TO STUDY AND ANALYSIS OF TENSILE STRENGTH AND HARDNESS THROUGH TIG WELDING ON DUPLEX STAINLESS STEEL

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I. INTRODUCTION

HISTORY OF GTAW (TIG WELDING)

TIG welding was, like MIG/MAG developed during 1940 at the start of the Second World War. TIG's development came about to help in the welding of difficult types of material, egg aluminium and magnesium. The use of TIG today has spread to a variety of metals like stainless mild and high tensile steels. GTAW is most commonly called TIG (Tungsten Inert Gas). The development of TIG welding has added a lot in the ability to make products that before the 1940's were only thought of. Like other forms of welding, TIG power sources have, over the years, gone from basic transformer types to the highly electronic power source of the world today.

Origin of Gas Tungsten Arc Welding

The Gas Tungsten Arc Welding (GTAW) process is sometimes referred to as TIG, or Heliarc. TIG is short for Tungsten Inert Gas Welding, and the term Heliarc was used because helium was the first gas used for the process. The aircraft industry developed the GTAW process for welding magnesium during the late 1930's and the early 1940's. During that time, helium was the primary shielding gas used, along with DCEP welding current. These caused many problems that limited application of GTAW welding process. But improve the process effectiveness and reduced its cost. Before the development of the GTAW process, welding aluminium and magnesium was difficult. The weld produced was porous and corrosion−prone. The tungsten inert gas process can be used for welding aluminium, magnesium, stainless steel silicon bronze titanium, copper and copper alloy, and wide range of different metal thickness in mild steel. Top quality welds made in the above metal need little, if any, cleaning after welding period. TIG Welding is most often used for joining aluminium from 1/32 inch to 1/8 inch (0.79 to 3.2 mm) thick. Although heavier sections can be joined by TIG welding, other processes are usually more economical. TIG welding is an easy method of joining metals that are considered hard−to−weld, and filler and base metals can be easily matched. With TIG welding, strip of scrap parent metal may be used for filler metal. Post−weld machining, grinding, or chipping can usually be eliminated due to the easily controlled weld reinforcement. The need for flux is eliminated, even on hard to weld metal such as aluminium.

Definition

It is an arc welding process wherein coalescence is produced by heating the job with an electric arc struck between a tungsten electrode and the job. A shielding gas (argon helium, nitrogen, etc.) is used to avoid atmospheric contamination of the molten weld pool. A filler metal may be added, if required.

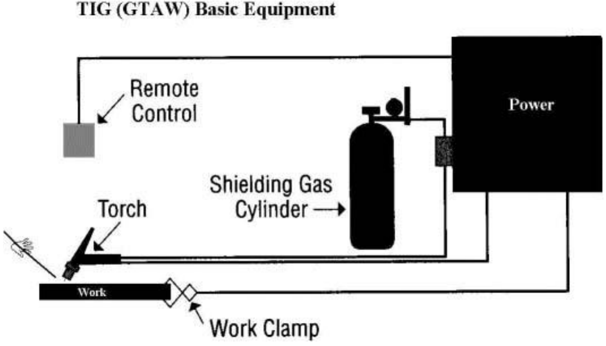


Fig. 1.1 Gas Tungsten Arc Welding Process

In gas tungsten−arc welding (GTW), formerly known as TIG welding (for tungsten inert gas), the filler metal supplied from a filler wire (because the tungsten electrode is not consumed in this operation, a constant and stable arc gap is maintained at a constant current level. The metal is similar to the metals to be welded, and flux is not used. The shielding gas is usually Argon or Helium, or a mixture of the two. Welding with GTAW is done without filler metals, as in welding close−fits joints. The power supply is either DC at 200 amps. Or AC at 500 ampere. Depending on the metal to be welded. In general, AC is preferred for aluminium and magnesium because the cleaning action of AC removes and improves weld quality.

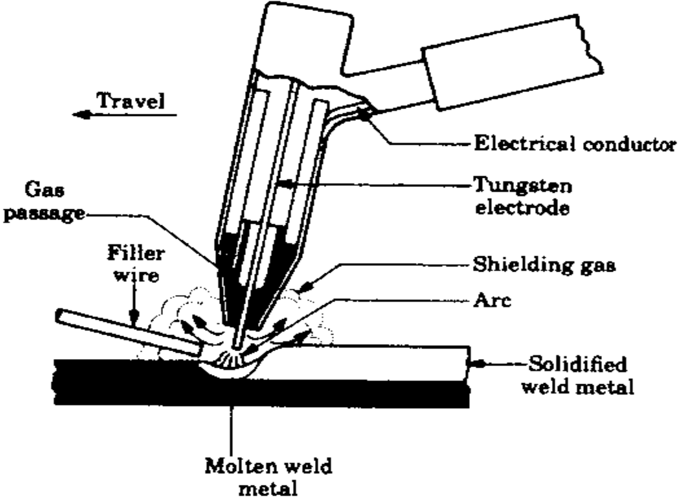


Fig. 1.2 TIG Welding

PRINCIPLES OF GTAW WELDING

The TIG welding machine may be either AC or DC. The type of machine for particular TIG weld jobs depends on the materials to be weld. All three types of welding current, or polarities, can be used for GTAW welding. Each current has individual featured that it makes more desirable for specific, conditions or with certain types of metals. The major difference among the current is in their heat distribution and the presence or degree of arc cleaning.

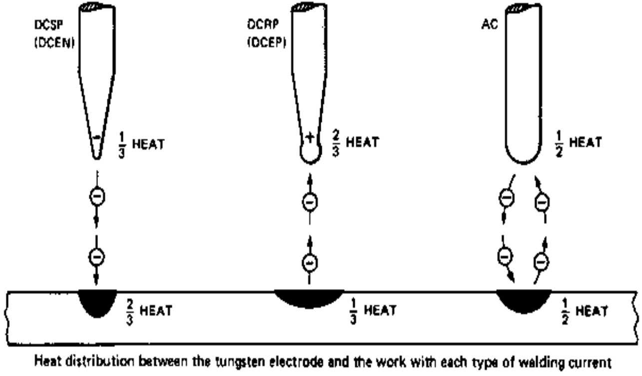


Fig. 1.3 Three types of welding current

Direct Current electrode negative (DCEN), which use to be called direct−current straight polarity (DCRP) current rates about two−thirds of its welding heat on the work and the remaining one−third on the tungsten.

- Direct Current electrode positive (DCEP), which used to be called direct−current reverse polarity (DCRP), concentrate only one−third of the arc heat on the plate and two−third of the heat on the electrode.
- There are many theories as to why DCEP has a cleaning action the most probable explanation that the electrons accelerated from the cathode surface lift the oxides that interfere with their movement. The positive ions accelerated to the metals surface provide additional energy. In combination, the electrons and ions cause the surface erosion needed to produce the cleaning. Although this theory is disputed, it is important to note that DCEP occurs, that it requires argon−rich shield gases and DCEP polarity, and that it can be used to advantage.
- Alternating Current (AC) concentrates about half of its heat on the work and the other half on the tungsten. Alternating current is DCEN half of the time DCEP the other half of the time. The frequency at which the current cycle is the rate at which it makes a full change in the direction. The current cycles at the rate of 60 times per second the current at its maximum points A and B the rate gradually decrease until stops at points C and D.

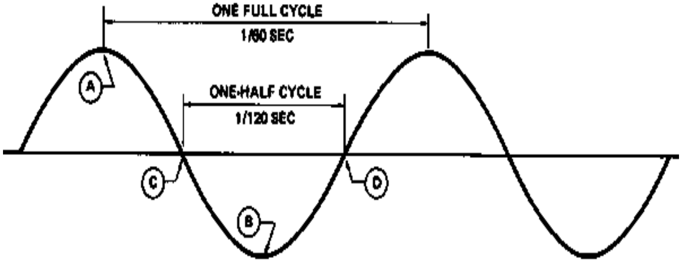


Fig. 1.4 Alternate current cycle

PROCESS VARIABLES

shielding-gases

To prevent weld contamination and electrode deterioration the gas shield must (a) prevent atmospheric contamination of the weld and (b) not react with molten or solidifying weld metal or the tungsten electrode.

The typical shielding gases used in TIG Welding are:

- Argon − Suitable for most applications
- Helium − Gives better penetration and heat input. This gas is more expensive than argon and because of this is sometimes used as a mixture of 5% helium and 95% argon for welding stainless steels.

More about gases for GTAW

- Shielding gases are usually supplied in cylinders. These should be used in an upright position supported in a cylinder stand falling and causing accidents.
- Argon shielding gas is supplied in BLUE cylinders.
- Helium shielding gas is supplied in BROWN cylinders.
- The cylinders are supplied pressurized at 170 bar (2500 lb/in2) and must not be exposed to direct sunlight, which might cause explosion.
- The moisture content of a gas in a cylinder can rise as the cylinder pressure falls. 'Wet' shielding gas can contaminate welded joints. To prevent this is to recommend that cylinders should not be used at pressures below 14 bar (200 lb/in2).
- A cylinder should never be emptied completely because if the pressure is allowed to fall below 30 lb/in2 the cylinder itself may become contaminated.
- The pressure of the gas delivered to the torch is controlled by a regulator, which reduces the cylinder pressure to operating pressure.
- A flow meter is also fitted so that the welder may adjust the rate of flow to keep it constant as the pressure in the cylinder falls.
- The flow meter may be combined with an economizer, which shuts off the gas when the torch is hung on the operating lever.

Electrodes

Electrodes are made from tungsten and contain small percentages of either THORIUM or ZIRCONIUM.

These additions ensure better arc striking ability and stability.

- Thoriated tungsten electrodes should be used for DC welding.
- Zirconiated tungsten electrodes should be used for AC welding, and are particularly suitable for welding aluminium and its alloys and magnesium and its alloys.
- Tungsten electrodes are identified by color code:

− 1 % Thoriated tungsten electrodes have a BLUE tip.
− 2 % Thoriated tungsten electrodes have a RED tip.
− 1 % Zirconiated tungsten electrodes have a BROWN tip.

Filler rods

Filler rods are specially designed for TIG welding and usually supplied in cut lengths of 1 meter in the following diameters:

- 1.6 mm
- 2.4 mm
- 3.2 mm
- 4.8 mm

The compositions of filler rods should be chosen to suit the parent metals being welded. Filler rods should be stored in clean dry conditions to prevent deterioration. They should be free from rust, scale, oil grease and moisture, which would contaminate welds, and be cleaned with stainless steel wool or smooth aluminium oxide cloth immediately before use.

After cleaning, filler rods should never be touched with bare hands. Wear clean, flexible soft leather or fire proofed cotton gloves.

WELD DEFECTS

Before describing specifics, it is important to point out the difference between a weld defect and a weld discontinuity. Every weld can be said to have some discontinuities, since there really is no perfect weld. Some welding instructors, specification books, or codes may allow for a certain amount of discontinuities without calling the weld defective. There is usually a certain point at which the weld will be considered defective. A defective weld would be rejected, for example, for a welder's qualifying test. A defective weld in a manufacturing situation would have to be ground out and replaced, or the entire base metal structure would be rejected. It is important that some discontinuities in a weld are allowable. When one or more discontinuities cause a weld to fail a particular weld test, this type of discontinuity would then be termed a defect. Acceptable limits can change due to many factors. If the weld requirements are very strict, acceptable limits for the number and size of discontinuities may be quite low. It is quite easy to encounter many kinds of discontinuities and defects when first learning the GTAW process.

Discontinuities and defects can be caused by many factors, including:

- Improper welding techniques
- Improper shielding gas
- Improperly prepared or contaminated base metal
- Dirty or contaminated electrode
- Improper secondary circuit
- Equipment problems

The most common weld defects are:

- Lack of Penetration
- Incomplete Fusion
- Porosity
- Undercutting
- Cracking

Lack of Penetration

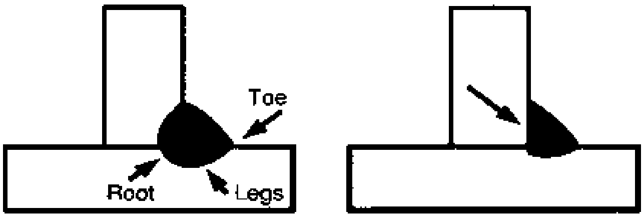
When molten weld metal has not sufficiently penetrated into the base metal, a weld defect can occur, called lack of penetration. Full strength of a joint is not possible if the penetration is not adequate. Lack of penetration can be caused by any one of a number of factors.

Controlled penetration is also difficult to achieve when poor fit–up of the base members occurs.

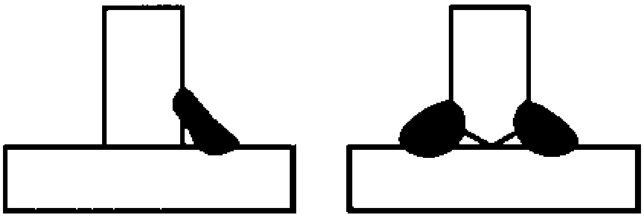
Incomplete Fusion (Cold Lap)

How well the base metal and weld metal are joined together is termed fusion. Fusion is important if full strength of a joint is to be achieved. Incomplete fusion means that at some point in a weld, the base metal and weld metal have not been joined properly. This could occur at any point in the weld. Possible causes for incomplete fusion or cold lap:

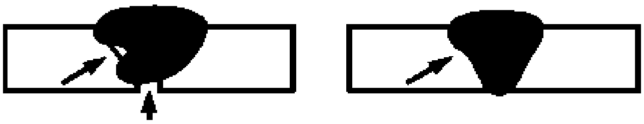
- Failure to raise the temperature of the weld area to the correct level
- Failure to remove large amounts of mill scale, oxides, or any other foreign materials present on the base metal. These materials could hinder the fusing of the weld metal to the base metal.
- Improper joint design basically refers to the size of the groove angle and root openings on a butt joint. Should these angles or openings be too small for proper electrode extension and gas shielding, incomplete fusion and possible other defects can occur.



Good Fusion Poor Fusion



Bridging Double Bevel Groove Fillet Weld With Incomplete Fusion



Incomplete Fusion In A Grooved Butt Joint Incomplete Fusion On One Leg Of A Butt Joint

Fig. 1.5 Fusion in Tig Welding

Porosity

Porosity is one of the more common weld defects. It can occur at the surface or face of the weld. Or, porosity can occur inside the weld, where it is difficult to detect. Subsurface porosity cannot be seen with the naked eye but can be detected with various means of testing. Gases being trapped in the solidifying weld cause porosity. Put another way, the metal is freezing before the gas has a chance to fully escape from the weld. Porosity looks like many small holes in a weld − much like the wormholes in a piece of wood. The gas pockets or pores are usually round in shape and can vary in size.

Primary sources for porosity:

- Moisture
- Dirty wire or base metal

Moisture:

The primary cause of porosity is moisture. This moisture is heated by the welding arc and molten metal, and becomes a gas. Hot metal will absorb some of this gas but the rest of it, being lighter than the metal, floats to the surface and out into the air. The problem comes from the gas that is absorbed by the molten metal. Hot metal will absorb more gas than cold metal. Therefore, as the weld bead begins to cool, the gas can no longer stay in the cooling metal and must come out. As the metal cools it becomes less liquid, and at some point the escaping gas can no longer float through the hardening metal. The gas is then trapped and causes porosity.

Sources for moisture:

- Contaminated, or wet base metal
- Excessive humidity or any moisture in the air

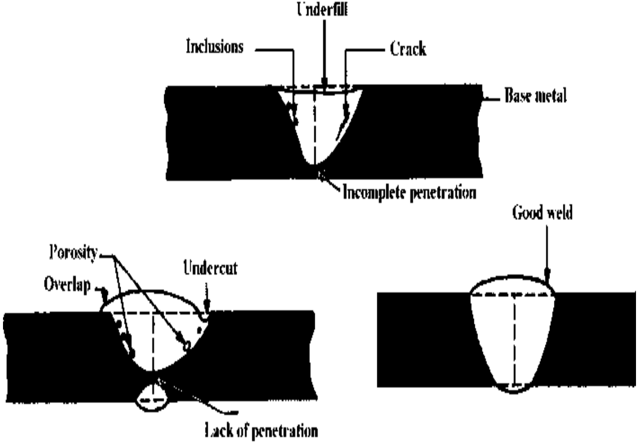


Fig. 1.6 Lack of Penetration

Undercutting

Undercutting is a defect that appears as a groove in the parent metal directly along the edges of the weld. This type of defect is most commonly caused by improper welding parameters particularly the travel speed and arc voltage. When the travel speed is too high, the weld bead will be very peaked because of its extremely fast solidification. The forces of surface tension have drawn the molten metal along the edges of the weld bead and piled it up along the centre. Melted portions of the base plate are affected in the same way. The undercut groove is where melted base material has been drawn into the weld and not allowed to wet back properly because of the rapid solidification. Decreasing the arc travel speed will gradually reduce the size of the undercut and eventually eliminate it. When only small or intermittent undercuts are present, raising the arc voltage or using a leading torch angle is also corrective actions. In both cases, the weld bead will become flatter.

Cracking

When a metal is put under stress it can crack. Cracks can occur on top of a weld bead, within the weld, or in the base metal. With the GTAW process and proper welding procedures, weld cracks are held to a minimum. Because GTAW filler wires have no flux coating to attract moisture, they are by nature low hydrogen in content. They can help avoid cracking in the weld and heat‒affected zone if kept clean and dry. The filler wire must be free of moisture while being used and when stored. A cracking defect is very often associated with the welding of aluminium. A crack can easily occur on aluminium due to metal contraction as the weld pool cools, while the base metal remains hot. This is especially possible in the weld crater at the end of a weld. Therefore, the crater should proper strength and weld size. Cracks may be more numerous with aluminium but they may also occur in stainless steel and steel and galvanized materials. For both stainless steel cracks may occur if excess heat input is used for the particular thickness of material being welded. Also, steels with high carbon content (over 30 %) are likely to crack due to their hardness.

ADVANTAGES:

The TIG process has the advantages of -

1) Narrow concentrated arc
2) Able to weld ferrous and non-ferrous metals
3) Does not use flux or leave a slag
4) Uses a shielding gas to protect the weld pool and tungsten
5) A TIG weld should have no spatter
6) TIG produces no fumes but can produce ozone

APPLICATION:

The TIG process is a highly controllable process that leaves a clean weld which usually needs little or no finishing. TIG welding can be used for both manual and automatic operations. The TIG welding process is so good that it is widely used in the so-called high-tech industry applications such as

1) Nuclear industry
2) Aircraft
3) Food industry
4) Maintenance and repair work
5) Some manufacturing areas

About Duplex stainless steel

Material Description

2205 is a duplex (austenitic-ferritic) stainless steel that combines many of the best properties of austenitic and ferritic stainless steels. High chromium and molybdenum contents provide excellent resistance to pitting and crevice corrosion. The duplex structure is highly resistant to chloride stress corrosion cracking. 2205 has outstanding strength and toughness and possesses good weld ability. Gas tungsten arc welding, also called TIG, and may be performed manually or by machine. A constant-current power supply should be used, preferably with a high-frequency circuit for starting the arc and a stepless control current delay unit incorporated in the power supply unit. GTAW should be done using direct current straight polarity (DCSP), electrode negative. Use of direct current reverse polarity (DCRP) will result in rapid electrode deterioration.

Choice of Filler Metal and Electrode

The non consumable electrode shall meet the requirements of AWS specification Classification EWTh-2 (2% thoriated tungsten electrode).Good arc control is achieved by grinding the electrode to a point. Vertex angles of 30–60 degrees with a small flat at the point are generally used. For automatic GTAW, the vertex angle will affect penetration. A few simple tests prior to actual fabrication should be made to determine the best electrode configuration.

II. LITERATURE REVIEW

Literature Survey

G. MAGUDEESWARAN et al Optimization of process parameters of the activated tungsten inert gas welding for aspect ratio of UNS S32205 duplex stainless steel welds the optimum welding parameters are found to be electrode gap of 1 mm, travel speed of 130 mm/min, current of 140 A, and voltage of 12 V. Average ferrite number (FN) in the weld zone for the joints fabricated using the optimized process parameters is 71.62, and the ferrite content is approximately 50.674% which is well within the acceptable range.

Nanda Naik Korra et al Multi-objective optimization of activated tungsten inert gas welding of duplex stainless steel using response surface methodology The experiment analysis Welding current from 202.817 to 208.678 A, torch speed from 119.997 to 120 mm/min, and the arc gap from 1.00 to 1.01107 mm are identified as the optimum input process parameters to obtain the desired weld bead geometry for the A-TIG welding of 10-mm-thick duplex stainless steel 2205 alloy plates.

A. Balaram Naik et al Characteristics Optimization of Different Welding Processes on Duplex Stainless Steels Using Statistical Approach and Taguchi Technique - A Review Guide It was found that the optimal mechanical properties were obtained when precipitation of sigma and the γ-to-δ ferrite transformation are suppressed i.e. at 10500C and 8.9% Ni electrode showed better performance.

Kezhao Zhang et all investigated on Laser-TIG-hybrid-welding (TIG – tungsten inert gas) process to investigate the microstructure and tensile properties of Ti–22Al–27Nb/TA15 dissimilar joints. The HAZ of the arc zone in Ti–22Al–27Nb was characterized by three different regions: single B2, B2+α2 and B2+α2+O, while the single B2 phase region was absent in the HAZ of the laser zone. As for the HAZ in TA15 alloy, the microstructure mainly contained acicular α′ martensites near the fusion line and partially remained the lamellar structure near the base metal. The fusion zone consisted of B2 phase due to the relatively high content of β phase stabilizing elements and fast cooling rate during the welding process. They revealed that the tensile strength of the welds was higher than that of TA15 alloy because of the fully B2 microstructure in the fusion zone, and the fracture preferentially occurred on the base metal of TA15 alloy during the tensile tests at room temperature and 650 °C.

A. Kumar et all Optimization of pulsed TIG welding process parameters on mechanical properties of AA 5456 Aluminum alloy weldments. They influence of pulsed welding parameters such as peak current, base current, welding speed, and frequency on mechanical properties such as ultimate tensile strength (UTS), yield strength, percent elongation and hardness of AA 5456 Aluminum alloy weldments. They used Taguchi method to optimize the pulsed TIG welding process parameters of AA 5456 Aluminum alloy welds for increasing the mechanical properties. They developed Regression models. Analysis of variance was employed to check the adequacy of the developed models. The effect of planishing on mechanical properties was also studied and observed that there was improvement in mechanical properties. They studied Microstructures of all the welds and correlated with the mechanical properties.

Xiaodong Qi et all investigated on Interfacial structure of the joints between magnesium alloy and mild steel with nickel as interlayer by hybrid laser-TIG welding. They investigated on joint shear strength. The characterization of interfaces in the joint with Ni interlayer was analyzed and discussed. The results show that the formation of intermetallic compound Mg2Ni and solid solution of Ni in Fe at the interface altered the bonding mode of joints which contributed to the increase of the tensile shear strength in contrast to the direct joining of Mg alloy to steel. from the view of the whole joint and the comparison with direct joining, the addition of Ni interlayer altered the bonding mode of Mg alloy to steel from mechanical bonding to semi-metallurgical bonding, it can also be seen that such transformation that advanced the joint strength in the present fusion welding process. However, it is noticeable that the corrosion problems may affect the properties of the joint.

P. Bharath et all investigated for optimization of 316 Stainless Steel Weld Joint Characteristics using taguchi Technique. They found that the welding speed (46.51% contribution) has greater influence on bend strength and current (96.75%) has highest influence on tensile strength. Further it has found that root gaps has some influence on both tensile and bend strengths. Micro structure study shows some inclusions near the heat affected zone due to change in weld material and also change in grain sizes that are developed during welding process.

Qiang Zhu et all investigated on effects of arc-ultrasonic on pores distribution and tensile property in TIG welding joints of MGH956 alloy. The results showed that the excitation current of arc-ultrasonic has great effect on the pores distribution and tensile property. They found that When current increased to 20 A or 30 A, few pores are in the joint and the tensile strength (about 550 MPa) was also improved. When the arc-ultrasonic frequency decreased from 60 kHz to 30 kHz, bubbles floated outside more easily, the tensile strength is increased to about 543 MPa. But arc-ultrasonic has little influence on weld joints microhardness change.

Zhizhong Jiang et all carried out experiment on China low activation martensitic (CLAM) steel for measured Microstructure and mechanical properties of the TIG welded joints. The results show that both hardening and softening occur in the weld joints before post-welding heat treatment [PWHT], but the hardening is not removed completely in the weld metal and the fusion zone after PWHT. In as-welded condition, the microstructure of the weld metal is coarse lath martensite, and softened zone in heat-affected zone (HAZ) consists of a mixture of tempered martensite and ferrite. After PWHT, a lot of carbides precipitate at all zones in weld joints. The microstructure of softened zone transforms to tempered sorbite. Tensile strength of the weld metal is higher than that of HAZ and base metal regardless of PWHT. However, the weld metal has poor toughness without PWHT.

The impact energy of the weld metal after PWHT reaches almost the same level as the base metal. So it is concluded that microstructure and mechanical properties of the CLAM steel welded joints can be improved by a reasonable PWHT.

Xiong Xie et all presented research worked on AZ31 magnesium alloy joints processed by nano-particles strengthening activating flux tungsten inert gas (NSA-TIG) welding, which was achieved by the mixed TiO2 and nano-SiC particles coated on the samples before welding tests. The macro/micro structural observation and mechanical properties evaluation of the welding joints were conducted by using optical microscope, scanning electron microscope, energy dispersive X-ray spectroscopy, X-ray diffraction and tension and microhardness tests. They showed that nano-particles strengthening activating flux effective improved the microstructure, microhardness in fusion zone, ultimate tensile strength of the TIG welding joints. They observed that the large heat input induced by the increase of the surface coating density of the nano-particles strengthening activating flux, increased the a-Mg grain sizes and weakened the mechanical properties of the welded joints.

Navid Moslemi et all presented studied to influence of Current on Characteristic for 316 Stainless Steel Welded Joint on investigation of Microstructure and Mechanical Properties. They carried out experiment on Mechanical characteristics of the welded alloys for tensile tests and hardness (HV). They conducted Metallographic examination to identify and observe the various fusion zones. They showed that the increase of welding current bring about the large amount of heat input in the welding pool, the enlargement of width and deepness of the welding pool, cumulative sigma phase in the matrix and reducing the chromium carbide percentage in 316 stainless steel welded joint. Arc current of 100A has been identified of the most suitable current since it gives the lowest defects and brings the highest value of strength and hardness for this material.

N. Kiaee et all worked on gas tungsten arc welding used for connecting of boiler parts made of A516-Gr70 carbon steel. They influenced various process parameters namely current, welding speed and shielding gas flow rate to optimized using response surface methodology (RSM). They evaluated tensile strength and hardness by simultaneous effects of these parameters. Also they generated mathematical equation. They optimized values of welding process parameters to achieve desired mechanical properties. They found that the Desired tensile strength and hardness were achieved at optimum current of 130 A, welding speed of 9.4 cm/min and gas flow rate of 15.1 l/min.

M. Ding et all presented the report on to joining of ferritic stainless steels and magnesium alloys is light and economic for weight reduction of automobiles. They had been worked on tensile strength. They observed that the melted Mg weld metal wets the ferritic stainless steels surface to form a brazed Mg–Cu to steel connection when the interlayer thickness is 0.02 mm. When the interlayer thickness is 0.1mm, the intermetallic compounds transition layer determined the tensile-shear strength of joints. Intermetallic compounds transition layer has been found in the 0.1 mm thick interlayer joints and no particle has been found in the 0.02 mm thick interlayer joints. They revealed that the thickness of the Cu interlayer increases, the joining mechanism changed. The joining and strengthen mechanisms are mainly determined by the thickness of the interlayer. They found that the tensile-shear strength of 0.1 mm thickness Cu interlayer joints is improved by 47% compared to 0.02 mm Cu.

Chalamalasetti Srinivasa Rao et all investigated on pulsed current micro plasma arc welded to investigate microstructure and mechanical property of inconel 625. The studying weld quality characteristic like weld pool, geometric, parametric, microstructure, grain size hardness etc. Result reveal that at welding speed of 260mm/m. Better weld quality characteristic can be obtained. Nickel alloys had gathered wide acceptance in the fabrication of components which require high temperature resistance and corrosion resistance, such as metallic bellows used in expansion joints used in aircraft, aerospace and petroleum industry.

Nirmalendhu Chaudhury et all optimization of Tig Welding using taguchi method and the present study to the improvement ultimate load of stainless steel and mild-steel weld of tungsten inert gas welding. L16 orthogonal array his been used to conduct the several level of current gas flow rate and filler rod diameter. Statically techniques analysis of variance (ANOVA), signal to noise (S/N) ratio by toguchi method. Confirmatory test has been conducted to validated the predicted setting.

Shekhar Rajendra Gulwade et all carried out experiment of joining metal by tig welding on the paper present the influence welding parameter like welding current welding voltage, gas flow rate on hardness of austenic stainless-steel 304 grade. The toguchi method orthogonal array (OA) and signal to noise (S/N) ratio. Finally the confirmation test have been carried out the predicted value with effectiveness in analysis hardness.

M.P. Chakravarthy et all investigated on the 70/30 cu-ni alloy weld of pulse tig welding. Toguchi technique the most influential control factor which will better tensile strength of 70/30 cu-ni alloy and the evaluate effect of process parameter such as pulsed frequency peak current base current. Tig welded 70/30 copper nickel alloy of 5mm thickness. The predicted optimal value of tensile strength pulse current gas tungsten arc welding of 70/30 copper nickel alloy weld arc 368.8 MPa.

Ravindra et all carried out experiment of tig welding on stainless-steel and mild-steel by using toguchi method and the process of this study method decide near optimal setting of the welding process parameter in tig welding. The paper present the influence of welding current arc voltage and gas flow rate stainless-steel 202 and mild-steel during welding. The study found that the control factor varying effect of tensile strength arc voltage having highest effect.

Kundan kumar et all investigated on surface response methodology for predicting the output response of tig welding process and attempt has been developed to study the effect of input variable (current voltage and travel speed) on output response (reinforcement height , weld bead, width, metal rate). When the experiment is completed then the desired inputs are given to the model and it gives the estimated output value. Confirmation test have also estimated the error between the actual and predicted results.

F. Sauza Neto et all investigated of the mechanical behavior AISI 4130 steel after Tungsten inert gas welding and laser welding process. In this paper as a comparative welding process for mechanical characterization of laser and tig weld tensile and hardness test were performed. This treatment prove to improve the ductility of the steel and reducing embrittlement in the welded region. Tigs welded were ten time larger than the laser welding. The hardness value observed in fusion zone and heat affected zone were similar in both cases.

SUMMARY

From the literature review, it has been found that the several researchers have been worked on various aluminium alloys and also some researcher has been worked on dissimilar material by TIG welding. They have been research for investigation of microstructure, mechanical properties like tensile strength, hardness, yield strength, percent elongation of bead weld.

Also it has been found that several industries facing various problem like poor mechanical properties in terms of excessive hardness of weld bead leads to brittleness of weld bead which are causing of breaking of weld or joint at higher load or cannot sustaining design load and does not full fill the service requirement. Numerous researches have been conducted to investigate the complicated microstructure–property relationship, and some meaningful progresses have been made on the preparation process.

Thus investigation of microstructure and mechanical properties like tensile strength, hardness, yield strength, percent elongation are very crucial for welding joint for engineering application. Also very less work carried out on hardness of weld joint.

From literature, it has been found that the several researchers had worked on only yield strength and microstructure for its improving strategies of joints. But it has been shown that the very less work has been carried out on tensile strength and hardness. It has been decide to investigate for tensile strength and hardness of weld of make by TIG welding.

It has been found that the very less literature or work carried out on Duplex stainless steel. Thus inherent advantages of Duplex stainless steel and widely used in industries. It has been decided to study goes on investigation of Duplex stainless steel on tungsten inert gas welding.

RESEARCH GAP FROM LITERATURE SURVEY

During welding, vaporization of alloying elements like nickel, magnesium can occur and this vaporization loss of any alloying elements can influence the mechanical properties of the welded joints by affecting the chemistry of the weld pool. The gas tungsten arc welding (GTAW) welding processes is very often used for welding of these alloys. However, GTAW process is generally preferred because it produces a very high quality welds.

Some of these challenges are similar to disadvantages of using Duplex stainless steel material already discussed:

Heat affected zone is major problem during welding which lead to worsing in appearance and also drastically change microstructure and brittleness.

It can be improve mention problem to investigation through suitable process parameters relationship with responses for tungsten inert gas welding. Also it may investigate to improve various mechanical properties by various statistical methods. It has been decide to work on improving mechanical properties and microstructure so that the it can lead to reduce chances of failure and joints can full fill service life of products.

OBJECTIVES

The main objectives of this research study are listed below:

To conduct experiment by varying process parameters of tungsten inert gas welding through design of experiment.

To study about the best combination of solution for mechanical properties like hardness and tensile strength with Response surface methodology.

Generate the data with ANOVA graph and ANOVA table to determine the effective parameters for the responses.

Optimize and analyze the data for TIG welding by using response surface methodology.

III. METHODOLOGY

SELECTION OF MATERIAL

Stainless steel grade UNS S322205 (Duplex 2205) is a general-purpose duplex. This steel possesses high tensile strength as well as high fatigue strength. Its high mechanical strength is same as other duplex grades, and its good corrosion resistance is equal to most standard stainless steel grades. All these properties are utilized to design products with strength, low maintenance, durability and long-term cost efficiency. The extrude plate of 6mm thickness, Duplex stainless steel will cut to the required dimension (150mm ×200mm X 6mm) by power hacksaw cutting and milling. The initial joint configuration will obtained by securing the plates in position to mechanical clamp. The direction of welding will normal to the rolling direction. Argon (purity 99.99%) will used as shielding gas. The welding rod will used an ESAB.SAI, 3.15mm diameter with electrode to be working angle 30o. The chemical composition and mechanical properties of the base metal are listed in Tables 1 and 2, respectively

From various literature survey efforts to identify in TIG welding process most of welding parameters like welding current, welding speed, depth to width ratio are generally used in research work. Also identify TIG welding carried out on different materials like mild steel , titanium alloy, brass, carbon, stainless steel etc.., But we may be choose work piece material differ from above for experimental work and most applicable in industrial practices. We may be try to find out welding hardness, tensile strength, by theoretical equations and experimentally measure with help of different input parameter.

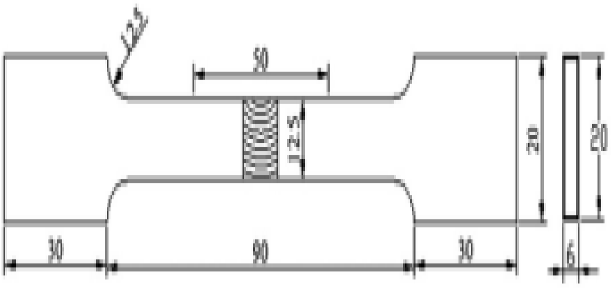


Fig. 3.1 tensile specimen

Tensile test specimen was prepared in according with ASTM standards, shown in Figure 3.1

Table 3.1 Chemical composition of UNS S32205

Element	Content (%)
Nickel	5.5
Chromium	21.5
Molybdenum	0.3
Carbon	0.03 max
Sulphur	Max

Special properties

- high strength (650-880 N/mm2)
- high resistance to pitting corrosion, crevice corrosion and
- stress corrosion cracking
- high resistance to abrasion and wear

SELECTION OF EXPERIMENTAL SETUP

In order to achieve the goal of this experimental work the welding carried out in an For TIG welding Saviour TIG 200 AC/DC welding machine is used. TIG welding machine setup consist of machining base, DC or AC power source, TIG torch, work return welding lead, shielding gas cylinder, foot control and filler rod. The experiment performed and constructed to control the electrode arc and linear displacement of torch along the weld pool pad centre. The tungsten electrode as cathode and work piece as anode is taken. TIG process employs on electrode made high melting point metal usually a type of tungsten which is not melt because of it is melting point 3500 ^{0}C.

[a]tig torch [b]tig machine [c]gas cylinder

Fig. 3.2 TIG set up (Courtesy Om Engineering & Works)

The electrode tungsten alloy and tungsten oxides are taken (zirconium or thorium). 2% thoriated for DC and 2% zirconiated for AC welding are recommended.

Table 3.3 Technical specification of TIG 200AC/DC

Rated input voltage	220
Input frequency (Hz)	50
Rated power at max. Current (KVA)	6.2
Duty cycle	60%
Weight	22.1 kg
Dimension	498 * 328 * 365 mm

SELECTION OF PROCESS PARAMETER

The four process cutting parameters in TIG welding are electric current, speed, gas flow rate and gap distance Other factors such as kind of material and voltage have a large influence, of course, but these four are the ones the operator can change by adjusting the controls, right at the machine.

Table 3.4 Proposed Ranges of process parameter

Sr. no.	parameters	Unit	Level1	Level2	Level3
1	Electric current	A	40	50	60
2	Gas flow rate	L/min	10	12	14
3	Gap distance	Mm	2	3	4

OUTPUT PARAMETERS

From literature review, it has been found that very few literatures has been carried out on proposed material. Hardness, bead geometry and tensile strength has been very crucial target parameter for all welding process as well as TIG. Thus, In this research study, hardness, bead geometry and tensile strength has been selected as output parameters.

HARDNESS

Hardness of the material depends upon the chemical composition of that material. But from the heat treatment process the hardness can be increase up to certain range. Generally the hardness can be measured by the portable hardness testing gun. This kind of instrument is portable and easy to use. The probe of that instrument is lying on the material to be tested. And pneumatic system will test the hardness in certain range of pressure.

Table 3.5: Specification Hardness Tester

Manufacturer	M/s Samarth Engineering, Maharastra
Model	SDE-VM-50 (PC)
Maximum test height	230 mm
Scale least count	0.001 mm
Throat depth	135 mm
Machine dimensions	1460 * W225 * H860 mm

Weights	70 kg
Test loads	5,10, 20, 30, 50 kgf

Fig. 3.4: Hardness testing gun[courtesy: CIPET]

TENSILE STRENGTH

In this work notched tensile strength (NTS) will investigated for 6 mm butt joints of Duplex stainless steel. Tensile strength will examine for the butt-joints of Duplex stainless steel. Tensile tests will perform in air using the universal testing machine model 4202 shown in Fig.

Fig. 3.5 Universal testing machine (Courtesy CIPET)

Table 3.6 Technical specification of tensile strength testing machine

Technical specifications	
Total Crosshead Trave	1200-1400 mm
Accuracy	~ 0.5 µm
Repeatability	~ 0.25 µm

IV. DESIGN OF EXPERIMENT

INTRODUCTION OF DOE

In industry, designed experiments can be used to systematically investigate the process or product variables that influence product quality. After you identify the process conditions and product components that influence product quality, you can direct improvement efforts to enhance a product's manufactur ability, reliability, quality, and field performance. Design of experiment is a series of tests in which purposeful changes are made to the input variables of a system or process and the effect on response variables are measured. Design of experiments is applicable to both physical processes and computer simulation models. Experimental design is an effective tool for maximizing the amount of information gained from a study while minimizing the amount of data to be collected. Factorial experimental designs investigate the effects of many different factors by varying them simultaneously instead of changing only one factor at a time. Factorial designs allow estimation of the sensitivity to each factor and also to the combined effect of two or more factors. In a highly competitive world of testing and evaluation, an efficient method for testing many factors is needed. The advantages of design of experiments are as follows:

- Numbers of trials is significantly reduced.
- Important decision variables which control and improve the performance of the product or the process can be identified.
- Optimal setting of the parameters can be found out.
- Qualitative estimation of parameters can be made.
- Experimental error can be estimated.
- Inference regarding the effect of parameters on the characteristics of the process can be made.

Design of experiment is powerful approach to minimize the number of experiments yet extract all the knowledge about the dependence of outcome on the process parameters. It is essential to follow a strategy of experimentation where input parameters of process may be varied simultaneously to study their effect on the process output. The relation between output and one or more input process parameters may be linear or non linear in nature. The selection of design of experiments depends on the linear or the non-linear nature of the process. The knowledge about nature of variation is necessary to categorize the problem either as linear or non-linear.

FULL FACTORIAL DESIGN FOR SINGLE OBJECTIVE OPTIMIZATION

Full factorial design is used for simultaneous study of several factor effects on the process. By varying levels of factors simultaneously we can find optimal solution. Responses are measured at all combinations of the experimental factor levels. The combination of the factor levels represent the conditions at which responses will be measured. Each experiment condition is a run. The response measurement is an observation. The entire set of run is a design of experiment. It is used to find out the variables which are the most influence on the response and their interactions between two or more factors on responses.

Factors

This are variables (also think of as ingredients or parameters) that have direct influence on the performance of the product or process under investigation.

Factors are of two types:

Discrete- Assumes known values or status for the level.

Example: Container, Vendor, Type of materials, etc.

Continuous- Can assume any workable value for the factor levels.

Example: Temperature, Pressure, Thickness, Welding current, Feed, Depth of cut etc.

Levels

This is the values or descriptions that define the condition of the factor held while performing the experiments.

Combination

An instance of the experiment unit with a particular level from each factor applied. For a full factorial design, if the numbers of levels are same then the possible design N is

$N = L^m$

Where, L = Number of levels for each factor,
M = Number of factors.

The three-level design is written as a 3^k factorial design. It means that k factors are considered, each at 3 levels. These are referred to as low, intermediate and high levels. These levels are numerically expressed as 0, 1, and 2. One could have considered the digits -1, 0, and +1, but this may be confusing with respect to the 2-level designs since 0 is reserved for centre points. Therefore, we will use the 0, 1, 2 scheme. Thus standard order (in terms of 0, 1 and 2 for coded test condition of -1, 0 and 1 respectively) 000 and 222 indicates all process parameters are at their low levels and higher levels respectively. Fig. shows the geometric representation of the design of experimentations. The set of 27 tests have been performed randomly however some experimental limitation has been considered in randomization. Table shows all possible combination of 3^3 full factorial design of experiment.

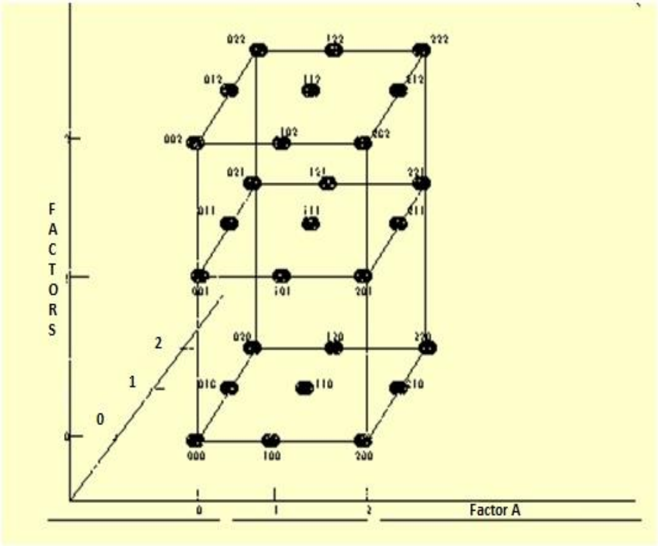


Figure 4.1- Schematic diagram of 3^3 full factorial design of experiment

Table 4.1- the scheme of 3^3 full factorial design of experimental

Standard order	**Coded Test Condition**		
Tests	**X(1)**	**X(2)**	**X(3)**
000	-1	-1	-1
100	0	-1	-1
200	1	-1	-1
010	-1	0	-1
110	0	0	-1
210	1	0	-1
020	-1	1	-1
120	0	1	-1
220	1	1	-1
001	-1	-1	0
101	0	-1	0
201	1	-1	0
011	-1	0	0
111	0	0	0
211	1	0	0
021	-1	1	0
121	0	1	0
221	1	1	0
002	-1	-1	1
102	0	-1	1
202	1	-1	1
012	-1	0	1
112	0	0	1
212	1	0	1
022	-1	1	1
122	0	1	1
222	1	1	1

SELECTION OF PROCESS PARAMETER

The four process cutting parameters in TIG welding are electric current, speed, gas flow rate and gap distance Other factors such as kind of material and voltage have a large influence, of course, but these four are the ones the operator can change by adjusting the controls, right at the machine.

Table 4.2 Proposed Ranges of process parameter

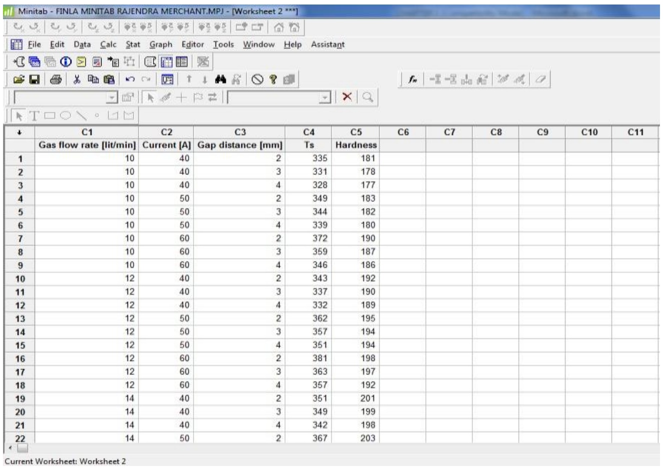
Sr. no.	parameters	Unit	Level1	Level2	Level3
1	Electric current	A	40	50	60
2	Gas flow rate	L/min	10	12	14
3	Gap distance	Mm	2	3	4

Sr. no.	Gas flow rate [lit/min]	Current [A]	Gap distance [mm]	Tensile strength [mpa]	Hardness [BHN]
1	10	40	2		
2	10	40	3		
3	10	40	4		
4	10	50	2		

5	10	50	3		
6	10	50	4		
7	10	60	2		
8	10	60	3		
9	10	60	4		
10	12	40	2		
11	12	40	3		
12	12	40	4		
13	12	50	2		
14	12	50	3		
15	12	50	4		
16	12	60	2		
17	12	60	3		
18	12	60	4		
19	14	40	2		
20	14	40	3		
21	14	40	4		
22	14	50	2		
23	14	50	3		
24	14	50	4		
25	14	60	2		
26	14	60	3		
27	14	60	4		

4.4 Analysis Software MINITAB16

Minitab is a statistics package used for analysis of experimental data. It was developed at the Pennsylvania state university by researchers Barbara F. Ryan, Jr., and Brian L. Joiner in 1972. The goal of robust experimentation is to find an optimal combination of control factor Settings that achieve robustness against noise factors. MINITAB generates main effects and interaction plots for signal-to-noise ratio (S/N ratios) vs. control factors. MINITAB is a powerful, easy-to-use, statistical software package that provides a wide range of basic and advanced data analysis capabilities. MINITAB's straightforward command structure makes it accessible to users with a great variety of background and experience. MINITAB runs on PC and Macintosh computers, and most of the leading workstations, minicomputers and mainframe computers. While MINITAB differs across releases and computer platforms, the core of MINITAB the worksheet and commands.



↓	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
	Gas flow rate [lit/min]	Current [A]	Gap distance [mm]	Ts	Hardness						
1	10	40	2	335	181						
2	10	40	3	331	178						
3	10	40	4	328	177						
4	10	50	2	349	183						
5	10	50	3	344	182						
6	10	50	4	339	180						
7	10	60	2	372	190						
8	10	60	3	359	187						
9	10	60	4	346	186						
10	12	40	2	343	192						
11	12	40	3	337	190						
12	12	40	4	332	189						
13	12	50	2	362	195						
14	12	50	3	357	194						
15	12	50	4	351	194						
16	12	60	2	381	198						
17	12	60	3	363	197						
18	12	60	4	357	192						
19	14	40	2	351	201						
20	14	40	3	349	199						
21	14	40	4	342	198						
22	14	50	2	367	203						

Current Worksheet: Worksheet 2

Figure-4.2 Screen view of MINITAB16 software

Fig.4.2 shows that screen view of MINITAB16 software described whole data which are used in present study.

Table 4.3 experiment reading

Sr. No.	Gas flow rate [lit/min]	Current [A]	Gap distance [mm]	Tensile strength [MPa]	Hardness [BHN]
1	10	40	2	335	181
2	10	40	3	331	178
3	10	40	4	328	177
4	10	50	2	349	183
5	10	50	3	344	182
6	10	50	4	339	180
7	10	60	2	372	190
8	10	60	3	359	187
9	10	60	4	346	186
10	12	40	2	343	192
11	12	40	3	337	190
12	12	40	4	332	189
13	12	50	2	362	195
14	12	50	3	357	194
15	12	50	4	351	194
16	12	60	2	381	198
17	12	60	3	363	197
18	12	60	4	357	192
19	14	40	2	351	201
20	14	40	3	349	199
21	14	40	4	342	198
22	14	50	2	367	203
23	14	50	3	361	199
24	14	50	4	353	197
25	14	60	2	387	207
26	14	60	3	372	201
27	14	60	4	369	199

Main Effects Plot of Tensile strength

The main effects plot for S/N ratio of Tensile strength versus Gas flow rate, welding current and Gap distance is shown in fig.4.3, which is generate from the value of mean of Tensile strength as per table 4.3 in minitab-16 statistical software is useful to find out optimum parameter value for response variable. Fig.4.3 shows that High Tensile strength will meet at Gas flow rate 14 lit/min, welding current 60 A and gap distance 2 mm. The graph generate by use of minitab-16 statistical software for Tensile strength is shown in fig.4.3

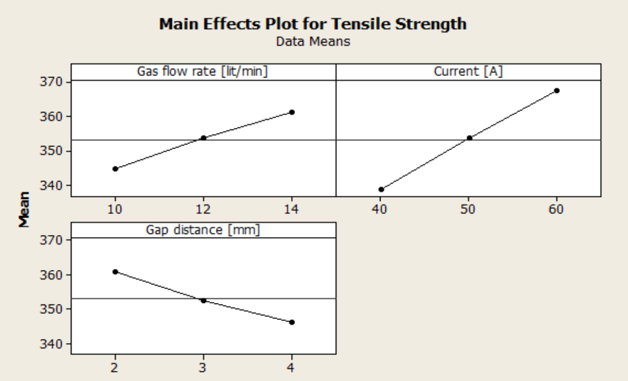


Fig.4.3 Effect of control factor on Tensile strength

From the fig.4.3, it has been conclude that the optimum combination of each process parameter for higher Tensile strength is meeting at high Gas flow rate [A3], high welding current [B3] and low Gap distance[C1].

Main Effects Plot of Hardness

The main effects plot for S/N ratio of Hardness value versus Gas flow rate, welding current and Gap distances shown in fig.4.4, which is generate from the value of S/N ratio of Hardness value as per table 4.3 in minitab-16 statistical software is useful to find out optimum parameter value for response variable. Fig.4.4 shows that low Hardness value will meet at Gas flow rate 14 lit/min, welding current 60 amp and Gap distance 2mm. The graph generate by use of minitab-16 statistical software for Hardness is shown in fig.4.5.

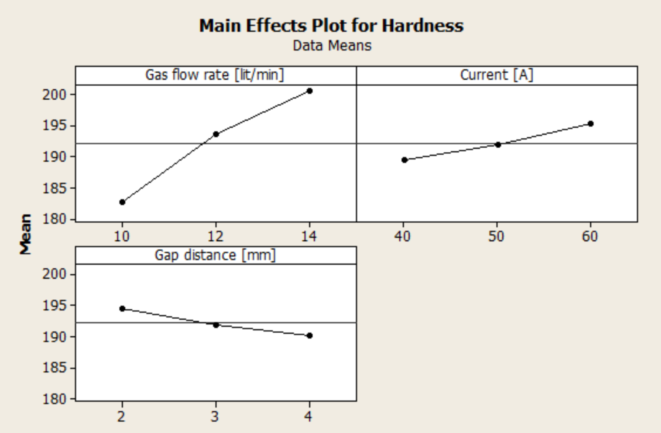


Fig. 4.4 Effect of control factor on hardness value

From the fig.4.4, it has been conclude that the optimum combination of each process parameter for high hardness value is meeting at Gas flow rate [A3], welding current [B3] and Gap distance [C1].

4.5 Analysis of Variance

Analysis of variance (ANOVA) is a statistical model which can be used for find out effect of independent parameter on single dependent parameter and also it can be use full to find out the significant machining parameters and the percentage contribution of each parameter. MINITAB16 statistical software used to analyze the ANOVA analysis for Tensile strength, Hardness and heat affected zone and their analyzed value is show in table 5.2. All the terms related to ANOVA table is explained in chapter no.3. This table concludes all information of analysis of variance and case statistics for further interpretation.

4.5.1 Analysis of Variance for Tensile strength

According to the analysis done by the MINITAB software, if the values of probability are less than 0.05, it indicated that the factors are significant to the response parameters. Comparing the p-value to a commonly used α- level = 0.05, it is found that if the p- value is less than or equal to α, it can be concluded that the effect is significant.

General Linear Model: Tensile Stre versus Gas flow rat, Current [A], ...

Factor Type Levels Values
Gas flow rate [lit/min] fixed 3 10, 12, 14
Current [A] fixed 3 40, 50, 60
Gap distance [mm] fixed 3 2, 3, 4

Analysis of Variance for Tensile Strength, using Adjusted SS for Tests

Source DF Seq SS Adj SS Adj MS F P Contribution
Gas flow rate [lit/min] 2 1219.56 1219.56 609.78 43.94 0.000 19.8%
Current [A] 2 3700.67 3700.67 1850.33 133.33 0.000 60.2%
Gap distance [mm] 2 944.89 944.89 472.44 34.04 0.000 15.3%
Error 20 277.56 277.56 13.88
Total 26 6142.67

R-Sq = 95.48% R-Sq(adj) = 94.13%

From ANOVA result it is observed that the Gas flow rate, welding current and Gap distance of welding influencing parameter for Tensile strength as they are all less than 0.05 p. Thus it can be concluded that the effect of all cutting parameters are significant. The confidence level (CL) used for investigation is taken 95% for this investigation. The parameter R-Sq described the amount of variation observed in Tensile strength is explained by the input factor. R-Sq= 95.48 % which indicate that the model is able to predicate the response with high accuracy.

4.5.2 Analysis of Variance for Hardness

From ANOVA result it is observed that the Gas flow rate, welding current and Gap distance of weld influencing parameter for Hardness as they are all less than 0.05 p. The confidence level (CL) is taken 95% for this investigation.

General Linear Model: Hardness versus Gas flow rate [l, Current [A], ...

Factor Type Levels Values
Gas flow rate [lit/min] fixed 3 10, 12, 14
Current [A] fixed 3 40, 50, 60
Gap distance [mm] fixed 3 2, 3, 4

Analysis of Variance for Hardness, using Adjusted SS for Tests

Source DF Seq SS Adj SS Adj MS F P Contribution
Gas flow rate [lit/min] 2 1443.63 1443.63 721.81 234.24 0.000 83.05
Current [A] 2 151.41 151.41 75.70 24.57 0.000 8.71
Gap distance [mm] 2 81.41 81.41 40.70 13.21 0.000 4.6
Error 20 61.63 61.63 3.08
Total 26 1738.07
S = 1.75541 R-Sq = 96.45% R-Sq(adj) = 95.39%

Response surface analysis for tensile strength

Response surface plot and response contour plot are one of the best methods to represent the experimental data. Figure 5.10 shows response surface plots of tensile strength.

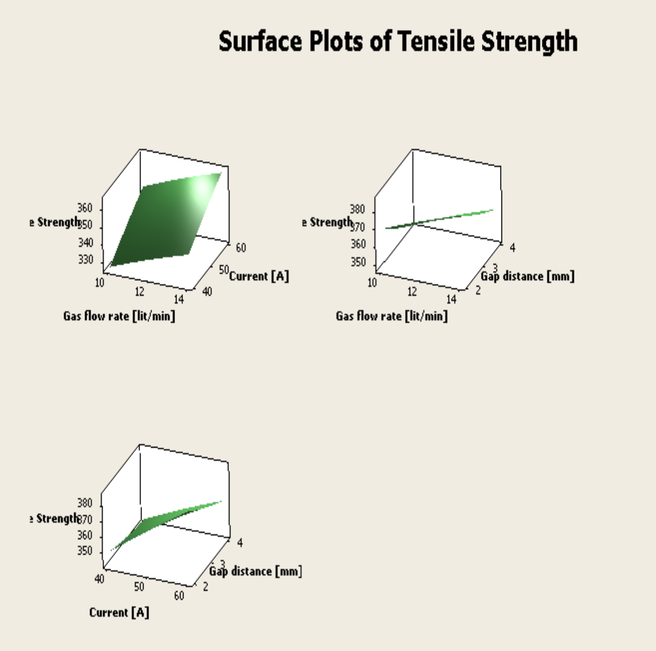


Fig.4.5 Surface plot for tensile strength vs. current, gas flow rate and gap distance

Figure [A] shows surface plot of tensile strength for interaction of current and gas flow rate, when gap distances taken as hold value. This surface plot indicates that tensile strength inrease in gas flow rate and current are increase from 10 to 14 lit/min.and 40 to 60 Amp. Figure [B] shows surface plot of tensile strength for interaction of gap distance and gas flow rate, when other parameter current taken as hold value. This surface plot indicates that tensile strength increase with gap distance as well as gas flow rate increase. It also shows that influence of both parameter are same. Figure [C] shows surface plot of tensile strength for interaction gap distance and current, other parameter taken as hold value.

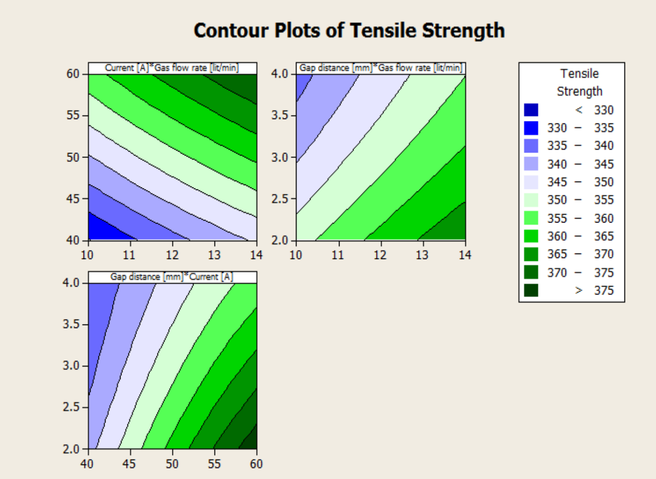


Fig. 4.6 Contour plot for tensile strength vs. current, gas flow rate and gap distance

The contour plots [A] indicate that the highest tensile strength is obtained when current levels are high and gas flow rate levels are high. This area appears at the upper right corner of the plot. The contour plots [B] indicate that the highest tensile strength is obtained when gap distance levels are low and gas flow rate levels are high. This area appears at the lower right corner of the plot. The contour plots [C] indicate that the highest tensile strength is obtained when current levels are high and gap distance levels are low. This area appears at the lower right corner of the plot.

4.7 Optimization of process parameters for tensile strength

Large number of conflicting factors and complex Machining phenomena in welding process making it difficult to predict the response characteristics based on simple analysis of factor variations. Hence, to determine the optimal setting of process parameters that will maximize the tensile strength with the use of response optimizer in response surface methodology shown in table 5.6

Table 4.4 Response optimization tensile strength parameters

Response	Goal	Optimal condition	Target	upper	RSM predicated	Experimental In
Tensile Strength	maximum	Gas flow rat = 14 Current = 60 Gap distance = 2	328	390	386.389	385

4.8 Response surface analysis for hardness

Response surface plot and response contour plot are one of the best methods to represent the experimental data. Figure 5.10 shows response surface plots of hardness.

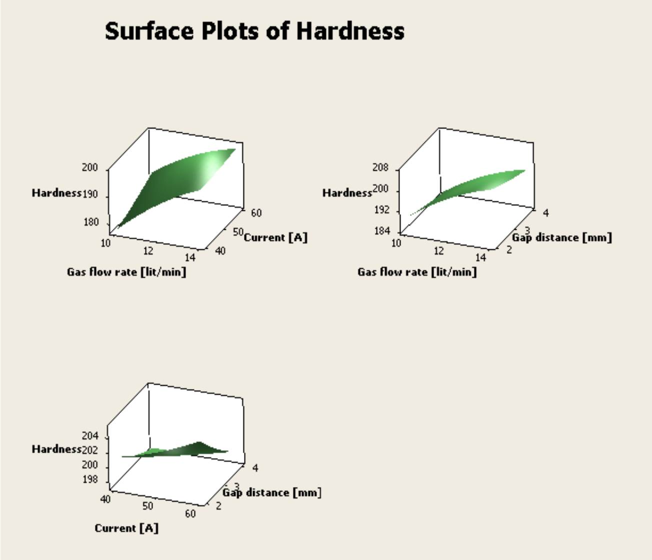


Fig.4.7 Surface plot for hardness vs. current, gas flow rate and gap distance

Figure [A] shows surface plot of Hardness for interaction of current and gas flow rate, when gap distances taken as hold value. This surface plot indicates that hardness increase in gas flow rate and current are increase from 10 to 14 lit/min. and 40 to 60 Amp. But graph indicate that minor change have been seen on hardness by current.

Figure [B] shows surface plot of hardness for interaction of gap distance and gas flow rate, when other parameter current taken as hold value. This surface plot indicates that hardness increase with decrease gap distance from 2 to 4 mm. as well as gas flow rate increase it will increase. It also shows that influence of both parameters is same.

Figure [C] shows surface plot of hardness for interaction gap distance and current, other parameter taken as hold value.

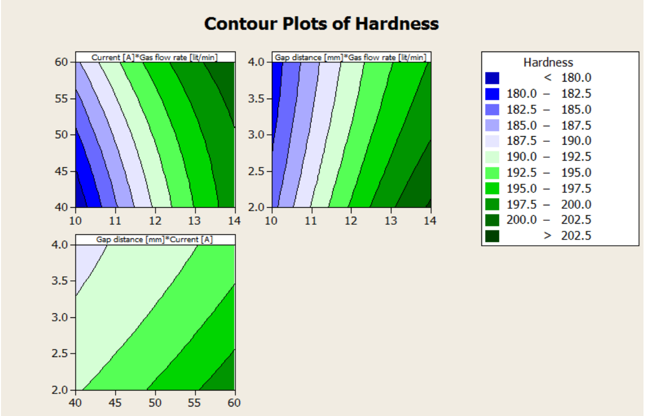


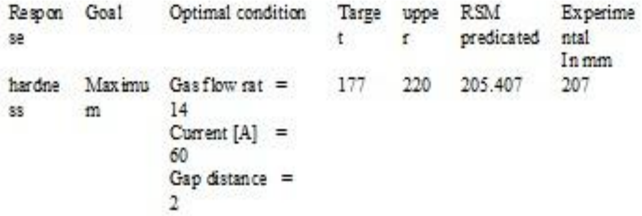
Fig. 4.8 Contour plot for tensile strength vs. current, gas flow rate and gap distance

The contour plots [A] indicate that the highest hardness is obtained when current levels are high and gas flow rate levels are high. This area appears at the upper right corner of the plot. The contour plots [B] indicate that the highest hardness is obtained when gap distance levels are low and gas flow rate levels are high. This area appears at the lower right corner of the plot. The contour plots [C] indicate that the highest hardness is obtained when current levels are high and gap distance levels are low. This area appears at the lower right corner of the plot.

Optimization of process parameters for hardness

Large number of conflicting factors and complex Machining phenomena in welding process making it difficult to predict the response characteristics based on simple analysis of factor variations. Hence, to determine the optimal setting of process parameters that will minimize the material removal rate with the use of response optimizer in response surface methodology shown in table 5.6

Table 4.5 Response optimization hardness parameters



Response	Goal	Optimal condition	Target	upper	RSM predicated	Experimental In mm
hardness	Maximum	Gas flow rat = 14 Current [A] = 60 Gap distance = 2	177	220	205.407	207

4.9 Justification of RSM

- To determine the factor levels that will simultaneously satisfy a set of desired specifications.
- To determine the optimum combination of factors that yields a desired response and describes the response near the optimum.
- To determine how a specific response is affected by changes in the level of the factors over the specified levels of interest.
- To achieve a quantitative understanding of the system behaviour over the region tested.
- To predict properties throughout the region-even at factor combinations not actually run.

V. LIMITATIONS

Experimental preparation is time-consuming or its duration is long.

FUTURE WORK

Analysis of microstructure and heat affected zone. Conduct response surface methodology for experiment data. To identify specific combination of process parameter for responses. To do validation of research study.

VI. CONCLUSION

Experimental investigation on Stainless steel grade UNS S32101 (Duplex 2101 LDX) material has been done using TIG welding. The following conclusions are made.

- The tensile strength increase with increase gas flow rate and current from 10 to 14 lit/min and 40 to 60 Amp respectively as well as tensile strength decrease with increase gap distance from 2 to 4 mm.
- While studying the effect of the process parameters on the tensile strength, it was observed that current play crucial roles in the effect on the tensile strength. The role of the both the gas flow rate and gap distance are not crucial to the same extent.
- The optimum condition for hardness would be A3 B3 C1. The gas flow rate kept at 14 lit/min, the current kept at 60 amp. and the gap distance 2mm.
- Through use of regression equation, engineer can manipulate range of process parameters for this particular work- material. Also it has been find out and predicted tensile strength and hardness at any combination of process parameter.
- Through use of response surface methodology, engineer can predicted and visualize manipulate range of process parameters for this particular work-material. Also it has been given intermediate value of process parameters which carried out the accurate study.
- It has been seen that global solution for tensile strength are following: Gas flow rate 14 lit/min , Current 60 Amp. and Gap distance 2 mm. At these level, tensile strength are 386.389 MPa.
- It has been seen that global solution for hardness are following: Gas flow rate 14 lit/min , Current 60

Amp. and Gap distance 2 mm. At these level, hardness are 205.407.

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