.80	0.79	4.58	10.99
31	250	40	26	10	27.80	0.80	4.57	10.67

The experiments were designed with a view to developing mathematical models to correlate independently controllable welding parameters i.e., welding current, Welding speed, nozzle to plate distance, and torch angle to clad quality parameters i.e., Bead Width, Depth of Penetration, Height of Reinforcement and Percentage Dilution

The selected design matrix shown in Table 4.2 is a central composite rotatable factorial design consisting of 31 sets of natural conditions. It comprises of a full replication of 2^4 (=16) factorial design plus seven center points and eight star points. All welding variables at the intermediate level constitute the center points and the combinations of each of the welding variables at either its lowest level or highest level with the other three variables at the intermediate levels constitute the star points. Thus the experimental runs allowed the estimation of the linear, quadratic and two-way interactive effects of the process parameters on the clad geometry.

4.4 DEVELOPMENT OF MATHEMATICAL MODELS

Representing the clad quality parameters, the response function can be expressed as given in equation 4.1

$$Y = f(I, S, N, T) \tag{4.1}$$

Different models were considered but giving the preference to the simplest, the relationship selected being a second degree response surface, expressed as in equation 4.2.

$$Y = \beta_0 + \beta_1 I + \beta_2 S + \beta_3 N + \beta_4 T + \beta_{11} I^2 + \beta_{22} S^2 + \beta_{33} N^2 + \beta_{44} T^2 + \beta_{12} IS + \beta_{13} IN + \beta_{14} IT + \beta_{23} SN + \beta_{24} ST + \beta_{34} NT \tag{4.2}$$

Using the above equation the mathematical models for clad parameters are obtained as in equation 4.3 for Bead Width, equation 4.4 for Depth of Penetration, equation 4.4 for Height of Reinforcement, equation 4.6 for Percentage Dilution.

Weld Bead Width Model

$$W=27.775+2.494I-3.244S+0.415N-0.610T-0.303I^2+1.066S^2+0.316T^2-0.616IS \tag{4.3}$$

Depth of Penetration Model

$$P=0.764+0.104I+0.074S-0.048N+0.110T+0.021S^2+0.061ST \tag{4.4}$$

Height of Reinforcement Model

$$R=4.535+0.128I-0.475S+0.054N+0.052T+0.053S^2-0.052SN \tag{4.5}$$

Percentage Dilution Model

$$D=11.702+1.466I+2.73S-1.037N+1.608T-0.751IS-0.593IN+1.482ST \tag{4.6}$$

CHAPTER 5

PARTICLE SWARM OPTIMIZATION

5.1 INTRODUCTION

Particle swarm optimization is an evolutionary computation technique developed by Eberhart et al. (1995). The underlying motivation for the development of PSO algorithm was social behavior of animals such as bird flocking, fish schooling, and swarm theory. Similar to Genetic algorithms , PSO is a population based optimization tool, both have fitness values to evaluate the population, both update the population and search for the optimum with random techniques, both systems do not guarantee success. However, unlike GA, PSO has no evolution operators such as crossover and mutation. In PSO, particles update themselves with the internal velocity. They also have memory, which is important to the algorithm. And the potential solutions, called particles, are 'flown through the problem space by following the current optimum particles.

Compared to GA, the information sharing mechanism in PSO is significantly different. In GA's chromosomes share information with each other. So the whole population moves like a group towards an optimal area. In PSO, only Gbest gives out the information to others. It is a one-way information sharing mechanism. The evolution only looks for the best solution. Compared with GA, all the particles tend to converge to the best solution quickly even in the local version in most cases. The advantages of PSO are that PSO is easy to implement and there are few parameters to adjust. PSO has been successfully applied in many areas, such as function optimization, artificial neural network training, and fuzzy system.

5.2 BACKGROUND

The background for the development of PSO algorithm was social behavior of animals such as bird flocking, fish schooling and swarm theory.

5.2.1 Artificial life

The term "Artificial Life" (ALife) is used to describe research into human-made systems that possess some of the essential properties of life. Alife includes two-folded.

1. ALife studies how computational techniques can help when studying biological phenomena.
2. ALife studies how biological techniques can help out with computational problems.

5.2.2 Biological system

There are already lots of computational techniques inspired by biological systems. For example, artificial neural network is a simplified model of human brain; genetic algorithm is inspired by the human evolution.

Here is another type of biological system - social system, more specifically, the collective behaviors of simple individuals interacting with their environment and each other. It is named as swarm intelligence.

There are two popular swarm inspired methods in computational intelligence areas. Ant colony optimization and particle swarm optimization (PS0). AGO was inspired by the behaviors of ants and has many successful applications in discrete optimization problems.

5.4 GENERAL PROCEDURE

The fundament to the development of PSO is a hypothesis that social sharing of information among conspeciates offers an evolutionary advantage. PSO is initialized with a group of random particles (solutions) by Yuhui Shi et al. (1998). However, each potential solution is also assigned a randomized velocity, and the potential solutions, call particles, corresponding to individuals. A set of moving particles is initially "thrown" inside the search space. Each particle has the following features:

- It has a position and a velocity
- It knows its position, and the objective function value for this position
- It remembers its best previous position
- It knows its neighbors, best previous position and objective function value

At each time step, the behavior of a given particle is a compromise between three possible choices:

1. To follow its own way
2. To go towards its best previous position
3. To go towards the best neighbor's best previous position

Two variants of the PSO algorithm were developed. One with a global neighborhood and one with a local neighborhood. According to the global variant, each particle moves towards its best previous position and towards the best particle in the whole swarm. On the other hand, according to the local variant, each particle moves towards its best previous position and towards the best particle in its restricted neighborhood.

After finding the two Global best values, changing the velocity and location of each particle toward its Pbest [] and Gbest [] locations according to the below equations 5.3 and 5.4

$$V[\,]=V[\,]+C1*rand()*(Pbest\,[\,]-present[\,])+C2*rand()*(Gbest[\,]-present[\,]) \qquad (5.3)$$

$$Present\,[\,] = Present\,[\,] + v\,[\,] \qquad (5.4)$$

Where,

V [] is the particle velocity,

Present [] is the current particle (solution),

Pbest [] is the particle best,

Gbest [] is the global best.

Present []: The location of the i^{th} particle is represented as Present []

Pbest []: The best previous position of the i^{th} particle is recorded and represented as Pbest []

Gbest []: The index of the best particle among all the particles in the population is represented by Gbest []

V []: The velocity for the i^{th} particle is represented as V []

The two social/cognitive coefficients C1. C2, respectively quantify:

- how much the particle trusts itself now
- how much it trusts its experience
- how much it trusts its neighbors

5.5 PSO PARAMETERS

There are not many parameter need to be tuned in PSO. Here is a list of the parameters and their typical values by Shi et al. (1998).

5.5.1 Number of particles: The typical range is 20 - 40. Actually for most of the problems, 10 particles are large enough to get good results. For some difficult or special problems, one can use 100 or 200 particles as well.

5.5.2 Dimension of particles: It is determined by the problem to be optimized.

5.5.3 Range of particles: It is also determined by the problem to be optimized, one can specify different ranges for different dimension of particles.

5.5.4 Learning factors: C1, C2 and are usually taken as 2. But in general, C1, C2 equals to and ranges from [0, 2].

5.5.5 **Stopping criterion:** PSO execution for specified maximum number of iterations. This condition depends on the problem to be optimized.

5.6 ALGORITHM

1. Initialization of each particle.
2. Calculation of fitness value for each particle .If the fitness value is better than the best fitness value (Pbest) in history .Set current value as the new Pbest.
3. Choosing the particle with the best fitness value of all the particles as the Gbest.
4. For each particle, calculation of particle velocity according to equation (5.3) is done. Updating the particle position according to equation (5.4).
5. Particle velocities on each dimension are clamped to a maximum velocity V_{max}. If the sum of accelerations would cause the velocity on that dimension to exceed V_{max} which is a parameter specified by the user, then the velocity on that dimension is limited to V_{max}.
6. Termination criteria are maximum number of iterations or minimum error conditions.

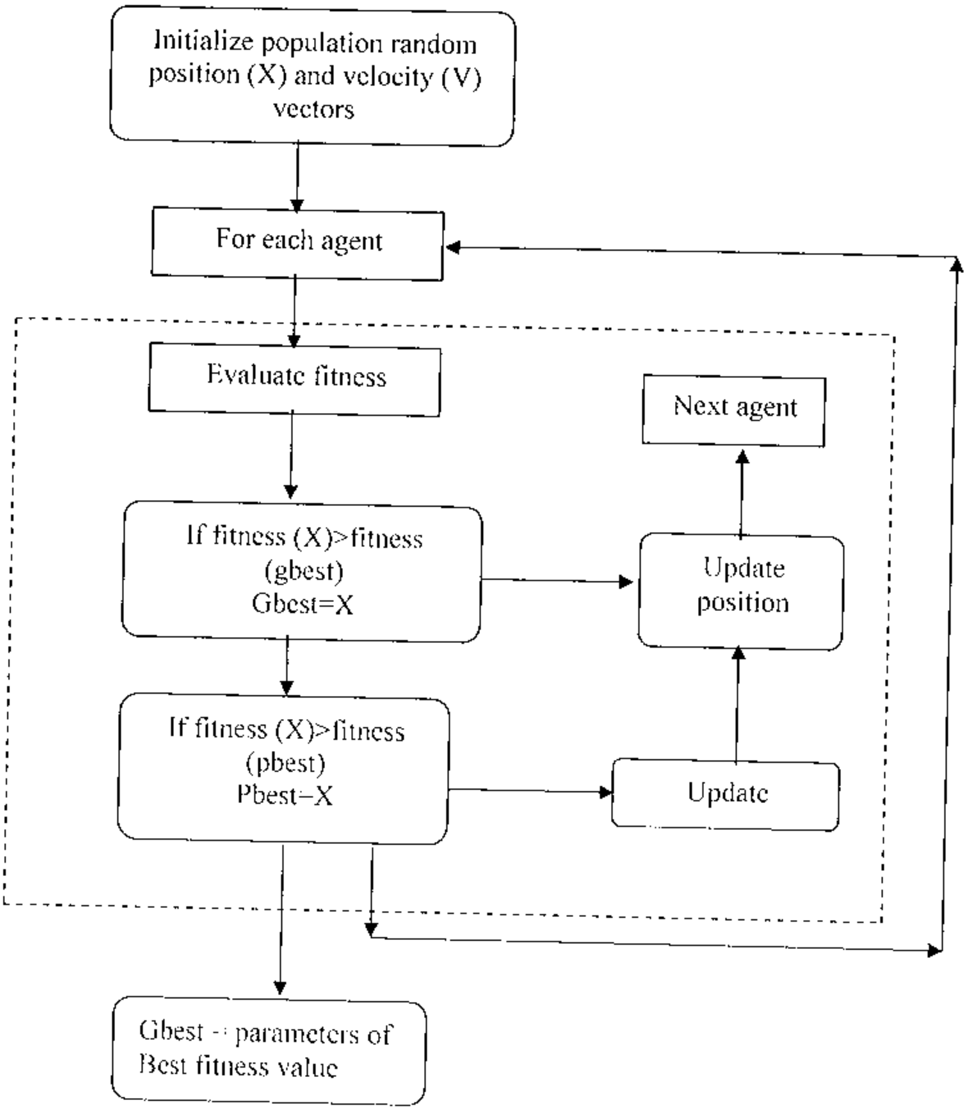

FIGURE 5.1 FLOW CHART FOR PSO ALGORITHM

5.7 OPTIMIZATION OF FCAW PROCESS USING PSO

No of particles: In this study, 5 particles are considered.

Dimension of particles: it is equal to the number of input parameters (i.e.,) 4

Representation of a particle:

The particle for this problem is represented as follows

I= 250.00 A
S= 20.00 m/min
N=26.00 mm
T= 10.00 deg

Estimating the Responses:

By substituting the above input values in the developed mathematical models we can obtain the responses as follows

P = 0.695 mm
W= 38.527 mm
R= 5.697 mm
D= 6.242 %

Target values

Maximum and minimum target values of clad quality parameters required are

P_{min} = 0.40 mm
D_{min} = 8 %
R_{max} = 5.68 mm
W_{max} = 39.53 mm

5.8 INITIAL SOLUTION

5.8.1 Percentage Dilution

Initial solution generated randomly for all 5 particles for minimizing the percentage dilution is shown below in the Table 5.1

TABLE 5.1: INITIAL SOLUTION FOR PERCENTAGE DILUTION USING PSO

S.No.	I (A)	S (mm/min)	N (mm)	T (deg)	D (%)
1	222.19	20.03	23.02	5.41	2.274153
2	250.00	20.00	26.00	10.00	6.242000
3	287.60	22.18	26.18	4.33	9.709846
4	287.60	22.18	26.18	4.33	9.709846
5	291.50	55.70	24.05	15.26	14.285721

5.8.2 Depth of Penetration

Initial solution generated randomly for all 5 particles for minimizing the depth of penetration is shown below in the Table 5.2

TABLE 5.2: INITIAL SOLUTION FOR DEPTH OF PENETRATION USING PSO

S.No.	I (A)	S (mm/min)	N (mm)	T (deg)	P (mm)
1	200.01	34.58	28.90	8.48	0.475679
2	269.39	44.31	26.17	17.40	0.674708
3	211.89	29.21	26.44	0.33	0.625140
4	246.50	27.05	22.95	1.42	0.815116
5	281.10	24.90	27.79	10.18	0.785674

5.8.3 Weld Bead Width

Initial solution generated randomly for all 5 particles for maximizing the weld bead width is shown below in the Table 5.3

TABLE 5.3: INITIAL SOLUTION FOR WELD BEAD WIDTH USING PSO

S.No	I (A)	S (mm/min)	N (mm)	T (deg)	W (mm)
1	274.39	28.45	29.57	11.51	36.737625
2	209.00	26.29	26.09	12.59	28.355518
3	205.10	32.75	28.20	1.67	24.744247
4	239.69	30.60	24.73	10.43	30.240025
5	247.50	57.66	28.48	4.60	25.451427

5.8.4 Height of Reinforcement

Initial solution generated randomly for all 5 particles for maximizing the height of reinforcement is shown below in the Table 5.4

TABLE 5.4: INITIAL SOLUTION FOR HEIGHT OF REINFORCEMENT USING PSO

S.No	I (A)	S (mm/min)	N (mm)	T (deg)	R (mm)
1	235.80	35.58	23.75	1.70	4.682313
2	219.00	45.29	28.23	10.63	4.162346
3	245.10	46.34	28.50	14.12	4.213035
4	279.70	44.18	25.02	15.21	4.427376
5	210.39	48.50	23.66	5.36	4.003581

CHAPTER 6

ANT COLONY OPTIMISATION

6.1 INTRODUCTION

Ant colony optimization is a kind of non traditional optimization technique in which the main idea underlying is that of a parallelizing search over several constructive computational threads, all based on a dynamic memory structure incorporating information on the effectiveness of previously obtained results and in which the behaviour of each single agent is inspired by the behaviour of real ants. Researchers are also fascinated by seeing the ability of the almost blind ants to establish the shortest route from their nests to the food source and back. These ants secrete a substance called "pheromone" and use its trials as a medium for communicating information among each other .the probability of the trial being followed by other ants is reinforced by increased trial deposition of others following this trial.

This cooperative search behaviour of real ants inspired the new computational paradigm for optimizing real life systems and it is suited for solving large scale optimization problem. ACO has also been applied to other optimization problems like the quadratic assignment problem. More recently, a modified ACO was presented as an effective global optimization procedure by introducing bi-level search procedure called local and global search. The important aspect in ACO is that the artificial ants select the solution. They move with the selection probability proportional to the pheromone trial.

6.2 BACKGROUND

6.2.1 OVERVIEW OF ACO

In the real world, ants (initially) wander randomly, and upon finding food return to their colony while laying down pheromone trails. If other ants find such a path, they are likely not to keep travelling at random, but to instead follow the trail, returning and reinforcing it if they eventually find food

Over time, however, the pheromone trail starts to evaporate, thus reducing its attractive strength. The more time it takes for an ant to travel down the path and back again, the more time the pheromones have to evaporate. A short path, by comparison, gets marched over faster, and thus the pheromone density remains high as it is laid on the path as fast as it can evaporate. Pheromone evaporation has also the advantage of avoiding the convergence to a locally optimal solution. If there were no evaporation at all, the paths chosen by the first ants would tend to be excessively attractive to the following ones. In that case, the exploration of the solution space would be constrained.

Thus, when one ant finds a good (short, in other words) path from the colony to a food source, other ants are more likely to follow that path, and positive feedback eventually leaves all the ants following a single path as shown in Figure 6.1. The idea of the ant colony algorithm is to mimic this behavior with "simulated ants" walking around the graph representing the problem to solve.

Ant colony optimization algorithms have been used to produce near-optimal solutions to the travelling salesman problem. They have an advantage over simulated annealing and genetic algorithm approaches when the graph may change dynamically; the ant colony algorithm can be run continuously and adapt to changes in real time. This is of interest in network routing and urban transportation systems.

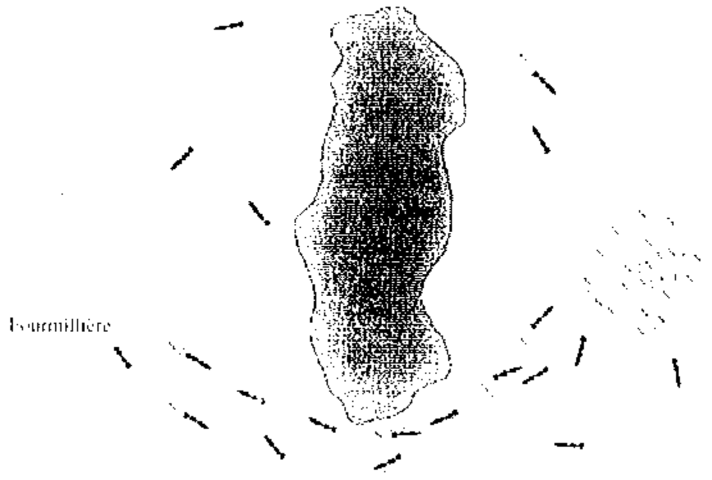

FIGURE 6.1 ANT COLONY MOVEMENT TOWARDS FOOD

6.3 BEHAVIOUR OF REAL ANTS

Real ants are capable of finding shortest path from a food source to the nest (Beckers, Deneubourg and Goss, 1992; Goss, Aron, Deneubourg and Pasteels, 1989) without using visual cues (Hölldobler and Wilson, 1990). Also, they are capable of adapting to changes in the environment, for example finding a new shortest path once the old one is no longer feasible due to a new obstacle (Beckers, Deneubourg and Goss, 1992; Goss, Aron, Deneubourg and Pasteels, 1989). Consider the following Figure 6.2 in which ants are moving on a straight line which connects a food source to the nest

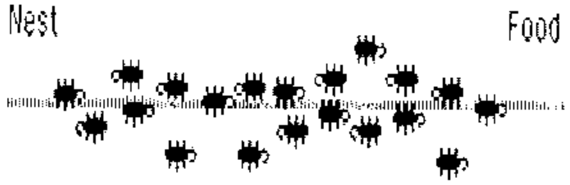

FIGURE 6.2 BEHAVIOUR OF ANTS -1

It is well-known that the main means used by ants to form and maintain the line is a pheromone trail. Ants deposit a certain amount of pheromone while walking, and each ant probabilistically prefers to follow a direction rich in pheromone rather than a poorer one. This elementary behavior of real ants can be used to explain how they can find the shortest path which reconnects a broken line after the sudden appearance of an unexpected obstacle has interrupted the initial path as in Figure 6.3.

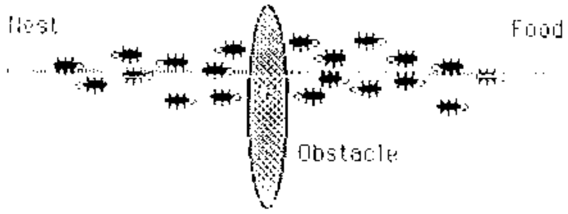

FIGURE 6.3 BEHAVIOUR OF ANTS -2

In fact, once the obstacle has appeared, those ants which are just in front of the obstacle cannot continue to follow the pheromone trail and therefore they have to choose between turning right or left. In this situation we can expect half the ants to choose to turn right and the other half to turn left. The very same situation can be found on the other side of the obstacle as in Figure 6.4.

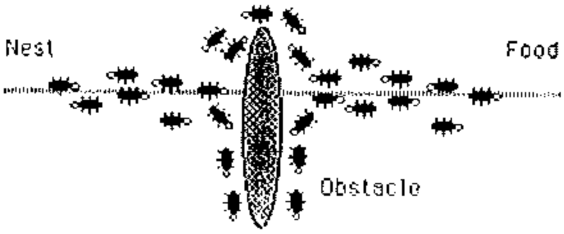

FIGURE 6.4 BEHAVIOUR OF ANTS -3

It is interesting to note that those ants which choose, by chance, the shorter path around the obstacle will more rapidly reconstitute the interrupted pheromone trail compared to those which choose the longer path. Hence, the shorter path will receive a higher amount of pheromone in the time unit and this will in turn cause a higher number of ants to choose the shorter path. Due to this positive feedback (autocatalytic) process, very soon all the ants will choose the shorter path as in Figure6.5.

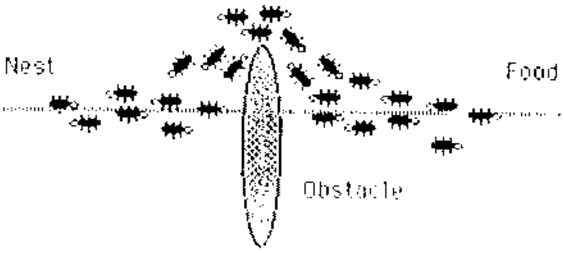

FIGURE 6.5 BEHAVIOUR OF ANTS -4

The most interesting aspect of this autocatalytic process is that finding the shortest path around the obstacle seems to be an emergent property of the interaction between the obstacle shape and ants distributed behavior: Although all ants move at approximately the same speed and deposit a pheromone trail at approximately the same rate, it is a fact that it takes longer to contour obstacles on their longer side than on their shorter side which makes the pheromone trail accumulate quicker on the shorter side. It is the ant's preference for higher pheromone trail levels which makes this accumulation still quicker on the shorter path.

6.4 Global Search

The global search creates g new regions by replacing the weaker portions of the existing domain. The global search procedure essentially consists of two genetic algorithm type methods. In the ants colony algorithm technology these are called random walk and trial diffusion. By random walk procedure, the ants move in new directions in search of newer and richer stocks of food source.

In the ants colony algorithm simulation such a global search in the entire domain is done by process equivalent to cross over and mutation operations in G.A. adding or subtracting with a probability proportional to the mutation probability carries out the mutation step in ants colony algorithm .the mutation step is reduced as per the relation

$$\Delta (T, R) = R [1-r^{(1-T)b}]$$

Where 'r' is a random number from [0, 1] 'R' is the maximum step size, 'T' is the ratio of the current iteration number that of the total number of iterations ,'b' is a positive parameter controlling the degree of non linearity .the scaling down enables enhanced probability of locating maximum by concentrated search procedure called trial diffusion.

The trial diffusion is quite similar to arithmetic cross over. In this two parents are selected at random from the parent population space. The elements of the child's vector can have either (1) the corresponding element from the first parent, (2) the corresponding element from the second parent & (3) a Combination arrived the weighted average of the above If the random number is less than 0.5.

$$X_{(child)} = \alpha X_{i\,(parent\ 1)} + (1-\alpha) X_{i\,(parent\ 2)}$$

Where α is a uniform random number in the range (0-1).

6.5 Local search

In the local search the local ants have the capability of selecting regions proportional to the current pheromone values of superior and inferior regions. Local updating is applied only on superior regions.

After selecting the destination, the ant moves through a short distance. The direction of the movement will be the same as that of the previous direction if there is an improvement in the fitness. If there is no improvement it searches in the random direction. If improvement is found in the above procedure, the regions position vector is updated. The pheromone deposited by the ant is proportional to the increase in the fitness. If in the above search higher the fitness is obtained, the age of the region is increased the age of the region is another important parameter in the Ants colony algorithm. The size of the ant movement in the local search depends on the current age. Initially all the regions are assigned with the pheromone value of 1.0 and an age of 10.0.the average pheromone for each region is calculated and the procedure is repeated as many number of times as many times as they are local ants.

6.6 ALGORITHM

1. Initializing 20 random solutions
2. Arranging them in ascending order or descending order depending on maximization or minimization problem
3. Total number of ants taken = (number of solutions)/2
4. The solutions generated are then classified into superior and inferior solutions.
5. Next dividing the ants for global search and local search in the ratio 4:1.then the global ants are divided in the ratio of 3:1 for random walk. mutation and trial diffusion.
6. Termination criteria are maximum number of iterations or minimum error conditions

6.7 OPTIMIZATION OF FCAW PROCESS USING ACO

No of particles: In this study, 20 solutions are considered

Dimension of particles: it is equal to the number of input parameters (i.e.,) 4

6.7.1 Random Walk

Solutions in the inferior most sequences are replaced with the randomly selected solutions from the superior regions. This procedure is done for all variables in this problem. This process of replacement is called as random walk.

6.7.2 Mutation

After the random walk step randomly adding or subtracting a value to each and every variable of new solutions with a probability called mutation probability.

$$A(T, R) = R\left[1-r^{(1-T)^{b}}\right]$$

r- random number [0-1]

R -maximum step size

T -current iteration number/maximum iteration

b - 10

6.7.3 Trial Diffusion

Two parents are selected from the inferior solutions. two random numbers are selected between 1&4.let it be 2 & 4.

	current	speed	nozzle to plate distance	torch angle
Before:	200.45	35.67	25.89	7.89
	267.88	29.77	29.23	45.67
After :	200.45	29.77	25.89	45.67
	267.88	35.67	29.23	7.89

6.7.4 Pheromone Iteration

It searches in the random direction. If improvement is found in the above procedure, the regions position vector is updated. The pheromone deposited by the ant is proportional to the increase in the fitness. Initially all the regions are assigned with the pheromone value of 1.0 and an age of 10.0.the average pheromone for each region is calculated and the procedure is repeated as many number of times as many times as they are local ants

6.7.5 Minimization function

New pheromone = old pheromone + (old value – new value)/old value

6.7.6 Maximization function

New pheromone = old pheromone + (new value- old value)/old value

New pheromone >average pheromone

The flow chart for the ant colony optimization has been shown in the Figure6.6

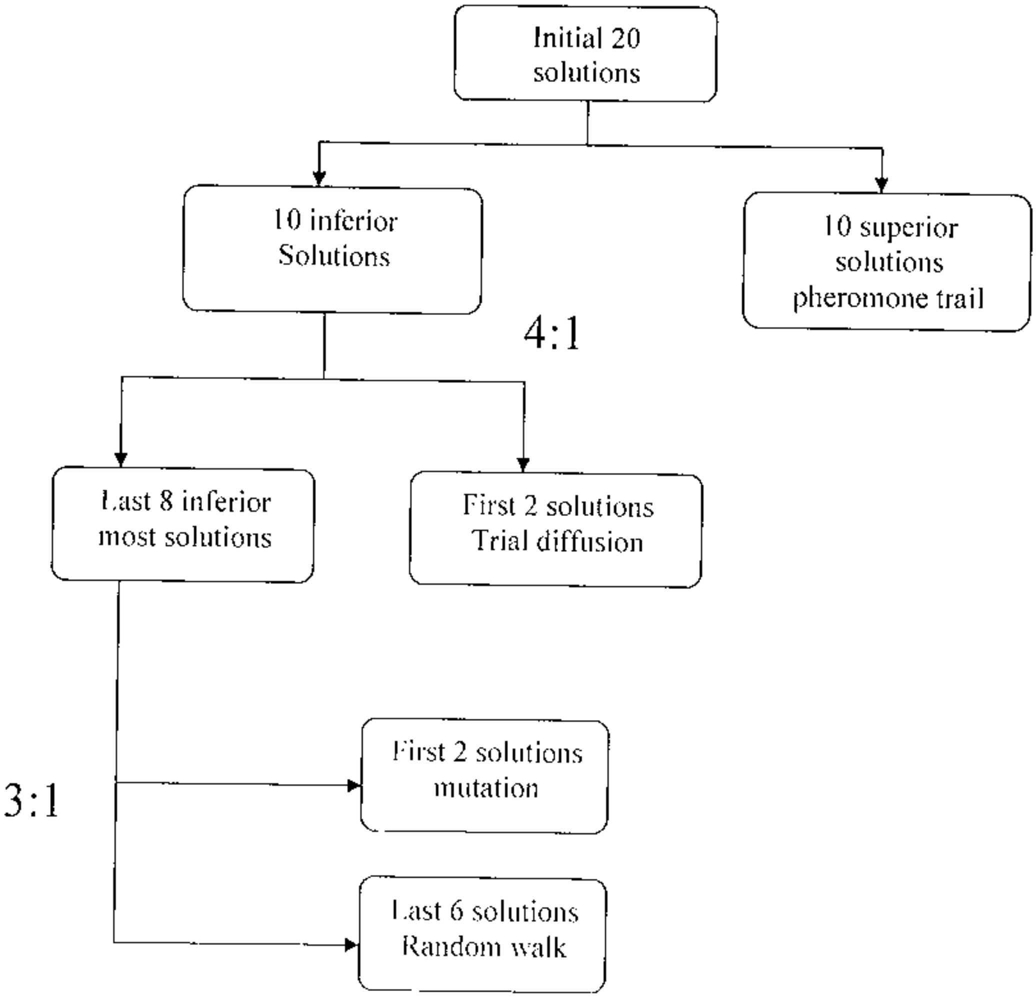

FIGURE 6.6 FLOW CHART FOR ACO ALGORITHM

6.8 INITIAL SOLUTION

6.8.1 Depth of penetration

Initial solution generated randomly for 20 particles for minimizing the depth of penetration is shown below in the Table 6.1

TABLE 6.1 INITIAL SOLUTIONS FOR DEPTH OF PENETRATION USING ACO

S.NO.	I (A)	S(mm/min)	N(mm)	T(deg)	P (mm)
1	226.60001	29.60000	29.11000	2.5900	0.606772
2	262.89999	29.37000	23.36000	8.9800	0.835303
3	265.00000	50.54000	27.19000	15.2900	0.714762
4	230.30000	25.92000	26.00000	1.7400	0.659321
5	215.69999	22.75000	24.32000	11.2600	0.595267
6	231.19999	31.41000	23.59000	0.6300	0.803506
7	274.20001	36.18000	27.33000	0.6100	0.970367
8	265.39999	41.68000	29.48000	6.6200	0.838856
9	265.39999	41.68000	29.48000	6.6200	0.838860
10	249.20000	33.19000	25.08000	14.0500	0.686650
11	270.50000	26.85000	25.43000	5.2100	0.830500
12	284.70001	53.92000	27.88000	4.9500	1.203790
13	240.60001	58.37000	25.19000	3.3600	1.246030
14	228.00000	50.71000	24.24000	1.3200	1.122440
15	275.60001	25.46000	22.75000	11.1200	0.880520
16	249.60001	59.49000	25.55000	5.1400	1.219610
17	277.39999	46.81000	26.14000	7.4700	1.011440
18	234.60001	52.35000	28.30000	6.1100	0.912350
19	202.30000	59.61000	26.36000	0.9900	1.196580
20	261.29999	27.45000	25.62000	3.6800	0.802610

6.8.2 Height of Reinforcement

Initial solution generated randomly for 20 particles for maximizing the Height of reinforcement is shown below in the Table 6.2

TABLE 6.2 INITIAL SOLUTIONS FOR HEIGHT OF REINFORCEMENT USING ACO

S.NO.	I (A)	S(mm/min)	N(mm)	T(deg)	R (mm)
1	233.00000	35.95000	22.08000	9.48000	4.50732
2	205.10001	31.26000	25.10000	3.87000	4.77975
3	252.89999	30.96000	25.73000	19.15000	4.91376
4	257.70001	39.56000	26.41000	14.74000	4.55767
5	240.70000	38.05000	29.54000	7.82000	4.71822
6	292.29999	38.34000	22.41000	6.11000	4.75992
7	219.20000	49.08000	27.61000	11.68000	3.97769
8	212.00000	54.30000	29.90000	4.67000	3.78530
9	258.70001	40.54000	22.46000	13.00000	4.43224
10	253.80000	58.08000	24.55000	10.86000	3.88897
11	239.50000	57.52000	24.76000	1.08000	3.92750
12	225.20000	41.00000	23.86000	0.69000	4.40566
13	218.70000	40.17000	29.04000	16.42000	4.38065
14	246.20000	58.76000	27.27000	4.79000	3.83750
15	232.80000	41.00000	29.11000	18.96000	4.38267
16	268.29999	45.15000	25.85000	8.57000	4.41096
17	295.10001	54.53000	29.65000	8.57000	4.16316
18	247.70000	46.24000	28.10000	17.54000	4.19167
19	234.20000	42.40000	27.62000	15.67000	4.31782
20	202.30000	31.64000	23.43000	19.32000	4.50274

6.8.3 Bead Width

Initial solution generated randomly for 20 particles for maximizing the bead width is shown below in the Table 6.3

TABLE 6.3 INITIAL SOLUTIONS FOR BEAD WIDTH USING ACO

S.NO.	I (A)	S(mm/min)	N(mm)	T(deg)	W (mm)
1	231.60001	21.42000	24.51000	16.71000	35.71882
2	291.50000	38.89000	22.86000	14.40000	31.69678
3	267.89999	39.53000	29.03000	17.68000	31.89215
4	279.60001	53.02000	26.19000	1.94000	26.81417
5	222.30000	26.03000	27.40000	2.29000	30.39971
6	228.89999	50.33000	24.49000	3.88000	23.19121
7	281.00000	35.67000	29.09000	15.18000	33.94922
8	245.39999	57.73000	22.02000	18.71000	26.30189
9	246.60001	35.35000	29.55000	1.14000	29.77815
10	265.29999	27.97000	24.26000	11.91000	35.00470
11	217.50000	49.63000	23.52000	14.85000	23.03093
12	278.00000	24.90000	28.79000	1.40000	39.02358
13	262.39999	44.41000	24.25000	1.21000	27.12057
14	289.39999	59.75000	25.06000	10.81000	26.69883
15	205.39999	39.72000	29.23000	9.71000	23.05816
16	254.80000	52.67000	27.69000	5.41000	25.75091
17	235.70000	31.68000	28.64000	18.15000	31.77474
18	221.50000	50.80000	28.31000	19.19000	25.70437
19	271.70001	41.21000	23.45000	0.99000	28.66766
20	286.10593	23.17627	24.22455	2.58215	40.13858

6.8.4 Dilution

Initial solution generated randomly for 20 particles for minimizing the percentage dilution is shown below in the Table 6.4

TABLE 6.4 INITIAL SOLUTIONS FOR PERCENTAGE DILUTION USING ACO

S.NO.	I (A)	S(mm/min)	N(mm)	T(deg)	D (%)
1	214.60001	26.89000	22.68000	5.62000	6.68714
2	208.80000	28.91000	23.17000	17.47000	7.02353
3	210.60001	27.67000	23.33000	0.44000	6.28358
4	214.60001	26.89000	22.68000	5.62000	6.68714
5	208.80000	28.91000	23.17000	17.47000	7.02353
6	210.60001	27.67000	23.33000	0.44000	6.28358
7	285.70001	59.31000	27.27000	2.39000	24.60295
8	296.50000	46.54000	27.35000	2.32000	19.81477
9	269.20001	45.46000	27.29000	3.79000	18.04307
10	297.29999	54.10000	23.67000	18.63000	14.45461
11	244.50000	55.19000	25.06000	6.19000	21.14407
12	297.00000	46.78000	25.24000	11.16000	17.56330
13	263.00000	30.42000	23.48000	2.94000	14.18405
14	290.79999	52.75000	26.87000	1.75000	22.91146
15	207.80000	46.73000	23.00000	9.24000	14.36788
16	223.10001	50.79000	29.70000	5.53000	18.07127
17	247.00000	38.62000	24.83000	8.44000	14.13981
18	256.10001	59.05000	27.26000	3.22000	24.17553
19	281.10001	53.43000	29.55000	8.21000	16.07553
20	290.70001	37.69000	29.39000	12.15000	11.80214

CHAPTER 7

RESULTS AND DISCUSSIONS

7.1 PARTICLE SWARM OPTIMIZATION

The software to find the optimal values for welding parameters using PSO has been written in C language. The present work is an optimization problem with Maximizing the Bead Width, Height of Reinforcement and minimizing the Percentage Dilution, depth of penetration. Every output parameter was separately iterated to find the optimum input values. Each one of them was given the particle size of 5 and allowed to make 100 iterations. The optimum results were calculated by inertia weight as 0.5.

7.1.1 Percentage Dilution

Table 7.1 shows the results of the optimized values of input parameters for minimum Percentage Dilution at the end of 100 iterations and inertia weight of 0.5. The optimum value is obtained at the 11th iteration. Figure 7.1 shows the solution history of optimized results for Percentage Dilution.

TABLE 7.1 RESULTS FOR PERCENTAGE DILUTION USING PSO

S.NO	I (A)	S(mm/min)	N(mm)	T(deg)	D (%)
1	224.80000	32.41000	27.22000	15.99000	8.730859

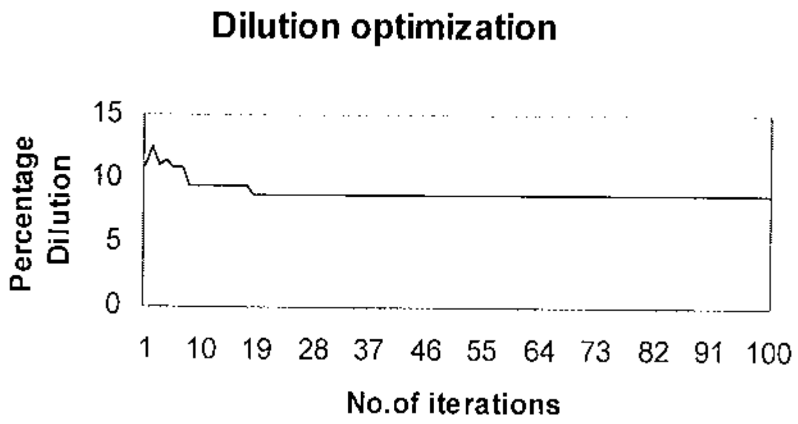

FIGURE 7.1 GRAPHICAL REPRESENTATION OF PSO FOR PERCENTAGE DILUTION

7.1.2 Depth of penetration

Table 7.2 shows the results of the optimized values of input parameters for minimum depth of penetration at the end of 100 iterations and inertia weight of 0.5. The optimum value is obtained at the 13th iteration. Figure 7.2 shows the solution history of optimized results for depth of penetration.

TABLE 7.2 RESULTS FOR DEPTH OF PENETRATION USING PSO

S.NO	I (A)	S(mm/min)	N(mm)	T(deg)	P(mm)
1	224.399933	42.419991	29.009993	17.349989	0.421002

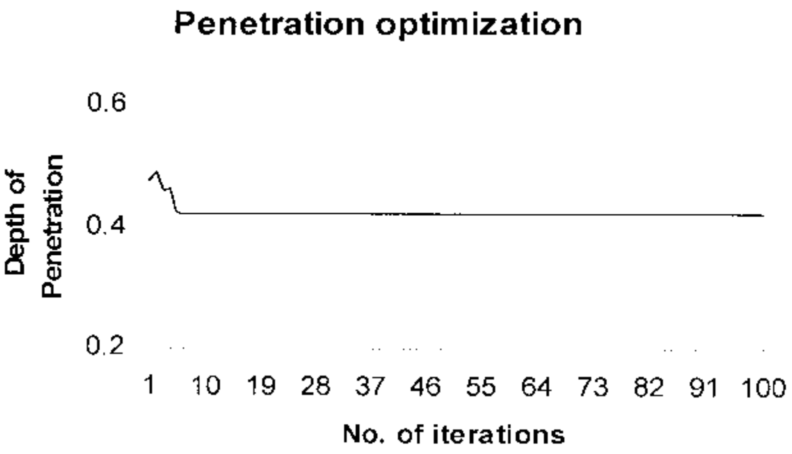

FIGURE 7.2 GRAPHICAL REPRESENTATION OF PSO FOR DEPTH OF PENETRATION

7.1.3 Height of Reinforcement

Table 7.3 shows the results of the optimized values of input parameters for maximum Height of Reinforcement at the end of 100 iterations and inertia weight of 0.5. The optimum value is obtained at the 16th iteration. Figure 7.3 shows the solution history of optimized results for Height of Reinforcement.

TABLE 7.3 RESULTS FOR HEIGHT OF REINFORCEMENT USING PSO

S.NO	I (A)	S(mm/min)	N(mm)	T(deg)	R(mm)
1	250.730652	20.118101	26.091854	9.743405	5.702532

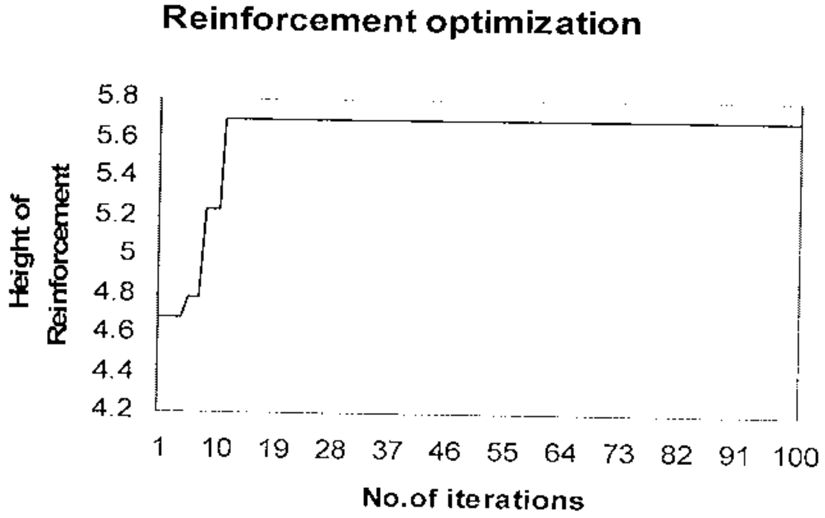

FIGURE 7.3 GRAPHICAL REPRESENTATION OF PSO FOR HEIGHT OF REINFORCEMENT

7.1.4 Bead Width

Table 7.4 shows the results of the optimized values of input parameters for maximum Bead Width at the end of 100 iterations and inertia weight of 0.5. The optimum value is obtained at the 15th iteration. Figure 7.4 shows the solution history of optimized results for Bead Width.

TABLE 7.4 RESULTS FOR BEAD WIDTH USING PSO

S.NO	I (A)	S(mm/min)	N(mm)	T(deg)	W(mm)
1	286.700012	20.4	22.139999	2.300000	42.018085

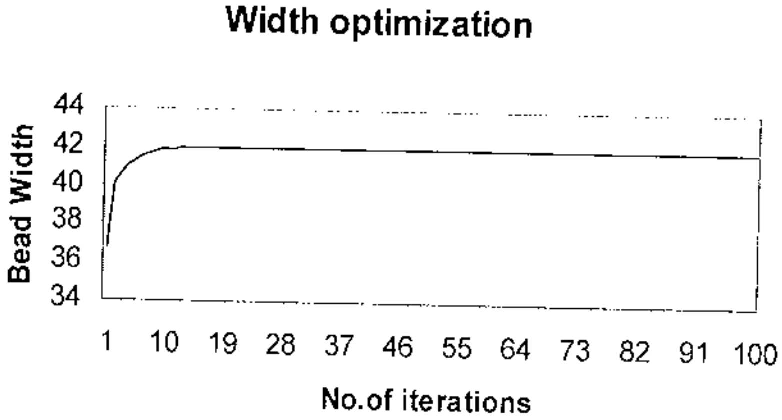

FIGURE 7.4 GRAPHICAL REPRESENTATION OF PSO FOR BEAD WIDTH

7.2 ANT COLONY OPTIMIZATION

The software to find the optimal values for welding parameters using ACO has been written in C language. The present work is an optimization problem with Maximizing the Bead Width, Height of Reinforcement and minimizing the Percentage Dilution, depth of penetration. Every output parameter was separately iterated to find the optimum input values. Each one of them was given the initial solution set of 20 and allowed to make 100 iterations.

7.2.1 Depth of penetration

Table 7.5 shows the results of the optimized values of input parameters for minimum depth of penetration at the end of 100 iterations. The optimum value is obtained at the 47th iteration. Figure 7.5 shows the solution history of optimized results for depth of penetration.

TABLE 7.5 RESULTS FOR DEPTH OF PENETRATION USING ACO

S.NO	I (A)	S(mm/min)	N(mm)	T(deg)	P(mm)
1	200	21.330	29.9	0	0.389667

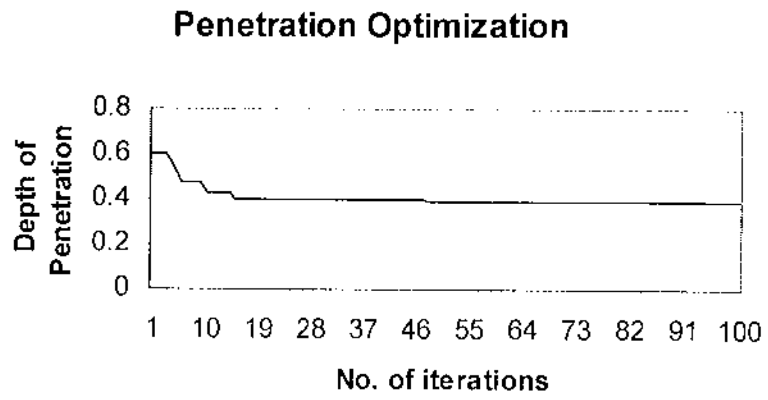

FIGURE 7.5 GRAPHICAL REPRESENTATION OF ACO FOR DEPTH OF PENETRATION

7.2.2 Percentage Dilution

Table 7.6 shows the results of the optimized values of input parameters for minimum Percentage Dilution at the end of 100 iterations. The optimum value is obtained at the 43rd iteration. Figure 7.6 shows the solution history of optimized results for Percentage Dilution.

TABLE 7.6 RESULTS FOR PERCENTAGE DILUTION USING ACO

S.NO	I (A)	S(mm/min)	N(mm)	T(deg)	D (%)
1	251.89999	24.98000	29.51000	11.09000	8.03437

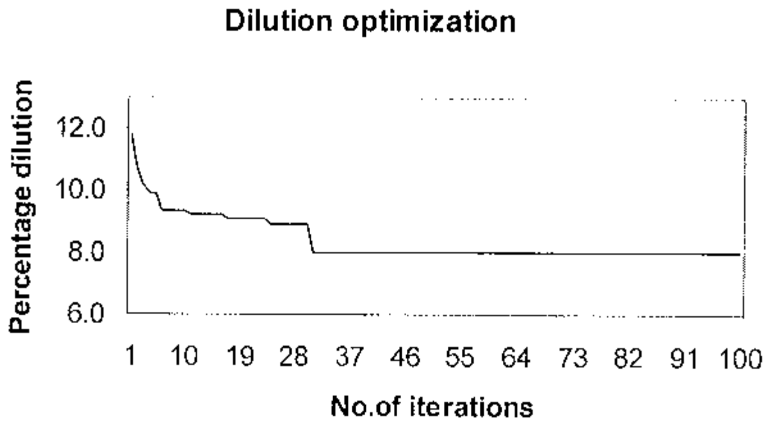

FIGURE 7.6 GRAPHICAL REPRESENTATION OF ACO FOR PERCENTAGE DILUTION

7.2.3 Bead Width

Table 7.7 shows the results of the optimized values of input parameters for maximum Bead Width at the end of 100 iterations. The optimum value is obtained at the 43rd iteration. Figure 7.7 shows the solution history of optimized results for Bead Width.

TABLE 7.7 RESULTS FOR BEAD WIDTH USING ACO

S.NO	I (A)	S(mm/min)	N(mm)	T(deg)	W (mm)
1	281.899994	20.29999	28.57	19.559999	45.394989

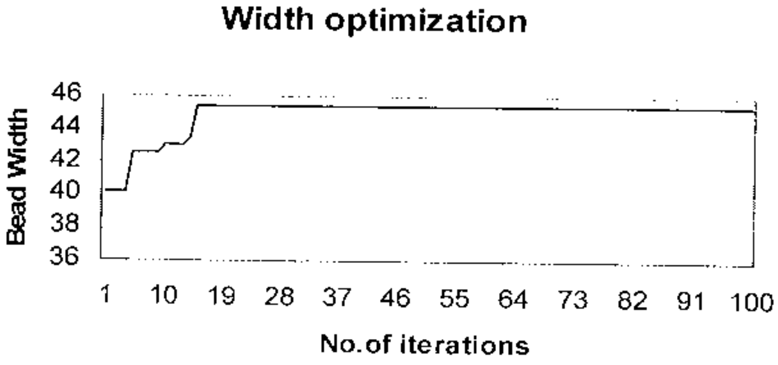

FIGURE 7.7 GRAPHICAL REPRESENTATION OF ACO FOR BEAD WIDTH

7.2.4 Height of Reinforcement

Table 7.8 shows the results of the optimized values of input parameters for maximum Height of Reinforcement at the end of 100 iterations. The optimum value is obtained at the 22nd iteration. Figure 7.8 shows the solution history of optimized results for Height of Reinforcement.

TABLE 7.8 RESULTS FOR HEIGHT OF REINFORCEMENT USING ACO

S.NO	I (A)	S(mm/min)	N(mm)	T(deg)	R (mm)
1	283.311188	21.768398	27	0	5.926124

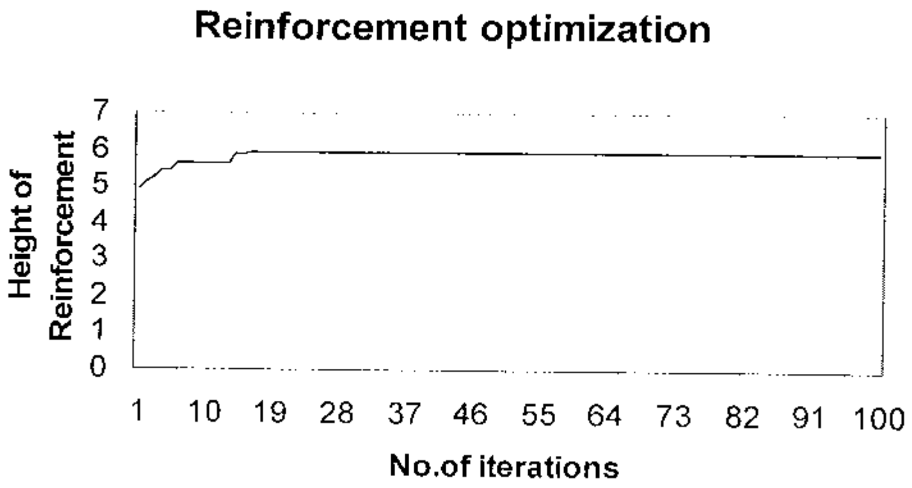

FIGURE 7.8 GRAPHICAL REPRESENTATION OF ACO FOR HEIGHT OF REINFORCEMENT

CHAPTER 8

CONCLUSIONS

8.1 CONCLUSION

The possibility of a flux cored arc welding optimization procedure using particle swarm optimization and ant colony optimization are investigated in this work. A particle swarm optimization and ant colony optimization has been used in this study to optimize the process parameters to achieve minimum penetration and dilution, maximum height of reinforcement and width. It was found that both particle swarm optimization and ant colony optimization can be a powerful tool in optimizing cladding parameters. This approach can be modified for other welding operations like Gas Metal Arc Welding, Submerged Arc Welding etc. Particle Swarm Optimization is an extremely simple algorithm that seems to be effective for optimizing a wide range of industrial problems. Ant colony optimization is found to give better results than particle swarm optimization.

REFERENCES

1. Anthony Carlisle, Gerry Dozier (2000), "Adapting Particle Swarm Optimization to Dynamic Environments", *Proceedings of International Conference on Artificial Intelligence*, pp.429-434.

2. Correia D. S and Goncalves C. V (2004), 'GMAW Welding Optimization Using Genetic Algorithms', *Journal of Brazilian Manufacturing Congress*, Vol XXVI, pp.28-33.

3. Gunaraj V, Murugan N (1999), 'Application of Response Surface Methodology for Predicting Weld Bead Quality in Submerged Arc Welding Pipes ', *Journal of Material Process Technology*, Vol. 88, pp.266-275.

4. Gunaraj V and Murugan N (2000), 'Prediction and Optimization of Weld Bead Volume for the Submerged Arc Process', *Welding Journal*, pp 331-338.

5. 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 Process Technology*, Vol. 95, pp. 246-261

6. James Kennedy and Russell Eberhart (1995). "Particle Swarm Optimization", *Proceedings of IEEE International Conference on Neural Networks*, Vol. IV, pp.1942-1948

7. Kannan.T and Murugan.N (2006) "Effects of Flux Cored Arc Welding Process Parameters on duplex Stainless Steel Quality", *Journal of Materials Processing Technology*, 176(2006), P.No:230-239

8. Loan Cristian Trelea (2003). "The Particle Swarm Optimization Algorithm: Convergence Analysis and Parameter Selection", *Information Processing létters*,Vol. 85, pp. 317-325.

9. Markelj F and Tusek J (2001). "Algorithmic Optimization of Parameters in Tungsten Inert Gas Welding of Stainless Steel Sheet", *Science and Technology of Welding and Joining* Vol. 6 No. 6.

10. Murugan N and Palani P.K, (2004), 'Optimization of Bead Geometry in Automatic Stainless Steel Cladding by MIG Welding Using Genetic Algorithm', *IE(I) Journal-Production Research*, Vol. 84 P.No 49-54.

11. Raveendra J and Parmar R S (1987), 'Mathematical models to predict Weld Bead Geometry for Flux Cored Arc Welding', *Journal of Metal Construction,* pp.31 R - 35R.

12. Ray T, Liew K.M, Saini P (2002), "An Intelligent Information Sharing Strategy within a Swarm for Unconstrained and Constrained Optimization Problems", *Journal of Soft Computing*, Vol.6, pp.38-44.

13. Srividhya P. K, Baskar N, Asokan P, (2003) "Optimizaton of Multi-pass Milling Operation via Particles Swarm Optimization", *Proceedings of the National Conference on Modeling and Analysis of Production Systems*, pp.322-327.

14. Sundara Vinayaga Murthy, Baskar N, and Asokan P (2003). 'Optimization of Machining Parameters for Multi Pass Face Milling Operation Using Particle Swarm Optimization", *Proceedings of the National Conference on Modeling and Analysis of Production Systems*, pp.1 9-25.

15. www.americanweldingsociety.com

16. www.indianweldignsociety.com

17. Xiao-Feng, Wen-jun, Zhi-Lian Yang (2002). "A Dissipative Particle Swarm Optimization ", *Proceedings on IEEE*. pp.1456-1461.

18. Xiaohui Hu and Russell C. Eberhart (2002). "Adaptive Particle Swarm Optimization: Detection and Response to Dynamic Systems", *Proceedings on IEEE*, pp.1666-i 670.

19. Yuhui Shi and Russell C. Eberhart. (1998). "Parameter Selection in Particle Swarm Optimization", *Proc Evolutionary Programming*, Vol. 98, pp. 591-600.