OPTIMIZATION OF WELDING PARAMETERS ON ANGULAR DISTORTION OF SS 202 IN GTAW

A PROJECT REPORT

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BONAFIDE CERTIFICATE

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ABSTRACT

Stainless steel grade 202 is extensively used in applications. Gas Tungsten arc welding is a welding process that produces coalescence of metals by heating them with an arc between a non-consumable electrode and the base metal. During welding process, the weldment is locally heated by the welding arc and the temperature distribution in the weldment is not uniform. Typically the weld metal and the base metal immediately adjacent to the fusion zone are at a temperature substantially above that of the unaffected base metal. During the welding cycle, non-uniform thermal strains are induced in both the weld metal and base metal near the fusion zone. The thermal strains produced during heating are accomplished by plastic upsetting. The nonuniform thermal stresses resulting from these strains combine and react to produce internal forces that cause welding distortion. It was found that the welding distortions can affect the fabrication, precision (the shape and dimensional tolerances required) and function (such as reliability and stability) in finished structures.

In this project work the effect of the welding process parameters on angular distortion was carried out for stainless steel 202 .The important process parameters are current(I),welding speed(S),Gas flow rate(Qg),Gun Angle(α) and Plate Length(L).The experiments are conducted using design of experiments technique. A five level factorial central composite rotatable design with 32 experimental runs were used to conduct the experiments .A mathematical model was developed correlating the process parameters and the angular distortion .The developed model is checked for the adequacy based ANOVA analysis and the validity of the model is checked by drawing scatter diagrams. Optimization of GTAW process parameters was carried out to obtain optimum angular distortion using the developed model.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AWS	American Welding Society
CTWD	Contact Tip to Work piece Distance
DF	Degree of Freedom
DOE	Design of Experiments
FCAW	Flux Cored Arc Welding
FN	Ferrite Number
GTAW	Gas Tungsten Arc Welding
IS	Indian Standards
MIG	Metal Inert Gas
MAG	Metal Active Gas
N	Nozzle to Plate Distance
RSM	Response Surface Methodology
SAW	Submerged Arc Welding
SMAW	Shielded Metal Arc Welding
SS	Sum of Squares
T	Welding gun angle
V	Welding Speed
A	Current
Q	Gas Discharge
L	Base Plate Length

INTRODUCTION

IMPORTANCE OF THE PROJECT:

Weld distortion is one of the major defects in a welding process. The distortion is an after effect of the changes caused due the shrinkage in the fusion region. During the process of welding the heat from the torch causes the metal to melt to liquid state. The temperature in the weldment is distributed in a non linear fashion with the peak in the welded region. Normally, the weld metal and the heat affected zone (HAZ) are at temperatures significantly above that of the unaffected base metal. Upon cooling, the weld pool solidifies and shrinks, exerting stresses on the surrounding weld metal and the HAZ. The resulting stresses are higher than the yield point of the metal , resulting in the deformation of the weld along longitudinal and traverse directions.

As an engineer, there is a great interest in minimizing the distortion caused by the welding process as designing is concerned. If the distortion due to welding is tried to minimize by using any restraints, these stresses will remain in the weld element as residual stresses which on the other hand would have been relieved from the metal but resulting in deformation of the metal without the restraints. The resulting deformation cause changes in the material property like weakening of the metal in its fatigue strength, tensile strength, corrosion resistance and also its crystal structure. The metal becomes less tensile in the welded region compared to unaffected base metal due to the sudden temperature rise and fall.

In today's engineering world its impossible to have any engineering project to be completed without having the contribution of welding technology in it. In such a real time situation weld distortion control is an important area which needs more attention. In individual structures the weld distortion can be analyzed by analyzing

the data i.e., the parameters and the output ,which is the angle distorted .In the case of huge structures where the number of welds are more and consequently the way of analysis gets proportionally complicated .The control over the angular distortion can be obtained by developing a mathematical model. Experiments have been made by observing the output of the experimental process(angle distorted) in austenitic stainless steel Grade 202 by varying the combination of the input parameters in an ordered manner and optimizing the model.

SEQUENCE OF THE PROJECT

The report starts with a brief introduction about welding and cladding. The gas metal arc welding process is explained in detail. Then a brief introduction is given to the types of stainless steel. An overview about the Design of Experiments is given next. The experimental set up is then explained. After this, the steps in the experimental design procedure are explained. Then, the sequence of developing the mathematical model with the help of regression equation is briefed. The steps involved in finding the regression coefficients using Quality America software are explained. Optimizing of the mathematical model is done using MATLAB 7.0 software. Finally, the interaction graphs are obtained using MATLAB 7.0 software. Based on the developed mathematical models, conclusions are made.

LITERATURE SURVEY:

In the paper "**Effects of Process Parameters on Angular Distortion** of Gas Metal Arc Welded Structural Steel Plates" presented by V.Vel Murugan and V.GunaRaj mathematical models were developed based on five level five factorial central composite design. The mathematical model was used to study the effects of

process variables on the angular distortion of multipass GMA welded structural steel plates

In the work '**Distortion control in ship building'** done by the 'Welding Technology Institute of Australia'. In this paper the various preparing techniques of the base metal and techniques to contain the distortion in the welds are discussed in detail.

Weld Distortion Control during Welding Process with Reverse-Side Heating presented by Masahito Mochizuki and Masao. In this work angular distortion was observed by performing reverse-side Tungsten inert gas (TIG) heating of the weld line at a fixed distance ahead of metal inert gas (MIG) welding during the weld process. The distance between TIG and MIG torches were varied and the effects of reverse side heating on the distortion were analyzed.

In the work '**Modeling of the Mechanical Effects Induced by the Tungsten Inert-Gas Welding of the IN718 Super alloy'** presented by D. DYE, O. HUNZIKER, S.M. ROBERTS, and R.C. REED the distortion and residual stresses arising during the Tungsten inert-gas (TIG) welding of the nickel based super alloy IN718 are modeled using sequentially coupled thermal-mechanical analyses. Processing trials have been carried out for validation purposes, and, for a number of rectilinear test pieces, the distortion has been quantified.

In the work **Measurement and modeling of residual stresses in a TIG weld'** presented by P.J. Webster ,N. Ananthaviravakumar , D.J. Hughes, G. Mills, R.V. Preston, H.R. Shercliff and P.J. Withers residual stresses due to TIG welding have been measured using neutron diffraction and the results are compared with a finite element model calculation. Stresses were derived using data collected in the three orthogonal symmetry directions. A finite-element model was generated using ABAQUS. The agreement between the calculated and measured results is good.

In the work 'In-**Plane shrinkage strains and their effects on welding distortion in Thin-Wall Structures'** presented by Wentao Cheng. In this work thin walled structures were welded and the corresponding shrinkage in the internal planes of the material and their effects on the structural distortion were analyzed.

In the work 'Math-**based Evaluation of Distortion in MIG Welded Body Structures'** presented by Cheng. W. and Huang, J .In this work a mathematical model was developed in order to predict the distortion.

In the work **'Effect of welding parameters on mechanical properties and optimization of pulsed TIG welding of Al-Mg-Si alloy'** presented by Kumar & S. Sundarrajan an attempt has been made to study the effect of pulsed TIG welding process parameters on dilution and mechanical properties such as notch tensile strength, hardness, and impact toughness in as-welded condition. Pulsed TIG welds exhibited lower notch tensile strength and impact toughness than the parent metal due to interdendritic network microstructure features.

In the work **'In Plane Shrinkage Strains and Their Effects on Welding Distortion in Thin-Wall Structures'** presented by Wentao Cheng, work was conducted to obtain better understanding and characterization of the plastic

deformation that leads to inplane shrinkage in thin-wall structures. The FEA was the tool used in this work to study welding plastic deformation. It's found that the accumulated plastic strains are determined by the peak temperature. Peak temperature is the thermal parameter that controls the plastic strains.

'Welding Distortion of a Thin-Plate Panel Structure' by C. L. Tsai, S. C. Park and W. T. Cheng ,study has been made on distortion behaviors, including local plate bending and buckling as well as global girder bending, were investigated using the finite element method. It was found that buckling doesn't occur in structures with a skin-plate thickness of more than 1.6 mm unless the stiffening girder bends excessively. Warping is primarily caused by angular bending of the plate itself.

SUMMARY:

Based on the literature survey its observed that the welding speed is inversely proportional to the angular distortion. Lower velocity would result in higher heat input and hence the distortion would be large. A relation between the angular distortion and the warping has been observed .It is found that increase in current would result in decrease due to the effects of larger charge of electrons transfer. The range for the parameters were fixed based acquiring smoother bead and minimum porosity levels.

2. WELDING AND DISTORTION

2.1 WELDING

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

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

2.2 CLASSIFICATION OF WELDING

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

- Fusion welding
- Solid state welding
- Semi – liquid welding

Most of the welding processes utilize heat and / or pressure for making a weld joint. A weld is made when separate pieces of material to be joined combine and form one piece when heated to a temperature high enough to cause softening or melting and flow together. Based on the method of heat generation and its application, the three major welding processes can be divided into several classes as shown in the fig. 2.1:

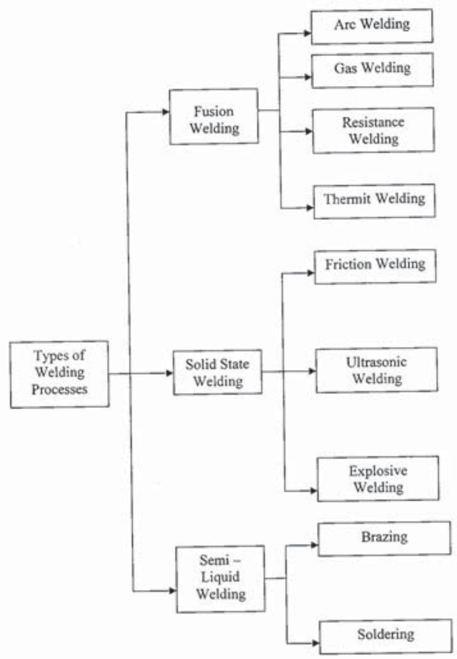


FIG. 2.1 SCHEMATIC REPRESENTATION OF THE TYPES OF WELDING PROCESSES

2.3 FUSION WELDING

2.3.1 ARC WELDING

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

2.3.1.1 SHIELDED METAL ARC WELDING

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

2.3.1.2 GAS TUNGSTEN ARC WELDING

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

2.3.1.3 GAS METAL ARC WELDING

In this welding, the electric arc is produced between a consumable metal electrode and the work. During welding, the arc and welding zone are surrounded by an inert gas. This inert gas covers and protects the weld from

atmospheric effects. Argon or helium is used as inert gas. This welding can be done manually or automatically. MIG welding is used for welding aluminium, stainless steel and magnesium without weld defects.

2.3.1.4 PLASMA ARC WELDING

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

2.3.1.5 SUBMERGED ARC WELDING

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

2.3.2 GAS WELDING

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

2.3.3 RESISTANCE WELDING

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

2.3.4 THERMIT WELDING

This is a fusion welding process in which, welding is done by pouring superheated liquid steel around the parts to be welded. Thermit steel is a mixture of fine aluminium powder and iron oxide. Barium peroxide powder is also added to the mixture and is added to the crucible and ignited Thermit reaction takes place and superheated liquid steel is produced. The temperature is around 3000^0C. The ends of the parts to be joined are kept parallel with a uniform gap between them. This gap is filled with wax which becomes the pattern. A flame is used to melt wax and the wax goes out leaving the ends of the work to preheated condition. Then heating is stopped and the liquid thermit steel is poured into mould between the ends of work pieces. The molten metal solidifies and the weld is completed.

2.4 SOLID STATE WELDING

2.4.1 FRICTION WELDING

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

2.4.2 ULTRASONIC WELDING

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

2.4.3 EXPLOSIVE WELDING

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

2.5 SEMI LIQUID WELDING

2.5.1 BRAZING

Brazing is the process of joining two similar or dissimilar metals by a fusible alloy called spelter. The melting temperature of the filler metal is higher. It is also known as filler rod. The spelter has its melting point (at about 600^0C) below the melting point of work piece. The work metals are heated to a temperature below their melting point. The filler metal is allowed to flow in the gap between the work pieces allowing it to join the work pieces. The spelter is made of copper and zinc alloy or silver alloy.

2.5.2 SOLDERING

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

torch is used. Soldering is used in repairing radiators, fitting covers to containers, etc.

2.6 CLADDING

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

2.7.1 DISTORTION:

Welding involves highly localized heating of the metal being joined together. The temperature distribution in the weldment is therefore nonuniform. Normally, the weld metal and the heat affected zone (HAZ) are at temperatures substantially above that of the unaffected base metal. Upon cooling, the weld pool solidifies and shrinks, exerting stresses on the surrounding weld metal and HAZ.

If the stresses produced from thermal expansion and contraction exceed the yield strength of the parent metal, localized plastic deformation of the metal

occurs. Plastic deformation results in lasting change in the component dimensions and distorts the structure. This causes distortion of weldments.

2.7.2CLASSIFICATION OF DISTORTION:

Several types of distortion are listed below:

- Longitudinal shrinkage
- Transverse shrinkage
- Angular distortion
- Bowing
- Buckling
- Twisting

2.7.2FACTORS AFFECTING DISTORTION:

If a component is uniformly heated and cooled distortion would be minimized. However, welding locally heats a component and the adjacent cold metal restrains the heated material. This generates stresses greater than yield stress causing permanent distortion of the component.

Some of the factors affecting the distortion are listed below:

- Amount of restraint
- Welding procedure
- Parent metal properties
- Weld joint design
- Part fit up
- Gas discharge
- Torch velocity

- Current
- Gun angle

2.7.2.1 RESTRAINT:

Restraint can be used to minimize distortion. Components welded without any external restraint are free to move or distort in response to stresses from welding. It is not unusual for many shops to clamp or restrain components to be welded in some manner to prevent movement and distortion. This restraint does result in higher residual stresses in the components.

2.7.2.2WELDING PROCEDURE

Welding procedure impacts the amount of distortion primarily due to the amount of the heat input produced. The welder has little control on the heat input specified in a welding procedure. This does not prevent the welder from trying to minimize distortion. While the welder needs to provide adequate weld metal, the welder should not needlessly increase the total weld metal volume added to a weldment.

2.7.2.3PARENT METAL PROPERTIES

Parent metal properties, which have an effect on distortion, are coefficient of thermal expansion and specific heat of the material. The coefficient of thermal expansion of the metal affects the degree of thermal expansion and contraction and the associated stresses that result from the welding process. This in turn determines the amount of distortion in a component.

2.7.2.4 WELD JOINT DESIGN

Weld joint design will effect the amount of distortion in a weldment. Both butt and fillet joints may experience distortion. However, distortion is easier to minimize in butt joints.

2.7.2.5 PART FIT UP

Part fit up should be consistent to fabricate foreseeable and uniform shrinkage. Weld joints should be adequately and consistently tacked to minimize movement between the parts being joined by welding.

2.7.2.6 TORCH VELOCITY

The velocity and angular distortion are related inversely. Increase in the torch velocity would result in lesser heat input and hence less distortion whereas on the other hand would result in higher distortion affects.

2.7.2.7 GAS DISCHARGE:

The gas discharge has lesser affect on the angular distortion. Higher gas discharge is required at high torch velocity welding. Lower discharge will result in oxide formation on the weld and consequently will result in a low quality weld joint.

2.7.2.8 CURRENT:

The current is the indication of the amount of charge travelling through per unit time, the higher the current, lower would be the effects of distortion due to effects of electrons on the weld pool.

2.7.2.9 BASE PLATE LENGTH:

The longer the plate length the lesser will be the rigidity of the plate and hence larger distortion.

3. GAS TUNGSTEN ARC WELDING

3. Gas tungsten arc welding:

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

GTAW is most commonly used to weld thin sections of stainless steel and light metals such as aluminium, magnesium, and copper alloys. The process grants the operator greater control over the weld than competing procedures such as shielded metal arc welding and gas metal arc welding, allowing for stronger, higher quality welds. However, GTAW is comparatively more complex and difficult to master, and furthermore, it is significantly slower than most other welding techniques. A related process, plasma arc welding, uses a slightly different welding torch to create a more focused welding arc and as a result is often automated.

3.1 GTAW Process

3.1.1 History of GTAW:

After the discovery of the electric arc in 1800 by Humphry Davy, arc welding developed slowly. C. L. Coffin had the idea of welding in an inert gas atmosphere in 1890, but even in the early 1900s, welding non-ferrous materials like aluminium and magnesium remained difficult, because these metals reacted rapidly with the air, resulting in porous and dross-filled welds. Processes using flux covered electrodes did not satisfactorily protect the weld area from contamination. To solve the problem, bottled inert gases were used in the beginning of the 1930s. A few years later, a direct current, gas-shielded welding process emerged in the aircraft industry for welding magnesium.

This process was perfected in 1941, and became known as heliarc or tungsten inert gas welding, because it utilized a tungsten electrode and helium as a shielding gas. Initially, the electrode overheated quickly, and in spite of tungsten's high melting temperature, particles of tungsten were transferred to the weld. To address this problem, the polarity of the electrode was changed from positive to negative, but this made it unsuitable for welding many non-ferrous materials. Finally, the development of alternating current units made it possible to stabilize the arc and produce high quality aluminium and magnesium welds.

Developments continued during the following decades. Linde Air Products developed water-cooled torches that helped to prevent overheating when welding with high currents.[4] Additionally, during the 1950s, as the process continued to gain popularity, some users turned to carbon dioxide as an alternative to the more expensive welding atmospheres consisting of argon and helium. However, this proved unacceptable for welding aluminium and magnesium because it reduced weld quality, and as a result, it is rarely used with GTAW today.

In 1953, a new process based on GTAW was developed, called plasma arc welding. It affords greater control and improves weld quality by using a nozzle to focus the electric arc, but is largely limited to automated systems, whereas GTAW remains primarily a manual, hand-held method. Development within the GTAW process has continued as well, and today a number of variations exist. Among the most popular are the pulsed-current, manual programmed, hot-wire, dabber, and increased penetration GTAW methods.

3.1.2 Advantages of GTAW:

- The greatest advantage of the GTAW process is that it will weld more kinds of metals and metal alloys than any other arc welding process.
- A narrow heat-affected zone is an advantage because this is where the base metal has undergone a change due to the superheating of the arc and fast cooling rate.
- There is no requirement for flux with this process; therefore, there is no slag to obscure the welder's vision of the molten weld pool.
- There are no molten globules of spatter to contend with and no sparks produced if the material being welded is free of contaminants.
- Also under normal conditions the GTAW arc is quiet without the usual cracks, pops, and buzzing of Shielded Metal Arc Welding (SMAW or Stick) and Gas Metal Arc Welding (GMAW or MIG).
- The process itself does not produce smoke or injurious fumes.

3.1.3 Limitations of GTAW:

- The main disadvantage of the GTAW process is the low filler metal deposition rate.
- Another disadvantage is that the hand-eye coordination necessary to accomplish the weld is difficult to learn, and requires a great deal of practice to become proficient.
- The arc rays produced by the process tend to be brighter than those produced by SMAW and GMAW
- The increased amounts of ultraviolet rays from the arc also cause the formation of ozone and nitrous oxides.
- When welding in confined areas, concentrations of shielding gas may build up and displace oxygen.

3.2 Equipment

The equipment required for the gas tungsten arc welding operation includes

- A welding torch utilizing a non-consumable tungsten electrode.
- A constant-current welding power supply
- A shielding gas source.
- A High - frequency arc start system.

3.2.1Welding Torch

GTAW welding torches are designed for either automatic or manual operation and are equipped with cooling systems using air or water. The automatic and manual torches are similar in construction, but the manual torch has a handle while the automatic torch normally comes with a mounting rack. The angle between the centreline of the handle and the centreline of the tungsten electrode, known as the head angle, can be varied on some manual torches according to the preference of the operator. Air cooling systems are most often used for low-current operations (up to about 200 A), while water cooling is required for high-current welding (up to about 600 A). The torches are connected with cables to the power supply and with hoses to the shielding gas source and where used, the water supply.

The internal metal parts of a torch are made of hard alloys of copper or brass in order to transmit current and heat effectively. The tungsten electrode must be held firmly in the centre of the torch with an appropriately sized collets, and ports around the electrode provide a constant flow of shielding gas. Collets are sized according to the diameter of the tungsten electrode they hold. The body of the torch is made of heat-resistant, insulating plastics covering the metal components, providing insulation from heat and electricity to protect the welder.

The size of the welding torch nozzle depends on the amount of shielded area desired. The size of the gas nozzle will depend upon the diameter of the electrode, the joint configuration, and the availability of access to the joint by the welder. The inside diameter of the nozzle is preferably at least three times the diameter of the electrode, but there are no hard rules. The welder will judge the effectiveness of the shielding and increase the nozzle size to increase the area protected by the external gas shield as needed. The nozzle must be heat resistant and thus is normally made of alumina or a ceramic material, but fused quartz, a glass-like substance, offers greater visibility. Devices can be inserted into the nozzle for special applications, such as gas lenses or valves to improve the control shielding gas flow to reduce turbulence and introduction of contaminated atmosphere into the shielded area. Hand switches to control welding current can be added to the manual GTAW torches.

3.2.2 Power supply

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

The preferred polarity of the GTAW system depends largely on the type of metal being welded.

- **Direct current with a negatively charged electrode (DCEN)**
- **Direct current with a positively charged electrode (DCEP)**

Direct current with a negatively charged electrode (DCEN)

Direct current with a negatively charged electrode (DCEN) is often employed when welding steels, nickel, titanium, and other metals. It can also be used in automatic GTA welding of aluminium or magnesium when helium is used as a shielding gas. The negatively charged electrode generates heat by emitting electrons which travel across the arc, causing thermal ionization of the shielding gas and increasing the temperature of the base material. The ionized shielding gas flows toward the electrode, not the base material.

Direct current with a positively charged electrode (DCEP)

Direct current with a positively charged electrode (DCEP) is less common, and is used primarily for shallow welds since less heat is generated in the base material. Instead of flowing from the electrode to the base material, as in DCEN, electrons go the other direction, causing the electrode to reach very high temperatures. To help it maintain its shape and prevent softening, a larger electrode is often used. As the electrons flow toward the electrode, ionized shielding gas flows back toward the base material, cleaning the weld by removing oxides and other impurities and thereby improving its quality and appearance.

Alternating current, commonly used when welding aluminium and magnesium manually or semi-automatically, combines the two direct currents by making the electrode and base material alternate between positive and negative charge. This causes the electron flow to switch directions constantly, preventing the tungsten electrode from overheating while maintaining the heat in the base material. Surface oxides are still removed during the electrode-positive portion of the cycle and the base metal is heated more deeply during the electrode-negative portion of the cycle. Some power supplies enable operators to use an unbalanced alternating current wave by modifying the exact

percentage of time that the current spends in each state of polarity, giving them more control over the amount of heat and cleaning action supplied by the power source. In addition, operators must be wary of rectification, in which the arc fails to reignite as it passes from straight polarity (negative electrode) to reverse polarity (positive electrode). To remedy the problem, a square wave power supply can be used, as can high-frequency voltage to encourage ignition.

3.2.3 Shielding gas

As with other welding processes such as gas metal arc welding, shielding gases are necessary in GTAW to protect the welding area from atmospheric gases such as nitrogen and oxygen, which can cause fusion defects, porosity, and weld metal embrittlement if they come in contact with the electrode, the arc, or the welding metal. The gas also transfers heat from the tungsten electrode to the metal, and it helps start and maintain a stable arc.

The selection of a shielding gas depends on several factors, including the type of material being welded, joint design, and desired final weld appearance. Argon is the most commonly used shielding gas for GTAW, since it helps prevent defects due to a varying arc length. When used with alternating current, the use of argon results in high weld quality and good appearance. Another common shielding gas, helium, is most often used to increase the weld penetration in a joint, to increase the welding speed, and to weld metals with high heat conductivity, such as copper and aluminium. A significant disadvantage is the difficulty of striking an arc with helium gas, and the decreased weld quality associated with a varying arc length.

Argon-helium mixtures are also frequently utilized in GTAW, since they can increase control of the heat input while maintaining the benefits of using argon. Normally, the mixtures are made with primarily helium (often about 75%

or higher) and a balance of argon. These mixtures increase the speed and quality of the AC welding of aluminium, and also make it easier to strike an arc. Another shielding gas mixture, argon-hydrogen, is used in the mechanized welding of light gauge stainless steel, but because hydrogen can cause porosity, its uses are limited. Similarly, nitrogen can sometimes be added to argon to help stabilize the austenite in austenitic stainless steels and increase penetration when welding copper. Due to porosity problems in ferritic steels and limited benefits, however, it is not a popular shielding gas additive.

3.2.4:High Frequency Arc Start Unit:

This equipment is used for starting the arc automatically.Sparks of high tension jump across the gap between electrode and workpiece rapidly to carry the welding current across to start welding in DC TIG welding, this will stop once the arc is struck, in AC TIG welding, this will normally continue to keep the arc alive as the AC output changes from a positive half cycle to a Negative half cycle and back again.

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

To strike the welding arc, a high frequency generator provides a path for the welding current through the shielding gas, allowing the arc to be struck when the separation between the electrode and the work piece is approximately

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

3.2.5 Electrode

- The electrode used in GTAW is made of tungsten or a tungsten alloy, because tungsten has the highest melting temperature among pure metals, at 3,422 °C (6,192 °F).
- The electrode is not consumed during welding, though some erosion (called burn-off) can occur.
- Electrodes can have either a clean finish or a ground finish clean finish electrodes have been chemically cleaned, while ground finish electrodes have been ground to a uniform size and have a polished surface, making them optimal for heat conduction.
- The diameter of the electrode can vary between 0.5 millimetre and 6.4 millimetres (0.02–0.25 in), and their length can range from 75 to 610 millimetres (3–24 in).
- A number of tungsten alloys have been standardized by the International Organization for Standardization and the American Welding Society in ISO 6848 and AWS A5.12, respectively, for use in GTAW electrodes, and are summarized in the adjacent table.

- Pure tungsten electrodes (classified as WP or EWP) are general purpose and low cost electrodes.
- Cerium oxide (or ceria) as an alloying element improves arc stability and ease of starting while decreasing burn-off.
- Using an alloy of lanthanum oxide (or lanthana) has a similar effect.
- Thorium oxide (or thoria) alloy electrodes were designed for DC applications and can withstand somewhat higher temperatures while providing many of the benefits of other alloys. However, it is somewhat radioactive. Inhalation of the thorium grinding dust during preparation of the electrode is hazardous to one's health.
- As a replacement to thoriated electrodes, electrodes with larger concentrations of lanthanum oxide can be used.
- Electrodes containing zirconium oxide (or zirconia) increase the current capacity while improving arc stability and starting and increasing electrode life.
- In addition, electrode manufacturers may create alternative tungsten alloys with specified metal additions, and these are designated with the classification EWG under the AWS system.
- Filler metals are also used in nearly all applications of GTAW, the major exception being the welding of thin materials.
- Filler metals are available with different diameters and are made of a variety of materials.
- In most cases, the filler metal in the form of a rod is added to the weld pool manually, but some applications call for an automatically fed filler metal, which often is stored on spools or coils.

3.3 MATERIALS APPLICABLE FOR GTAW

Gas tungsten arc welding is most commonly used to weld stainless steel and nonferrous materials, such as aluminium and magnesium, but it can be applied to nearly all metals, with notable exceptions being lead and zinc. Its applications involving carbon steels are limited not because of process restrictions, but because of the existence of more economical steel welding techniques, such as gas metal arc welding and shielded metal arc welding. Furthermore, GTAW can be performed in a variety of other-than-flat positions, depending on the skill of the welder and the materials being welded.

3.3.1 Steels

For GTA welding of carbon and stainless steels, the selection of a filler material is important to prevent excessive porosity. Oxides on the filler material and work pieces must be removed before welding to prevent contamination, and immediately prior to welding, alcohol or acetone should be used to clean the surface. Preheating is generally not necessary for mild steels less than one inch thick, but low alloy steels may require preheating to slow the cooling process and prevent the formation of martensite in the heat-affected zone. Tool steels should also be preheated to prevent cracking in the heat-affected zone. Austenitic stainless steels do not require preheating, but martensitic and ferritic chromium stainless steels do. A DCEN power source is normally used, and thoriated electrodes, tapered to a sharp point, are recommended. Pure argon is used for thin workpieces, but helium can be introduced as thickness increases.

3.3.2 Dissimilar metals

Welding dissimilar metals often introduces new difficulties to GTAW welding, because most materials do not easily fuse to form a strong bond.

However, welds of dissimilar materials have numerous applications in manufacturing, repair work, and the prevention of corrosion and oxidation. In some joints, a compatible filler metal is chosen to help form the bond, and this filler metal can be the same as one of the base materials (for example, using a stainless steel filler metal with stainless steel and carbon steel as base materials), or a different metal (such as the use of a nickel filler metal for joining steel and cast iron). Very different materials may be coated or "buttered" with a material compatible with a particular filler metal, and then welded. In addition, GTAW can be used in cladding or overlaying dissimilar materials.

When welding dissimilar metals, the joint must have an accurate fit, with proper gap dimensions and bevel angles. Care should be taken to avoid melting excessive base material. Pulsed current is particularly useful for these applications, as it helps limit the heat input. The filler metal should be added quickly, and a large weld pool should be avoided to prevent dilution of the base materials.

3.4 TYPES OF GTAW PROCESS:

- **Pulsed-current**
- **Dabber**
- **Hot Wire**

3.4.1Pulsed-current

- In the pulsed-current mode, the welding current rapidly alternates between two levels.
- The higher current state is known as the pulse current, while the lower current level is called the background current.

- During the period of pulse current, the weld area is heated and fusion occurs. Upon dropping to the background current, the weld area is allowed to cool and solidify.
- Pulsed-current GTAW has a number of advantages, including lower heat input and consequently a reduction in distortion and warpage in thin work pieces.
- In addition, it allows for greater control of the weld pool, and can increase weld penetration, welding speed, and quality.
- A similar method, manual programmed GTAW, allows the operator to program a specific rate and magnitude of current variations, making it useful for specialized applications.

3.4.2 Dabber

- The dabber variation is used to precisely place weld metal on thin edges. The automatic process replicates the motions of manual welding by feeding a cold filler wire into the weld area and dabbing (or oscillating) it into the welding arc.
- It can be used in conjunction with pulsed current, and is used to weld a variety of alloys, including titanium, nickel, and tool steels.
- Common applications include rebuilding seals in jet engines and building up saw blades, milling cutters, drill bits, and mower blades.

3.4.3 Hot Wire

- Welding filler metal can be resistance heated to a temperature near its melting point before being introduced into the weld pool.

- This increases the deposition rate of machine and automatic GTAW welding processes. More pounds per hour of filler metal is introduced into the weld joint than when filler metal is added cold and the heat of the electric arc introduces all of the heat.
- This process is used extensively in base material build up before machining, clad metal overlays, and hard facing operations.

3.5 Operation Modes

GTAW can use

- **Direct Current**
- **Negative Direct Current**
- **Alternating Current**

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

3.6 Quality

Engineers prefer GTAW welds because of its low-hydrogen properties and the match of mechanical and chemical properties with the base material. Maximum weld quality is assured by maintaining the cleanliness of the operation—all equipment and materials used must be free from oil, moisture, dirt and other impurities, as these cause weld porosity and consequently a decrease in weld strength and quality. To remove oil and grease, alcohol or similar commercial solvents may be used, while a stainless steel wire brush or chemical process can remove oxides from the surfaces of metals like aluminium. Rust on steels can be removed by first grit blasting the surface and then using a wire brush to remove any embedded grit. These steps are especially important when negative polarity direct current is used, because such a power supply provides no cleaning during the welding process, unlike positive polarity direct current or alternating current. To maintain a clean weld pool during welding, the shielding gas flow should be sufficient and consistent so that the gas covers the weld and blocks impurities in the atmosphere. GTA welding in windy or drafty environments increases the amount of shielding gas necessary to protect the weld, increasing the cost and making the process unpopular outdoors.

Because of GTAW's relative difficulty and the importance of proper technique, skilled operators are employed for important applications. Welders should be qualified following the requirements of the American Welding Society or American Society of Mechanical Engineers. Low heat input, caused by low welding current or high welding speed, can limit penetration and cause the weld bead to lift away from the surface being welded. If there is too much

heat input, however, the weld bead grows in width while the likelihood of excessive penetration and spatter increase. Additionally, if the welder holds the welding torch too far from the work piece, shielding gas is wasted and the appearance of the weld worsens.

If the amount of current used exceeds the capability of the electrode, tungsten inclusions in the weld may result. Known as tungsten spitting, it can be identified with radiography and prevented by changing the type of electrode or increasing the electrode diameter. In addition, if the electrode is not well protected by the gas shield or the operator accidentally allows it to contact the molten metal, it can become dirty or contaminated. This often causes the welding arc to become unstable, requiring that electrode be ground with a diamond abrasive to remove the impurity.

3.7 Safety

Like other arc welding processes, GTAW can be dangerous if proper precautions are not taken. The process produces intense ultraviolet radiation, which can cause a form of sunburn and, in a few cases, trigger the development of skin cancer. Flying sparks and droplets of molten metal can cause severe burns and start a fire if flammable material is nearby, though GTAW generally produces very few sparks or metal droplets when performed properly. It is essential that the welder wear suitable protective clothing, including leather gloves, a closed shirt collar to protect the neck (especially the throat), a protective long sleeve jacket and a suitable welding helmet to prevent retinal damage or ultraviolet burns to the cornea, often called arc eye. The shade of welding lens will depend upon the amperage of the welding current. Due to the absence of smoke in GTAW, the arc appears brighter than shielded metal arc welding and more ultraviolet radiation is produced. Exposure of bare skin near a GTAW arc for even a few seconds may cause painful sunburn. Additionally, the

tungsten electrode is heated to a white hot state like the filament of a light bulb, adding greatly to the total radiated light and heat energy. Transparent welding curtains, made of a polyvinyl chloride plastic film, dyed in order to block UV radiation, are often used to shield nearby personnel from exposure.

Welders are also often exposed to dangerous gases and particulate matter. Shielding gases can displace oxygen and lead to asphyxiation, and while smoke is not produced, the arc in GTAW produces very short wavelength ultraviolet light, which causes surrounding air to break down and form ozone. Metals will volatilize and heavy metals can be taken into the lungs. Similarly, the heat can cause poisonous fumes to form from cleaning and degreasing materials. For example chlorinated products will break down producing poisonous phosgene. Cleaning operations using these agents should not be performed near the site of welding, and proper ventilation is necessary to protect the welder.

3.8 Applications:

- While the aerospace industry is one of the primary users of gas tungsten arc welding, the process is used in a number of other areas.
- Many industries use GTAW for welding thin work pieces, especially nonferrous metals.
- It is used extensively in the manufacture of space vehicles, and is also frequently employed to weld small-diameter, thin-wall tubing such as those used in the bicycle industry.
- In addition, GTAW is often used to make root or first pass welds for piping of various sizes.
- In maintenance and repair work, the process is commonly used to repair tools and dies, especially components made of aluminium and magnesium. Because the weld metal is not transferred directly across the

electric arc like most open arc welding processes, a vast assortment of welding filler metal is available to the welding engineer.

- In fact, no other welding process permits the welding of so many alloys in so many product configurations.
- Filler metal alloys, such as elemental aluminium and chromium, can be lost through the electric arc from volatilization.
- This loss does not occur with the GTAW process. Because the resulting welds have the same chemical integrity as the original base metal or match the base metals more closely, GTAW welds are highly resistant to corrosion and cracking over long time periods, GTAW is the welding procedure of choice for critical welding operations like sealing spent nuclear fuel canisters before burial.

4. STAINLESS STEEL

4.1 INTRODUCTION

Stainless steels are defined as iron base alloys which contain at least 10.5% chromium. The thin but dense chromium oxide film which forms on the surface of a stainless steel provides corrosion resistance and prevents further oxidation. Less welding heat is required to make a weld clad because the heat is not conducted away from a clad as rapidly as in carbon steel. In resistance welding, lower current can be used because resistivity is higher.

4.2 TYPES OF STAINLESS STEELS

There are five types of stainless steels depending on the other alloying additions present, and they range from fully austenitic to fully ferritic types

1. Austenitic stainless steels include the 200 and 300 series of which type 304 is the most common. The primary alloying additions are chromium and nickel.
2. Ferritic stainless steels are non-hardenable Fe-Cr alloys. Types 405, 409, 430, 422 and 446 are representative of this group.
3. Martensitic stainless steels are similar in composition to the ferritic group but contain higher carbon and lower chromium to permit hardening by heat treatment. Types 403, 410, 416 and 420 are representative of this group.
4. Duplex stainless steels are supplied with a microstructure of approximately equal amounts of ferrite and austenite. They contain roughly 24% chromium and 5% nickel. Their numbering system is not included in the 200, 300 or 400 groups.
5. Precipitation hardening stainless steels contain alloying additions such as aluminum which allow them to be hardened by a solution and aging heat treatment. They are further

classified into sub groups as martensitic, semi austenitic and austenitic precipitation hardening stainless steels. They are identified as the 600-series of stainless steels (e.g., 630, 631, and 660).

Special Alloying Elements appearing in stainless steels are classified as ferrite promoters and austenite promoters and are listed below:

1. Ferrite Promoters:

   Chromium - provides basic corrosion resistance.

   Molybdenum - provides high temperature strength and increases corrosion resistance.

   Niobium (Columbium), Titanium - strong carbide formers.

2. Austenite Promoters:

   Nickel - provides high temperature strength and ductility.

   Carbon - carbide former, strengthener.

   Nitrogen - increases strength, reduces toughness.

4.2.1 AUSTENITIC STAINLESS STEELS

The austenitic stainless steels contain 16 - 26% Cr, 8 - 24% Ni + Mn, up to 0.40% C and small amounts of a few other elements such as Mo, Ti, and Nb. The balance between the Cr and Ni + Mn is normally adjusted to provide a microstructure of 90 - 100% austenite. These alloys are characterized by good strength and high toughness over a wide temperature range and oxidation resistance to over 1000°F (538°C). This group includes Types 302, 304, 310, 316, 321 and 347. Filler metals for these alloys should generally match the base metal, but for most alloys, a microstructure with some ferrite can be provided to avoid hot cracking. The filler materials are available as coated electrodes, solid bare wire and cored wire.

The material chosen for the experiment is Stainless Steel 202.Its Composition is given the table

Table: Composition Of Stainless Steel Grade 202

Element	Weight%
C	0.15
Mn	7.5-10.0
Si	1.0
Cr	17.0-19.0
Ni	4.0-6.0
P	0.06
S	0.03
N	0.25

4.2.2 FERRITIC STAINLESS STEELS

The ferritic stainless steels contain 10.5 to 30% Cr, up to 0.20% C and sometimes ferrite promoters Al, Nb (Cb), Ti and Mo. They are ferritic at all temperatures and, therefore, do not transform to austenite and are not hardenable by heat treatment. This group includes the more common types 405, 409, 430, 442 and 446. These types of stainless steel are characterized by weld and heat affected zoned (HAZ) grain growth which can result in low toughness of welds. To minimize grain growth, weld heat input should be minimized, preheat should be limited to 300 - 450°F (149 - 232°C) and used only for the higher carbon ferritic stainless steels (e.g., 430, 434, 442 and 446).

Many of the highly alloyed ferritic stainless steels are only available in sheet and tube forms and are usually welded by GTAW (Gas Tungsten Arc Welding) or TIG welding without filler metal.

4.2.3 MARTENSITIC STAINLESS STEELS

The martensitic stainless steels contain 11 to 18% Cr, up to 1.20% C and small amounts of Mn and Ni and, sometimes, Mo. These steels will transform to austenite on heating and, therefore, can be hardened by formation of martensite on cooling. This group includes Types 403, 410, 414, 416, 420, 422, 431 and 440. They have a tendency toward weld cracking on cooling when hard brittle martensite is formed. Chromium and carbon content of the filler metal should generally match these elements in the base metal. Preheating and interpass temperatures in the 400 - 600°F (204 - 316°C) range is recommended for most martensitic stainless steels. Steels with over 0.20% carbon often require a post weld heat treatment to soften and toughen the weld.

4.2.4 DUPLEX STAINLESS STEELS

Duplex stainless steels solidify as 100% ferrite, but about half of the ferrite transforms to austenite during cooling through temperatures above approximately 1900°F (1040°C). This behavior is accomplished by increasing chromium and decreasing nickel as compared to austenitic grades. Nitrogen is deliberately added to speed up the rate of austenite formation during cooling. Duplex stainless steels are ferromagnetic. They combine both the higher strength and fabrication properties of austenitic steels with the resistance to chloride stress corrosion cracking of ferritic stainless steels. The most common grade

is 2205 (UNS S32205), consisting of 22%Cr, 5%Ni, 3%Mo and 0.15% N.

4.2.5 PRECIPITATION HARDENING STAINLESS STEELS

There are three categories of precipitation hardening stainless steels – martensitic, semi austenitic and austenitic. The martensitic stainless steels can be hardened by quenching from the austenitizing temperature [around 1900°F (1038°C)] then aging between 900 - 1150°F (482 - 621°C). Since these steels contain less than 0.07% carbon, the martensite is not very hard and the main hardening is obtained from the aging (precipitation) reaction. The semi austenitic stainless steels will not transform to martensite when cooled from the austenitizing temperature because the martensite transformation temperature is below room temperature. These steels must be given a conditioning treatment which consists of heating in the range of 1350 to 1750°F (732 to 954°C) to precipitate carbon and/or alloy elements as carbides or intermetallic compounds. This removes alloy elements from solution, thereby destabilizing the austenite, which raises the martensite transformation temperature so that a martensite structure will be obtained on cooling to room temperature. Aging the steel between 850 - 1100°F (454 - 593°C) will stress relieve and temper the martensite to increase toughness, ductility, hardness and corrosion resistance.

The austenitic precipitation hardening stainless steels remain austenitic after quenching from the solutioning temperature even after substantial amounts of cold work. They are hardened only by the aging reaction. This would include solution treating between 1800 and 2050°F (982 to 1121°C), oil or water quenching and aging at 1300 to

1350°F (704 to 732°C) for up to 24 hours. If maximum strength is required in martensitic and semi austenitic precipitation hardening stainless steels, matching or nearly matching filler metal should be used and the component, before welding, should be in the annealed or solution annealed condition. After welding, a complete solution heat treatment plus an aging treatment is preferred. If the post weld solution treatment is not feasible, the components should be solution treated before welding then aged after welding. Thick sections of highly restrained parts are sometimes welded in the over aged condition. These would require a full heat treatment after welding to attain maximum strength. The austenitic precipitation hardening stainless steels are the most difficult to weld because of hot cracking. Welding should preferably be done with the parts in the solution treated condition, under minimum restraint and with minimum heat input.

4.3 SELECTION OF ELECTRODES

Selecting the proper filler metal for use with GMAW is similar to the process that must be employed when determining the applicable electrode for any welding process. The primary requirements are as follows:

1. The electrode must deposit welds that will have the mechanical and chemical properties needed for the proper performance of the weld cladded material.
2. The electrode must be suitable to address the unique circumstances associated with the particular application.
3. The electrode must meet the welder's expectations in terms of arc action and puddle control.

4. The selected electrode should result in the total overall lowest cost of weld cladding.

GMAW is a two-component welding process, in terms of the consumables that will be used: both a gas and an electrode are required. The electrode selection process cannot be made separate from consideration of the type of shielding gas that will be used. The most efficient means of selection of the proper filler metal for GMAW is to consider electrode/gas combinations when making comparisons. For example, a more expensive shielding gas, with a less expensive electrode, may or may not be more economical than a low cost gas and more expensive electrode. Thus, the electrode/gas combination must be considered. The gas selection can have an effect on mechanical properties as well. The effect of shielding gas on weld clad properties is more significant for the higher strength, and more alloyed, filler metals. Some of the factors affecting the welding electrode selection are explained as follows.

4.3.1 ELECTRODE DIAMETER

The diameter of the electrode used with GMAW is an important decision. Considerations have to be made for the various welding positions, the material thickness and the selected mode of metal transfer. Before the electrode diameter can be determined, a basic understanding of the welding procedure variables must be known. Larger diameter electrodes usually cost less, feed better, and can carry more current. Smaller diameters are appropriate for minimizing melt through on thinner materials, as well as to maximize deposition rates per amp of output.

4.3.2 WELD DEPOSIT CHEMISTRY

Under some conditions, it is important for the deposited weld metal to have a specific chemistry in order to meet service conditions. For example, when the weld is to have atmospheric corrosion resistance similar to "weathering" steels (such as A588), the weld is typically required to have a nickel content of 1%.

4.3.3 FINAL WELD CLAD APPEARANCE

The surface condition is another factor to be considered. Mill scale, rust, and other surface contaminants may justify the use of an electrode with a higher level of deoxidizers. When flat weld faces, low levels of spatter and other visual criteria are important, higher levels of silicon in the electrode may be helpful.

4.4 PURPOSE OF SELECTING ER 308L STAINLESS STEEL WIRE

The selection of a particular type stainless steel will depend on the requirement of the application. In most cases the primary consideration is corrosion resistance, tarnish resistance or oxidation resistance at elevated temperature. In addition to these requirements, the selected stainless steel must have some minimum mechanical properties such as strength, toughness, ductility and fatigue strength. Several types and grades of stainless steel may provide the corrosion resistance and mechanical properties required.

In this case, the final selection should be made on the basis of the lowest cost available alloy which will fulfill the service requirements. Generally, selection of the type of stainless steel is made by the designer of the equipment or component based on the knowledge,

experience and data on corrosion behavior of various alloys in the environment of interest. Other factors which must be considered in selecting a stainless steel are resistance to pitting, crevice corrosion and intergranular attack. If the application involves service at elevated temperature, then elevated temperature mechanical properties such as creep strength, stress rupture strength and oxidation resistance must be considered.

As mentioned Austenitic Stainless Steel has a high corrosion resistant property. The coefficient of thermal expansion for the Austenitic types is 50% greater than that of carbon steel and this must be considered to minimize distortion. ER 308L Stainless Steel wire is a type of Austenitic Stainless Steel. The low thermal and electrical conductivity of austenitic stainless steel is generally helpful. This facilitates its use in the weld cladding of the IS 2062 Carbon plate. The chemical composition of the ER 308L Stainless Steel in percentage is as follows:

4.4.1 USES OF INDIVIDUAL CHEMICAL ELEMENTS

1. Carbon (C) - Carbon is a critical element found in ER 308L SS wires. It is added in precise amounts to provide strength and ductility in the weldment.
2. Manganese (Mn) - Manganese is another element that adds strength to the weld. It is added to GMAW electrodes to act as a deoxidizer, removing oxygen from the weld, and reducing the chance of weld metal porosity.
3. Silicon (Si) - Silicon is also added to GMAW electrodes to act as a deoxidizer, removing oxygen from the weld, and reducing the chance of weld metal porosity. In general, the higher the

level of silicon in the metal, the more fluid the weld puddle. Additions of silicon increase tensile and yield strength.
4. Phosphorus (P) - The level of phosphorus is limited in ER 308L SS wires, as it is generally undesirable to the weld deposit. It can contribute to weld cracking
5. Sulphur (S) - The level of sulphur is limited in ER 308L SS wires, as it is generally undesirable for weldability and can contribute to weld cracking. However, in limited amounts, it improves fluidity and wetting.
6. Chromium (Cr) - Chromium is added to ER 308L SS wires for corrosion resistance. It is a primary element found in all Stainless steel electrodes.
7. Nickel (Ni) - Nickel found in ER 308L Stainless Steel wire is used as deoxidizers. Deoxidizers aid in removing oxygen and nitrogen from the weld, reducing the occurrence of weld metal porosity.

5. DESIGN OF FIXTURE

DESIGN OF FIXTURE :

A Fixture for holding the welding torch on the manipulator table was designed .The objective of the fixture is to provide a support to the GTAW torch and allow to rotate along its longitudinal axis. This feature allows the torch to set in a desired gun angle. The vertical motion of the torch is allowed by turning the nut (M16) on the vertical screw rod allowing the torch to move up and down depending on the direction of rotation of the nut. This feature allows the torch to vary the arc gap i.e. the distance between the torch tip and the base metal. The holder is made of wood .The holder is inserted through the hole in a rod. The hole can be decreased in its diameter with the help of Allen screw provided for tightening the slot in the front of the rod .The rod itself is seated in a bush by loose fitting .This feature allows the rod to slide along its longitudinal axis, as its surface is lubricated .The whole set up is supported by a 'L' shaped rod which in turn is mounted in the manipulator table. The material used for making the fixture is Mild Steel. This fixture is designed by keeping in mind that the features of fixture should be easy to use and requires less time to set.

6.EXPERIMENTAL DESIGN PROCEDURE

6.1 STEPS IN EXPERIMENTAL DESIGN PROCEDURE

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

1. Identification of factors and responses
2. Finding the limits of process variables
3. Development of design matrix
4. Conducting experiments as per the design matrix
5. Recording the response
6. Development of mathematical models
7. Checking adequacy of the developed models
8. Conducting conformity tests
9. Optimizing the mathematical model.
10. Generating interaction graphs.

6.1.1 IDENTIFICATION OF FACTORS AND RESPONSES

The input parameters were identified based on the literature survey.

- Current
- Welding speed
- Welding gun angle
- Gas Discharge and
- Base Plate Length

These parameters were found to be the vital independently controllable process parameters affecting the output parameters. Angular distortion is chosen as the response. The response was chosen based on the impact these parameters has on the final composition and properties of the composite material.

6.1.2 FINDING THE LIMITS OF THE PROCESS VARIABLES

The working ranges of all selected factors are fixed by conducting trial runs. This was carried out by varying one of the factors while keeping the rest of them as constant values. The working range of each process parameters was decided upon by inspecting the bead for a smooth appearance without any visible defects such as surface porosity, undercut, etc. The upper limit of a given factor was coded as +2 and the lower limit was coded as –2. The coded values for intermediate values were calculated using the equation (5.1):

$$X_i = 2\,[2X - (X_{max} + X_{min})] \,/\, [(X_{max} - X_{min})] \quad \text{--- (5.1)}$$

where X_i is the required coded value of a parameter X; X is any value of the parameter from X_{min} to X_{max}; X_{min} is the lower limit of the parameter and X_{max} is the upper limit of the parameter. The chosen levels of the selected process parameters with their units and notations are given in Table 5.1.

TABLE 6.1 WELDING PARAMETERS AND THEIR LEVELS

PARAMETER	UNIT	NOTATION	LEVELS				
			-2	-1	0	1	2
Gun Angle	Degrees	θ	50	60	70	80	90
Welding Speed	mm/min	V	80	90	100	110	120
Plate Length	mm	L	100	125	150	175	200
Current	Ampere	A	70	80	90	100	110
Gas Flow Rate	Litre/min	Q	5	10	15	20	25

6.1.3 DEVELOPMENT OF DESIGN MATRIX

The design matrix chosen to conduct the experiments was a central composite rotatable design. This design matrix comprises a full replication of $2^4 = 16$ factorial design plus 7 center points and 8 star points which is shown in Table 5.2. All welding parameters in the intermediate levels (0) constitute the center points and the combination of each welding parameters at either its

highest value (+2) or lowest value (-2) with other three parameters of the intermediate levels (0) constitute the star points.

TABLE 6.2 DESIGN MATRIX

EXP NO	Angle	Velocity	BaseMetal	Current	GasDischarg.
1	-1	-1	-1	-1	1
2	1	-1	-1	-1	-1
3	-1	1	-1	-1	-1
4	1	1	-1	-1	1
5	-1	-1	1	-1	-1
6	1	-1	1	-1	1
7	-1	1	1	-1	1
8	1	1	1	-1	-1
9	-1	-1	-1	1	-1
10	1	-1	-1	1	1
11	-1	1	-1	1	1
12	1	1	-1	1	-1
13	-1	-1	1	1	1
14	1	-1	1	1	-1
15	-1	1	1	1	-1
16	1	1	1	1	1
17	-2	0	0	0	0
18	2	0	0	0	0
19	0	-2	0	0	0
20	0	2	0	0	0
21	0	0	-2	0	0
22	0	0	2	0	0
23	0	0	0	-2	0
24	0	0	0	2	0
25	0	0	0	0	-2
26	0	0	0	0	2
27	0	0	0	0	0
28	0	0	0	0	0
29	0	0	0	0	0
30	0	0	0	0	0
31	0	0	0	0	0
32	0	0	0	0	0

6.1.4 CONDUCTING THE EXPERIMENTS AS PER DESIGN MATRIX

The experiments were conducted at Kumaraguru College of Technology, Coimbatore. In this work, thirty two experimental runs were allowed for the estimation of the linear, quadratic and two – way interactive effects of the process parameters on the distortion corresponding to each treatment combination of parameters as shown in Table 5.2 at random. At the end of each

run, settings for all parameters were disturbed and reset for the next deposit. This is essential to introduce variability caused by errors in experimental settings.

6.1.4.1 EXPERIMENTAL SET UP

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

1. A constant Gas Tungsten Arc Welding machine
2. Welding manipulator
3. Gas cylinder consisting a mixture of 100% argon
4. Grade 202 Stainless steel plate
5. High Frequency equipment

The main experimental set up used consists of a traveling carriage with a table for supporting the specimens. A power source is present . The welding gun is held stationary in a frame above the table, and it is provided with an attachment for setting the required nozzle to plate distance and welding gun angle respectively.

The experiments were conducted using the Lincoln Electric digital welding machine (GMAW & GTAW). Test plates of various sizes were cut from Grade 202 Stainless steel plate and one surface was cleaned to remove oxide scale and dirt before welding. Argon gas flow rate were varied for each experiments as per the requirements. The discharge was controlled using the flow meter in liters per minute.

6.1.5 RECORDING THE RESPONSES:

Procedure for measuring the distorted angle using Co-ordinate Measurement Machine (CMM):

STEPS:

1: The Microscribe G2 is switched on, it is indicated by a green light.

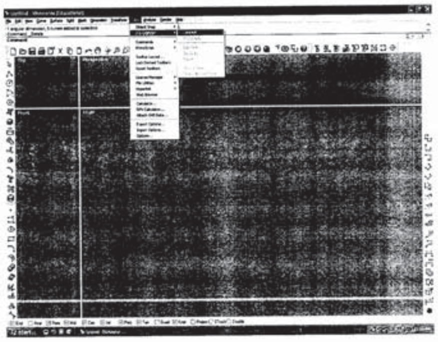
2: The work piece under observation is clamped to the desk with the help of C-clamp.

3: With the help of tri-square, straight lines are drawn to scribe at three or four places in the work pieces.

4: The Rhino 4.0 software is started.

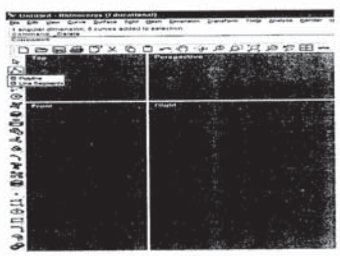
5: The Microscribe G2 is interfaced with the Rhino 4.0 software through a RS232 interface port. This interface between Rhino 4.0 and the CMM is initiated by clicking

TOOLS→3-D DIGITIZER→CONNECT



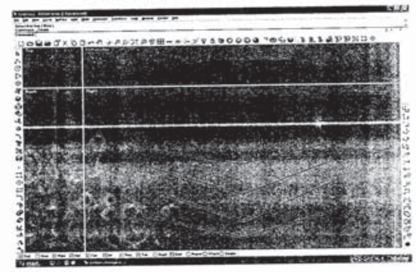
5: The limits for the work piece in X and Y direction are fixed ie, boundary for indicating the domain of the work piece .

6: Before scribing the points in the work piece, the polyline is selected. Usually all the four views will be visible in the screen.

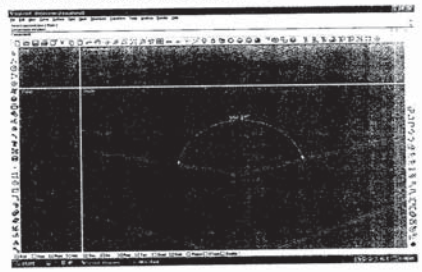


7: Scribe three or four points on all the straight lines marked already on the plates.

8: Lines will be plotted through the points which will be visible on the three view windows along with a perspective view.



9: By using the Angle dimension tool from the Dimension toolbar on the left of the window, the angle between the two lines can be measured.



The angle measured is the angle between the two lines i.e. β,The distorted angle α can be obtained by the relation

$$\alpha = (180° - \beta)/2$$

Four readings were taken randomly on each welded plate and the average value is recorded.

TABLE 6.3 DESIGN MATRIX AND THE OBSERVED VALUES OF THE ANGULAR DISTORTION

EXP NO	Angle	Velocity	BaseMetal	Current	GasDischarg	Angle
1	-1	-1	-1	-1	1	8.09
2	1	-1	-1	-1	-1	1.12
3	-1	1	-1	-1	-1	11.99
4	1	1	-1	-1	1	7.68
5	-1	-1	1	-1	-1	6.78
6	1	-1	1	-1	1	2.43
7	-1	1	1	-1	1	0.73
8	1	1	1	-1	-1	1.68
9	-1	-1	-1	1	-1	0.88
10	1	-1	-1	1	1	3.88
11	-1	1	-1	1	1	4.3
12	1	1	-1	1	-1	3.2
13	-1	-1	1	1	1	0.45
14	1	-1	1	1	-1	5.52
15	-1	1	1	1	-1	2.17
16	1	1	1	1	1	1.22
17	-2	0	0	0	0	5.78
18	2	0	0	0	0	5.46
19	0	-2	0	0	0	4.38
20	0	2	0	0	0	3.1
21	0	0	-2	0	0	2.51
22	0	0	2	0	0	1.76
23	0	0	0	-2	0	4.48
24	0	0	0	2	0	2.3
25	0	0	0	0	-2	0.92
26	0	0	0	0	2	1.73
27	0	0	0	0	0	2.65
28	0	0	0	0	0	3.42
29	0	0	0	0	0	3.14
30	0	0	0	0	0	3.52
31	0	0	0	0	0	8.78
32	0	0	0	0	0	5.4

6.1.6 DEVELOPMENT OF MATHEMATICAL MODELS

Using the observed values as obtained from Table 5.3, mathematical models were developed. The response function representing any of the clad bead geometry can be expressed using the equation (5.2)

$$Y = f(X_1, X_2, X_3, X_4, X_5) \quad \text{---- (5.2)}$$

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

X_1 = Welding Torch Angle (θ) in Degrees

X_2 = Torch Velocity (V) in mm/min

X_3 = Plate Length (L) in mm

X_4 = Current (I) in Ampere

X_5 = Gas Flow Rate (Q) in liter/min

The second order response surface model for the four selected factors is given by the equation (5.3):

$$Y = \beta_0 + \sum_{i=1}^{4} \beta_i X_i + \sum_{i=1}^{4} \beta_{ii} X_i^2 + \sum_{\substack{i=1 \\ i<j}}^{4} \beta_{ij} X_i X_j \quad \text{---- (5.3)}$$

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

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X5 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{33} X_3^2 + \beta_{44} X_4^2 + \beta_{55} X_5^2 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{14} X_1 X_4 + \beta_{15} X_1 X_5 + \beta_{23} X_2 X_3 + \beta_{24} X_2 X_4 + \beta_{25} X_2 X_5 + \beta_{34} X_3 X_4 + \beta_{35} X_3 X_5 + \beta_{45} X_4 X_5 \quad \text{---- (5.4)}$$

where β_0 is the free term of the regression equation, the coefficients β_1, β_2, β_3 and β_4 are linear terms, the coefficients β_{11}, β_{22}, β_{33} and β_{44} are the quadratic terms, and the coefficients β_{12}, β_{13}, β_{14}, β_{24} and β_{34} are the interaction terms. The coefficients were calculated using QA six sigma software (DOE-PC IV). After determining the coefficients, the insignificant coefficients are eliminated using backward propagation and the final mathematical model is developed. The developed mathematical model is given below:

- **Angular Distortion =** 4.207 - 0.388θ - 0.902V - 0.968L + 0.465θ^2 - .406V^2 -.608I^2 + 0.631θV + 1.294θL +.746θI -1.411QV + 0.898VL - 1.130VI

6.1.7 CHECKING THE ADEQUACY OF THE DEVELOPED MODELS

The adequacies of the developed model is tested using the analysis of variance (ANOVA) technique. As per this technique, if the F – ratio values for the developed models do not exceed the standard tabulated values for a desired level of confidence (95%) and the calculated R – ratio values of the developed model exceed the standard tabulated values for a desired level of confidence (95%), then the models are said to be adequate within the confidence limit. These conditions were satisfied for the developed models. The values are shown in Table 5.4.

ANALYSIS OF VARIANCE FOR TESTING ADEQUACY OF THE MODELS

The conditions for a mathematical model to be adequate

- F ratio< Standard Tabulated Value

- R ratio>Standard Tabulated Value

F Ratio = Lack of Fit: Pure Error

R Ratio = Factors: Pure Error

The observed values from the ANNOVA calculations are..

TABLE 6.4 Table Analysis of variance for testing adequacy of models

Pure Error	8
Factors	12
Lack Of Fit	11

The tabulated Value:

F (11, 8) =3.31 for 95% confidence level

R (12, 8) =3.35

The observed values of F-ratio and R-ratio were found to satisfy the conditions for a mathematical model to be adequate.

7.DEVELOPMENT OF MATHEMATICAL MODEL USING QUALITY OF AMERICA SOFTWARE

7.1 SOFTWARES USED FOR THE DEVELOPMENT OF REGRESSION MODEL

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

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

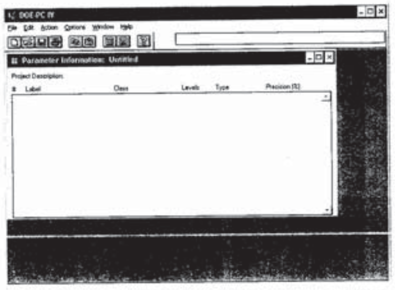
Among these softwares, using the Quality America Six Sigma Software (DOE - PC IV) has been found to be easier to calculate the regression coefficients. Hence, this software is used for the experimental study purpose.

7.2 STEPS IN FINDING REGRESSION COEFFICIENTS

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

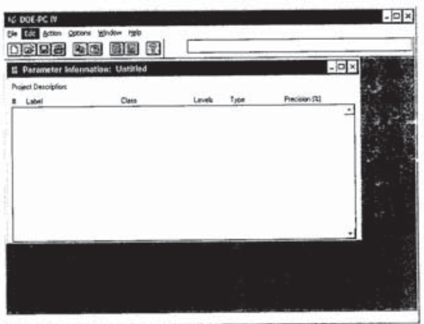
STEP 1:

A new file of DOE – PC 1V software is opened.



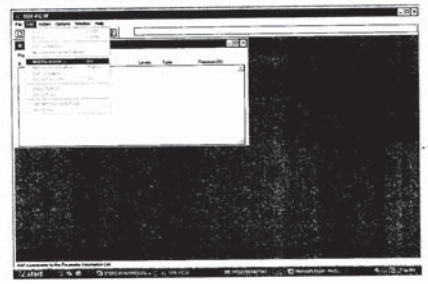
STEP 2:

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



STEP 3:

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

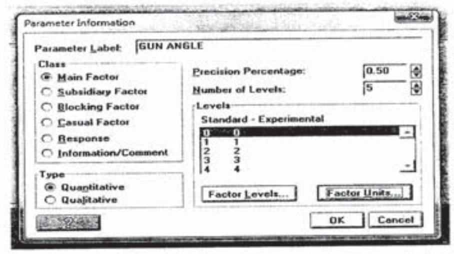


STEP 4:

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

STEP 5:

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



STEP 6:

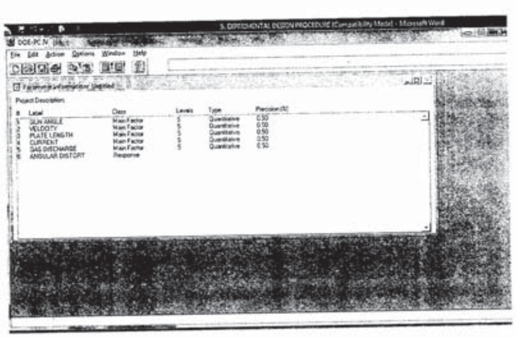
Similarly, steps 3 to 5 are followed to enter all the input parameters along with their respective units and limit values.

STEP 7:

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

STEP 8:

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

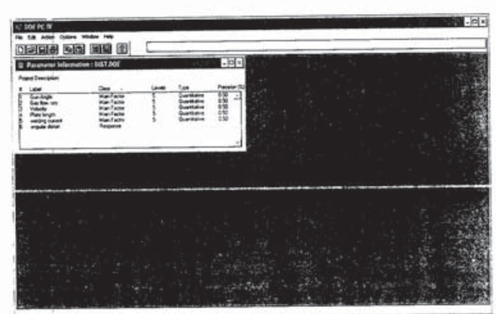


STEP 9:

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

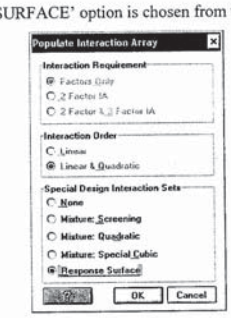
STEP 10:

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



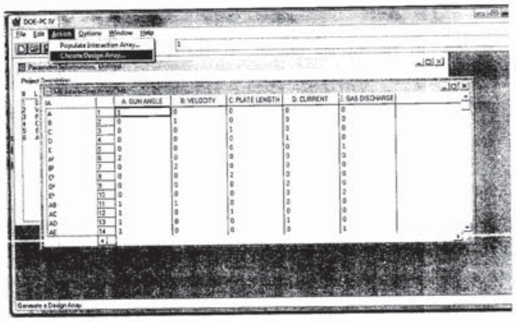
STEP 11:

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



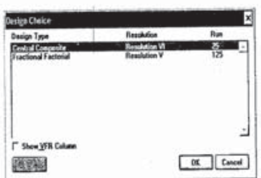
STEP 12:

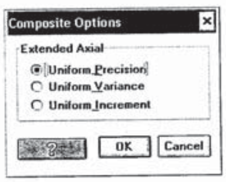
Now the 'CHOOSE DESIGN ARRAY' option is chosen from the drop down menu.

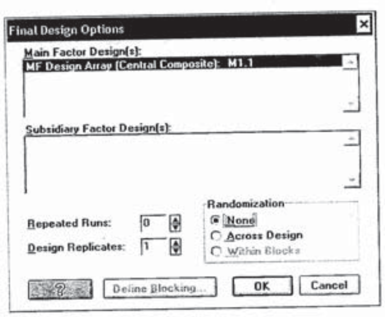


STEP 13:

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

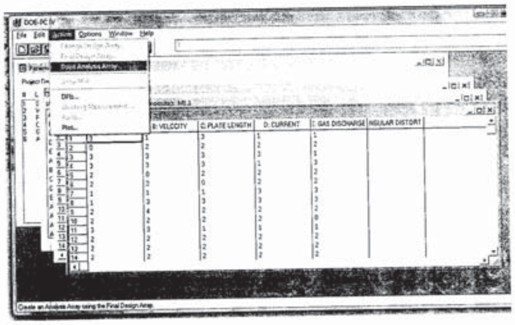






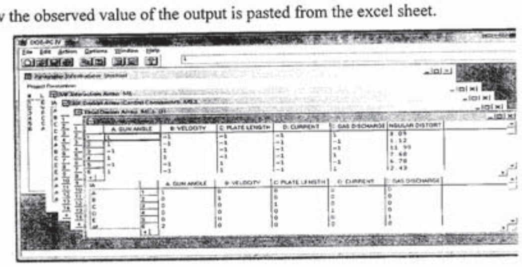
STEP 16:

Then the 'BUILD ANALYSIS ARRAY' option is chosen.



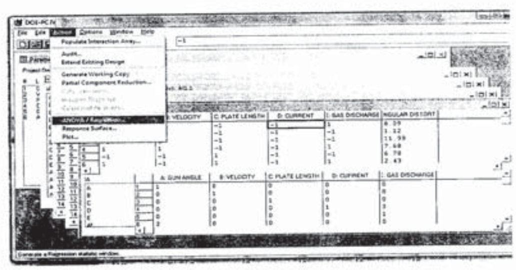
STEP 17:

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



STEP 18:

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



STEP 19:

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

8.OPTIMIZATION OF MATHEMATICAL MODEL:

8.1 THE SOFTWARES USED FOR THE OPTIMIZATION OF MATHEMICAL MODEL

Some of the softwares used for optimizing the mathematical model are….

- MATLAB 7.0
- SYSTAT
- LINGO
- SWARMOPS

MATLAB 7.0 is chosen among these softwares for its diversity of techniques available in it for optimization .Some of the optimization features available in MATLAB 7.0 are

- Optimization Tool
- Genetic algorithm Tool
- Particle Swarm Optimization Technique

Among these GENETIC ALGORITHM optimization technique is chosen for finding the best fitness value for its advantages.

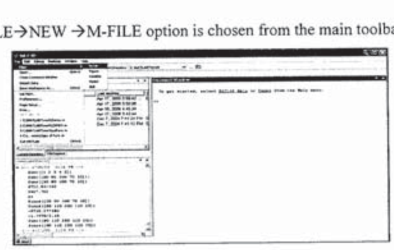
- Optimizes with continuous or discrete variables,
- Doesn't require derivative information,
- Simultaneously searches from a wide sampling of the cost surface,
- Deals with a large number of variables,
- Optimizes variables with extremely complex cost surfaces (they can jump out of a local minimum),
- Provides a list of optimum variables, not just a single solution,
- May encode the variables so that the optimization is done with the encoded variables, and works with numerically generated data, experimental data, or analytical functions.

8.2 PROCEDURE TO FIND THE FITNESS VALUE:

STEPS:

1.Open the MATLAB software.

2.FILE→NEW →M-FILE option is chosen from the main toolbar



3.The function to be optimized is entered in the m-file in the MATLAB format and saved as 'filename.m'.

4.The Genetic Algorithm tool is opened by either by clicking on the START button on the bottom right corner and then

- START→TOOLS→MORE→GENETIC ALGORITHM→GATOOL

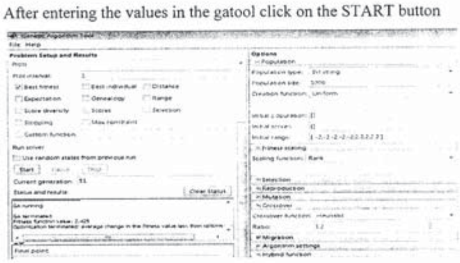
or either by typing

- 'gatool' in command window

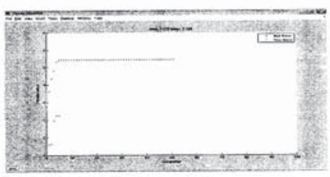
5. The function handle of the file in the format '@filename' which contains the function is typed in the objective function box.

6. The following options are changed as…

- Number Of variables…………………...5
- population type…………………………Bit string
- Initial Range ……………………………[-2,-2,-2,-2,-2,2,2,2,2,2] Crossover Function ………………………………Heuristic
- After entering the values in the gatool click on the START button



Thus best fitness value and the corresponding values for the input parameters are obtained as



RESPONSE	Angular Distortion	(Degrees)	2.428
INPUT	Gun Angle	(Degrees)	60
PARAMETERS	Torch Velocity	(mm/min)	90
	Base Plate length	(mm)	125
	Current	(Ampere)	80
	Gas Discharge	(liter/min)	10

Fig 8.1 Best Fitness Value

9.INTERACTION GRAPHS

9.1 SOFTWARE USED FOR PLOTTING THE GRAPHS :

Some of the software packages used for generating graphs are…….

- MATLAB
- SYSTAT

Among the softwares available MATLAB is chosen for plotting the interaction graphs due its availability of variety of functions to display 3-D data. The Interaction graphs are plotted between three variables among which one variable is the response 'Angular Distortion' and the remaining two are any of the two input parameters among:

- Gun Angle — Degrees
- Torch Velocity — mm/min
- Base Plate Length — mm
- Current — Ampere

Parameters		Values corresponding the 0^{th} level
Gun Angle	Degrees	70
Torch Velocity	mm/min	100
Current	Ampere	90
Gas Discharge	litre/min	15
Base Plate Length	mm	150

- Gas discharge litre/min

The remaining three parameters which are not included in the graph are kept constant at their middle levels i.e. at level '0'.

9.2 PROCEDURE TO PLOT THE GRAPH:

An example for plotting the interaction between Angular Distortion , Gas Discharge and Base Plate Length is illustrated:

STEPS:

1.Open the MATLAB software

2. The Command window will be displayed. Type the following code in command window.

```
x = -2:.1:2;

y=-2:.1:2;

[XY]=meshgrid(x,y);

Z= 4.207-.968*x(:,3);

mesh (X,Y,Z);
```

The function Z represents the relation netween the response and the two variables under considerations i.e.X and Y.

INTERACTION GRAPHS

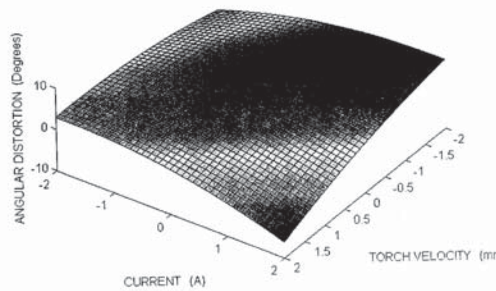


Fig 9.1 Angular Distortion-Current-Torch Velocity

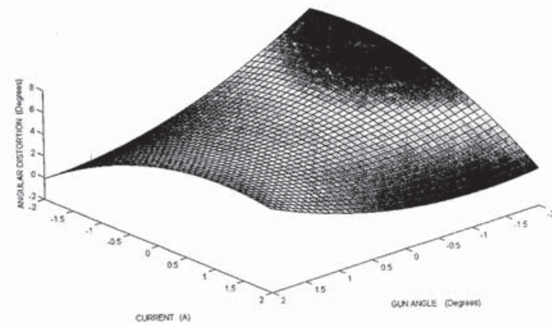


Fig 9.2 Angular Distortion-Current-Gun Angle

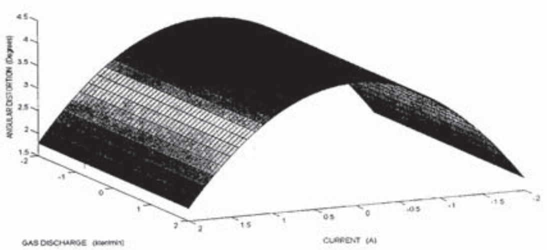


Fig 9.3 Angular Distortion-Current-Gas Discharge

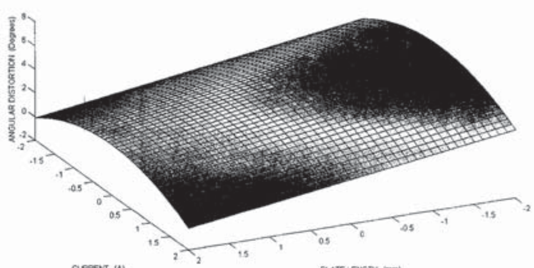


Fig 9.4 Angular Distortion-Current-Base Plate Length

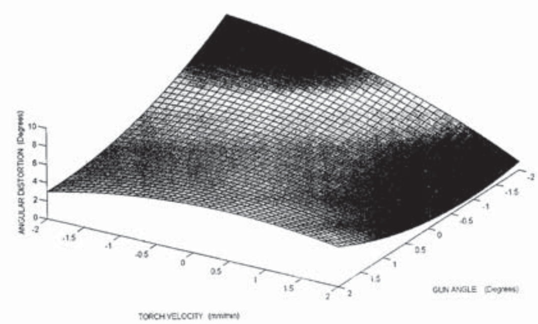


Fig 9.5 Angular Distortion-Velocity-Gun Angle

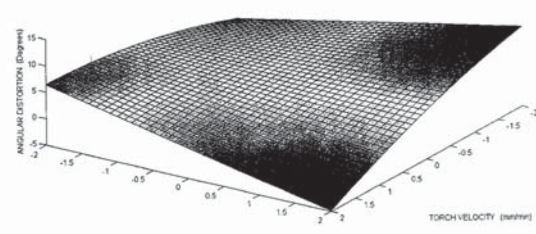


Fig 9.6 Angular Distortion-Velocity-Gas Discharge

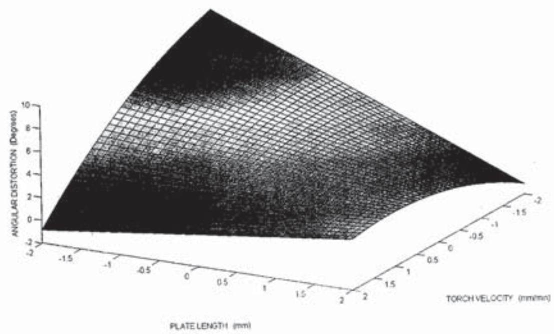


Fig 9.7 Angular Distortion-Velocity-Base Plate Length

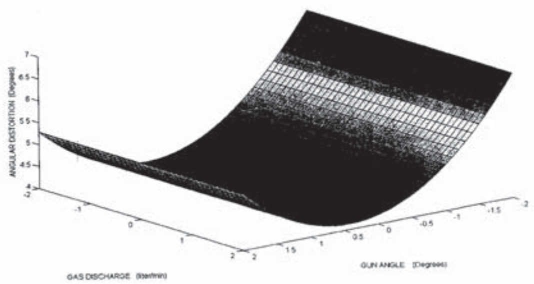


Fig 9.8 Angular Distortion-Gun Angle-Gas Discharge

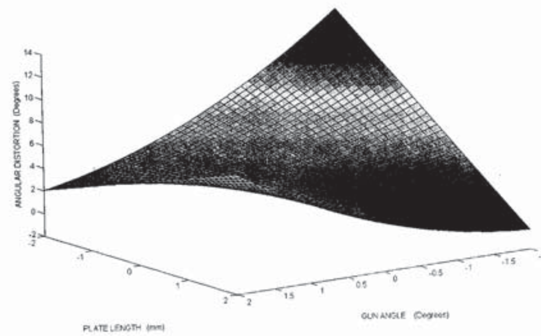


Fig 9.9 Angular Distortion-Gun Angle-Base Plate Length

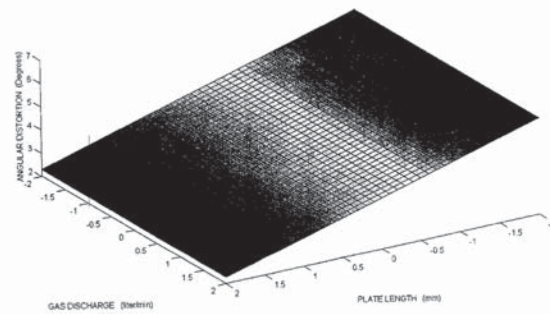


Fig 9.10 Angular Distortion-Base Plate Length-Gas Discharge

OBSERVATION:

- Fig 9.1 its observed that decrease in velocity has resulted in increased distortion at higher current value but the response is slightly lower at lower current .Minimum distortion is obtained at higher current and higher velocity but the distortion increases as the current reduces.

- Fig 9.2Maximum distortion is observed at lower gun angle and lower current but the distortion reduces as the current increases .Minimum distortion is obtained at lower current and higher gun angle.

- Fig 9.3The angular distortion is observed to be independent of gas discharge but a uniform increase and decrease of distortion is observed along the current. There is no interaction between gas discharge and current.
- Fig 9.4An uniform increase in distortion is observed as the plate length decreases. Maximum distortion is obtained at lower plate length and along the middle range of current. The distortion increases and decreases as the current increases.
- Fig 9.5Maximum distortion is obtained at the lower velocity and lower gun angle.As the velocity is increased the distortion is reduced, but an increasing trend in distortion is observed as the gun angle increases.
- Fig 9.6Maximum distortion is obtained at lower velocity and gas discharge but reaches maximum as the velocity decreases. An increasing trend in distortion is observed as the gas discharge is decreased at higher velocity.

The distortion is observed quite constant above 5 degrees in the remaining interaction domain.

- Fig 9.7Maximum distortion is observed at lower velocity and lower plate length but the distortion decreases as the plate length increases. Minimum distortion is observed at higher velocity and lower plate length and also at lower velocity higher plate length.

- Fig 9.8 Angular distortion is observed to be independent of the gas discharge but an increasing and decreasing trend in the response is observed as the gun angle is reduced .No interaction between gas discharge and gun angle is observed.
- Fig 9.9 Increased distortion s observed at lower plate length and lower gun angle but the distortion is suppressed as the plate length increases. Increased distortion is also observed at higher plate length and higher gun angle .minimum distortion is observed at lower plate length and lower gun angle.
- Fig 9.10 Angular distortion observed to be independent of gun angle but an uniformly increasing trend is observed as the plate length decreases. No interaction is observed between gas discharge and plate length.

10.CONCLUSION

The following conclusions were arrived from the investigation.

1. The second order quadratic equation has been developed successfully to predict the values of Angular distortion for SS 202 in GTAW. It allows industry to reduce the process and minimize angular distortion by using a relatively smaller number of experimental runs and cost to achieve superior quality welds.

2. The central composite rotatable design can be used to predict the main effects and the interaction effects of different combination of process parameters within the range of investigation on angular distortion in GTAW.

3. The calculated angular distortion is compared with experimental angular distortion value and the deviation falls with the limit of 95% confidence level.

4. Optimization of process parameters is done using MATLAB software and interactive effects of the parameters that is Angular distortion-Gun angle-Plate length, Angular distortion-Plate length-Gas discharge, Angular distortion-Velocity-Plate length, Angular distortion-Gun angle-Gas discharge, Angular distortion-Velocity-Gas discharge, Angular distortion-Velocity-Gun angle, Angular distortion-Current-Gas discharge, Angular distortion-Current-Plate length, Angular distortion-Current-Velocity, Angular distortion-Current-Gun angle are studied and optimized.

5. It's observed that increase in welding velocity has a decreasing effect on the angular distortion. longer plates tend to distort little than the shorter plates from the distortion. Gas discharge has no interaction effects on the other parameters other than the velocity. Increased gun angle along with the velocity tend to produce less distortion whereas along with the parameters Length and the current decreased gun angle produce less distortion.

11. APPENDIX

EQUIPMENT PHOTOS:

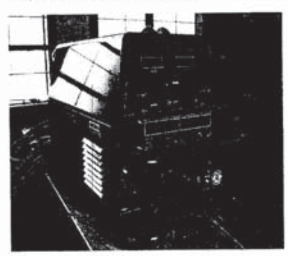
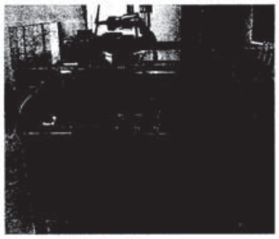


Fig 11.1GTAW Power Supply

Fig 11.2 High Frequency Unit

Fig 11.3 Argon Gas Cylinder and Presure gauge unit

Fig 11.4 GTAW welding torch



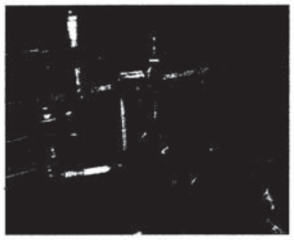


Fig 11.5 Manipulator **Fig 11.6 Torch Fixture Set Up**

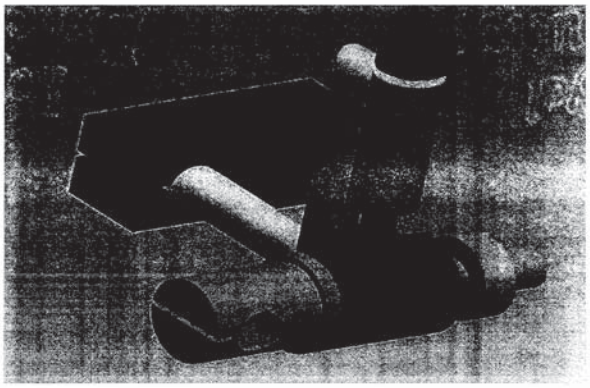


Fig 11.7 Pro-E model of Fixture Design

Fig 11.8 Angular and Camber Distortion in welded plates

Fig 11.9 Welded Plates

Fig 11.10 Microscribe G2-CMM **Fig 11.11 CMM interfaced with the Computer**

Fig 11.12 Welded plate clamped to the desk for measurement **Fig 11.13 Measurement Of angular Distortion**

12.REFERENCES

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