Study on Mechanical properties of TIG welded joints of AISI 202 and AISI 316 steels

A project report submitted in partial fulfillment of the requirements for the Award of the Degree of

BACHELOR OF ENGINEERING
IN
MECHANICAL ENGINEERING

by

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CERTIFICATE

This is to certify that the Project Report entitled **"STUDY ON MECHANICAL PROPERTIES OF TIG WELDED JOINTS OF AISI 202 AND AISI 316 STEELS"** being submitted by NANDHIKOLLA SIVA PRASAD (317126520100), PANDIRI HARSHABHAVANI (317126520106), GUDIPALLE RANJITH KUMAR (317126520083), KINTADA GANESH (318126520L23), ANDHAVARAPU NAVEEN (317126520063) in partial fulfillments for the award of degree of **BACHELOR OF TECHNOLOGY** in **MECHANICAL ENGINEERING, ANITS**. It is the work of bona-fide, carried out under the guidance and supervision of **MR.G.UMA MAHESWARA RAO**, Assistant Professor, Department Of Mechanical Engineering, ANITS during the academic year of 2017-2021.

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ABSTRACT

Tungsten Inert Gas (TIG) welding is one of the most common welding process used for joining steels. In the present work AISI 202 and AISI 316 steels are joined using TIG welding process. Welding Current, Welding Speed, Flow rate of inert gas, filler wire diameter are considered as welding input parameters. Tensile strength, hardness and impact Strength is considered as output responses. Experiments will be performed by using Design Of Experiments. Multi-objective optimization technique will be used for optimization of the Input parameters to obtain the desired output responses.

CONTENTS

Para No	Description	Page No
	CHAPTER-I	
	INTRODUCTION	
1.1	Introduction to welding	1
1.2	Classification of welding	1
1.3	Arc welding	2
1.4	TIG welding	4
1.4.1	History of TIG welding	5
1.4.2	Principle of operation	10
1.4.3	Equipment and description	11
1.4.4	Power source	12
1.4.5	Output control	13
1.4.6	TIG Torch	15
1.4.7	Electrodes	16
1.4.8	Shielding gas	19
1.4.9	Welding process	20
1.4.10	TIG Welding applications	21
1.5	Advantages of TIG welding	9
1.6	Disadvantages of TIG welding	9
	CHAPTER-II	
	LITERATURE REVIEW	
2.1	Design of experiments	22
2.2	Finite element analysis(FEA)	25
2.3	Hybrid welding (TIG & MIG)	26
2.4	Microstructure and mechanical properties	27
2.5 2.6	Corrosion Others	34 36
	CHAPTER-III	
	DESIGN OF EXPERIMENTS	
3.1	Introduction to Design of Experiments	37

3.2	Advantages & Disadvantages of DOE	38
3.3	Response Surface Method	38
3.3.1	Central Composite Designs	39
3.3.2	Box-Behnken Designs	40
3.4	Application of Design of Experiments	41
3.4.1	Identification of the Process Parameters	41
3.4.2	Finding the Limits of the Process Variables	41
3.4.3	Developing the Design Matrix	42
3.4.4	Conducting the Experiments as per the Design Matrix	43
	CHAPTER-IV	
	EXPERIMENATAL DETAILS	
4.1	Stainless Steels	44
4.2	Base Material	44
4.3	Weld Joint preparation	44
4.4	Experimental Procedure	45
4.5	Equipment Used for Testing	47
4.5.1	Brinell Hardness Machine	48
4.5.2	Rockwell Hardness Machine	53
	CHAPTER-V	
	STATISTICAL ANALYSIS AND OPTIMIZATION	
5.1	Conducting the Experiments as per the Design Matrix	55
5.2	Mathematical models	55
5.3	Effect of welding parameters	56
5.4	Optimization	57
5.5	Graphs for Brinell and Rockwell Hardness Numbers	57
	CHAPTER-VI	
	CONCLUSIONS & FUTURE SCOPE	
6.1	Conclusions	60
6.2	Future scope	61

	REFERENCES	62

LIST OF TABLES

Table No	Table Description	Page No
3.1	Comparison of CCD’s	41
3.2	Process parameters and their limits	43
3.3	Welding conditions	43
3.4	Typical Design Matrix	44
4.1	Chemical composition of AISI 316 (weight %)	47
4.2	Mechanical properties of AISI 316	47
4.3	Chemical composition of AISI 202 (weight %)	47
4.4	Mechanical properties of AISI 202	47
4.5	Welding conditions	47
4.6	Input parameters	48
4.7	Specifications of Brinell Harndness Machine	52
4.8	Specifications of Rockwell Harndness Machine	54
5.1	Experimental Results	55

LIST OF FIGURES

Figure No	Figure description	Page No
1.1	Flow chart of welding classification	2
1.2	ARC welding representation	3
1.3	Representation of TIG welding	10
1.4	Parts of TIG welding	11

1.5	Parts of Torch	15
1.6	Line Diagram of TIG Welding	19
3.1	Circumscribed, Inscribed and Faced designs	40
3.2	Box-Behnken design	41
4.1	Dimensions of welded joint	46
4.2	Brinell Hardness Number	52
4.3	Rockwell Hardness Machine	54
5.5.1	Graphs for Brinell Hardness Number	57
5.5.2	Graphs for Rockwell Hardness Number	59

NOMENCLATURE

DOE	Design of Experiments
RSM	Response Surface Method
TIG	Tungsten Inert Gas welding
GMAW	Gas Metal Arc Welding
F-test	Fishers Test
B.H.N	Brinell Hardness Number
R.H.N	Rockwell Hardness Number

CHAPTER-I

INTRODUCTION

1.1 Introduction to welding

Welding is a fabrication process that joins materials, usually metals or thermoplastics, by using high heat to melt the parts together and allowing them to cool causing fusion. Welding is distinct from lower temperature metal-joining techniques such as brazing and soldering, which do not melt the base metal.

In addition to melting the base metal, a filler material is typically added to the joint to form a pool of molten material (the weld pool) that cools to form a joint that, based on weld configuration (butt, full penetration, fillet, etc.), can be stronger than the base material (parent metal). Pressure may also be used in conjunction with heat, or by itself, to produce a weld. Welding also requires a form of shield to protect the filler metals or melted metals from being contaminated or oxidized.

Many different energy sources can be used for welding, including a gas flame (chemical), an electric arc (electrical), a laser, an electron beam, friction, and ultrasound. While often an industrial process, welding may be performed in many different environments, including in open air, under water, and in outer space. Welding is a hazardous undertaking and precautions are required to avoid burns, electric shock, vision damage, inhalation of poisonous gases and fumes, and exposure to intense ultraviolet radiation.

1.2 Classification of welding

With reference to the Fig-1, the welding is broadly classified into fusion and solid state welding processes. Fusion welding is a process that uses heat to join or fuse two or more materials by heating them to melting point. Whereas, in solid state welding two work pieces are joined under a pressure, providing an intimate contact between them, at a temperature essentially below the melting point temperature of parent metal.

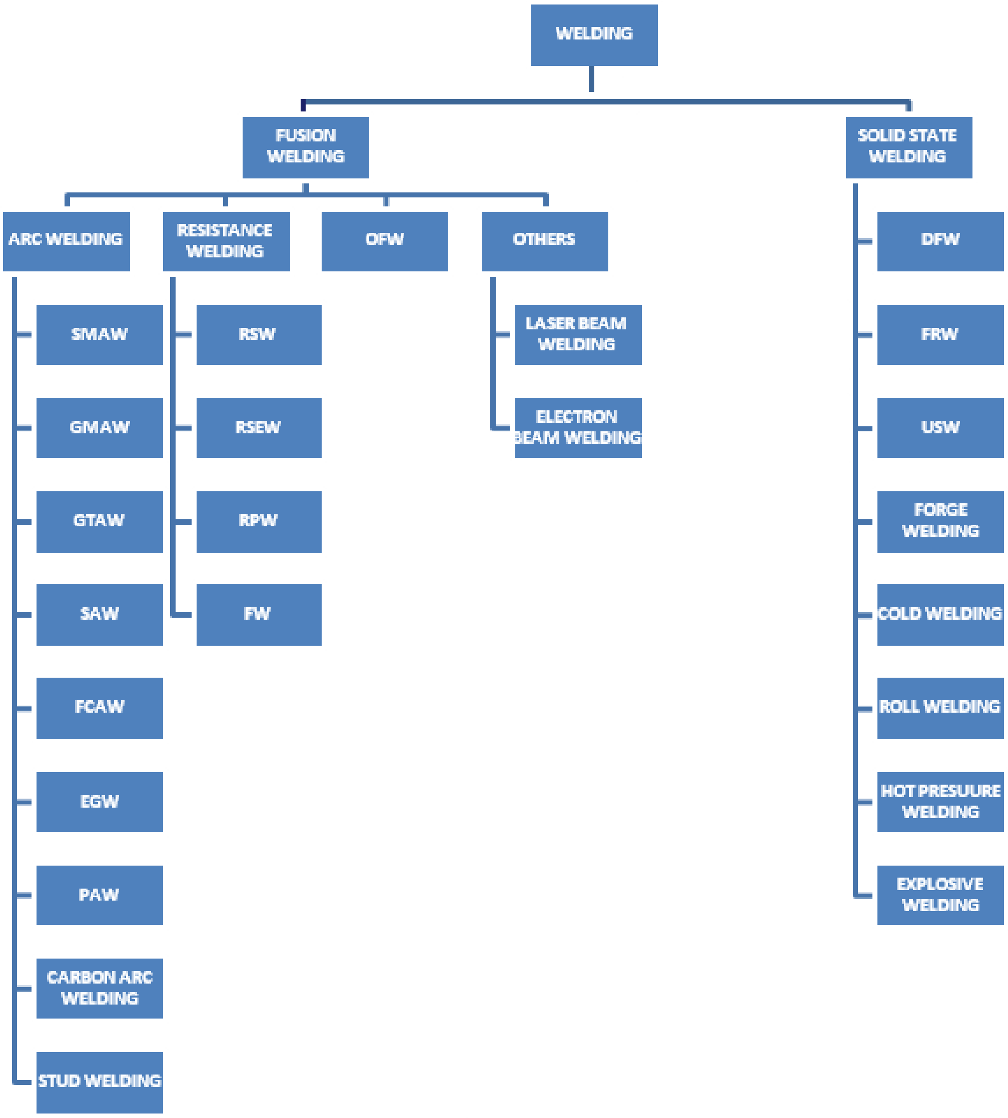


Fig 1.1 Flow chart Welding classification

1.3 Arc welding

Arc welding is a fusion welding process used to join metals. An electric arc from an AC or DC power supply creates an intense heat of around 6500°F which melts the metal at the joint between two work pieces, as shown in Fig-1.2.

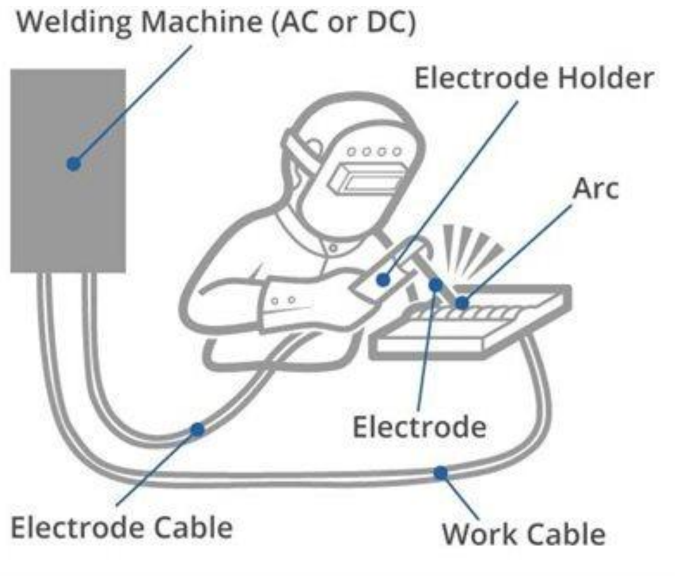


Fig-1.2 ARC welding representation

The arc can be either manually or mechanically guided along the line of the join, while the electrode either simply carries the current or conducts the current and melts into the weld pool at the same time to supply filler metal to the join.

Because the metals react chemically to oxygen and nitrogen in the air when heated to high temperatures by the arc, a protective shielding gas or slag is used to minimize the contact of the molten metal with the air. Once cooled, the molten metals solidify to form a metallurgical bond.

The arc welding is classified into

1. Plasma Arc Welding
2. Metal Arc Welding
3. Carbon Arc Welding
4. Gas Tungsten Arc Welding
5. Gas Metal Arc Welding
6. Submerged Arc Welding

Advantages

There are a number of advantages to using arc welding compared with many other formats:

1. Cost – equipment for arc welding is well-priced and affordable, and the process often requires less equipment in the first place because of the lack of gas
2. Portability – these materials are very easy to transport
3. Works on dirty metal
4. Shielding gas isn’t necessary – processes can be completed during wind or rain, and spatter isn’t a major concern

Disadvantages

There are a few reasons why some people look to other options beyond arc welding for certain kinds of projects. These downsides can include:

1. Lower efficiency – more waste is generally produced during arc welding than many other types, which can increase project costs in some cases
2. High skill level – operators of arc welding projects need a high level of skill and training, and not all professionals have this
3. Thin materials – it can be tough to use arc welding on certain thin metals

1.4 TIG 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 and electrode is protected from oxidation or other atmospheric contamination by an inert shielding gas (argon or helium), and a filler metal is normally used, though some welds, known as autogenous welds, do not require it. When helium is used, this is known as heli arc welding. A constant-current welding power supply produces electrical energy, which is conducted across the arc through a column of highly ionized gas and metal vapors known as plasma.

GTAW is most commonly used to weld thin sections of stainless steel and non-ferrous metals such as aluminum, magnesium, and copper alloys. The process grants the operator greater control over the weld than competing processes 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.

1.4.1 History of TIG Welding

Middle Ages

Welding can trace its historic development back to ancient times. The earliest examples of welding come from the Bronze Age. Small gold circular boxes were made by pressure welding lap joints together. It is estimated that these boxes were made more than 2,000 years ago. During the Iron Age the Egyptians and people in the eastern Mediterranean area learned to weld pieces of iron together. Many tools were found that were made in approximately 1000 B.C.

During the middle Ages, the art of blacksmithing was developed and many items of iron were produced that were welded by hammering. It was not until the 19th century that welding as we know it today was invented.

1800

Edmund Davy of England is credited with the discovery of acetylene in 1836. The production of an arc between two carbon electrodes using a battery is credited to Sir Humphry Davy in 1800. In the mid-19th century, the electric generator was invented and arc lighting became popular. During the late 1800s, gas welding and cutting was developed. Arc welding with the carbon arc and metal arc was developed and resistance welding became a practical joining process.

1880

Auguste De Meritens, working in the Cabot Laboratory in France, used the heat of an arc for joining lead plates for storage batteries in the year 1881. It was his pupil, a Russian, Nikolai N. Benardos, working in the French laboratory, who was granted a patent for welding. He, with a fellow Russian, Stanislaus Olszewski, secured a British patent in 1885 and an American patent in 1887. The patents show an early electrode holder. This was the beginning of carbon arc welding. Benardos' efforts were restricted to carbon arc welding, although he was able to weld iron as well as lead. Carbon arc welding became popular during the late 1890s and early 1900s.

1890

In 1890, C.L. Coffin of Detroit was awarded the first U.S. patent for an arc welding process using a metal electrode. This was the first record of the metal melted from the electrode carried across the arc to deposit filler metal in the joint to make a weld. About the same time, N.G. Slavianoff, a Russian, presented the same idea of transferring metal across an arc, but to cast metal in a mold.

1900

Approximately 1900, Strohmenger introduced a coated metal electrode in Great Britain. There was a thin coating of clay or lime, but it provided a more stable arc. Oscar

Kjellberg of Sweden invented a covered or coated electrode during the period of 1907 to 1914. Stick electrodes were produced by dipping short lengths of bare iron wire in thick mixtures of carbonates and silicates and allowing the coating to dry.

Meanwhile, resistance welding processes were developed, including spot welding; seam welding, projection welding and flash butt welding. Elihu Thompson originated resistance welding. His patents were dated 1885-1900. In 1903, a German named Goldschmidt invented thermite welding that was first used to weld railroad rails.

Gas welding and cutting were perfected during this period as well. The production of oxygen and later the liquefying of air, along with the introduction of a blow pipe or torch in 1887, helped the development of both welding and cutting. Before 1900, hydrogen and coal gas were used with oxygen. However, in about 1900 a torch suitable for use with low-pressure acetylene was developed.

World War I brought a tremendous demand for armament production and welding was pressed into service. Many companies sprang up in America and in Europe to manufacture welding machines and electrodes to meet the requirements.

1919

Immediately after the war in 1919, 20 members of the Wartime Welding Committee of the Emergency Fleet Corporation, under the leadership of Comfort Avery Adams, founded the American Welding Society as a nonprofit organization dedicated to the advancement of welding and allied processes.

Alternating current was invented in 1919 by C.J. Holslag; however, it did not become popular until the 1930s when the heavy-coated electrode found widespread use.

1920

In 1920, automatic welding was introduced. It utilized bare electrode wire operated on direct current and used arc voltage as the basis of regulating the feed rate. Automatic welding was invented by P.O. Nobel of the General Electric Company. It was used to build up worn motor shafts and worn crane wheels. It was also used by the automobile industry to produce rear axle housings.

During the 1920s, various types of welding electrodes were developed. There was considerable controversy during the 1920s about the advantage of the heavy-coated rods versus light-coated rods. The heavy-coated electrodes, which were made by extruding, were developed by Langstroth and Wunder of the A.O. Smith Company and were used by that company in 1927. In 1929, Lincoln Electric Company produced extruded electrode rods that were sold to the public. By 1930, covered electrodes were widely used. Welding codes appeared that required higher-quality weld metal, which increased the use of covered electrodes.

1930

Stud welding was developed in 1930 at the New York Navy Yard, specifically for attaching wood decking over a metal surface. Stud welding became popular in the shipbuilding and construction industries.

The automatic process that became popular was the submerged arc welding process. This under powder or smothered arc welding process was developed by the National Tube Company for a pipe mill at McKeesport, Pennsylvania. It was designed to make the longitudinal seams in the pipe. The process was patented by Robinoff in 1930 and was later sold to Linde Air Products Company, where it was renamed Union melt welding. Submerged arc welding was used during the defense buildup in 1938 in shipyards and ordnance factories. It is one of the most productive welding processes and remains popular today.

1940

Gas tungsten arc welding (GTAW) had its beginnings from an idea by C.L. Coffin to weld in a no oxidizing gas atmosphere, which he patented in 1890. The concept was further refined in the late 1920s by H.M.Hobart, who used helium for shielding, and P.K. Devers, who used argon. This process was ideal for welding magnesium and also for welding stainless and aluminum. It was perfected in 1941, patented by Meredith, and named Heliarc welding. It was later licensed to Linde Air Products, where the water-cooled torch was developed. The gas tungsten arc welding process has become one of the most important.

The gas metal arc welding (GMAW) process was successfully developed at Battelle Memorial Institute in 1948 under the sponsorship of the Air Reduction Company. This development utilized the gas shielded arc similar to the gas tungsten arc but replaced the tungsten electrode with a continuously fed electrode wire. One of the basic changes that made the process more usable was the small-diameter electrode wires and the constant-voltage power source. This principle had been patented earlier by H.E. Kennedy.

1950

In 1953, Lyubavskii and Novoshilov announced the use of welding with consumable electrodes in an atmosphere of carbon dioxide gas. The CO_2 welding process immediately gained favor since it utilized equipment developed for inert gas metal arc welding but could now be used for economically welding steels. The CO_2 arc is a hot arc and the larger electrode wires required fairly high currents. The process became widely used with the introduction of smaller-diameter electrode wires and refined power supplies. This development was the short-circuit arc variation that was known as Micro-wire, short-arc and dip transfer welding, all of which appeared late in 1958 and early in 1959. This variation allowed all-position welding on thin materials and soon became the most popular of the gas metal arc welding process variations.

1960

Another variation was the use of inert gas with small amounts of oxygen that provided the spray-type arc transfer. It became popular in the early 1960s. A recent variation is the use of pulsed current. The current is switched from a high to a low value at a rate of once or twice the line frequency.

Soon after the introduction of CO_2 welding, a variation utilizing a special electrode wire was developed. This wire, described as an inside-outside electrode, was tubular in cross section with the fluxing agents on the inside. The process was called Dual shield, which indicated that external shielding gas was utilized as well as the gas produced by the flux in the core of the wire for arc shielding. This process, invented by Bernard, was announced in 1954, but was patented in 1957, when the National Cylinder Gas Company reintroduced it.

In 1959, an inside-outside electrode was produced that did not require external gas shielding. The absence of shielding gas gave the process popularity for noncritical work. This process was named Inner shield.

Most recent

Friction welding, which uses rotational speed and upset pressure to provide friction heat, was developed in the Soviet Union. It is a specialized process and has applications only where a sufficient volume of similar parts is to be welded because of the initial expense for equipment and tooling. This process is called inertia welding.

Laser welding is one of the newest processes. The laser was originally developed at the Bell Telephone Laboratories as a communications device. Because of the tremendous concentration of energy in a small space, it proved to be a powerful heat source. It has been used for cutting metals and nonmetals. Continuous pulse equipment is available. The laser is finding welding applications in automotive metalworking operations.

1.4.2 Principle of operation

TIG welding works on the same principle as that of arc welding. As shown in Fig-3, in a TIG welding process, a high intense arc is produced between tungsten electrode and work piece. In this welding mostly work piece is connected to the positive terminal and electrode is connected to negative terminal. This arc produces heat energy which is further used to join metal plate by fusion welding. A shielding gas is also used which protect the weld surface from oxidization.

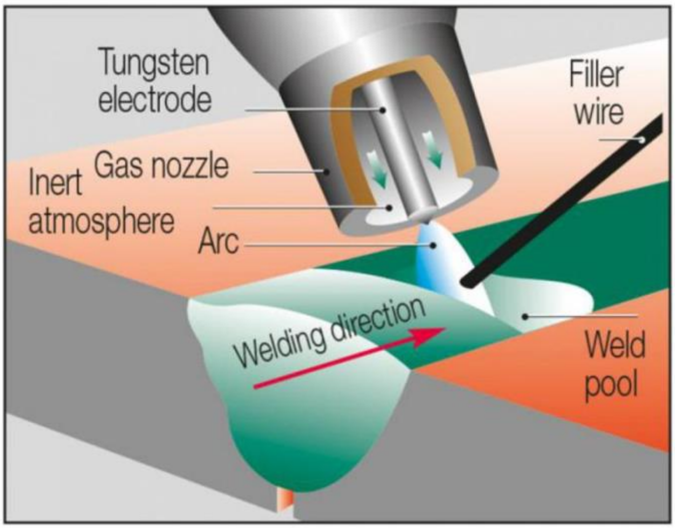


Fig-1.3 Representation of TIG welding

1.4.3 Equipment and Description

- DC or AC / DC Power Source
- Output control
- TIG Torch
- Electrodes
- Shielding gas supply line, (normally from a cylinder)
- Foot Control Unit (common option\

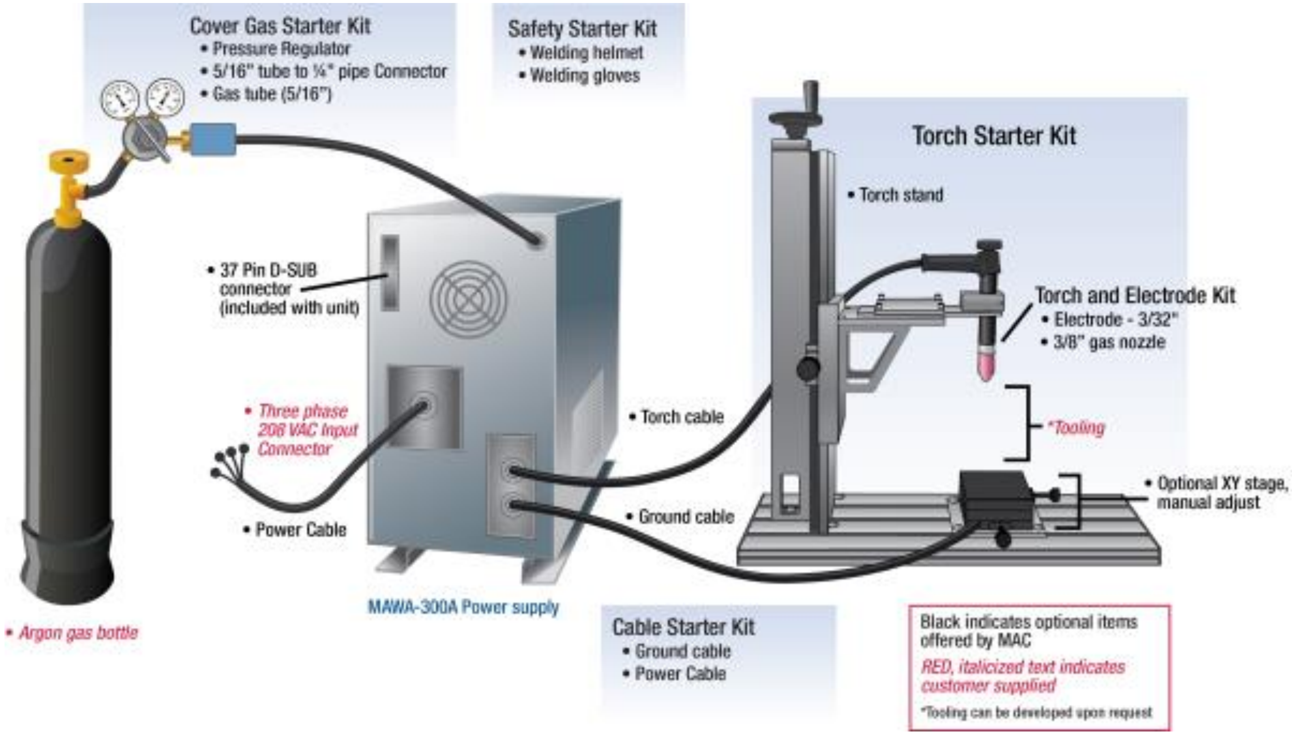


Fig-1.4 Parts of TIG welding

1.4.4 Power Source

TIG welding can be carried out using DC for Stainless Steel, Mild Steel, Copper, Titanium, Nickel Alloys etc. and AC for Aluminum and its Alloys and Magnesium. Further information on the TIG Welding Process follows information on equipment used in this document.

The Power Source is of a transformer design with or without a rectifier, with a drooping characteristic (constant current power source).

The output is generally controlled by either a moving core within the main transformer of the power source or by using electronic control of power thyristors. DC power sources could be of 1 phase or 3 phase design, with an inductor to provide a smooth output. AC and AC / DC Power Sources are of a single phase design.

Other important functions in TIG power sources are

Arc Starting Circuit: - Sparks of high tension jump across the gap between electrode and work piece 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.

Lift Arc: - The electrode is touched onto the work piece, the TIG Torch switch or foot control switch is operated, the equipment circuits detect a short circuit on the output and allow only a very low current typically 5 - 8 amps to flow. The electrode is lifted off the work piece, the equipment circuits now detect a voltage between electrode and work piece and welding current strikes across that very tiny gap as the electrode lifts off and welding continues.

Scratch Start: - The electrode is scratched or dragged and lifted off the work piece, much the same as striking an electrode in MMA (Stick) welding.

Using the HF method, no cross contamination from electrode and work piece takes place as they never touch, with Lift arc correctly set and used, only minimal cross contamination occurs because of the low current when electrode is in contact with work piece, scratch start TIG is a low cost option for general TIG welding, but cross contamination can occur

1.4.5 Output Control

TIG output voltage is not controlled by the power source (as with MIG), but is determined by the process and output welding current. Welding current is normally controlled by either a moving core in the main transformer or by electronic power components.

Crater fill / Slope down Control: - If not using a remote control, but simply a torch ON / OFF switch the output can be A sloped down A to finish the weld without a crater at the end of the molten pool, an electronic timer gradually reduces the output from welding valve to off over an adjustable time.

AC Waveform Balance:-A pot can be fitted, when welding in AC mode the positive half cycle cleans the oxides on the Aluminum and the Negative half cycle produces weld penetration during welding self rectification occurs and causes an imbalance of the waveform, a balance control allows the operator to adjust the amount of time the cleaning or penetration takes in each cycle.

Gas Flow Control The TIG process relies entirely on the shielding gas to protect the hot electrode and molten pool and it is therefore essential for good arc striking that the flow of gas is initiated and allowed to stabilize before the arc is struck. Preflow timers are commonly fitted to better TIG power sources. Equally the gas shield must be allowed to flow after the arc is extinguished, to prevent oxidation of the electrode and cooling weld. Post flow timers are fitted to most TIG power sources.

DC Output Pulse Control

For DC welding use, there is often a pulsing facility which allows the welding current to be switched between a low current (say approximately 15 amps), sufficient to keep the arc alight but not produce much heat and the main pulse current (say 50 - 350 amps

), dependent on the design control of the following parameters can be adjusted to provide high quality welding.

- Peak Current Valve
- Peak Time
- Base Current Valve
- Base Current Time
- Frequency of Pulses

The use of pulsed current greatly extends the control which can be exercised on the process allowing:

- Improved consistency in the under head of unbaked butt welds.
- The ability to overcome differences in heat sink and therefore to join thick to thin material.
- The ability to make cylindrical or circular welds without a build up of heat and an increase in weld width.
- The ability to produce stable TIG welds at very low level.

Moving Core Control : - The main drawback of this method of control, is its slow response to change when required and due to the mechanical movement remote controls (such as foot control) are so difficult and expensive to provide, that it is thought of as not possible.

Power Control :- This system has many advantages over the previous system. The possibility to have a remote control of welding current, so the operator can raise or lower the output as required while welding.

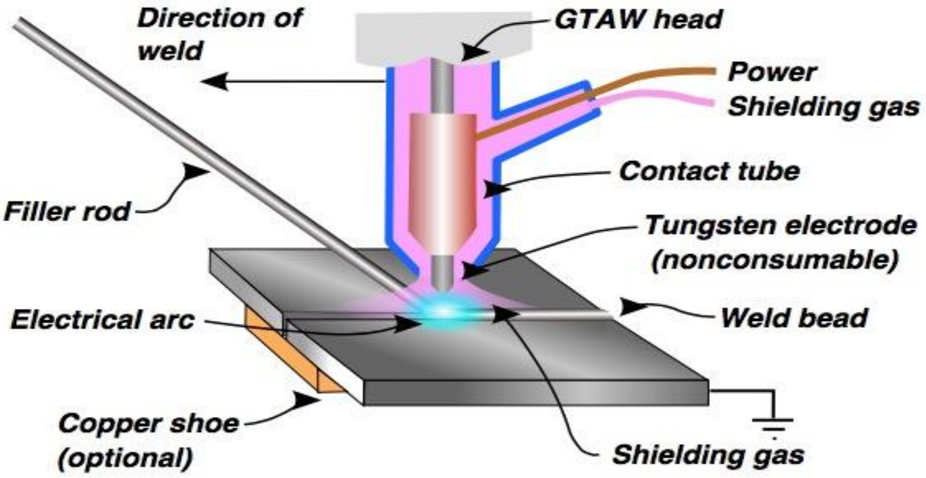
1.4.6 TIG Torch

The TIG torch can be air cooled or water cooled and of vastly different shapes and sizes dependant on access to the area to be welded and welding current required. TIG torch for use on equipment without a electric operated valve normally scratch start systems

) can have a finger operated gas valve fitted to the torch head. If the operator is using a foot control unit, the torch will not need a switch fitted. For welding in difficult to get to areas, a flexible head torch can be used and bent to the best position for welding.

In water cooled torches, the current cable is a bore copper conductor within a water carrying hose, this means the conductor can be greatly reduced in size and weight. The gas shield are now invariably alumina ceramics and are available in a wide range of sizes. When access is difficult, it may be necessary to project the electrode well beyond the end of the gas nozzle, this may result in inferior gas shielding because of turbulence. This can usually be overcome by employing a Gas Lens System replacing the standard collet and collet body system, this producing improved directional and stability of the gas flow.

Fig-1.5 Parts of torch



Connection to the power source can be via a special lug if the equipment has a stud output fitting, or a universal dinse type TIG adaptor if output fittings are dinse type sockets. Electrodes for TIG welding are Pure Tungsten or a Tungsten oxide, generally 2 % Thoriated tungsten are used for DC welding and 2 % Zirconiated tungsten are recommended for AC welding. The diameter of the electrode is chosen to match the current required. For DC welding, a sharp point is required but for AC welding only, a small bevel is needed as the end of the electrode becomes rounded when the arc is operated.

1.4.7 Electrodes:

Electrodes for DC welding are normally pure tungsten with 1 to 4% thorium to improve arc ignition. Alternative additives are lanthanum oxide and cerium oxide which are claimed to give superior performance (arc starting and lower electrode consumption). It is important to select the correct electrode diameter and tip angle for the level of welding current. As a rule, the lower the current the smaller the electrode diameter and tip angle. In AC welding, as the electrode will be operating at a much higher temperature, tungsten with a zirconia addition is used to reduce electrode erosion. It should be noted that because of the large amount of heat generated at the electrode, it is difficult to maintain a pointed tip and the end of the electrode assumes a spherical or 'ball' profile.

Different Types of Tungsten Electrodes

Several factors will influence TIG welding and how well it turns out. One of that is the equipment used. Tungsten electrodes are some of the tools you will need for TIG welding. The material tungsten is preferable because of its hardness and its resistance to high temperatures. Tungsten can withstand temperatures of up 3,410° C, which makes it suitable for arc welding. Welders have several choices nowadays when picking tungsten electrodes. When making this decision, a welder has to consider the type of current used, whether AC or DC, the thickness of the base material and how the electrodes are prepared. Tungsten electrodes come in color codes to make it easier for welders to pick the right ones. Here is a look at some common choices and their color codes.

Rare-earth, Grey

Rare-earth tungsten material comes with various additives such as rare-earth or hybrid combinations of oxides. How the electrodes perform will depend on these additives. In some cases, the electrodes may provide a more stable arc compared to other tungsten materials. Another benefit of rare-earth tungsten electrodes is that a welder can have them in small diameters, and they will still provide good service. There is also less tungsten splitting when using the electrodes. Compared to thoriated tungsten, this type of electrode lasts longer.

Pure, Green

For starters, pure tungsten is suitable for use with AC but not DC. Pure tungsten electrodes are 99.5% tungsten, and that gives them the capability to ball easily. The ball tip shape is what makes the electrodes good with arc stability. Pure tungsten is also suitable for application of low to medium amperages with magnesium and aluminum alloys.

Lanthanide, Gold

Lanthanide tungsten electrodes are suitable for use with direct current. Or transformer-based constant current power sources. They contain 97.8% tungsten and between 1.3 and 1.7% lanthanum. These electrodes are said to be 1.5% lanthanide. The incorporation of lanthanum adds to the capacity of the electrodes to carry current to an arc by almost 50%. Some of the traits that make this electrode a good choice include great arc starting and stability, impressive re-ignition properties and low burn-off rate. For preparations, lanthanide electrodes can be balled or with a pointed end. Welders sometimes switch between 1.5 lanthanated tungsten electrodes with 2% thoriated because they have the same properties.

Ceriated, Orange

The principal oxide in ceriated tungsten electrodes is cerium oxide and is present in about 1.8 to 2.2%, whereas the pure tungsten composition is at a minimum of 97.3%. These types of electrodes are called 2% ceriated and are suitable for low-current AC usage. It is also possible to use them in DC applications. Ceriated tungsten electrodes are ideal for welding small and delicate parts like in thin sheet metal work, pipe fabrication, and orbital tube manufacturing. Some of the compounds that can be used with ceriated electrodes include non-corroding steels, carbon, nickel, aluminium, magnesium, titanium and copper alloys. Properties include longevity, excellent arc stability, low erosion rate, good ignition and re-ignition. They should be used at low amperage ranges. Welders nowadays prefer to use ceriated tungsten electrodes in place of pure tungsten because the former offers better current carrying properties at the same diameters.

Thoriated, Red

Thoriated tungsten electrodes contain 97.3% pure tungsten and 1.7-2.2% thorium oxide, which has low radioactivity. The increased current carrying ability of thoriated tungsten electrodes is one reason it suits arc welding. The electrodes are easy to use and last a long time, which offers added advantages. They also provide a low consumption rate because they function below their melting point. Thoriated tungsten electrodes are suitable for both AC and DC applications. They are ideal for welding thin steel because they maintain sharpened edges during manufacturing. Caution is, however, recommended when sharpening the points of thoriated tungsten electrodes. Welders also prefer thoriated tungsten electrodes because they cause less contamination during the process. They are suitable for use in medium amperage ranges, have a medium erosion rate and tendency to split is average compared to other materials.

Zirconiated, Brown

Zirconiated tungsten electrodes consist of 99.1% pure tungsten and 0.15-0.4 Zirconium. The ability of zirconiated electrodes to retain balled tips is what makes them perfect for AC welding. These types of electrodes don’t contaminate easily and are highly resistant to splitting. Zirconiated tungsten has high current-carrying ability resulting in an extremely stable arc. It also handles high amperages very well. Zirconiated tungsten electrodes are not suitable to use with DC.

1.4.8 Shielding Gas:-

The most commonly used gas for TIG welding is argon which can be used on all metals. Argon - Hydrogen mixtures containing 2 - 5 % Hydrogen are frequently used for stainless steel and nickel-base alloys having the advantage of producing cleaner welds, giving deeper penetration.

Argon + 2 to 5% H_2 - the addition of hydrogen to argon will make the gas slightly reducing, assisting the production of cleaner-looking welds without surface oxidation. As the arc is hotter and more constricted, it permits higher welding speeds. Disadvantages include risk of hydrogen cracking in carbon steels and weld metal porosity in aluminium alloys.

Helium and helium/argon mixtures - adding helium to argon will raise the temperature of the arc. This promotes higher welding speeds and deeper weld penetration. Disadvantages of using helium or a helium/argon mixture is the high cost of gas and difficulty in starting the arc. These mixtures can be used for Aluminium and Copper Alloys.

1.4.9 Welding Process

In most Arc welding processes, the arc is struck from a consumable electrode to the work piece and metal has been melted from electrode, transferred across the arc and finally incorporated into the molten pool. TIG process employs on electrode made from high melting point metal, usually a type of TUNGSTEN, which is not melted. The electrode and the molten pool is shielded from the atmosphere by a stream of inert gas which flows around the electrode and is directed onto the work piece by a nozzle which surrounds the electrode.

In TIG welding, the primary functions of the arc is to supply heat to melt the work piece and any filler metal which may be necessary. This filler metal is fed manually into the molten pool at its leading edge. The second function of the arc is to clean the surface of the molten pool and the immediately surrounding parent metal of surface oxide films and therefore no flux is required. The shielding gas MUST be inert with respect to the tungsten electrode and the choice is therefore more limited than with the MIG process. When using DC the DCEN electrode negative polarity is almost invariably employed, (if DCEP is used most of the heat is in the electrode not the work piece, so if this polarity is used, very much larger electrodes MUST be used).

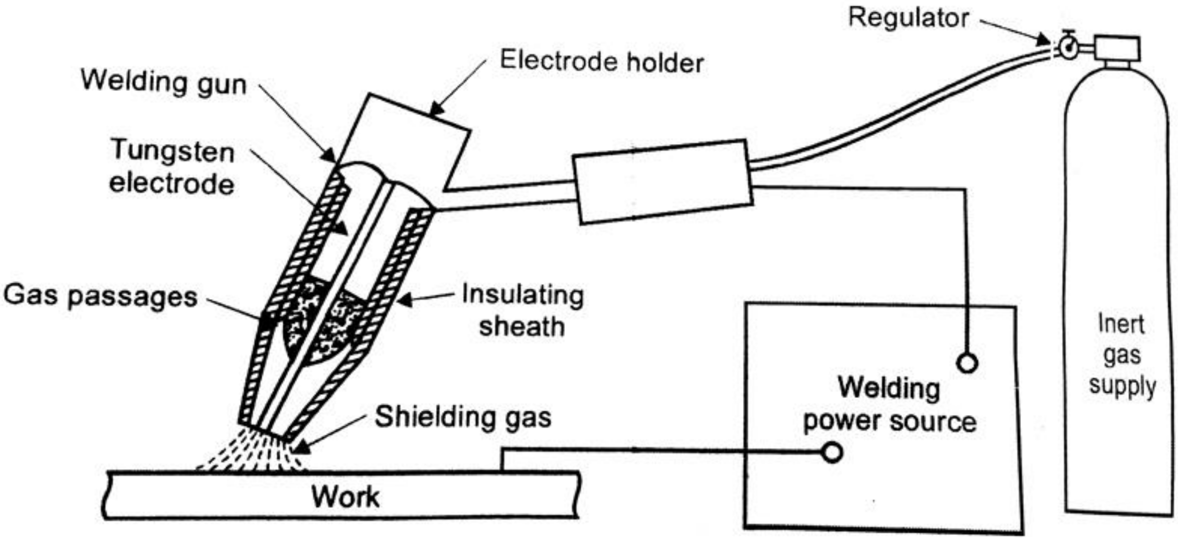


Fig-1.6 Line diagram of TIG welding

The cleaning function of the arc does not take place on the DCEN polarity, so metals forming refractory oxide surface films such as aluminum cannot be readily welded on this polarity. For Aluminum the electrode positive polarity on which cleaning takes place, would therefore appear desirable. In fact on this polarity, more energy is dissipated at the electrode which therefore becomes overheated. Aluminum is therefore welded using AC and the cleaning action takes place on the electrode positive half cycles and weld penetration takes place on the electrode negative half cycle. Zirconiated tungsten electrodes are used for AC welding because Zirconia helps the electrode to maintain the desired stable end.

1.4.10 TIG Welding Applications

Because TIG welding can be used with such a large variety of metals, the process can be applied to several industries and aid in the creation and repair of many items. This form of welding is common in the aerospace, automotive, repair and art fields. For instance, here are some types of TIG welding jobs:

Aerospace – Aircraft and spacecraft are constructed in part by means of TIG welding. So, the commercial planes used every day, as well as complex craft like the International Space Station have benefitted from such processes as TIG welding which is known for its strength and precision.

Automotive – Safe and secure construction is essential in the auto industry, as is making vehicles stand the test of time. For these reasons, TIG welding is widely used in the automotive industry. TIG strategies are known to reduce corrosion over time, so car fenders are frequently welded in this way to avoid rust. Besides this, the better the vehicle is constructed, the safer it will be for those travelling in it.

Repair – TIG may be used in a number of repair applications. From fixing a child’s toy, like a wagon or old-fashioned pedal car, to repairing aluminum tools, this welding method comes in handy.

Art – TIG is touted for the superior cosmetic appearance it results in. Artworks are about the artist’s message, yes, but they also rely on appearance

1.5 Advantages of TIG Welding

Similar to MIG welding, the usage of TIG welding requires high-quality appliances. An accurate result comes out when the parts and equipment you use provide you various advantages.

1. Detailed Precision

This visually appealing tool gives detailed precision, provides controlling the temperature and ensures less spattering. The arc is transparent due to shielding of inert gas, enabling the welder to clearly observe the work and electrode in the weld puddle.

2. Various Applications and Positions

TIG welding includes a high range of materials for various applications, for instance, industrial equipment, furnishings, vehicles, and more. Also, it enables you to fix your project with various positions, including vertical, horizontal and thickness dimensions. What’s more, the multiple sizes and shapes allow you to use it in open, restricted and narrow spaces.

3. Extremely Complex Metal Welding

Refractory materials like tantalum require a high melting point. TIG welding includes two chambers one of which is specifically for welding such refractory metals as tungsten, molybdenum, niobium, and titanium.

4. Non-consumable Electrodes

TIG welding is able to provide perfect joints every time. You don’t need to stop the tool to replace the electrode continuously. There are some consumable welding tools that require you to stop the tool at first. But a TIG welder is incomparable at this point.

1.6 Disadvantages of TIG Welding

There are several disadvantages or threats related to this machine e.g. radiation and welding fumes. On the other hand, the welding process requires a lot of time, includes complicated appliances, and costs a lot for operation.

1. A Time-Consuming Process

As said earlier, this process requires a lot of time to finish. When talking about time and speed, the TIG welding machine is slower than any other welding machine you might find out there. In addition, the filler deposition rate is much lower in this machine.

2. Complicated Appliances

The complicated appliances of this machine always require a professional's hands. As the machine is appropriate mostly for thin materials, it requires especially skilled welders to be operated.

3. The Cost of Inert Gas

This machine's inert gas is very costly when compared to any flux material used in different types of welding. Also, it requires proper cleaning prior to operation as the inert gas doesn't feature any cleaning action.

CHAPTER-II

LITERATURE REVIEW

This chapter describes about various works reported by earlier researchers in TIG welding.

2.1 Design of Experiments

Atul Kumar et al.[1] examined various parameters and their effect on the strength of the welds of SS202 and SS410 stainless steel of 3 mm thick. The experiment is to optimize the factors affecting the tensile strength of austenitic stainless steel at varied welding parameters. The Taguchi method is applied using input parameters viz. current, gas pressure and weld rate and the desired response output namely ultimate tensile strength was evaluated.

Iqbal jeet Singh Grewal et al.[2] researched the mechanical properties such as tensile strength and impact toughness of the welded joints are evaluated using Taguchi method using (welding current, gas flow rate and filler metal) as three input parameters each having three levels each (low, medium and high). The tensile properties of the weld metal have been identifying using Universal Testing Machine (UTM) and impact toughness has been identifying using charpy test.

Owunna1 and A. E.Ikpe [3] investigated mechanical properties (Ultimate Tensile Strength (UTS), modulus of elasticity (E), elongation and strain (e)) for twenty samples of AISI 4130 Low carbon steel plate were studied in this paper. Statistical design of experiment (DOE) using the central composite design method.

Mukesh Hemnani et al. [4] carried out bead on bar welds were carried out on EN8 & EN24 solid cylindrical bar using Tungsten Inert Gas (TIG) welding process. The input process variables considered here are - welding current, welding voltage & gas flow rate. A total no of 9 experiments were conducted as suggested by Taguchi method. The proposed optimal parameters it is possible to increase the efficiency of welding joint by which tensile strength of joint can be increased with suitable set of parameter.

K. Nageswara Rao et al. [5] studied a variety of problems come up in dissimilar welding like cracking, large weld residual stresses, migration of atoms during welding causing stress concentration on one side of the weld, compressive and tensile stresses, stress corrosion cracking are optimized.

Baljeet Singh et.al [6] experimented TIG welding parameters influence on weld-ability of both stainless steel304 and mild steel 1018 specimens the microstructure and mechanical properties. The work aims at joining of dissimilar material are stainless steel and mild steel done by TIG welding with the various parameters like voltage, welding speed and gas flow rate

S. Mohan Kumar and N. Siva Shanmugam [7] studied the weldability, mechanical properties and microstructural characterization of activated flux TIG welding of AISI 321 austenitic stainless steel. Effect of Activated Tungsten Inert gas (A-TIG) welding on the surface morphology of type 321 austenitic stainless steel welds are SS compared with conventional TIG welding.

G.Venkatesan et al. [8] studied the effect of ternary fluxes viz. SiO_2, TiO_2 and Cr_2O_3 on depth of penetration in A-TIG welding of AISI 409 ferritic stainless steel. It was observed that SiO_2 flux is having maximum influence in improving depth of penetration, though the effect of the flux having 100% sio_2 on depth of penetration is not significant.

Mukesh and Sanjeev Sharma [9] analysed the study of mechanical properties in austenitic Stainless steel using Gas Tungsten Arc Welding (GTAW) and the influence of different input parameters such as welding current, gas flow rate and welding speed on the mechanical properties during the gas tungsten arc welding of austenitic stainless steel 202 grade. The microstructure, hardness and tensile strength of weld specimen are investigated.

Ketan C. Parmar et al.[10]represented the influence of welding parameters like welding speed, welding voltage, welding current, wire feed rate on weld bead geometry and bead hardness of medium carbon steel material during MIG welding process. Depth of penetration, bead height and bead width will be considered as bead geometry in this paper. Taguchi technique has been used as acquire the data and Taguchi orthogonal array play most important role for minimize the experimental reading

Salah Sabeeh Abed alkareem [11] compared heat flus generated during welding with and without fillers. The study covered the effect of welding current, welding time, welding velocity, gas flow from cylinder, gas flow before welding and gas flow on the generated heat flux during this comparison.

Mohamed Farid Benlamnouar et al. [12] optimized mechanical properties of the welded joints using Taguchi experimental designs associated with experimental techniques and laboratory characterizations. The aim of this work is to propose a method of optimization of the mechanical performances of a TIG dissimilar welding of two grades of steels: a high strength low alloy steel X70 and an austenitic stainless steel 304L.

S.C. Juang and Y.S. Tarng [13] investigated process parameter selection for optimizing the weld pool geometry in the tungsten inert gas welding of stainless steel and to analyse the effect of each welding process parameter on the weld pool geometry, and then to determine the process parameters with the optimal weld pool geometry.

WichanChuaiphan et al. [14] studied the feasibility of dissimilar welding between AISI 304 stainless steel and AISI 1020 carbon steel plates with the thickness of 15 mm. The processes applied in this work were gas tungsten arc welding (GTAW) and shield metal arc welding (SMAW). The aspect of mechanical and corrosion properties of the weld, GTAW was considered as a promising process that could be used for dissimilar welding between these two metals.

Ajaykumar et al. [15] carried out experimental process of tungsten inert gas welding of a stainless steel plate and to analyse the effects of process parameters on metal deposition rate of TIG welded stainless steel plate of SS304 grade. Design of experiment (DOE) approach was used to plan and design the experiments to study the effect of welding process parameters on metal deposition rate of TIG welded SS304 stainless steel plate.

C. Balaji et al. [16] analysed the mechanical properties of SS 316 l weldments using tungsten inert gas welding, and joining of similar grades of stainless steel by TIG welding with the various parameters like current, bevel angle and gas flow rate. The SS 316L is selected over other grades due to its lesser carbon content it is used in pressure vessels for corrosive liquids etc. The rod of SS 316L of 25 mm diameter and 75 mm length was used as the base material.

PiyushRana et al. [17] carried out parametric study of dissimilar material on gas tungsten arc welding. The properties of the welded joints are affected by a large number of welding input parameter such as welding current waveform, welding current, welding speed and gas flow rate and butt weld joint of Copper and Stainless Steel (SS304) is obtained by using autogenous GTAW process.

2.2 Finite Element Analysis(FEA)

S.Giridharan et al.[18] investigated the technical considerations of dissimilar metal welding between IS2062 Grade C mild steel and 316L stainless steel using the GTAW process. Finite element analysis of dissimilar metal joints are also analyzed and compared with experimental work. Experiments are performed to study about the microstructure, Tensile strength and bending behavior of dissimilar metal joints.

Britto Joseph G et al. [19] studied corrosion on steels and make it economically feasible. The corrosion resistance is done by performing welding of these two dissimilar metals by using electrode 309L. After the welding is performed properly it is forwarded to proceed further tests like tensile test, Rockwell hardness test, macro examination test, micro examination test and corrosion resistance test.

S.A.A. AkbariMousavi and R. Miresmaeili [20] carried out experimental and numerical analyses of residual stress distributions in TIG welding process for 304L stainless steel, to analyze the residual stresses produced in the TIG welding process using 2D and 3D finite element analyses, the effect of geometry configurations on the residual stress distributions are predicted from the 3D computer analysis using a thermo elasto plastic constitutive equation and compared with the X-ray diffraction method. In this study, the effects of conduction, radiation and convection due to both air and inert gas flow rate are considered.

2.3 Hybrid Welding

Radha Raman Mishra et al.[21] studied stainless steel of grades 202, 304, 310 and 316 were welded withMild steel by Tungsten Inert Gas (TIG) and Metal Inert Gas (MIG) welding processes. The percentage dilutions of joints were calculated and tensile strength of dissimilar metal joints was investigated. The Results were compared for different joints made by TIG and MIG welding processes.

Raghurampradhan et al.[22] examined stainless steel of grades of SS202 & SS304 of dimensions(40×50×6) mm was welded by butt joint by Tungsten Inert Gas (TIG) and Metal Inert Gas (MIG)Welding processes. Then various tests were conducted to the joints such as tensile strength, bendingTest, micro structural test, grain size test.

Harishkumar Parmar et al. [23] carried out review on Alloy Steel Welded by Plasma Arc Welding and Gas Tungsten Arc Welding for Comparative Study of Mechanical Properties and increasing the welding speed, increasing the Penetration, decreasing the reject rate and reducing the pre and post welding and mainly focus on the process parameter of the GTAW and PAW process for one to one comparison and evaluation of the process.

N. Arivazhagan et al. [24] Presented the investigations carried out to study the microstructure and mechanical properties of AISI 304 stainless steel and AISI 4140 low alloy steel joints by Gas Tungsten Arc Welding (GTAW), Electron Beam Welding (EBW) and Friction Welding (FRW). For each of the weldments, detailed analysis was conducted on the phase composition, microstructure characteristics and mechanical properties.

Radha Raman Mishra et al.[25] studied stainless steel of grades 202, 304, 310 and 316 were welded with mild steel by Tungsten Inert Gas (TIG) and Metal Inert Gas (MIG) welding processes. The percentage dilutions of joints were calculated and tensile strength of dissimilar metal joints was investigated. The results were compared for different joints made by TIG and MIG welding processes.

Md. Gaffaretal. [26] studied the effect of TIG (Tungsten Inert Gas) and MIG (Metal Inert Gas) welding processes, when stainless steel is welded with mild steel. The scope of the current work also includes, investigating the effect of filler material on weld quality, strength and hardness of the joint when stainless steel and mild steel filler materials are used. Further, micro structural analysis is also taken up on the weld zone to study the quality of the joint.

2.4 Microstructure and Mechanical properties

K. Devendranath Ramkumar et al.[27] investigated the weldability, microstructure and mechanical properties of dissimilar AISI 304 and Monel 400 welds using continuous and pulse-current GTA welding processes. These welding processes are carried out using three filler wires, namely E309L, enicu-7 and enicrfe-3. In addition, a comparative analysis on the micro hardness, tensile test values on these welds using the above-said filler materials is also studied.

I.O. Oladele et al. [28] studied the microstructural and mechanical properties of dissimilar metal welded joint (DMWJ) of austenitic stainless steel (304L; 18/8) and mild steel plates of 5mm thickness were experimentally investigated. A single V butt joint was prepared and the plates were welded using Gas Tungsten Arc Welding (GTAW) process with ER308L as filler metal. The mechanical properties were examined by tensile, hardness and bending tests while the microstructural characteristics were studied using the Scanning Electron Microscope.

Ankur V. Bansod et al. [29] investigated the effect of dissimilar metal welding of low nickel stainless steel (SS) and 304 SS employing tungsten inert gas (TIG) welding process by using three different filler materials (316L, 308L and 310 SS). Microstructural, mechanical properties and corrosion behavior in 3.5% NaCl solution was studied. The microstructural investigation revealed the formation of δ-ferrite and γ-austenite in the weld (welded by 316L and 308L filler).

PoojaAngolkar et al.[30] investigated the Weld ability of dissimilar materials Monel 400 and SS316 of thickness 5mm with V groove configuration by Gas Tungsten Arc Welding (GTAW) technique employed ernicrmo-3 filler wire. Experiment has been conducted using following process parameters, the gas flow rate, voltage, current and no of passes. The mechanical properties like tensile strength, hardness and residual stresses are calculated at the welded joint.

A.Devaraju [31] analysed the microstructures of DSS and 316L SS before and after the TIG welding. The welded joint revealed the acceptable mechanical properties, the hardness and impact strength of the welded zone using X- ray test, impact test, hardness test, tensile test and bending test.

T.Eswara Raoetal. [32] discussed the effect of welding variables on the microstructure analysis, mechanical properties of welded 5 mm thick of 301 stainless steel plate and 1020 mild steel plate, welded using the Tungsten Inert Gas (TIG) welding method.

O. K. Thirugnanasambandam and T. Senthil Kumar [33] analyzed the long-term service of the component of T23 material. At present, T23 material is procured by most of the boiler manufacturers, it is important to evaluated it's properties.

Shamsul Baharin Jamaludina et al. [34] studied joining of stainless steel type 304 to mild steel was carried out using a gas tungsten arc welding (GTAW). Samples were welded using stainless steel welding electrode: (AWS: e308l-16) and mild steel welding electrode: (AWS: E6013). The mechanical properties of welded joint were investigated by tension test.

KeyurPanchal [35] studied the effect of TIG welding on stainless steel and mild steel plates. TIG welded plates majorly used in industries purpose. He discussed discuss about effect of welding on MS and S.S plate and study the result like hardness, tensile, bend test

A.R. Khalifeh et al. [36] evaluated the micro structure characteristics and mechanical properties of the weldments were studied using optical and scanning electron microscopy, ferrit-ometry, hardness, tensile and impact tests.

M.F.Mamat et al. [37] investigated the effect of filler metals on the microstructures and mechanical properties of dissimilar low carbon steel and 316L stainless steel welded joints. Samples were welded using AWS: ER309L welding electrode for GMAW and AWS: ER316L welding electrode for GTAW process. It can be concluded that, for dissimilar 316L stainless steel to low carbon steel joint ER316L filler material presents the optimum mechanical properties.

Manuel Thomas et al. [38] studied the crack growth rate studies in stainless steel 316L(N) welds processed by A-TIG and MP-TIG welding at 823 K. From the study it was found that MP-TIG has the process for improving the fatigue crack growth rate resistance of material.

Ankur V. Bansod et al. [39] studied microstructure, mechanical and electrochemical evaluation of dissimilar low Ni SS and 304 SS in 3.5% NaCl solution, using 316L, 308L and 310 SS as filler materials. The welded zone produced by 316L and 308L SS filler mainly consisted of austenite and δ-ferrite in its microstructures whereas the microstructure developed by 310 SS electrode showed cellular structure.

K. DevendranathRamkumar et al. [40] studied the structure–property relationships and corrosion behavior of TIG welding of UNS S32750 using the activated fluxes NiO, MoO_3 and SiO_2. The results showed that the joint efficiencies were found to be 91.6%, 87.4% and 93.06% respectively. It was also found that complete penetration could be achieved in a single pass with the use of activated flux.

Z. Brytan and J. Niagaj [41] studied the corrosion resistance and mechanical properties of TIG and A-TIG welded joints of lean duplex stainless steel S82441 / 1.4662 using different amounts of heat input and shielding gases like pure Ar and Ar+N2 and Ar+He mixtures. It was found that the surface of A-TIG welded joints shows a much lower tendency to pitting corrosion than the welds made by conventional TIG welding.

G. Madhusudhan Reddy et al. [42] studied the influence of welding processes on microstructure and mechanical properties of dissimilar austenitic-ferritic stainless steel welds using GTAW, EBW, and FW. The results showed that hardness and residual stresses are maximum on the ferritic stainless steel side of the interface in dissimilar metal fusion and metal friction welds.

Anil Kumar et al. [43] analysed the effect of filler and autogenous TIG welding on micro structure, mechanical properties and corrosion resistance of nitronic 50 stainless steels. Weldability of Nitronic 50 in terms of microstructural analysis results, mechanical properties and corrosion behavior are investigated with the help of optical microscopy, scanning electron microscopy equipped with energy-dispersive spectrometer, X-ray diffraction and electrochemical assessment.

Anwar Ul-Hamid et al. [44] experimented Light optical metallography and scanning electron microscopy, combined with energy dispersive X-ray spectroscopy, inductively coupled plasma and microhardness testing were used to determine the most probable cause of failure. Analysis showed that the cracks originated at the interface between the CS pipe and the SS root weld.

HimanshuVashishtha et al. [45] investigated the compatibility of most widely used conventional austenitic stainless steel (type 304) employing dissimilar weldments with high nitrogen austenitic stainless steel (type 201) using scanning electron microscope coupled with EDS and X-ray diffraction techniques. The weld defects and their integrity were investigated by radiographic analysis. The effect of welding speeds on microstructural characteristics and grain boundary precipitation was analyzed.

L.O. Osoba et al. [46]studied the effect of heat treatment on the dissimilar metal welding of austenitic stainless steel (AISI 304L) and low carbon ferritic steel (AISI 1005) using Tungsten Inert Gas (TIG) welding process with a view to minimize and/ or eliminate the previously reported danger of inhomogeneous hardness distribution experienced across the fusion zone, Micro structural evaluation and mechanical properties of the fusion zone (FZ), heat affected zone (HAZ) and the base metals (BM) were performed using microscopy and micro hardness evaluation.

Keyur Panchal [47] studied the effect of TIG welding on stainless steel and mild steel plates. TIG welded plates majorly used in industries purpose. The welding of dissimilar metals is most useful in structural applications discuss about effect of welding on MS and S.S plate and study the result like hardness, tensile, bend test etc.

Nixon Poulose et al.[48]joined and assessed the development of gas tungsten arc welding (GTAW) on dissimilar materials like austenitic stainless steel and low carbon steel. This GTAW weld is best suited for the thin cross-section metals. This welding process can be used for continuous, spot or intermittent weld joints. The mechanical properties and microstructures and the chemical composition of the joint of the gas tungsten arc welding joints are examined

Aamir R. Sayedetal.[49] studied various welding parameter like welding current, voltage, gas flow rate, inert gas, welding speed, electrode etc. In this work we discuss about the Tungsten Inert Gas Welding of joining heat treatable of stainless steel and mild steel. Output parameters such as hardness of welding, tensile strength of welding, DPT, spectrography by using optimization philosophy.

Lokesh Kumar G etal.[50] presented some fundamental observations on the microstructure and mechanical properties in SMAW and GTAW process, formed by AISI 304 (ASS) and AISI 430 (FSS) with AWS E308L austenitic stainless steel covered electrode, being a dissimilar welding procedure.

S.Senkathir et al[51] discussed about the dissimilar welding involving Inconel 718 and AISI 410 that is more challenged by Tungsten inert gas(TIG) welding. That was carried out using three different flux and without using flux to fabricate this bimetals. Micro structure at the welded zone, base metal zones and heat affected zone were characterized using optical microscopy.

Kumar Rahul Anand et al. [52] studied the mechanical properties of the joint of austenitic stainless steel (AISI 316) and mild steel welded by TIG welding. In this paper with the use of Taguchi method of optimization we have tried to optimized the various process parameter such as current, voltage and gas flow ratio (GFR) which has influence on tensile strength and hardness of the joint.

Jun Yan et al. [53] studied the microstructure and mechanical properties of 304 stainless steel joints by TIG, laser and laser TIG hybrid welding. The X-ray diffraction was used to analyze the phase composition, while the microscopy was conducted to study the microstructure characters of joints. The laser welding and hybrid welding are suitable for welding 304 stainless steel owing to their high welding speed and excellent mechanical properties.

V.Anand Rao and R.Deivanathan [54] investigated welding aspects of stainless steel 310 for the process of TIG Welding. Carried out analysis and optimization of joining similar grades of stainless steel by TIG welding. The parameters like current, filler materials, welding speed are considered in their study.

F. Souza Neto et al. [55] studied the mechanical behavior of AISI 4130 steel after TIG and Laser welding process, the mechanical characterization of laser and TIG welds, tensile and hardness tests were performed. The weld was autogenous and a post weld heat treatment was conducted to evaluate its influence on mechanical properties. This treatment proved to improve the ductility of the steel and reducing the embrittlement in the welded region.

AhmetDurgutlu [56] investigated the effect of hydrogen in argon as shielding gas for tungsten inert gas welding of 316L austenitic stainless steel. The microstructure, penetration and mechanical properties were examined. After bending test, cracks, tearing and surface defection were not observed on the samples that were welded under all three shielding media.

Halil İbrahim Kur and RamazanSamur [57] studied the microstructure evaluation and mechanical properties of 304 austenitic stainless steels (SS) jointed by tungsten inert gas (TIG) welding by using 308 stainless steel filler wire. Microstructures of BM, HAZ and WM were studied with scanning electronic microscopy (SEM) and electron dispersive spectrum (EDS) analysis, optical microscopy (OM) and stereo microscopy (SM).

WichanChuaiphan and Loeshpahn Sri jaroenpramong [58] investigated the effect of welding speed on microstructures, mechanical properties and corrosion behavior of GTA-welded AISI 201 stainless steel sheets. Three welding speeds designated as low (1.5 mm/s), medium (2.5 mm/s) and high (3.5 mm/s) were oper-ated during the gas tungsten arc welding (GTAW) process and joints made were subjected to analysis of the microstructures, mechanical and corrosion properties of the joints.

Shaik Mahaboob Subhani et al. [59] evaluated the mechanical properties for TIG welding aspects of SS 310 and MS materials and to investigate the influence of various parameters namely welding current, diameter of filler rod and gas flow rate on the responses such as tensile strength, percentage elongation and Rockwell hardness. Welding is performed to join 1.5 mm thick SS 310 and MS plates which were then made to ASTM standard tensile specimens to carry out the tensile test. The mechanical strength is also evaluated usingrockwell hardness test.

WichanChuaiphan and Loeshpahn Sri jaroenpramong [60] studied the effect of filler alloy on microstructure, mechanical and corrosion behavior of dissimilar weldment between AISI 201 stainless steel and low carbon steel sheets produced by a gas tungsten arc welding. Consumables were ER308L, ER309L, ER316L stainless steel wires, and AWS A5.18 carbon steel wire.

Subhas Chandra Moi et al. [61] studied the effect of heat input on the mechanical and metallurgical characteristics of TIG welded joints. Three different heat input combinations selected as low heat (0.75kj/mm), medium heat (0.90kj/mm) and high heat (1.05kj/mm) have been applied during the operation of TIG welding process on 316L austenitic stainless steel. The effect of heat input is investigated on the weld bead geometry and mechanical-metallurgical characteristics of the joints.

Subodh Kumar and A.S. Shahi [62] studied the effect of heat input on the microstructure and mechanical properties of gas tungsten arc welded AISI 304 stainless steel joints and to analyze the effect of thermal arc energy on the microstructure and mechanical properties of these joints. The results of this investigation indicate that the joints made using low heat input exhibited higher ultimate tensile strength (UTS) than those welded with medium and high heat input.

G.R. Mirshekari et al. [63] studied the microstructure and corrosion behavior of multipass gas tungsten arc welded 304L stainless steel and 308 stainless steel filler metal was used. Microstructures and hardness of the weldments were investigated using optical microscopy, scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), X-ray diffraction analysis (XRD) and Vickers micro hardness (HV0.5).

2.5 Corrosion

Luis Henrique Guilherme et al. [64] reported on corrosion behavior of a dissimilar joint TIG weld between austenitic AISI 316L and ferritic AISI 444 stainless steels and to test the corrosion resistance of the welded joint, the following tests were applied:

sensitisation, mass loss from room temperature up to 90 °C and electrochemical corrosion tests in 0.5 mol/L HCl and 0.5 mol/L H_2SO_4 electrolytes.

Dan Hu et al. [65] reported on effects of TIG process on corrosion resistance of 321 Stainless Steel Welding Joint. Intergranular corrosion, stress-strain curves of SSRT and the fracture surface of the welding joint by means of intergranular corrosion test, SCC test and SEM. The analysis of the fracture surface of joints, the joint welded in current of 130A presented a tendency to brittle fracture, while the joints in the current of 170 A and190 A were characterized with ductile fracture.

M. Dadfar et al. [66] analysed the effect of TIG welding on corrosion behavior of 316L stainless steel. Corrosion behavior in physiological solution at 37°C was investigated with potentio dynamic polarization curves. Microstructure of base metal (BM) and weld metal (WM) was studied with scanning electronic microscopy (SEM). For detecting microstructure and phases in BM and WM, X-ray diffraction analysis.

A. S. Alcantara et al. [67] reported on corrosion resistance of TIG welded joints of stainless steels. Analyzed the performance of joints made by TIG (Tungsten Inert Gas) welding process in austenitic and duplex stainless steels with special regards to their corrosion resistance. This work focuses on the weldability of the 2304, 2404 and 304 type stainless steel heterogeneous welds.

Britto Joseph G et al. [68] reported on welding of dissimilar metals 409 stainless steel and 439 stainless steel by TIG welding and to increase the effort of corrosion and to balance the cost of the material and to make it economically feasible. The corrosion resistance is done by performing welding of these two dissimilar metals by using electrode 309L and performed tests like tensile test, Rockwell hardness test, macro examination test, micro examination test and corrosion resistance test.

M. Gnanasekaran et al. [69] investigated the effect of oxide layer and activating flux on corrosion behavior of TIG welding of 304 austenitic stainless steel weldments. The influence of thin oxide layer on base material surface and the activating flux on the weld bead geometry of AISI 304 stainless steel TIG weldments. All the TIG and A-TIG welds were analyzed to study the corrosion behavior of weld bead geometry were determined by using potentio dynamic polarization test.

D.Devakumar and D. B Jabaraj [70] reported on Gas Tungsten Arc Welding of Stainless Steel and Stainless steel is extensively used in industries as an important material, because of its excellent corrosion resistance. TIG welding is one of the welding processes, often used to weld similar and dissimilar stainlesssteel joints and characterization of weld, dissimilar metal welding, parameter optimization, process modeling, failure analysis and automation of TIG welding process.

Rahul Unni krishnan et al. [71] studied the effect of heat input on the microstructure, residual stresses and corrosion resistance of 304L austenitic stainlesssteel weldments, 304L austenitic stainless steel was subjected to different heat inputs by shielded metal arc welding process using a standard 308L electrode. The microstructural developments were characterized by using optical microscopy and electron backscattered diffraction, while the residual stresses were measured by X-ray diffraction using the sin2ψ method. This study shows that electron backscattered diffraction is necessary to bring out changes in the grain size quantitatively in the fusion zone/heat affected zone as it can consider twin boundaries as a part of grain in the calculation of grain size.

2.6 Others

J. Kalpana et al. [72] studied the effect of vibratory dissimilar TIG (Tungsten Inert Gas) welding process on impact strength of welded joins with respect to change of frequency of specimens to be welded. In this study, new vibratory setup has been developed with two metal engravers for inducing mechanical vibrations to the specimens to be welded. Finally, analyse the effect of vibration frequency on impact strength of welded joints.

Cheng-Hsien Kuo et al. [73] investigated the effect of activated TIG flux on performance of dissimilar welds between mild steel and stainless steel and to investigate the effect of oxide fluxes on surface appearance, weld morphology, angular distortion, and weld defect obtained with activated tungsten inert gas (TIG) process

applied to the welding of 6 mm thick dissimilar metal plates between JIS G3131mild steel and SUS 316L stainless steel.

CHAPTER-III

DESIGN OF EXPERIMENTS

3.1 Introduction to Design of Experiments

Design of Experiment is an experimental or analytical method that is commonly used to statistically signify the relationship between input parameters to output responses. DOE has wide applications especially in the field of science and engineering for the purpose of process optimization and development, process management and validation tests. DOE is essentially an experimental based modeling and is a designed experimental approach which is far superior to unplanned approach whereby a systematic way will be used to plan the experiment, collect the data and analyze the data. A mathematical model has been developed by using analysis techniques such as ANOVA and regression analysis whereby the mathematical model shows the relationship between the input parameters and the output responses. Among the most prominently used DOE techniques are Response Surface Methodology with Central Composite Design, Taguchi's method and Factorial Design. In DOE, synergy between mathematical and statistical techniques such as Regression, Analysis of Variance (ANOVA), Non-Linear Optimization and Desirability functions helps to optimize the quality characteristics considered in a DOE under a cost effective process. ANOVA helps to identify each factor effect versus the objective function.

Experimental design was first introduced in the 1920s by R. A. Fischer working at the agricultural field station at Rothamsted in England. Fischer concerned with arranging trials of fertilizers on plots to protect against the underlying effect of moisture, gradient, nature of soils, etc. Fischer developed the basic principles of factorial design and the associated data analysis known as ANOVA during research in improving the yield of agricultural crops.

3.2 Advantages & Disadvantages of DOE

DOE became a more widely used modeling technique superseding its predecessor one-factor-at- time (OFAT) technique. One of the main advantages of DOE is that it shows the relationship between parameters and responses. In other words, DOE shows the interaction between variables which in turn allows us to focus on controlling important parameters to obtain the best responses. DOE also can provide us with the most optimal setting of parametric values to find the best possible output characteristics. Besides from that, the mathematical model generated can be used as a prediction model which can predict the possible output response based on the input values. Another main reason DOE is used because it saves time and cost in terms of experimentation. DOE function in such manner that the number of experiments or the number of runs is determined before the actual experimentation is done. This way, time and cost can be saved as we do not have to repeat unnecessary experiment runs. Most usually, experiments will have error occurring. Some of them might be predictable while some errors are just out of control. DOE allows us to handle these errors while still continuing with the analysis. DOE is excellent when it comes to prediction linear behavior. However, when it comes to nonlinear behavior, DOE does not always give the best results.

3.3 Response Surface Method

RSM is an anthology of statistical and mathematical methods, helpful in generating improved methods and optimising the process. RSM is more frequently used in analyzing the relationships and the influences of input parameters on the responses. The method was introduced by G. E. P. Box and K. B. Wilson in 1951. RSM uses a set of designed experiments to obtain an optimal response. Box and Wilson used first-degree polynomial model to obtain DOE through RSM and acknowledged that the model is only an approximation and is easy to estimate and apply, even when little information is known about the process. RSM explores the relationships between several independent variables and one or more response variables; the response variables can be graphically viewed as a function of the process variables (or independent variables). According to Clurkin and Rosen , the RSM was constructed to check the model part accuracy which uses the build time as function of the process variables and other parameters. Asiaban pour et al. developed the regression model that describes the relationship between the factors and the composite desirability. RSM also improves the analyst’s understanding of the sensitivity between independent and dependent variables [102]. RSM is an experimental strategy and has been employed by research and development personnel in the industry, with considerable success in a wide variety of situations to obtain solutions for complicated problems.

The following two designs are widely used for fitting a quadratic model in RSM.

3.3.1 *Central Composite Designs*

Central Composite Designs (CCDs), also known as Box-Wilson designs [103], are appropriate for calibrating the full quadratic models described in Response Surface Models. There are three types of CCDs, *viz.* circumscribed, inscribed and faced. The geometry of CCD's is shown in the Figure 3.1

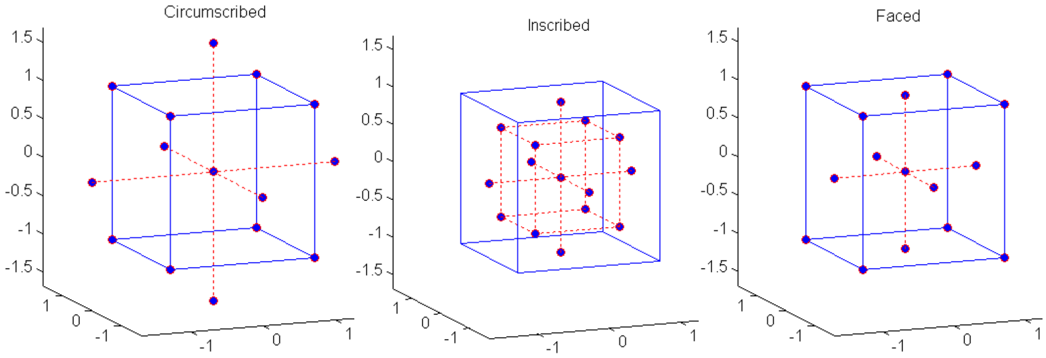


Fig 3.1.Circumscribed, Inscribed and Faced designs.

Each design consists of a factorial design (the corners of a cube) together with *center* and *star* points that allow estimation of second-order effects. For a full quadratic model with n factors, CCDs have enough design points to estimate the $(n+2)(n+1)/2$ coefficients in a full quadratic model with n factors.

The type of CCD used (the position of the factorial and star points) is determined by the number of factors and the desired properties of the design. Table 3.1 summarizes some important properties of CCDs. A design is rotatable if the prediction variance depends only on the distance of the design point from the center of the design.

Table 3.1: Comparison of CCD's

Design	Rotatable	Factor Levels	Uses Points Outside ±1	Accuracy of Estimates
Circumscribed (CCC)	Yes	5	Yes	Good over entire design space
Inscribed (CCI)	Yes	5	No	Good over central subset of design space
Faced (CCF)	No	3	No	Fair over entire design space; poor for pure quadratic coefficients

3.3.2 Box-Behnken Designs

Box-Behnken designs (Figure 3.2) are used to calibrate full quadratic models. These are for a small number of factors (four or less), rotatable and require fewer runs than CCDs. By avoiding the corners these designs allow researchers to work around extreme factor combinations like an inscribed CCD.

Some extensions of RSM deal with the multiple response problem. Multiple response variables create difficulty, as the optimal for one response may not be optimal for others. Significant criticisms of RSM include the fact that in most of the cases the **optimization** is done with a model for which the coefficients are estimated and not known. Thus, an optimum value may only look optimal, but is far from the real value because of variability in the coefficients.

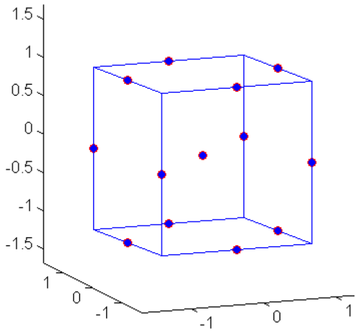


Fig 3.2.Box-Behnken design.

3.4 Application of Design of Experiments

The present work involves the following sequence of activities:

1. Identifying the important process control variables
2. Finding the upper and lower limits of the control variables, *viz.* peak current, back current, pulse rate and pulse width.
3. Developing the design matrix.
4. Conducting the experiments as per the developed design matrix.

3.4.1 Identification of the Process Parameters

The following independently controllable process parameters were identified to carry out the experiments based on earlier works : peak current, base current, pulse rate and pulse width.

3.4.2 Finding the Limits of the Process Variables

Based on trial experiments, the levels of each individual input variable are decided. The level of each variable is decided by varying its value from minimum to maximum keeping other variables constant and based on visual inspection ranges of each variable are fixed.

The upper limit of a factor was coded as +1 and the lower limit as -1, the coded values being calculated from Equation -1.

$$X_i = 2[2X-(X_{max} + X_{min})] / (X_{max} - X_{min}) \qquad \ldots\ldots (1)$$

Where X_i is the required coded value of a variable X, varying from X_{min} to X_{max}. The selected process parameters with their limits, units and notations are given in Table 3.1. The conditions shown in Table 3.2 are kept constant during welding.

Table 3.2 Process parameters and their limits

PARAMETER	**Level**		
	-1	0	+1
Welding Current(Amperes)	100	120	140

Wire Feed Rate (mm/min)	60	70	80
Edge Included Angle (Degrees)	30	45	60

Table 3.3 Welding conditions

Power source	ESAB(Tig 400i)
Polarity	DCEN
Mode of operation	Continuous mode
Electrode	2% thoriated tungsten electrode
Electrode Diameter	2mm
Plasma gas	Argon
Plasma gas flow rate	6 Lpm
Shielding gas	Argon
Copper Nozzle diameter	2.5mm
Nozzle to plate distance	1mm
Welding speed	200mm/min
Torch Position	Vertical
Operation type	Semi Automatic

3.4.3 Developing the Design Matrix

The selected design matrix, (shown in Table 3.3), is a Box- Benhken Design matrix consisting of 15 sets of coded conditions. All welding variables at the intermediate level (0) constitute the center points and the combinations of each of the welding variables at either its lowest (-1) level or highest (+1) level with the other three variables at the intermediate levels constitutes the star points. Thus the 15 experimental runs allowed the estimation of the linear, quadratic and two-way interactive effects of the process parameters.

3.4.4 Conducting the Experiments as per the Design Matrix

The experiments were conducted as per the design matrix at random, to avoid the possibility of systematic errors infiltrating the system.

Table 3.4 Typical Design Matrix

Exp.No.	**welding current(Amps)**	**Wire Feed rate(mm/min)**	**Edge Included Angle (Deg)**
1	100	60	45
2	140	60	45
3	100	80	45
4	140	80	45
5	100	70	30
6	140	70	30
7	100	70	60
8	140	70	60
9	120	60	30
10	120	80	30
11	120	60	60
12	120	80	60
13	120	70	45
14	120	70	45
15	120	70	45

CHAPTER-IV

EXPERIMENTAL DETAILS

4.1 Stainless Steels

Around the turn of the twentieth century it was discovered that by adding at least 12% chromium by weight steels become more corrosion resistant than common carbon steels. The addition of chromium caused the spontaneous formation of a passive protective layer, which reduced the rate of surface dissolution . As the science of metallurgy progressed, it was found that by further alloying steels with elements such as nickel, molybdenum, copper, titanium, aluminum, silicon, niobium, nitrogen, sulfur and selenium, other desirable properties could be selectively created. While stainless steels are generally defined as an iron alloy containing a minimum of 12 wt. % chromium, they may be further categorized into several sub-categories. These categories are martensitic, ferrite, duplex, precipitation, hardenable and austenitic.

4.2 Base Material

AISI 202 Stainless Steel is a type of Cr-Ni-Mn Stainless steel. It is one of the most widely used precipitation hardening grades, and possesses good corrosion resistance, toughness, high harness, and strength. It is one of the most widely used precipitation hardening grades, and possesses good corrosion resistance, toughness, high harness, and strength.

AISI 316 is the standard molybdenum-bearing grade, second in importance to 304 amongst the austenitic stainless steels. The molybdenum gives 316 better overall corrosion resistant properties. It has excellent forming and welding characteristics. The austenitic structure also gives these grades excellent toughness, even down to cryogenic temperatures.

4.3 Weld Joint preparation

AISI 316 and AISI 202 plates of 5 mm thickness was chosen for welding. First the plates were cut into 100mm x 200mm size using shearing machine and cleaned by using Ultrasonic cleaning and further cleaned with PCL 21 cleaner before welding. Copper sinks are fixed to the fixture to minimize weld distortion and extreme care has been taken for proper cutting of plates. Details about weld joint dimensions are shown in Figure 4.1.

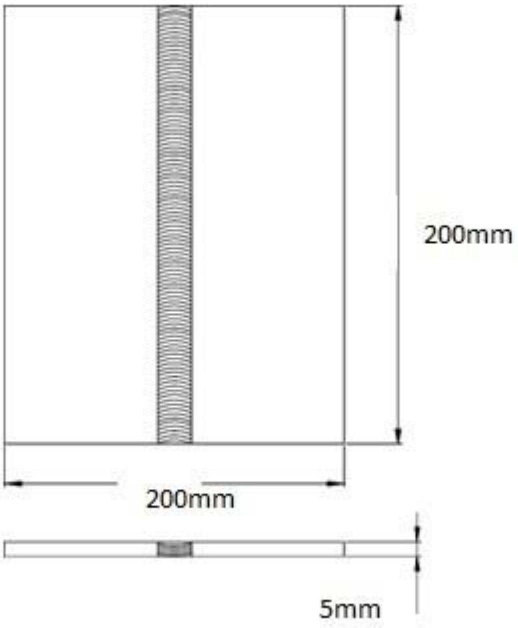


Fig. 4.1 Dimensions of welded joint

4.4 Experimental Procedure

AISI 316 plates of 100 x 200 x 5mm was welded to AISI 202 plates of 100 x 200 x 5mm with edge preparation. The chemical composition and tensile properties of AISI 316 and AISI 202 stainless steel plate are given in Table 4.1 to 4.4. The welding has been carried out under the welding conditions presented in Table 4.5. From the earlier works carried out on GTAW it was understood that the Welding Current, filler wire feed rate, flow rate of gas and edge included angle are the dominating parameters which effect the weld quality characteristics. The values of process parameters used in this study are the optimal values obtained from our earlier papers .Hence Welding Current, filler wire feed rate and edge included angle are chosen and their values are presented in Table 4.6.

Table 4.1 Chemical composition of AISI 316 (weight %)

Element	C	Mn	P	S	Si	Cr	Ni
Weight %	0.08	2.0	0.045	0.030	1.0	18.0-20.0	8.0-10.5

Table 4.2 Mechanical properties of AISI 316

Property	Ultimate Tensile Strength(MPa)	Yield Tensile Strength(MPa)	Vickers Hardness(BHN)	Charpy Strength(J)
Value	520	205	220	105

Table 4.3 Chemical composition of AISI 202 (weight %)

Element	C	Mn	P	S	Si	Cr	Ni	N
Weight %	0.15	7.5-10.0	0.060	0.030	0.75	17.0-19.0	4.0-6.0	0.25

Table 4.4 Mechanical properties of AISI 202

Property	Ultimate Tensile Strength(MPa)	Yield Tensile Strength(MPa)	Vickers Hardness(BHN)	Charpy Strength(J)
Value	515	275	240	100

Table 4.5 Welding conditions

Power source	ESAB(Tig 400i)
Polarity	DCEN
Mode of operation	Continuous mode
Electrode	2% thoriated tungsten electrode

Electrode Diameter	2mm
Plasma gas	Argon
Plasma gas flow rate	6 Lpm
Shielding gas	Argon
Copper Nozzle diameter	2.5mm
Nozzle to plate distance	1mm
Welding speed	200mm/min
Torch Position	Vertical
Operation type	Semi Automatic

Table 4.6 Input parameters

PARAMETER	**Level**		
	-1	**0**	**+1**
Welding Current (Amperes)	**100**	**120**	**140**
Wire Feed Rate (mm/min)	**60**	**70**	**80**
Edge Included Angle (Degrees)	**30**	**45**	**60**

4.5 Equipment Used for Testing

4.5.1 Brinel Hardness Machine

These **machines** measure the **hardness** of a material by pressing a chromium-steel or tungsten-carbide ball against the smooth material surface under standard **test** conditions. The **hardness** is expressed in HBW, where the ball indenter is made of tungsten carbide.

The **Brinell hardness test** method as used to determine **Brinell hardness**, is defined in ASTM E10. Most commonly it is used to **test** materials that have a structure that is too coarse or that have a surface that is too rough to be **tested** using another **test** method, e.g., castings and forgings.

The types of Brinell Hardness Number :

Analogue:

Analogue Brinell Hardness Testers are designed with a hydraulic power pack and control circuit to make the loading and unloading operation smooth. Dial gauge measures the depth of the ball penetration.

These machines are engineered precisely to conform IS 1500 (II): 2013, ISO 6506: 2005, BS: 240 and ASTM: E 10. These testers ensure production testing within tolerance limits by compression method. These testers are capable of measuring hardness of castings, forgings, other metals and alloys of all kinds (hard, soft, flat, round or irregular in shape).

Optical:

Optical Brinell Hardness Testers are very similar to the analogue testers in machine design and operations. In addition, an optical device with 14x magnification is in-built to project diameter of ball impression on glass screen with a micrometer measuring system. It projects the diameter of ball impression immediately after unloading, saving additional time for measurement of ball impression.

These machines are engineered precisely to conform IS 1500 (II): 2013, ISO 6506: 2005, BS: 240 and ASTM : E 10. They are most suitable for production testing, ensuring production testing within tolerance limits by compression method. The testers are capable of measuring hardness of castings, forgings, other metals and alloys of all kinds (hard, soft, flat, round or irregular in shape).

Computerised:

Computerised Brinell Hardness Testers measure Brinell Hardness Number directly and accurately, using state-of-the-art image processing technology. An in-built camera captures the image of the impression on the specimen and displays on the monitor. The software calculates the diameter (manual/semi-auto/auto) and converts it into measured hardness value. The software also segregates low/high and performs statistical evaluation. Repeated measurements at all loads yield higher productivity. Options for data storage and reports generation are also provided to save time.

They have algorithms for precise calculation of hardness numbers with various options to cover all ranges of specimen. These testers strictly conform to IS 1500(II): 2013, ISO 6506: 2005, BS: 10003-2 and ASTM E-10. The testers are suitable for measuring the hardness of metallic parts from soft to hard.

Semi-automatic:s

Semi-automatic Brinell hardness testers are flexible testers which can use multiple output methods, unlike other testers. Here, the reading of indentation is made through standard microscope or through optional electronic microscope with auto-measure.

Fully Automatic:

Fully Automatic Brinell Hardness Testers are fabricated from steel plates and are designed for precise loading systems. Once the job is placed on the testing table and “Cycle Start" button is placed, it takes care of all the operations till the job is lowered down at the end of auto cycle. Operationally the machine can be operated without the push button, so that user has to do only loading and unloading of jobs on the machine. The diameter of indentation is measured by PC and the Brinell Hardness is displayed on the monitor.

These testers strictly conform to IS 1500 (II): 2013, ISO 6506: 2005, BS: 10003-2 and ASTM E-10. The testers are fully automatic machines for production testing and are suitable for measuring the hardness of metallic parts from soft to hard.

The Brinell hardness test consists of applying a constant load or force, usually between 187.5 and 3000Kgf, for a specified time (from 10 - 30 seconds) typically using a 2.5 or 10mm diameter tungsten carbide ball

The time under load (dwell) period is required to ensure that plastic flow of the metal has ceased. Lower forces and smaller diameter balls are also used in specific applications. Similar to Knoop and Vickers testing, the Brinell test applies only a single test force. After removal of the load, the resultant recovered round impression is measured across the indent at right angles using a low-power microscope or an automatic measuring device and the average value used to calculate hardness.

The actual Brinell hardness (HB) is calculated by factoring the indent size and the test force, such that:

$$\mathbf{BHN = 2P / \pi D(D - \sqrt{(D2 - d2)})}$$

Where P= load applied

D = diameter of the ball indenter

d=diameter of the indentatio.

It is not necessary to make the actual calculation for each test - calculation tables have been published for various combinations of diameters of impressions, load and ball size. In addition various forms of automatic Brinell reading devices are available to perform these tasks.

Applications

Brinell hardness testing is typically used in testing aluminum and copper alloys (at lower forces) and steels and cast irons at the higher force ranges. As the Brinell test uses relatively high loads, and therefore relatively large indent, it is frequently used to determine the hardness in circumstances where the overall material properties are being ascertained and local variations in hardness or surface conditions make other methods unsuitable, such as forgings or castings of large parts.

Highly hardened steel or other materials are usually not tested by the Brinell method. As such, Brinell hardness testing machines often manufactured to accommodate large parts such as engine castings and large diameter piping. A minimum material thickness of at least 8x the testing depth is recommended (ISO 6506).

Due to the wide number of ball sizes and loads available, it is possible to test a very wide range of hardness values using the Brinell method. This is constrained by the indenter ball itself, which can become deformed by testing harder materials.

It should be noted that there is a relationship between load and ball diameter (L/D2), whereby tests with load/indenter combinations having the same ratio give the equivalent HB values. Tests with different ratios are not comparable. Errors in Brinell measurement are usually attributable to poor surface condition or operator errors in optical measurement, but due to the large size of indent these errors tend to be limited.

Fig4.2BrinellHardnessMachine

Table 4.7 Specifications of Brinell HardnessNumber

Specifications	Unit	B-3000(O)	B-3000(H)	B-3000(J)
Loads	200	500 to 3000 in stages of 250	500 to 3000 in stages of 250	500 to 3000 in stages of 250
Initial Load	Kgf.	Nil	250	Nil
Max. Test Height	mm.	380	410	254
Depth of throat	mm.	200	200	154
Max. Depth of elevating screw below base	mm.	180	180	0
Size of base	mm.	370x670	370x670	255x495
Machine Height	mm.	1185	1127	860
Net Weight (Approx.)	Kg.	500	450	210
Drive Motor	HP	0.33-415v/p	0.33-415v/p	Nil

4.5.2 Rockwell Hardness Machine

The Rockwell Hardness Test is generally a non-destructive test performed on samples when it is necessary to determine how hard a material is. Hugh M. Rockwell (1890–1957) and Stanley P. Rockwell (1886–1940) from Connecticut co-invented the first tester and a patent was granted in 1919. The Rockwell Hardness test is generally considered easier to perform compared to other methods such as Vickers or Brinell.

Hardness is defined as a material’s resistance to permanent indentation. Current Rockwell Hardness test methods are specified in ASTM E-18 and anyone wishing to perform a Rockwell Hardness test should become familiar with this test standard.

Procedure for rockwell hardness test:

1. The Rockwell hardness test consists of indenting the test material with a diamond cone or hardened steel ball indenter.

2. Each time a test is performed two loads are applied to the sample being tested.

3. First, the indenter is forced into the test material under a preliminary minor load and this depth is recorded.

4. With the minor load still applied an additional load is introduced known as the major load which increases the depth of penetration on the sample.

5. The Major load is then removed, and the force on the sample is returned to the minor load.

6. The increase in the depth of penetration that results from applying and removing the major load is used to calculate the Rockwell hardness value.

Fig.4.4RockwellHardnessTestMachine

Table 4.8 specifications of rockwell hardness test machine

Testing Range:
20-88 HRA
20-100 HRB
20-70 HRC

Scales:
HRA, HRB, HRC, HV, HB

Tensile Strength:
110-363 Lb/ln2
77 – 266 Kg/cm2

Accuracy:
0.1 HR

Operation Temperature:
Operation 32 °F to 104 °F (0 °C to 40 ° C)
Storage -4 °F to 122 °F (-15 °C to 50 ° C)

Battery:
Rechargeable Li-Ion

Battery Life:
Work Time: 6 Hours per charge
Full Charge Period: 2 Hours

Data Storage:
Automatically records up to 1000 test results, includes native Rockwell readings, converted readingss and averages.

Tester dimension:
7.9” x 4.3" x 1.8” (200mm x 110mm x 46mm)

Weight:
4.5lb (2Kg)

CHAPTER-V

STATISTICAL ANALYSIS & OPTIMIZATION

5.1 Conducting the Experiments as per the Design Matrix

The experiments were conducted as per the design matrix at random, to avoid the possibility of systematic errors infiltrating the system.

5.2 Mathematical models

Brinell Hardness Number(B.H.N)

$$(\text{B.H.N}) = 2P / \pi D(D - \sqrt{(D2 - d2)})$$

Where P= Load applied = 187.5 kgf.

D= Diameter of the indenter = 2.5mm

d= Diameter of the indentation.

Rockwell Hardness Number(R.H.N)

Load applied = 100kgf.

Scale reading for mild steel = ‘C’ scale

Indenter = Diamond.

Table 5.1 Experimental Results

		BASE MATERIAL	HEATED ZONE	FUSION ZONE	HEATED ZONE	BASE MATERIAL
	AISI	**202**	**202**	**309**	**316**	**316**

TEMP		1	2	3	4	5	6	7	8	9	10	11
30°C	B.H.N	272.12	284.81	238.59	228.73	187.21	224.02	155.59	215.00	180.20	190.85	224.02
30°C	R.H.N	114	127	128	126	116	85	120	132	118	121	120

200°C	**B.H.N**	**254.59**	**278.39**	**284.84**	**249.10**	**180.23**	**187.23**	**187.23**	**152.87**	**228.76**	**187.23**	**170.39**
200°C	**R.H.N**	**127**	**129.5**	**129**	**128**	**94.5**	**113.5**	**116**	**126**	**82**	**115**	**114**
400°C	**B.H.N**	**254.59**	**272.15**	**249.10**	**243.78**	**180.23**	**187.23**	**219.47**	**187.23**	**224.05**	**228.76**	**206.52**
400°C	**R.H.N**	**127**	**127.5**	**130**	**125.5**	**156**	**145**	**79**	**153**	**121**	**116**	**119**
600°C	**B.H.N**	**219.47**	**238.62**	**249.10**	**228.76**	**180.23**	**187.23**	**187.23**	**194.63**	**219.47**	**224.05**	**187.23**
600°C	**R.H.N**	**114**	**110**	**106**	**121**	**97**	**100**	**117**	**121**	**100**	**107**	**106**

5.3 Effect of welding parameters

The parameters that affect the quality and outcome of the TIG welding process are given below.

a) Welding Current

Higher current in TIG welding can lead to splatter and work piece become damage. Again lower current setting in TIG welding lead to sticking of the filler wire. Sometimes larger heat affected area can be found for lower welding current, as high temperatures need to applied for longer periods of time to deposit the same amount of filling materials. Fixed current mode will vary the voltage in order to maintain a constant arc current.

b) **Welding Voltage**

Welding Voltage can be fixed or adjustable depending on the TIG welding equipment. A high initial voltage allows for easy arc initiation and a greater range of working tip distance. Too high voltage, can lead to large variable in welding quality.

c) **Inert Gases:**

The choice of shielding gas is depends on the working metals and effects on the welding cost, weld temperature, arc stability, weld speed, splatter, electrode life etc. it also affects the finished weld penetration depth and surface profile, porosity, corrosion resistance, strength, hardness and brittleness of the weld material. Argon or

Helium may be used successfully for TIG welding applications. For welding of extremely thin material pure argon is used. Argon generally provides an arc which operates more smoothly and quietly. 7 Penetration of arc is less when Argon is used than the arc obtained by the use of Helium. For these reasons argon is preferred for most of the applications, except where higher heat and penetration is required for welding metals of high heat conductivity in larger thicknesses. Aluminium and copper are metals of high heat conductivity and are examples of the type of material for which helium is advantageous in welding relatively thick sections. Pure argon can be used for welding of structural steels, low alloyed steels, stainless steels, aluminium, copper, titanium and magnesium. Argon hydrogen mixture is used for welding of some grades of stainless steels and nickel alloys. Pure helium may be used for aluminium and copper. Helium argon mixtures may be used for low alloy steels, aluminium and copper.

d) **Welding speed:**

Welding speed is an important parameter for TIG welding. If the welding speed is increased, power or heat input per unit length of weld is decreases, therefore less weld reinforcement results and penetration of welding decreases. Welding speed or travel speed is primarily control the bead size and penetration of weld. It is interdependent with current. Excessive high welding speed decreases wetting action, increases tendency of undercut, porosity and uneven bead shapes while slower welding speed reduces the tendency to porosity.

The four important **parameters** are the **welding** current, wire electrode extension, **welding** voltage and arc travel speed. These **parameters** will affect the **weld** characteristics to a great extent. Because these factors can be varied over a large range, they are considered the primary adjustments in any **welding** operation.

Welding speed is an important **parameter** for **TIG welding**. If the **welding** speed is increased, power or heat input per unit length of **weld** is decreases, therefore less **weld** reinforcement results and penetration of **welding** decreases. **Welding** speed or travel speed is primarily control the bead size and penetration of **weld**.

5.4 Optimization

It was also clear that GRA can be used to **optimize** the **TIG welding** process parameter to obtain the desired quality weldments. In this work, multi-objective **optimization** using GRA has been carried out to **optimize** the **TIG welding** process parameter (**welding** speed,

5.5 Graphs For Brinell amd Rockwell Hardness Tests

From fig 5.9 shows that the graph between distance between the welded specimen to the Brinell and Rockwell Hardness Numbers. As we move away from the welded (fusion) zone the Hardness Numbers are changes

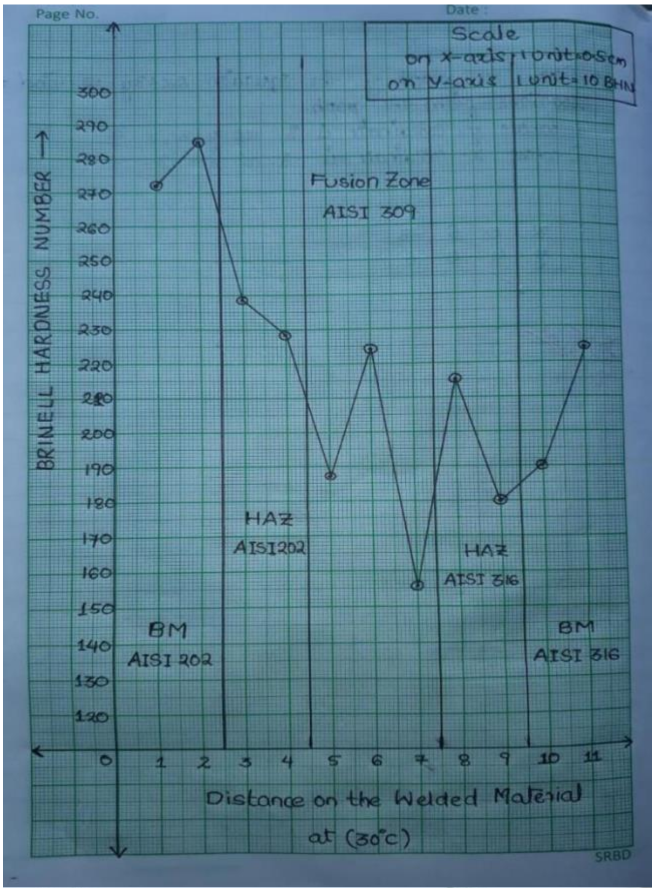
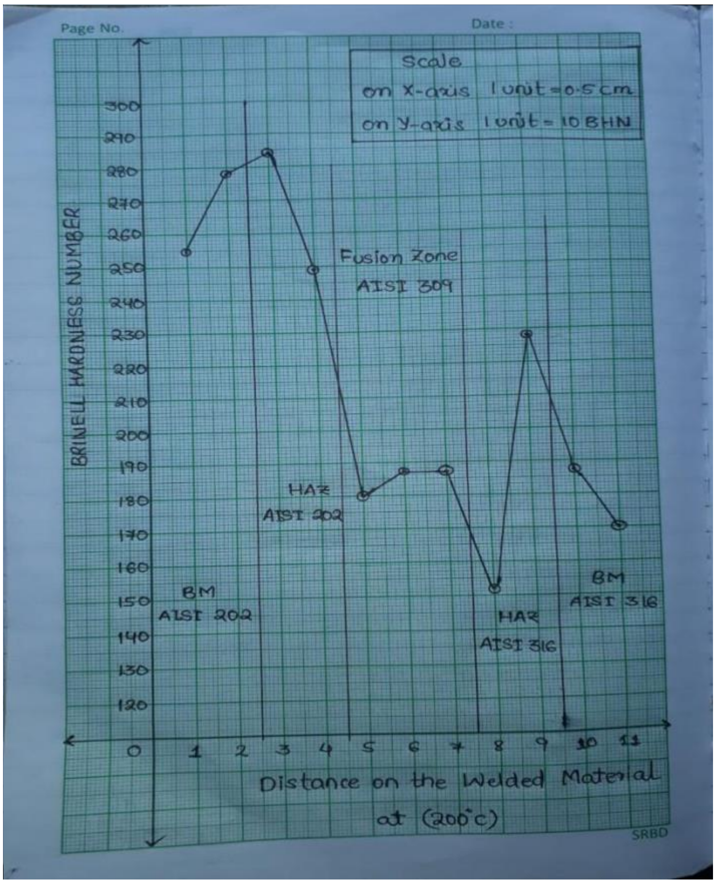


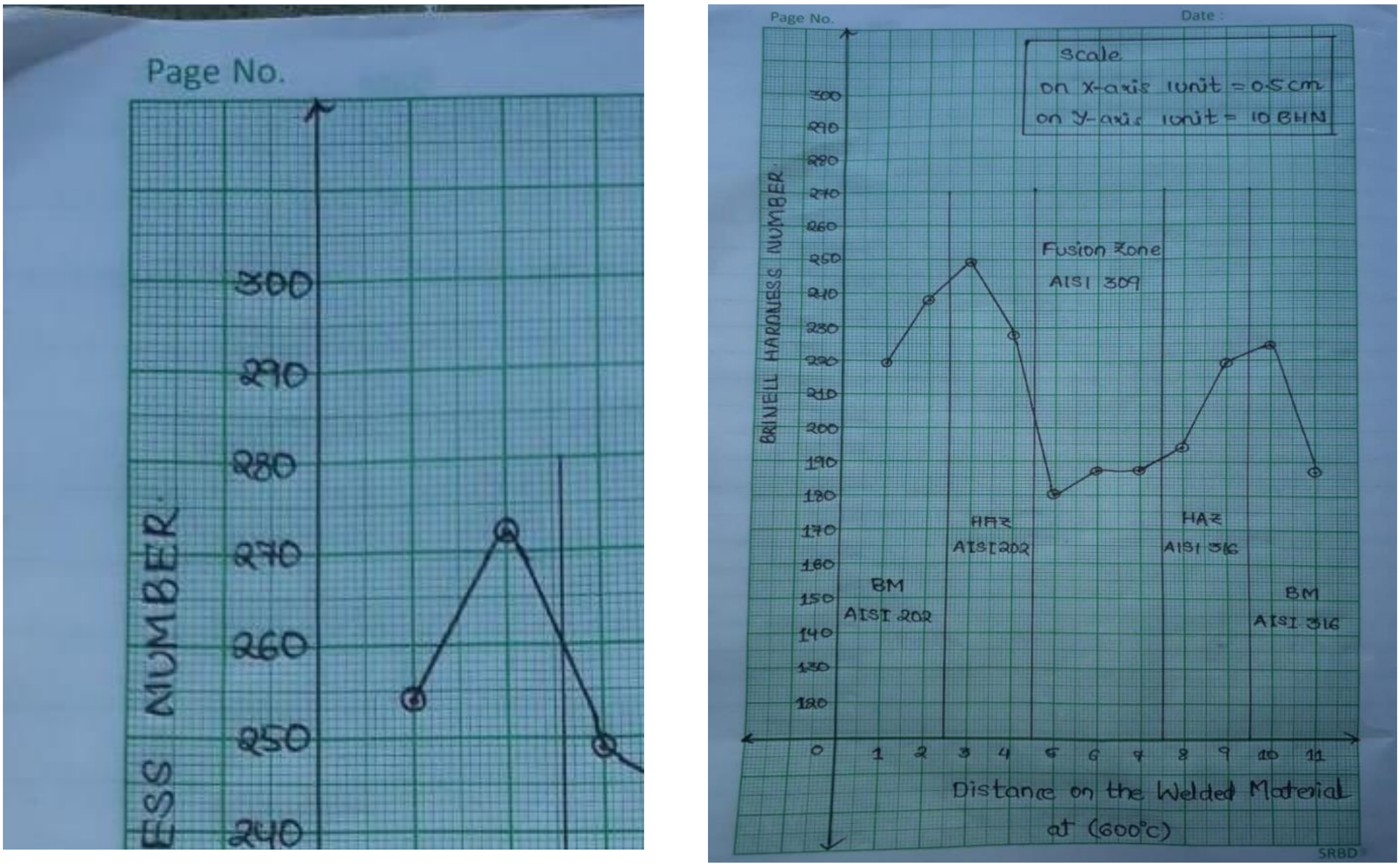
Fig 5.5.1Graph For Brinel Hardness Test

From fig   shows that the graph between distance between the welded specimen to the Brinell Hardness Numbers. As we move away from the welded (fusion) zone the Hardness Numbers are changes. The graphs are drawn four different temperature which were taken at the time of the experimentation.



B.H.N at 30

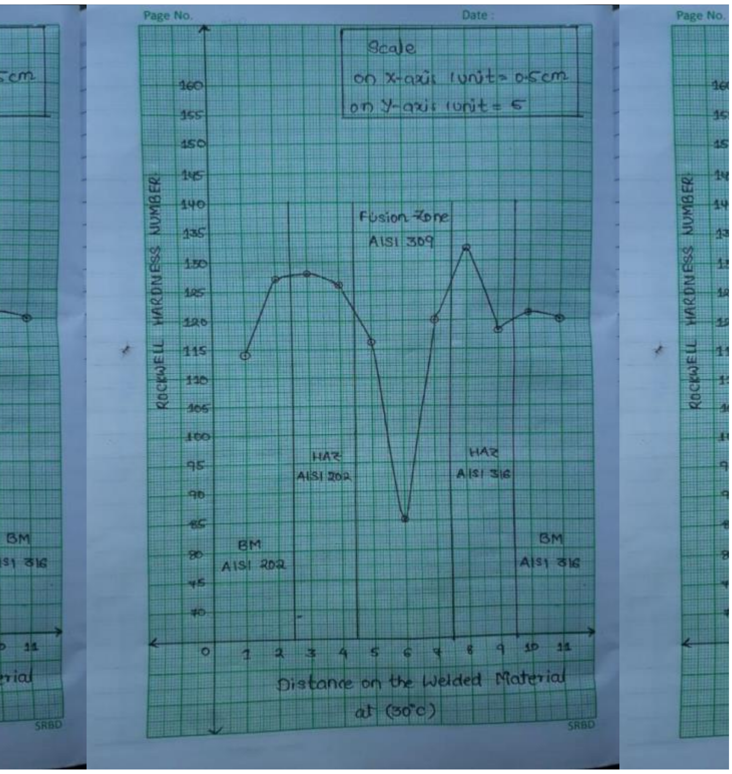
B.H.N at 200

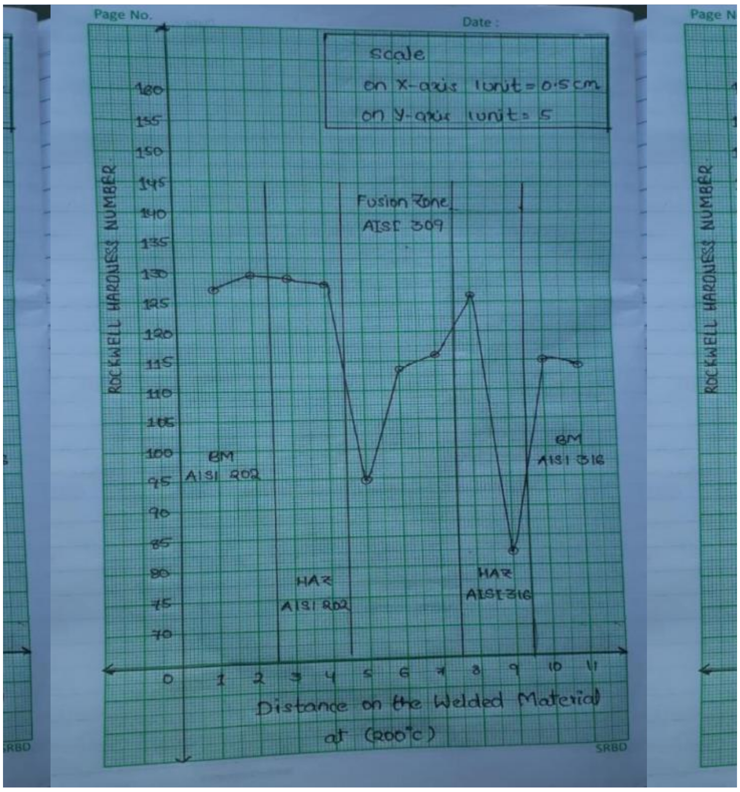


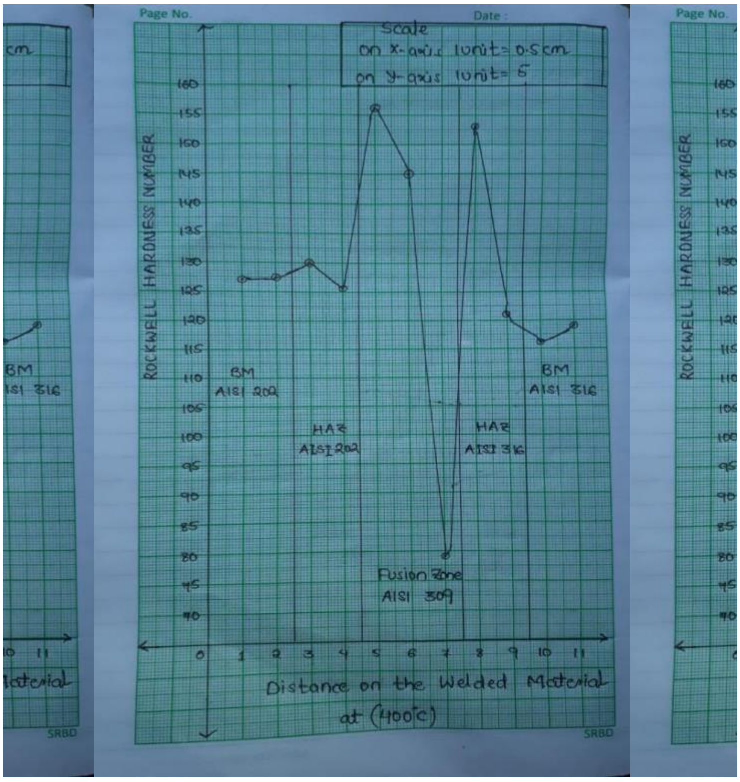
B. H.N at 400 **B.H.N at 600**

Fig 5.5.2Graph For Rockwell Hardness Test

From fig shows that the graph between distance between the welded specimen to the Rockwell Hardness Numbers. As we move away from the welded (fusion) zone the Hardness Numbers are changes. The graphs are drawn four different temperature (30,200,400,600)which were taken at the time of the experimentation.



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ROCKWELL HARDNESS NUMBER
160
155
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95
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75
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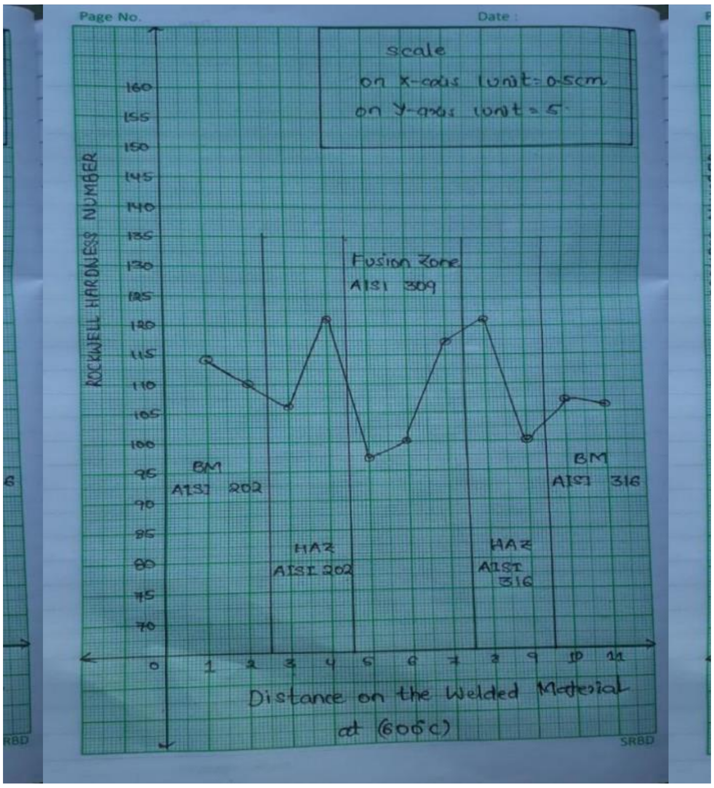
BM
AISI 202
HAZ
AISI 202
Fusion Zone
AISI 309
HAZ
AISI 316
BM
AISI 316
Distance on the Welded Material
at (400°c)
SRBD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Scale
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ROCKWELL HARDNESS NUMBER
160
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120
115
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105
100
95
90
85
80
75
70
0 1 2 3 4 5 6 7 8 9 10 11
Fusion Zone
AISI 309
BM
AISI 202
HAZ
AISI 202
HAZ
AISI 316
BM
AISI 316
Distance on the Welded Material
at (600°c)
SRBD

CHAPTER-VI

CONCLUSIONS & FUTURE SCOPE

6.1 CONCLUSIONS

Based on the experiments performed the following conclusions are drawn:

S

1) AISI 202 and AISI 316 are successfully welded using continuous TIG welding process.

2) Experiments are performed as per Box Behnken Design matrix of Response Surface Method.

3) Empirical mathematical models are developed for Brinell and Rockwell Hardness Number for AISI 202, AISI 309 and AISI 316 by considering the significant coefficients of the welding parameters considered.
4) For welding performed with high current (180 A),
5) With the automated welding system uniform welding of Steel plate can be possible.

6) Welding strength of the weld joint depends on the welding parameters like welding speed and welding current.
7) Hardness value of the weld zone change with the distance from weld centre due to change of microstructure.
8) At lower welding speeds strength is more due to more intensity of current.
9) In this method, we use a ball indenter of 2.5 diameter. Due to low load and less ball diameter, this **test** is used in commercial practices. ... Therefore it concludes that **Brinell hardness** number (BHN) is dependent on the load applied.
10) From this experiment, we can conclude that, Rockwell hardness of a steel specimen increases with increase in the carbon content, keeping the cooling rate constant.

11) From the graph plots, it is revealed that experimental and values are varying as we move away from the welded zone.

6.2 FUTURE SCOPE

In present work welding is performed without any filler material. A filler rod/wire feeding system can be included in the system so that by using filler rod/wire thicker plate can be welded. Welding setup can also be use for welding of some other materials.

1) In the present work we had carried out welding in continuous current mode, one may adopt pulsed current mode.
2) The number of levels of the welding parameters may be increased to improve the accuracy of the developed models.

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