“Investigate the effect of TIG welding process parameters on weld distortion of AA6061"

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CERTIFICATE

It is certified that the work contained in this project report entitled "**Investigate the effect of TIG Welding process parameters on weld distortion"** submitted by **Makwana Gautam K. (200044003)** studying at Mechanical Engineering Department, Faculty of Engineering & Technology, for the award of M.Tech is absolutely based on his/her own work carried out under my/our supervision and that this work/thesis has not been submitted elsewhere for any degree/diploma.

Date:- **Place:-**

Signature and Name of internal supervisor **Signature and Name Head of Department**

Signature and Name of external supervisor

Seal of Institute

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I am also thankful to all other faculty members and my friends of Mechanical Engineering Department of Atmiya university and Mr. Marubhai workshop incharge, providing help me directly or indirectly in bringing of this dissertation work successful completion.

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Date:

Gautam K. Makwana
200045003

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“Investigate the effect of TIG welding process parameters on weld distortion of AA6061’’

(200044003)

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ABSTRACT

Aluminum is one of the most adaptable common foundry metals, and the ratio of cast to wrought aluminium alloy products is increasing, owing to the increased use of welding in automotive applications. All metallic materials considered for airframe design have heterogeneous, hierarchical microstructures with interacting characteristics on many length scales, allowing for the best possible combination of qualities like as strength, toughness, and corrosion resistance. Tungsten Inert Gas (TIG) welding is extremely significant, especially when welding aluminium and other metals. A TIG welding procedure would result in a large improvement in weld penetration in aluminium and improve the weldability. The AA6061 is largely used in automotive, aircraft, marine and pipelines. Due to uneven parameters selection is cause into the decrease the tensile strength and makes the distortion in the material and also affects the mechanical properties. For the better welding the input parameter selection play a most important role in the welding. For the TIG welding the most influential input parameters are selected from the ASME section IX. In this experimental work, the effect of different welding parameters like welding current, gas floe rate and included angle is selected for the project work and others is constant for the same.

The filler wire which is used for the project work is ER4043 for similar welding of AA6061, 6mm thick plate joints. The most affecting input parameter on the output result is determined using a general Full Factorial and response surface methodology. Experiments is used for the optimization with MINITAB 21 version is used. Response surface optimizer is used to improve chosen parameters. After the optimization, validate the result obtained.

Keywords: AA6061, TIG welding, Welding Procedure Specification, Weld Distortion, Hardness, Tensile strength, Full Factorial method

CHAPTER -1

INTRODUCTION TO MATERIAL

1.1 Aluminium

Aluminum (Al) is a light silvery white metal in the periodic table's major Group 13. Aluminum is the most common nonferrous metal and the most plentiful metallic element in the Earth's crust. Aluminum is never found in its metallic form in nature due to its chemical activity, but its compounds can be found in varying degrees in practically all minerals, flora, and animals. Aluminum is concentrated in the outer 16 km (10 miles) of the Earth's crust, where it makes up around 8% of the total weight; only oxygen and silicon come close. Aluminum is added in small amounts to certain metals to improve their properties for specific uses, as in aluminum bronzes and most magnesium-base alloys; or, for aluminum-base alloys, moderate amounts of other metals and silicon are added to aluminum. The metal and its alloys are used extensively for aircraft construction, building materials, consumer durables (refrigerators, air conditioners, and cooking utensils), electrical conductors, and chemical and food-processing equipment. Commercial aluminium (99 to 99.6% pure) with modest concentrations of silicon and iron is robust and strong; pure aluminium (99.996%) is soft and feeble.

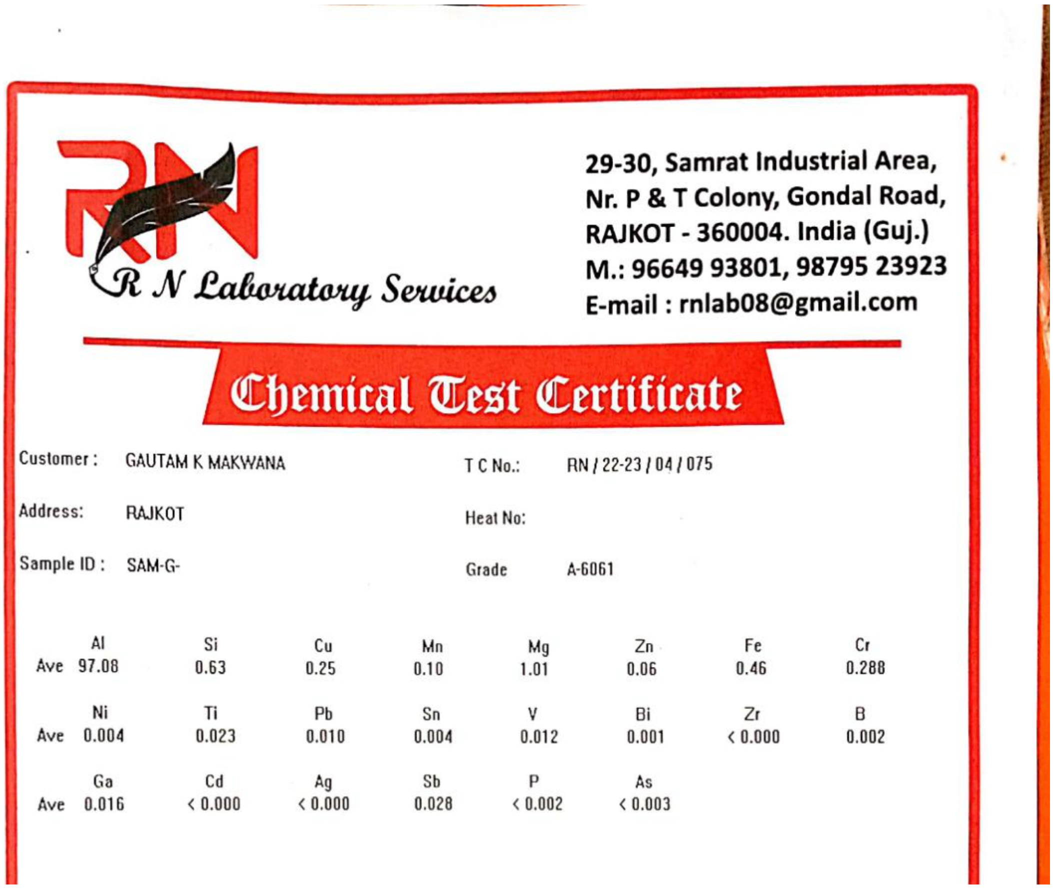
Aluminum is a ductile and malleable metal that may be pulled into wire or rolled into thin foil. The metal has a density of about one-third that of iron or copper. Aluminum is highly corrosion-resistant, while being chemically active, because it creates a thick, strong oxide film on its surface when exposed to air. Aluminum is a great heat and electrical conductor. It has half the heat conductivity of copper and two-thirds the electrical conductivity. It forms a face-centered cubic structure when it crystallizes. Aluminum-27 is the stable isotope of all natural aluminium. Aluminum oxide and hydroxide, as well as metallic aluminium, are harmless.

Aluminum and its alloys have a unique mix of qualities that make them one of the most versatile, cost-effective, and appealing metallic materials for a wide range of applications, from soft, highly ductile wrapping foil to the most demanding engineering applications. In terms of structural metals, aluminium alloys are second only to steels. Aluminum surfaces can be highly reflective. Radiant energy, visible light, radiant heat, and electromagnetic waves are efficiently reflected, while anodized and dark anodized surfaces can be reflective or absorbent. The reflectance of polished aluminum, over a broad range of wave lengths, leads to its selection for a variety of decorative and functional uses.

1.2 Aluminum Alloy Grades

Table 1.1 ALUMINIUM ALLOY GRADES

Grade Series	Material Properties	Main Alloying Elements	Heat Treatability	Uses
1000	Excellent Corrosion Resistance & Workability.	Pure Aluminum (99% or above)	NO	In chemical & food processing industries.
2000	Needs heat treatments for Best properties.	Copper + Aluminum	YES	In aircraft structures, propellers, automotive parts.
3000	Moderate Strength, Good corrosion Resistance.	Manganese + Aluminum	NO	Heat exchangers, cooking utensils
4000	Silicon brings down the melting point of this AA without causing brittleness.	Silicon + Aluminum	NO	Mostly used for welding & brazing aluminum, also in architectural properties.
5000	Moderate to high strength, good workability & corrosion resistance in marine environment.	Magnesium + Aluminum	NO	Constructions, storage tanks and pressure vessel, electronics and beverage cans.
6000	High formability, machinability & workability.	Silicon & Magnesium + Aluminum	YES	In aircraft, automotive and marine applications.
7000	Highest Strength when Heat treated.	Zinc & magnesium + Aluminum	YES	Aircrafts structures, mobiles and hydraulic equipments and high- stress parts.
8000	High Strength & stiffness.	Iron & Nickel, Aluminum – Lithium (Tin) + Aluminum	NO	In aerospace applications



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Chemical Test Certificate

Customer : GAUTAM K MAKWANA — T C No.: RN / 22-23 / 04 / 075

Address: RAJKOT — Heat No:

Sample ID : SAM-G- — Grade A-6061

	Al	Si	Cu	Mn	Mg	Zn	Fe	Cr
Ave	97.08	0.63	0.25	0.10	1.01	0.06	0.46	0.288
	Ni	Ti	Pb	Sn	V	Bi	Zr	B
Ave	0.004	0.023	0.010	0.004	0.012	0.001	< 0.000	0.002
	Ga	Cd	Ag	Sb	P	As		
Ave	0.016	< 0.000	< 0.000	0.028	< 0.002	< 0.003		

Fig 1.1 Chemical Test Certificate

Table 1.2 AA6061 Chemical Compositions

Elements	Weight percentage
Aluminum	95-98
Magnesium	0.8-1.2
Iron	0.7-0.10
Manganese	0.15
Silicon	0.40-0.8
Chromium	0.04-0.35
Copper	0.15-0.40
Zinc	0.25
Tin	0.15

- Figure 1.1 listed above indicates chemical properties of the metal Aluminium Alloy 6061 which is according to ASME SECTION II PART A.
- The chemical composition is showed in table 1.2.
- Table 1.3 listed below indicates Mechanical properties of the metal 5052 aluminum alloy.

Table 1.3 AA6061 Mechanical Properties

Mechanical Property	Value
Yield x strength	302 MPA
Ultimate strength	334 MPA
Hardness	105 VHN
Elongation(%)	18

Table 1.4 AA6061 Physical Properties

Physical Property	Value
Atomic number	13
Density	2.68 g/cm^3
Valency	3
Crystal structure	FCC
Melting Point	660.2 ℃
Thermal Expansion	23.5*10^-6/K
Modulus Of Elasticity	68.3 GPa
Thermal Conductivity	138 W/m.K
Electrical Resistivity	2.69 Ω.m

1.3 AA 6000 Applications

Aluminum 6061 is often used in certain heavy duty structural applications that involve:

- Truck frames
- Rail coaches
- Military and commercial bridges
- Ship building operations
- Towers and pylons
- Aerospace applications (i.e. helicopter rotor skins)
- Rivets
- Transport operations
- Motorboats
- Exercise equipment
- Boiler making

CHAPTER - 2

INTRODUCTION TO PROCESS

2.1 Background:

In today's world, manufacturing industries play a critical part in the development of any country. Any emerging country's economic strength is determined by the success of manufacturing companies. Furthermore, the expansion of the industrial sector can increase employment opportunities for individuals, allowing any country to thrive.

In the manufacturing industry, one of the most important phenomena is joining. In other terms, joining can be defined as "the joining of metals, either metal or non-metal, to serve some desired purpose," which can be anything depending on the application. Welding, soldering, and brazing are some of the joining processes that can be utilized depending on the application.

Welding is defined as "the fusion of two comparable or different metals with or without the application of pressure, with or without the use of a filler metal if required specifically for the purpose."

For the fabrication of household appliance products, the G.T.A.W welding technique is the most preferred welding process. This method is frequently utilized in industries since it is inexpensive, simple to implement, and can be automated with simplicity.

2.1.1 Welding

Amongst the manufacturing processes welding is primarily used for joining metal parts and is required when larger lengths of standard sections are required or when several pieces are to be joined together to fabricate a desired structure. Welding is the technique of joining metals and plastics by such methods which do not employ fasteners and adhesives.

2.1.2 Definition

Welding is a process of joining metallic components with or without application of heat, with or without pressure and with or without filler metal. A range of welding processes have been developed so far using single or a combination above factors namely heat, pressure and filler.

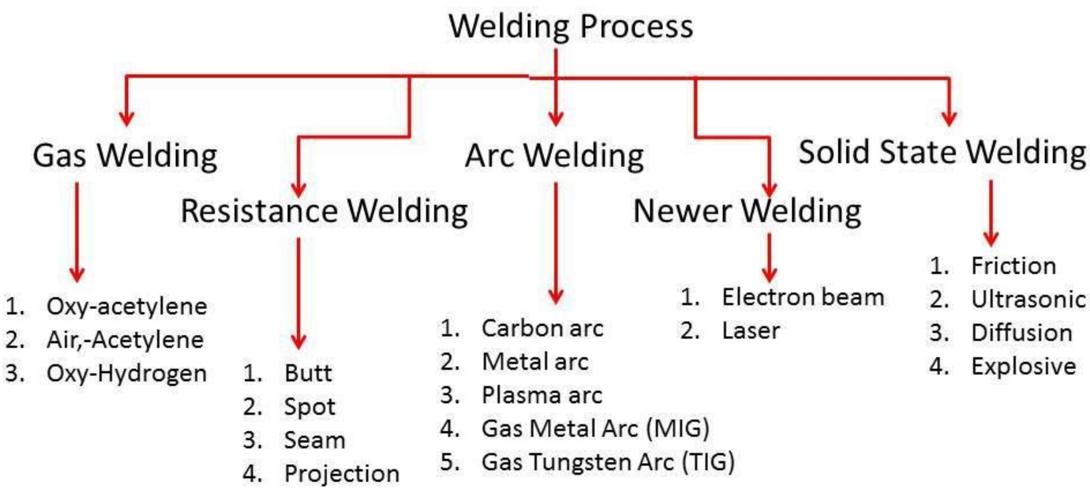


Fig.2.1 Welding Classification

2.2 Weldability

The ability to be welded into inseparable joints with specified features such as determined weld strength and correct structure has been characterized as weldability.

The weldability of any metal depends on five major factors :-

- Melting point
- Thermal conductivity
- Thermal expansion
- Surface condition
- Change in microstructure.

The American Welding Society defines weldability as,

"The capacity of a metal to be welded under the fabrication conditions imposed into a specific, suitably designed structure and to perform satisfactorily in the intended service."

2.3. Factors Affecting Weldability

There are several factors which influence the weldability of metals. Below are some of the most important ones.

- Metallurgy
- Welding Process
- Joint Design
- Weld Preparation
- Melting Point
- Electrical Resistance

2.4 Tungsten inert gas welding process:

Manual GTAW welding is the most difficult of all the welding methods typically employed in industrial applications since it is entirely dependent on the skill of the craftsman. Welders must maintain a short arc length during welding to avoid electrode corrosion, hence WPQ is required for welding pressure vessels. With only one hand, the welder manually feeds filler metal into the weld region while manipulating the welding torch in the form of a weave bead.

The GTAW welding method is classified as a fusion welding procedure, as seen in fig. 1.2. The connecting procedure of two similar or dissimilar metals is done with the parent metal in this sort of welding technique.

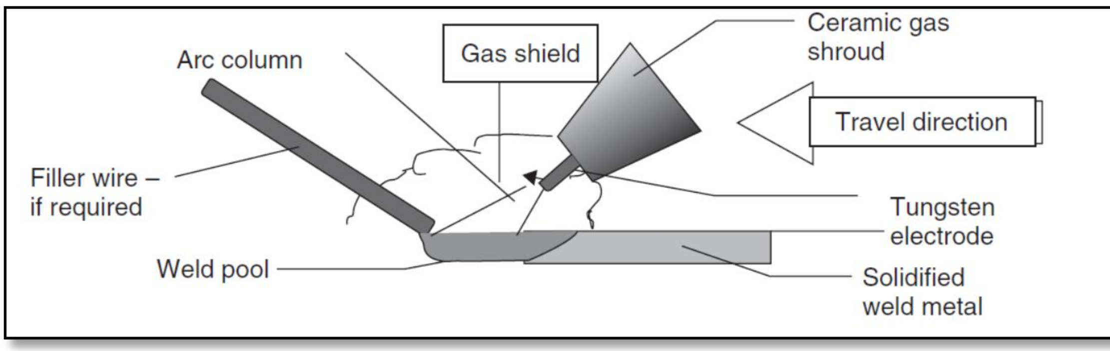


Fig. 2.2- Tungsten inert gas welding process

The procedure of gas tungsten arc welding (GTAW) is the most popular and widely utilized in the fabrication sector for producing various products. In the GTAW welding technique, a non-consumable tungsten electrode is used to weld the pieces. Different shielding gasses, such as argon, helium, or a combination of them, are utilized. The shielding gas is used to protect against other types of contamination as well as oxidation. In general, argon is employed as a shielding gas in the fabrication sector since it is less expensive than helium. On the other hand, helium is also used, but only when deeper penetration is required. Whether or not filler wire is utilized during GTAW welding is determined by the application.

This welding procedure is commonly employed in the fabrication, chemical, and food processing industries, as well as producing vessels, storage tanks, and nuclear power plants, as well as pharmacy firm plants, to join ferrous and non-ferrous materials that are comparable or dissimilar.

2.5 Distortion

- Distortion is produce in welding because of the residual stress due to heating and cooling of heat affected zone and contraction of weld metal.
- The stress deriving from this shrinkage results in distortion.

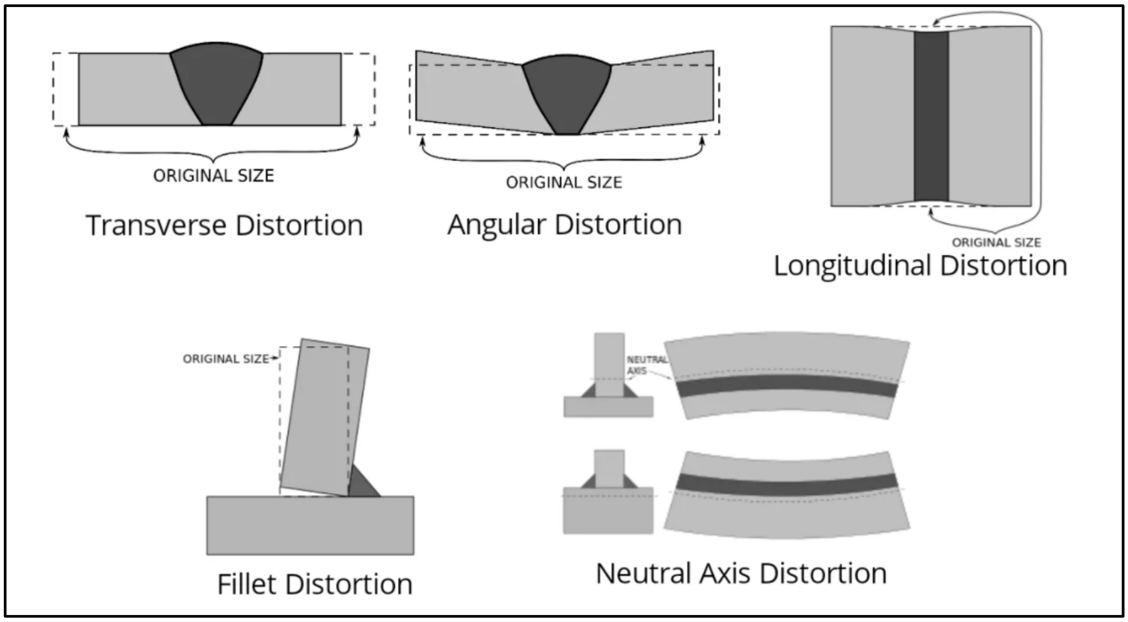


Fig 2.3 Types of Distortion

2.5.1 Types of distortion

- Transverse distortion
- Angular distortion
- Longitudinal distortion
- Fillet distortion
- Neutral axis distortion

2.5.2 Causes of distortion

- Employing incorrect welding orders.
- Using a large number of passes with small diameter electrodes.
- Because of high residual stresses in the plate to be welded.
- Due to the slow speed of arc travel.
- Not using any measuring instrument for dimension purpose.
- Using too much time for the welding process.

2.5.3 Remedies of distortion

- Ensure to use the correct welding order.
- Using the appropriate number of weld passes.
- Make sure you use the appropriate amount of weld metal as required by the joint.
- Maintaining the speed of arc travel.
- If required you can use a measuring instrument, so that dimensional accuracy is accurate.

CHAPTER - 3

INTRODUCTION TO INDUSTRY

3.1 Introduction

Shree Mayur Engineering Company was the industry in which I was permitted to work. The industry is located near TIP TOP FORGE in SHAPAR Industrial Area.

The Company is the manufacturer of the Investment casting machineries where large requirement of aluminum alloy is needed for the making of tanks.

Investment casting is typically utilized to create complex-shaped components with tighter tolerances, thinner walls, and a superior surface polish than sand casting can provide. The method of making the mould is what distinguishes investment casting. Wax is used to create a part design, which is subsequently dipped in fine ceramic slurry including colloidal silica and alumina.

The wax is melted out of the mould by heating it in an oven, leaving a ceramic shell mould for casting. Precision casting of aerospace components such as gas turbine blades is done using the investment casting method, often known as the lost wax process.

The company's annual revenue is in the range of $4 to $5 million.

Product being manufactured in plant listed below-
1] Vertical Wax Injector
2] C-FRAME- 20 ton side and bottom wax injector 30
3] Semi Auto wax injection press

3.2 VERTICAL WAX INJECTION MACHINE

The figure 3.2 (A & B) shown below indicates vertical wax injection machine for advanced and thermic oil model manufactured by shree mayur engineering co.

(A) Advanced model

(B) Thermic Oil Model
Fig 3.1 Vertical wax injection machine

3.3 Wax Conditioning Machine

Fig 3.2 Wax Conditioning Machine

3.4 Semi automatic wax injection press:

The figure 3.4 (A & B) shown below indicates semi auto wax injection press manufactured by shree mayur engineering company.

(A) 12 TON Press **(B) 35 TON Press**

Fig 3.3 Semi Auto wax injection press

3.5 Machineries Available at the Industry

1] TIG Welding Machine
2] Arc Welding Machine
3] Auto Shearing Machine
4] Rolling Machine
5] Bending Machine
6] Hand Grinding Machine
7] Plasma Cutter

CHAPTER - 4
LITERATURE REVIEW

4.1Literature Review

Amirreza KHOSHROYAN, Armin Rahmati DARVAZI (2020),[1] The distribution of temperature and then the distribution of residual stress and distortion in the stiffened aluminum alloy Al6061-T6 plates under the metal inert gas welding process were investigated by three dimensional thermo-mechanical coupled finite element model using Ansys software. The properties of materials were considered temperature-dependent and the filler metal was added to the workpiece by the element birth and death technique. In three modes of current, two different speeds and two various sequences, the distribution of residual stress and distortion were calculated and analyzed.

Ahmed Khalid Hussain, Abdul Lateef(2010), [2] Tungsten Inert Gas welding is one of the widely used techniques for joining ferrous and non ferrous metals. TIG welding process offers several advantages like joining of unlike metals, low heat effected zone, absence of slag etc compared to MIG welding. The accuracy and quality of welded joints largely depends upon type of power supply (DCSP or DCRP), welding speed, type of inert gas used for shielding. This paper deals with the investigation of effect of welding speed on the tensile strength of the welded joint. Experiments are conducted on specimens of single v butt joint having different bevel angle and bevel heights.

Umair Aftab , Muhammad Mujtaba Shaikh, Muhammad Ziauddin Umer (2020), [3] They focus on the variable use of TIG welded specimen of 6061 aluminum alloys to homogenize its hardness properties by heat treatment. Investigation proceeds by perceiving the effect of different precipitation hardening conditions on Aluminum alloy through their micro and macro-structural behavior and microhardness analysis. The statistical examination was conducted to evaluate the integrity of heat treated samples. A new and efficient measure – the coefficient of reliability – is introduced to outline the best hardness preserving samples. The statistical analysis shows the effectiveness of the coefficient of reliability to outline the best samples. The experimental results show that the samples aged at 175oC for 12 hours preserve the hardness profile of the welded alloy. The result is also verified from the mean hardness, coefficient of reliability and standard deviation values and in agreement with literature.

R. Ahmad,M.B.A. Asmael(2015), [4] This study was to determine the influences of post-weld heat treatment (PWHT) on the tensile and microstructure properties of friction stir-welded AA6061 aluminum alloy joints. Friction stir welding (FSW) of aluminum alloys has the potential to retain good mechanical and metallurgical properties. 3 mm plate AA6061 aluminum alloy was used to fabricate the joints. Solution heat treatment, quenching plus an artificial aging treatment with different times of aging were adopted. The fracture surface of the welded specimens was analyzed by using a scanning electron microscope, and an optical microscope was used for microstructure analysis, where finer dimples were obtained and formed inter-metallic compound at the highest aging time. Tensile properties were improved by about 4.7% after PWHT for 16 hrs.

Fatih HAYAT1, Servet DAGIDIR, Muhammet KARCI(2020), [5] In this study, 6xxx series aluminum alloy is joined with TIG welding method. Welds were used as additional metal (5356 AlMg type additional wire) was in the joints. Tensile tests were applied to samples prepared in two different standard sizes in order to determine the strengths of welded joints. In addition, hardness measurements of welded samples were obtained from welding zone, HAZ and base material.

Pratik T Kikani,[6] The study pertains to the improvement of mechanical properties of aluminum alloy welds through pulsed Tungsten Inert Gas (TIG) welding process. The study aims at selecting optimum parameters on Pulsed TIG welding aluminum alloy 6061 butt joint. Input process parameters (peak current, base current and frequency) are varied, and tensile strength and hardness are determined. Full factorial method is employed to optimize the pulsed TIG welding process parameters of aluminum alloy welds for increasing the mechanical properties. Optimization of selected parameters is done by response optimizer. After optimization, the results are validated.

S. Jannet, P.K. Mathews, R. Raja (2013), [7] In this paper, the mechanical properties of welded joints of 6061 T6 and 5083 O aluminium alloy obtained using friction stir welding (FSW) with four rotation speed (450, 560, 710 and 900 rpm) and conventional fusion welding are studied.FSW welds were carried out on a milling machine. The performance of FSW and Fusion welded joints were identified using tensile, hardness and microstructure. Better tensile strength was obtained with FSW welded joints. The width of the heat affected zone of FSW was narrower than Fusion welded joints welded joints Properties FSW and Fusion Welded processes were also compared with each other to understand the advantages and disadvantages of the processes for welding applications of the Al alloy.

Prantik Mukhopadhyay (2012), [8] The strength-to-weight ratio offered by AA6XXX alloys and their enhanced mechanical properties have become crucial criteria for their use in light weight military vehicles, rockets, missiles, aircrafts, and cars, used for both defence and civil purpose. The focus of this review paper is to put together the latest knowledge available from various sources on alloy design, industrial processing, development of properties, and potential use of AA6XXX alloys. The direct chill (DC) cast AA6XXX wrought alloys which are subsequently processed by fabrication process like hot working, cold working, process annealing, and age hardening heat treatments are the foci of this review though designation section also contains the designations of cast alloys to provide the reader a broad overview on designation. The effects of the alloying elements which are generally used for AA6XXX wrought alloys are discussed incorporating their interactions during wrought AA6XXX alloy fabrication. The significance of the alloying and also the processing to develop the certain properties and the underlying strengthening mechanisms are discussed. The frequent and versatile uses of these AA6XXX alloys for the structural applications both in defence and civil purpose are put forth.

T. Sathish, S. Tharmalingam, V. Mohanavel (2021), [9] TIG welding method is an easy, friendly process to perform welding widely applicable wrought aluminium AA8006 alloy, which was not considered for TIG welding in earlier studies, is considered in this investigation. For optimizing the number of experiments, the Taguchi experimental design of L9 orthogonal array type experimental design/plan was employed by considering major influencing process parameters like welding speed, base current, and peak current at three levels. Welded samples are included to investigate mechanical characterizations like surface hardness and strengths for standing tensile and impact loading. results of the investigation on mechanical characterization of permanent joint of aluminium AA8006 alloy TIG welding were statistically analyzed and discussed. 3D profilometric images of tensile-tested specimens were investigated, and they suggested optimized process parameters based on the result investigations.

Chennaiah MB1*, Kumar PN2 and Rao KP(2015), [10] The mechanical properties (Hardness) and microstructure characteristic of weld metal depends upon the microstructure of the weld. The microstructure of the weld depends upon pulsed parameters peck current, base current, pulse frequency, pulse duration. The objective
of present project is to achieve better mechanical properties. So, controlling of pulsed parameter is needed in this investigation. An increase in the pulse frequency has been found to refine the grain structure of weld metal especially when welding is done using short pulse duration. Long pulse duration lowers the pulse frequency up to which refinement of constituents in weld metal takes place. Effect of the pulse frequency on the grain structure was found to be determined by pulse duration. For a given pulse frequency, long pulse duration produced a coarser structure thanshort pulse duration. An increase in the peak current coarsened the grain structure.

A. Kumar1 and S. Sundarrajan(2006), [11] In this paper, the selection of welding process parameters for obtaining the optimum weld butt-joint ultimate tensile strength (UTS) of aluminum alloy (6061-T6) is presented. Considering weld-joint UTS as the quality characteristic in the selection of process parameters, the Taguchi method is used to analyze the effect of each individual process parameter and of their interaction and then to determine process parameters for the optimum weld-joint UTS. Analysis of variance (ANOVA) technique is applied to investigate which welding process parameter has significant effect on the weld-joint UTS. Experimental results are provided to illustrate the proposed approach.

J M GMEZ DE SALAZAR, A UREMA(2015), [12] Series 6XXX and 7XXX aluminium alloys are considered to be of medium and high strength and are widely used in different industries, such as the aeronautical and automotive. However, their application as structural materials depends on the proper development of their joining processes. The present article describes the results obtained from evaluating the microstructures, using both optical microscopy (OM) and scanning electron microscopy (SEM), as well as the mechanical properties (hardness variations) of welds performed on the alloys with two different arc welding techniques: GTAW (TIG) and GMAW (MIG). For the Iatter, filler metal with AI-5Mg composition and A5.10-92 AWS denomination (AA5356) was used.

D. Maisonnettea, M. Sueryb, D. Neliasa(2018), [13] This paper describes the mechanical behavior of the 6061-T6 aluminium alloy at room temperature for various previous thermal histories representative of an electron beam welding. A fast-heating device has been designed to control and apply thermal loadings on tensile specimens. Tensile tests show that the yield stress at ambient temperature decreases if the maximum temperature reached increases or if the heating rate decreases. This variation of the mechanical properties is the result of micro structural changes which have been observed by Transmission Electron Microscopy (TEM).

Pratik T. Kikani, Dr. Hemantkumar R. Thakkar(2020), [14] The current investigation is intended to discover the effect of pulsed current TIG welding process parameters on tensile properties of Alloy AA6061 T6 material. Peak current, base current and frequency were cautiously decided with the intention of producing complete penetrate joints. Taguchi method was used to prepare the experimentation design and statistical methods such as ANNOVA and regression technique were employed to obtain optimized weld parameters. At 180 A Ip, 60 A Ib and 6 Hz frequency the tensile and yield properties is better and the value are 185.55 Mpa and 156.62 Mpa respectively. This is due to the fact that equiaxed dendrite structures can be observed during higher Ip and f.

N.Jeyaprakash, Adisu Haile(2015), [15] In this case study, we discuss the influence of the power source, type of current, gas flow rate, electrodes, filer wire, TIG Machines settings, and shielding gases which are most important in determine arc stability, arc penetration and defect free welds. To do this a thorough literature survey is carried out on various aspects of the proposed topic, in various peer-reviewed journals, patents, books and other research resources. We have identified the suitable range of current, the thickness of the base metal, the diameter of electrode, the composition of electrode and filler wire, the gas flow rate required for high quality TIG welding process.

M. Ishak, N.F.M. Noordin, A.S.K. Razali(2015), [16] Innovative welding technology in joining aluminum alloys in the automobile, aviation, aerospace and marine industries would achieve weight reduction and high specific strength as well as increasing fuel efficiency and reducing environmental pollution. This study presents an appropriate welding filler to join similar AA6061 aluminum alloys using the tungsten inert gas (TIG) process. The TIG welding of AA6061 was butt joined with three different fillers: ER5356 (4.5–6% Mg), ER4043 (4.5–6% Si) and ER4047 (11–13% Si). The experiments were conducted in order to investigate the macrostructure and microstructure of the samples as well as the mechanical properties. The effect of preheating was also investigated.

Rishi Kumar, Ramesh N Mevada, Santosh Rathore(2017), [17] To improve Welding quality of aluminum (Al) plate, the TIG Welding system has been prepared, by which Welding current, Shielding gas flow rate and Current polarity can be controlled during Welding process. In the present work, an attempt has been made to study the effect of Welding current, current polarity, and shielding gas flow rate on the tensile strength of the weld joint. Based on the number of parameters and their levels, the Response Surface Methodology technique has been selected as the Design of Experiment. For understanding the influence of input parameters on Ultimate tensile strength of weldment, ANOVA analysis has been carried out. Also to describe and optimize TIG Welding using a new metaheuristic Nature - inspired algorithm which is called as Firefly algorithm which was developed by Dr. Xin-She Yang at Cambridge University in 2007. A general formulation of firefly algorithm is presented
together with an analytical, mathematical modeling to optimize the TIG Welding process by a single equivalent objective function.

Ameth Faye, Yannick Balcaen, Loic Lacroix(2021), [18] In this study, the effects of Yb: YAG laser welding parameters on the microstructure and mechanical properties of AA6061-T4 joints were analysed. Samples without any welding defects such as porosity, melt pool collapse, and hot cracking were produced with different welding parameters. Energetic processing parameters had a significant influence on the fusion zone (FZ) and heat-affected zone (HAZ) microstructure and dimensions, in addition to local and global mechanical properties. The weld bead width increased with increasing power and energy densities and reduced the weld bead tensile properties. High welding travel speed produced a more elongated weld pool and ripples resulted in a 'V' shape. A significant quantity of axial heterogeneous nucleation was observed in the FZ centre of these weld beads because of the low-energy density. In contrast, low welding travel speed produced C-shaped ripples and a few axial grain nucleation sites in the FZ. The latter was evidence of a slower solidification rate. Dendrite secondary arm spacing measurements confirmed this hypothesis. It was observed that axial grains in the FZ centre improve the weld bead tensile properties. Compared to the base material (BM), the hardness in the FZ was reduced and identical in the HAZ. The FZ hardness depended on the welding parameters. Digital image correlation (DIC) strain measurements indicated higher deformation near the FZ, but when geometrical defects were removed, the FZ deformed more homogeneously.

Pratik Kikani, Dr. Hemantkumar R Thakkar(2017), [19] Aluminium has high expansion coefficient at large solidification shrinkage and wide solidification temperature range, due to these properties; Al-alloys are known to be susceptible to cracking. This paper is study about the defects which occurs during welding of aluminium Al-alloys crack is the most significant defect and it affects the mechanical properties in the material such as hardness, yield strength and tensile strength. During Aluminum welding some aluminium Al-alloys such as al-Cu, al-Mg, Al-Mg-Si etc. are more sensitive to solidification cracking. Hot cracking susceptibility depends on alloy content of the material. Same way liquation cracking susceptivity is increasing with increasing cooling temperature range.

Leo Joseph Besky, Mahadevan. G(2019), [20] The present investigation is aimed to study the supply effect of alternate of the shielding gas in different alternating frequencies in comparison with the conventional method of GTA welding with pure argon gas. In this investigation, a gas alternator is used to control and supply the argon and helium shielding gases cyclically to the weld pool for a particular period of time. There are three types of alternating frequencies 1s (Ar) : 0 s (He), 0.5 s (Ar): 0.5 s (He) and 0.75 s (Ar): 0.25 s (He) are used in the supply of alternating shielding gases. Bead on plate welding is performed on AA6061 aluminium alloy plate at different combinations of input parameters like welding current (I) and alternating frequencies of shielding gases (T) at constant welding speed. From the bead on plate welding experiments, the influence of alternating shielding gases on the bead profile characteristics like depth of penetration, area of penetration, width of weld, reinforcement height, wetting angle and percentage of dilution have been studied. Influence of alternating shielding gases on micro hardness and micro structural characteristics of beads also been investigated. The alternate supply of the shielding gas produced better bead profile characteristics with improved mechanical properties as compared with the conventional method of pure argon.

Arun M, Ramachandran k,(2015), [21] This paper investigates the mechanical and metallurgical properties of AA6061 ALUMINIUM ALLOY lap joint by making welding process such as GTAW, GMAW and FSW. The frequently used welding process is GTAW and GMAW which is better economy and easier. During weld metal hardening because of thermal properties the rough columnar grains appears on alloy of weld fusion zones. This frequently source inferior weld mechanical and metallurgical properties and . Friction stir welding (FSW) is a new innovative welding process developed principally for welding alloys and metal that before now had been arduous to weld using more orthodox fusion techniques. Here 6.35 mm thickness of rolled plates are used for this process. For preparing lap welded joints Rolled plates of have been used. The filler metal used for joining the plate is AA4043 (Al.SSi (wt %) grade aluminium alloy. The tensile properties, micro hardness, microstructure of the GMAW, GTAW and FSW joints are compared and evaluated.From this work, it is to be observed that GMAW joints of AA6061 aluminium alloy have superior mechanical properties when compared to GTAW and FSW joints.

Ishteyaque Ahmad, Somvir Arya (2018), [22] Tungsten Inert Gas welding is the process in which heat is produced from an arc between the non-consumable tungsten electrode and the work piece. This paper deals with the study of Micro-structural and mechanical properties of the welded joints of the aluminum alloy AA-6061 welded by Tungsten Inert Gas(TIG) welding by using welding current as varying parameter. The filler wire used during the experiment of the grade as AA-4047 which has the more content of the silicon (11.0%-13.0%). Due to high content of silicon in the wire it will improve the fluidity during the welding operation. By this experiment we will examine the optimal value of the welding current. The welded specimens are to be investigated by using the optical microscopy, Vickers micro-hardness test and surface roughness testing. The optical microscopy test was used to characterize the micro-structure of the base metal and of the welded zone and the micro-hardness test was conducted to find the hardness of the welding zone and surface roughness test was conducted to check the roughness of the welded surface.

V.VARA Prasad, D.Lingaraju (2016), [23] Joining and welding are key enabling technologies for manufacture. The quality and reliability of a manufactured product are often determined by the quality of its joints. Aluminium alloy AA6082 find their greatest strength combined with good corrosion resistance, ease of formability and excellent ability to be anodized. Removing material along the edges of metal surfaces that are to be joined by welding is called a joint design or an edge preparation. These designs determine the penetration depth of the filler material in the weld joint. As the strength of a particular welded joint is related to the penetration depth achieved in a welded joint, edge penetration plays a pivotal role in determining the strength of the welded joint. In the present paper, different edge preparations of butt joints like single V, double V and single Y are fabricated on 6082 Aluminium alloy with different values of weld face openings. They are welded with GTAW with Al 4043 as a filler material. Tensile strengths of each weld is obtained and compared with different curve fitting equations.

Jayashree P K, SS Sharma (2017), [24] Aluminium in pure form has comparably less strength, though some of its alloys are stronger than structural steels. 6061Al alloy is so strong and hence used in aggressive conditions like aerospace applications. Possessing these superior properties, the defects like porosity, hot cracking and stress corrosion cracking during welding of aluminium alloy is yet to be optimized. This paper focus to determine the favourable welding conditions for Tungsten Inert Gas (TIG) welding of 6061Al alloy based on Taguchi’s design of experiments. Hence the concentration is on experimentally identifying the effect of the different welding parameters on hardness and weld bead geometry at weld zone under different welding condition obtained by L9 Orthogonal array using Taguchi’s design of experiments.

V. Mohanavel, M. Ravichandran, S. Suresh Kumar (2017), [25] This research article exhibits experimental and numerical results of TIG welding of AA6061. TIG welding process parameters like gas flow rate, welding current and welding speed was optimized using the Taguchi technique for joining AA6061 plates. The combinations of parameters were carefully selected with the objective of producing weld joint with maximum impact strength. Experimental tests were performed with four levels of parameters according to L16 orthogonal array. Signal-to-noise (SN) ratio and ANOVA were used to evaluate the experimental results. The results indicate that the gas flow rate is the significant parameter on impact strength of weld joints, followed by welding speed and welding current.

Aaradhya Bansal, M. Senthil Kumar(2020), [26] This work studies the outcomes of welding parameters on 5 mm thick AA6061 sample welded by using the gas tungsten arc welding. TIG welding process is chosen because of its superior technique and better economy. For the selected parameters, the welding was carried on the sample as per the standard American Welding Society (AWS) in four passes by using MGS 525/409 as the filler metal using argon as the shielding gas. Microstructure, hardness and tensile strength were determined to analyze the properties and various parameters of the welded joint. The yield and tensile strength of the sample welded at 160A was found to be 245 MPa and 105 MPa which represents 20% reduction in the ultimate tensile strength and reduction of 61% in yield stress. The hardness was found to be highest for the sample welded at 190A at the metal surface, heat-affected zone and weld zone measured was 103 HRC, 90 HRC and 87 HRC respectively.

Sharda Pratap Shrivas, Sanjay Kumar Vaidya(2020), [27] Various welding process are present, among the various welding process, Tungsten inert gas (TIG) welding plays a major role in the welding of mild steel or thin sections of non-ferrous metals such as copper alloys, aluminum alloys, magnesium and stainless steel. Many advantages obtain in TIG welding to joining of dissimilar metals like slag avoidance, minimise heat affected zone etc. Since input parameters playa major role in determining the quality of a welded specimen. A plan of experiments based on L9 orthogonal array has been used to design of experiment, acquire the data and to maximize tensile strength of variation in welding parameters. Finally the tests have been carried out to evaluate the best process parameters for given aluminum alloy with the experimental values confirm its effectiveness by SEM in the analysis of strength.

A. Kumara, S. Mukherjee(2009), [28] This paper is aimed to study in detail about dissimilar welding of aluminium alloy (AA 1100) with mild steel (MS) of thicknesses 3.0mm and 2.0mm respectively. This paper also gives emphasis on the multi-objective optimization by using grey relational analysis (GRA) for samples welded with gas tungsten arc welding (GTAW). The welding input parameters are crucial in obtaining the desired weld quality. The experiments have been performed according to the L-8 orthogonal array. The input parameters chosen are the pulsed DC parameters such as pulsed current, base current, pulse on time percentage and frequency. The weld quality determining parameters are the ultimate tensile strength and Rockwell hardness. Grey relational analysis is used to obtain the optimum input values for the optimum weld quality.

A. Rafey Khan1, S. Nisar(2016), [29] Solution-treated AA 6061 alloy contains residual stresses which cause unwanted deformation during the machining operation rendering the parts unacceptable for use. Usually for AA 6061 alloy, stress relieving is performed by re-heating the parts at 343°C for 1 h. This stress relieving is however accompanied by a considerable loss of material strength which subsequently reduces the functionality of the parts. This paper is based on an effort to evaluate the effectiveness of lower re-heating temperatures for stress relieving without significant loss of strength. Temperatures within the range of 200–343°C were used and treated samples were tested for both the strength and machining distortion. The experimental results indicate 60% reduction in machining distortions with 21% decrease in the strength.

A. K. Lakshminarayanan & V. Balasubramanian, K. Elangovan (2007), [30] The present investigation is aimed at to study the effect of welding processes such as GTAW, GMAW and FSW on mechanical properties of AA6061 aluminium alloy. The preferred welding processes of these alloys are frequently gas tungsten arc welding (GTAW) and gas metal arc welding (GMAW) due to their comparatively easier applicability and better economy. In this alloy, the weld fusion zones typically exhibit coarse columnar grains because of the prevailing thermal conditions during weld metal solidification. This often causes inferior weld mechanical properties and poor resistance to hot cracking. Friction stir welding (FSW) is a solid phase welding technique developed primarily for welding metals and alloys that heretofore had been difficult to weld using more traditional fusion techniques. Rolled plates of 6 mm thickness have been used as the base material for preparing single pass butt welded joints. The filler metal used for joining the plates is AA4043 (Al-5Si (wt%)) grade aluminium alloy. In the present work, tensile properties, micro hardness, microstructure and fracture surface morphology of the GMAW, GTAW and FSW joints have been evaluated, and the results are compared. From this investigation, it is found that FSW joints of AA6061 aluminium alloy showed superior mechanical properties compared with GTAW and GMAW joints, and this is mainly due to the formation of very fine, equiaxed microstructure in the weld zone.

4.2 Research summary

- The previous research work shows which the parameters is affected in the TIG welding process of AA6061.
- It is shows the welding current is most influent parameter in the TIG welding.
- In TIG Welding the increasing of welding current which is affect the weldability and hardness.
- When heat input increase the hardness will be decrease.
- The filler wire ER4043 is good for best result.

4.3 Problem identification

- In TIG welding of AA6061 due to its light weight and ductility during welding without clamping metal will be formulated in distortion. So reduce this effect to study the most influencing parameters and to know it and solve that type of problem. Higher current in TIG welding can work piece become damage.
- In other hand lower current setting in TIG welding lead to sticking of the rod and base metal not melt properly. So weld ability is not good.
- Not good appearance.

4.4 Research objective

- To evaluate process parameters of TIG welding for AA6061.
- To analyze impact of process parameters such as welding current, gas flow rate and included angle on distortion, hardness and tensile strength.
- To find out optimum result with the help of response surface optimizer.
- To validate the analytical results with respect to optimized results.

4.5 Boundary condition

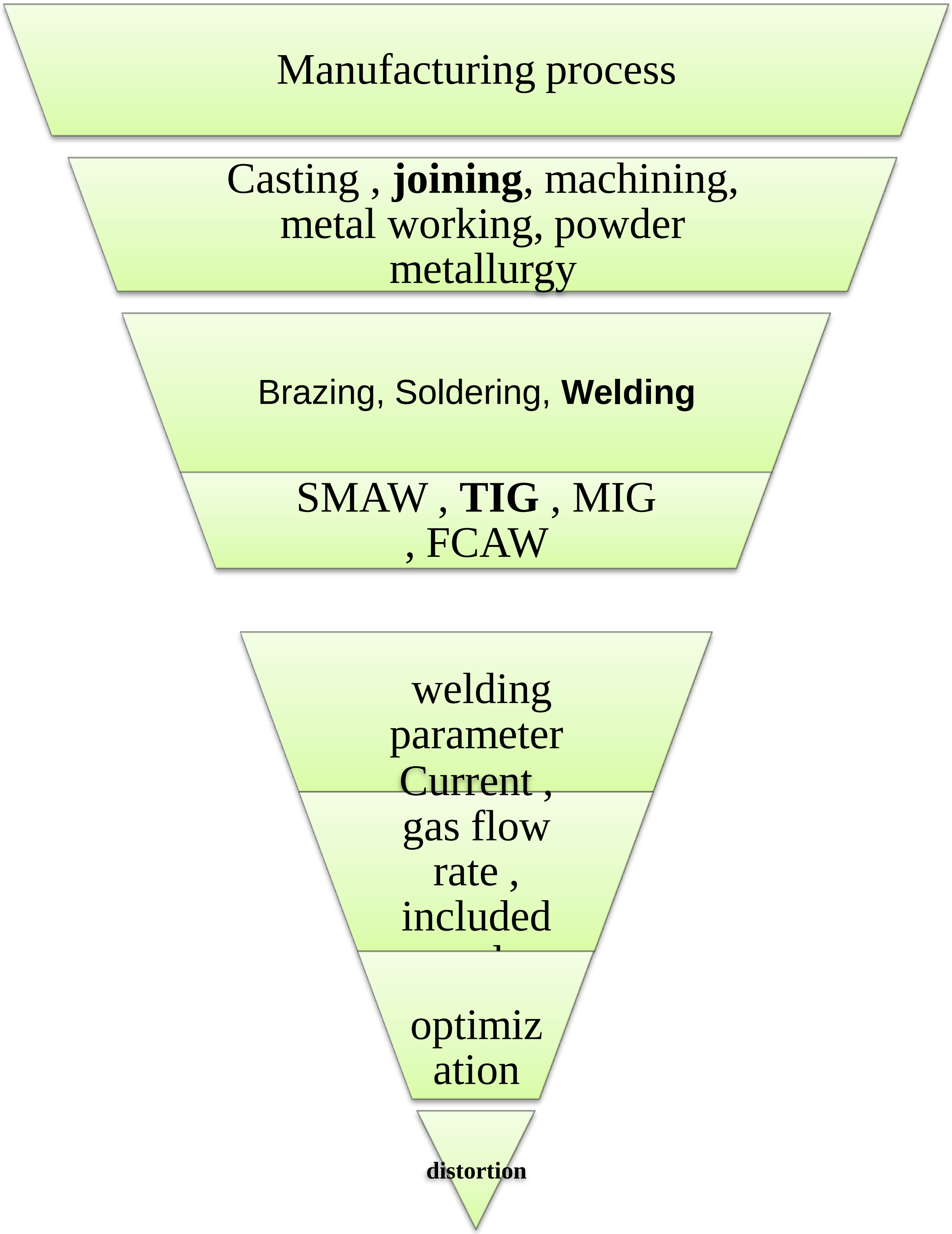


Fig. 4.1 Boundary condition

CHAPTER -5

METHODOLOGY

The steps taken during the complete project study in the company are outlined below:

1. Pilot tests should be carried out in order to determine the material's suitability for welding.

2. For a good mechanical property, choose input and output process parameters carefully, and optimize this input parameter.

3. Create a Design of Experiments (DOE) for the input parameter optimization using the Full Factorial Method.

4. Carry out the tests using the input parameter values that I have chosen.

5. Inspection and tensile strength testing of experimental samples, as well as hardness testing of the weldment sample.

6. Regression analysis is used to generate mathematical equations for the Full Factorial model.

7. To acquire a better outcome, optimize the input parameters and compute the values of the output parameters for the same.

8. Test the tensile strength and hardness of the weldment by performing a sample weld with the optimum input parameters.

9. MINITAB software can be used to compare and validate results.

The below figure shows the flow chart of the entire work done during the Dissertation study.

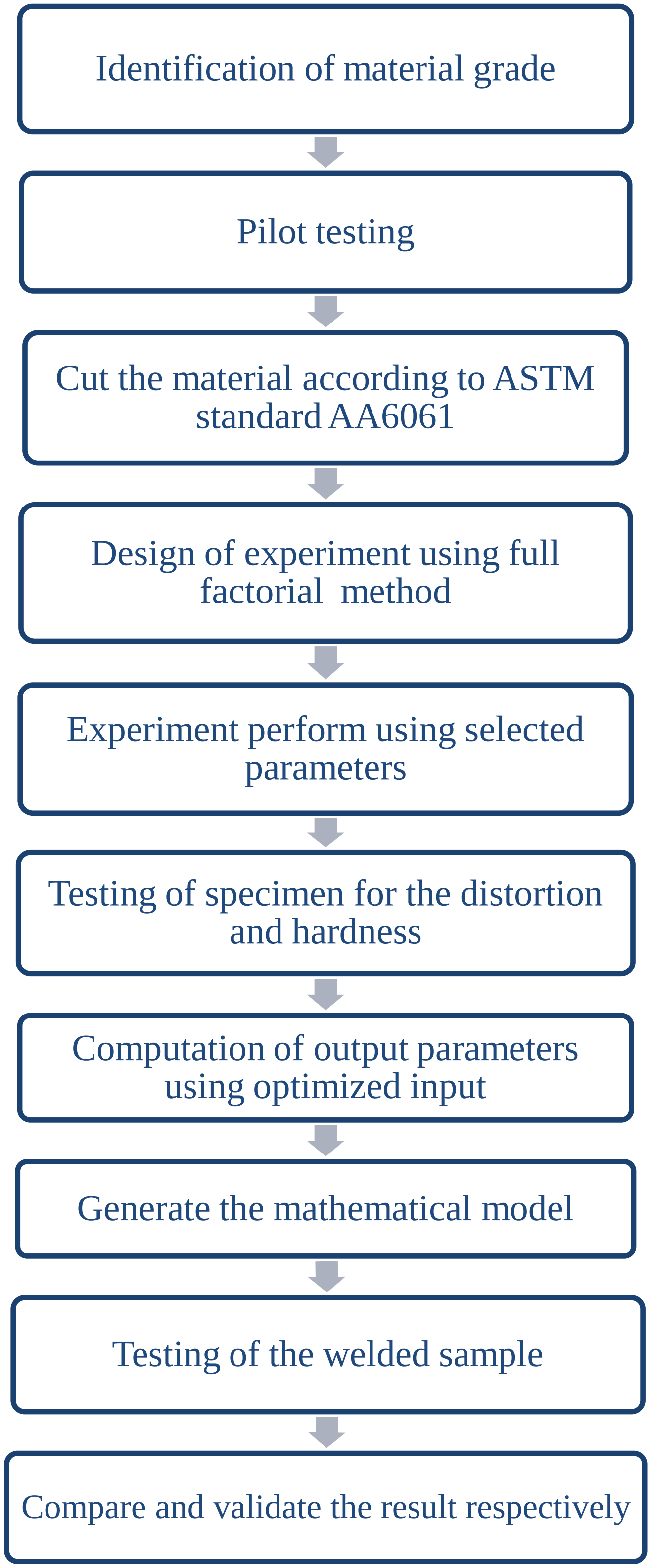


Fig 5.1 Methodology

5.1 Input - Output Parameters

Table 5.1 Input-output parameters

Input parameter	Output parameter
Current (A)	Distortion(mm)
Gas flow rate (LPM)	Hardness(HRC)
Included Angle(°)	Tensile strength(MPA)

5.2 Range of parameters

Table 5.2 Range of parameter

Parameter	Level-1	Level-2	Level-3
Current(A)	150	175	200
Gas flow rate (LPM)	8	9	10
Included angle(°)	30	60	90

CHAPTER – 6
Design of Experiment

6.1 Experimental Design:

The steps taken during the complete project study in the company are outlined below:

1. Pilot tests should be carried out in order to determine the material's suitability for welding.

2. For a good mechanical property, choose input and output process parameters carefully, and optimize this input parameter.

3. Create a Design of Experiments (DOE) for the input parameter optimization using the Full Factorial Method.

4. Carry out the tests using the input parameter values that I have chosen.

5. Inspection and tensile strength testing of experimental samples, as well as hardness testing of the weldment sample.

6. Regression analysis is used to generate mathematical equations for the Full Factorial model.

7. Design of Experiments (DOE) or we can say Experimental Design is a procedure under SPC (Statistical Process Control) respectively.

8. In this procedure, different experimentaldesign are utilized for getting the better result.

9. These experimental design are also can demonstrated mathematically to optimize the parameter.

10. There are mainly three type ofexperimental design are available respectively.

4.1.1 Full-factorial Method

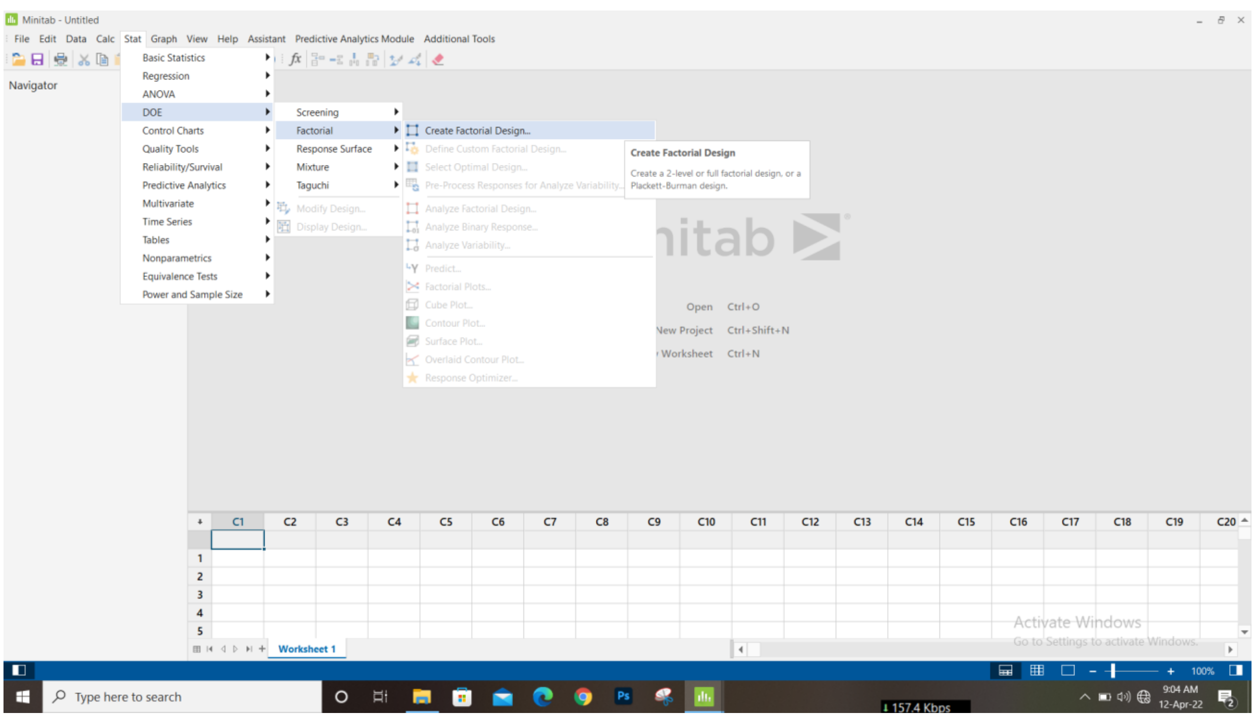
4.1.2 Response Surface Method

4.1.3 Taguchi Method

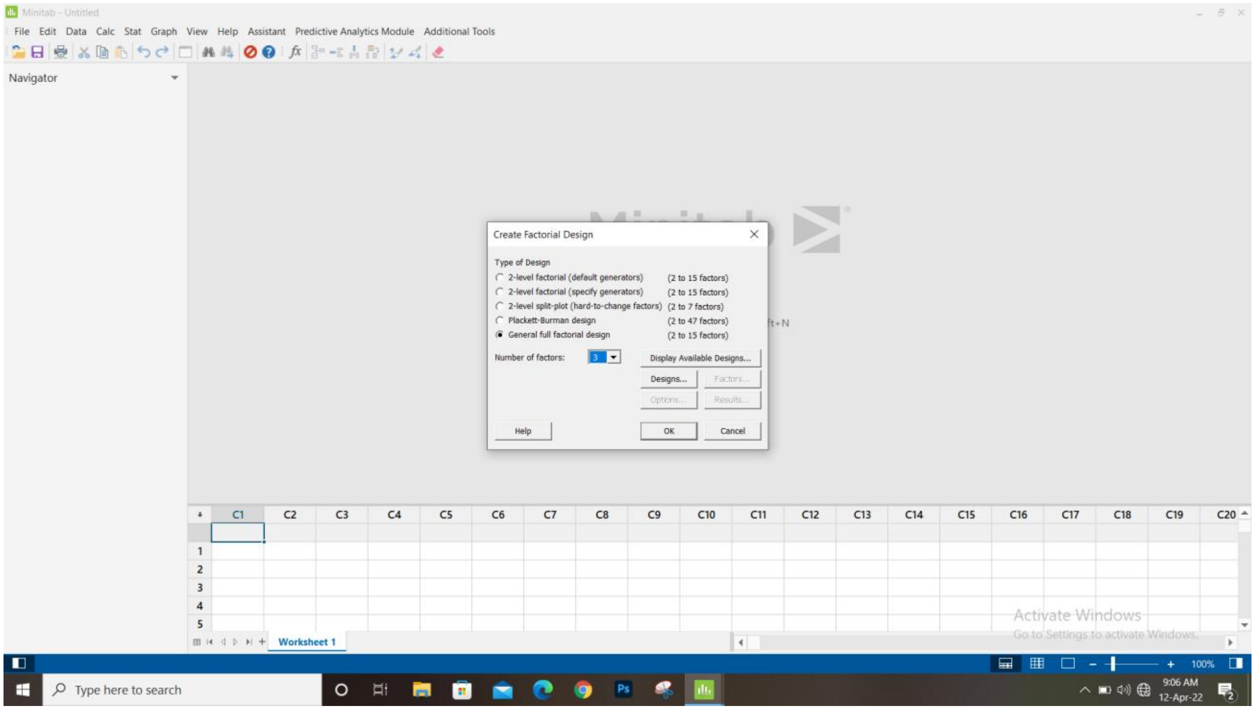
6.2 Full factorial method :

- This Statistical technique of design of experiments or we can say DOE method including different factors was first created by Englishman, Sir R. A. Fisher respectively. The technique is generally known as the factorial design of experiments respectively.
- It is widely accepted that the most commonly used experimental designs in manufacturing companies are full and fractional factorial designs at 2-levels and 3-levels.
- A full factorial designed experiment consists of all possible combinations of levels for all factors.
- The total number of experiments for studying k factors at N-levels is N^{k}.
- The purpose of the DOE is to determine at what levels of the inputs will you optimize your outputs.

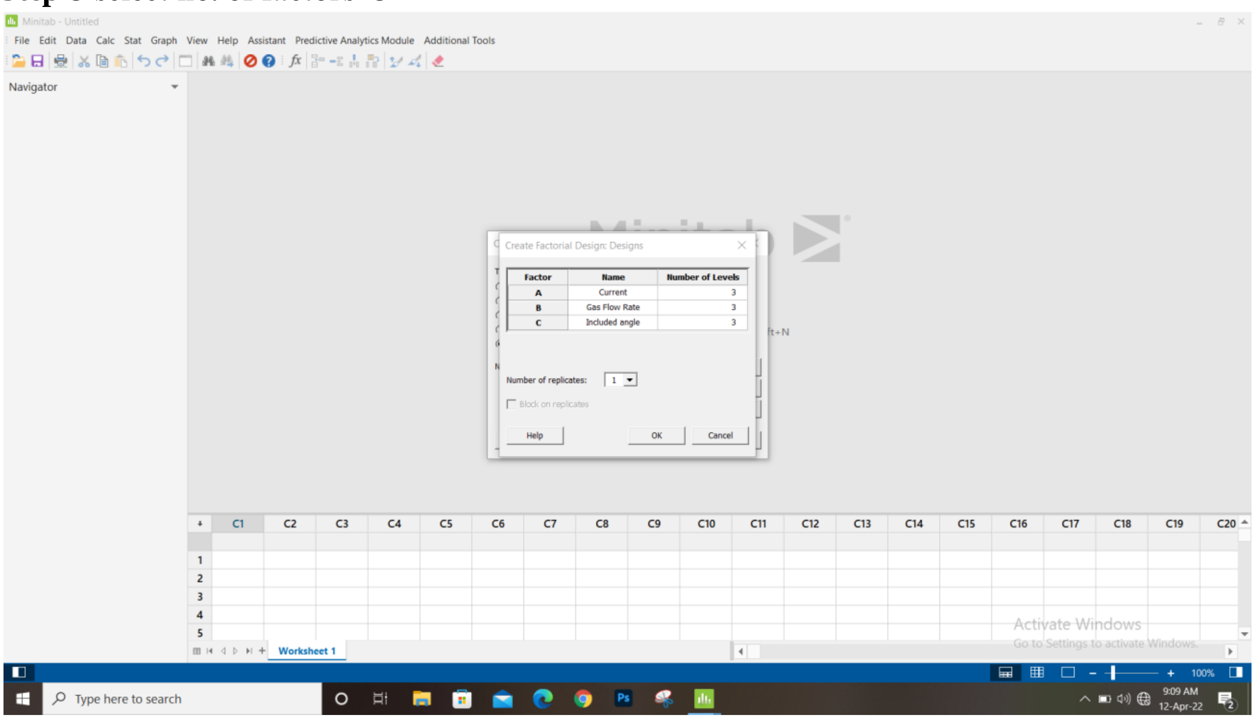
Step-1 select start/DOE/factorial/create factorial design



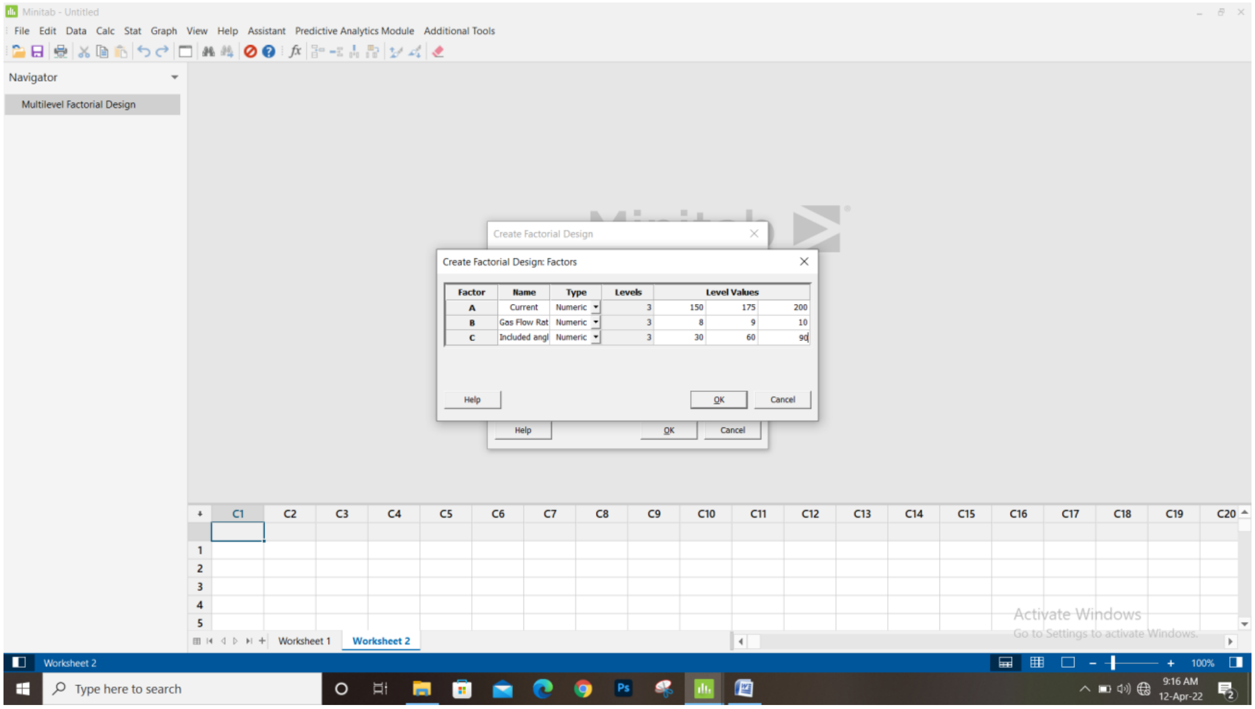
Step-2 select general full factorial design



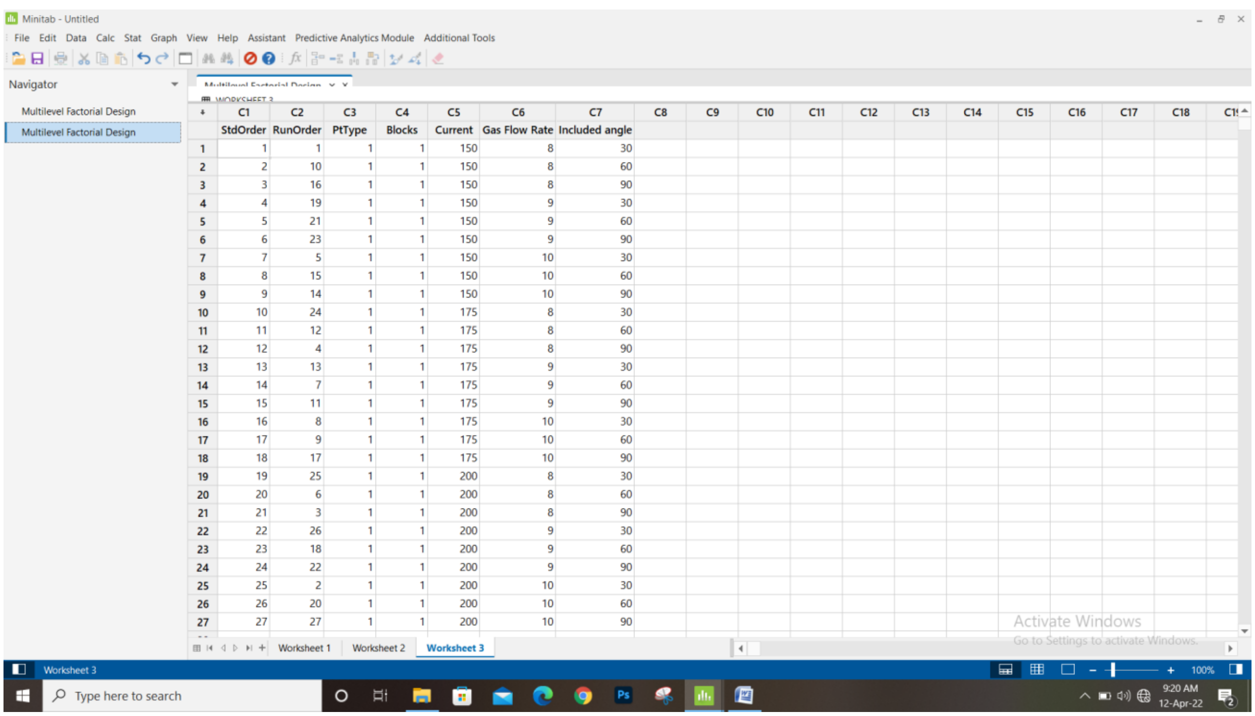
Step-3 select no. of factors '3'



Step-4 select input parameters and their value



Step-5 D.O.E for full factorial method



	C1 StdOrder	C2 RunOrder	C3 PtType	C4 Blocks	C5 Current	C6 Gas Flow Rate	C7 Included angle
1	1	1	1	1	150	8	30
2	2	10	1	1	150	8	60
3	3	16	1	1	150	8	90
4	4	19	1	1	150	9	30
5	5	21	1	1	150	9	60
6	6	23	1	1	150	9	90
7	7	5	1	1	150	10	30
8	8	15	1	1	150	10	60
9	9	14	1	1	150	10	90
10	10	24	1	1	175	8	30
11	11	12	1	1	175	8	60
12	12	4	1	1	175	8	90
13	13	13	1	1	175	9	30
14	14	7	1	1	175	9	60
15	15	11	1	1	175	9	90
16	16	8	1	1	175	10	30
17	17	9	1	1	175	10	60
18	18	17	1	1	175	10	90
19	19	25	1	1	200	8	30
20	20	6	1	1	200	8	60
21	21	3	1	1	200	8	90
22	22	26	1	1	200	9	30
23	23	18	1	1	200	9	60
24	24	22	1	1	200	9	90
25	25	2	1	1	200	10	30
26	26	20	1	1	200	10	60
27	27	27	1	1	200	10	90

Table 6.1 Design of Experiments (DOE)

Sr no.	Welding Current(A)	Gas Flow Rate(LPM)	Included Angle(°)
1	150	8	30
2	150	8	60
3	150	8	90
4	150	9	30
5	150	9	60
6	150	9	90
7	150	10	30
8	150	10	60
9	150	10	90
10	175	8	30
11	175	8	60
12	175	8	90
13	175	9	30
14	175	9	60
15	175	9	90
16	175	10	30
17	175	10	60
18	175	10	90
19	200	8	30
20	200	8	60
21	200	8	90
22	200	9	30
23	200	9	60
24	200	9	90
25	200	10	30
26	200	10	60
27	200	10	90

CHAPTER – 7
Experimental work

7.1Apparatus

7.1.1 Base material

The experimental work has been carried out on aluminium alloy 6061type. Its chemical composition and mechanical properties which is shown in table.

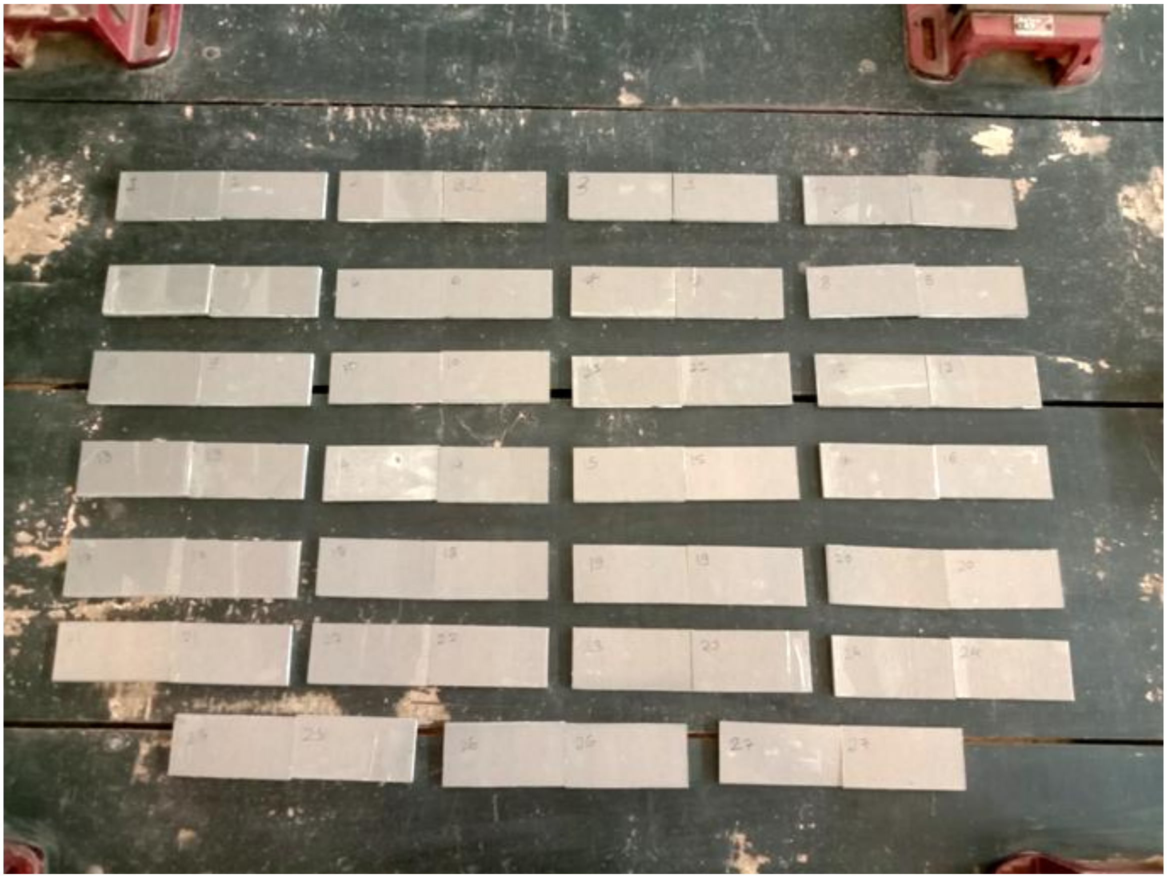


Fig 7.1 Base metal

7.1.2 Consumable and electrode

The consumable used in the welding process is ER4043 type of solid rod of 1-meter length. The electrode used in the welding process is tungsted zirconium coated diameter of 2mm.

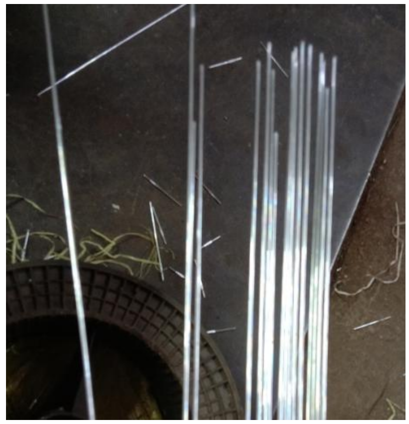


Fig 7.2 Filler Wire ER4043

7.2 Pilot experiment

Before doing actual experiments on base metal; bead on plate trials are done to select suitable range for selected parameters.

Table 7.1 Pilot Experiment Range

Sr no.	Welding Current(A)	Gas Flow Rate(LPM)	Included Angle(°)	Thickness(mm)
1	100	5	30	6
2	100	5	60	6
3	100	5	90	6
4	100	10	30	6
5	100	10	60	6
6	100	10	90	6
7	100	15	30	6
8	100	15	60	6
9	100	15	90	6
10	150	5	30	6
11	150	5	60	6
12	150	5	90	6
13	150	10	30	6
14	150	10	60	6
15	150	10	90	6
16	150	15	30	6
17	150	15	60	6

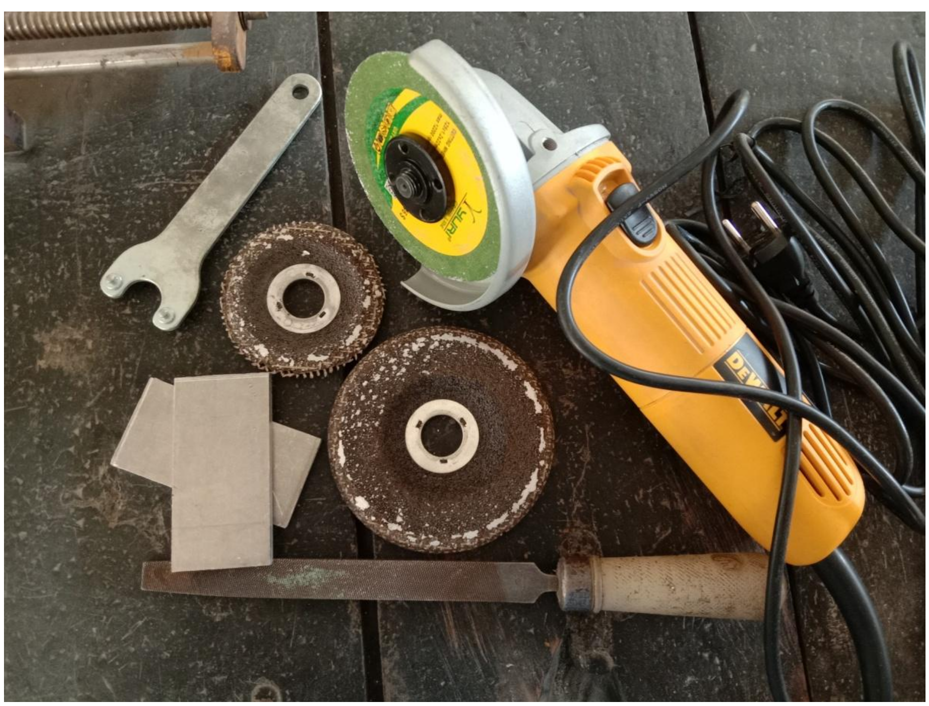
18	150	15	90	6
19	200	5	30	6
20	200	5	60	6
21	200	5	90	6
22	200	10	30	6
23	200	10	60	6
24	200	10	90	6
25	200	15	30	6
26	200	15	60	6
27	200	15	90	6

In above table welding current is in ampere, Gas flow rate in liter per minute, included angle in (degree) and plate thickness is in mm. So the current range is 150-200A and gas flow rate range of 8-10 LPM is selected according to Welding procedure specification for aluminium alloy 6061and filler rod is dia. of 2mm. Bead on plate trials are done to check sound welding.

7.3 Weld edge preparation

7.3.1 Groove design

Single ‘V’ groove of angle 30°, 60° and 90° are made on base material with the help of grinding machine.



(A)

(B)

(C)

Fig. 7.3 Included angle (A) 30° (B) 60° (C) 90°

7.4 Welding Trials

A DOE of three parameter and three level is created using MINITAB-21 software. Table shows the selected three parameters and its three levels.

Table 7.2 Range of parameters

Input Parameters	Level 1	Level 2	Level 3	Output Parameters
Welding current(A)	150	175	200	**Distortion (mm)**
Gas flow rate(LPM)	8	9	10	**Hardness (HRC)**
Included angle(°)	30	60	90	**Tensile Strength(MPA)**

The above table is generated by Full Factorial method in MiniTab-21 software. In that software by selecting 3 levels and putting value of each factor above table is generated. The method used for generating this table is for General Full factorial method which contains 3 parameter and its 3 levels. Parameters are selected according to its priority analysis while range of parameters is selected according to pilot experiments.

Brief discussion about full factorial method is provided in chapter 5. Thus range selected for groove angle is 30°, 60°, 90°; for welding current is 150A, 175A and 200A and gas flow rate is 8LPM, 9LPM and 10LPM).

Thus three levels of each factors are putted in table containing the combination of the parameters is gives as the output. This tables is shown in table

The welding experiments are carried out on the basis of the combination of parameters. The distortion and hardness results should be maintained in front of the respective combination of the parameter.

7.4.1 Design of Experiment

Table 7.3 Design of Experiments (DOE)

Sr no.	Welding Current(A)	Gas Flow Rate(LPM)	Included Angle(°)
1	150	8	30
2	150	8	60
3	150	8	90
4	150	9	30
5	150	9	60
6	150	9	90
7	150	10	30
8	150	10	60
9	150	10	90
10	175	8	30
11	175	8	60
12	175	8	90
13	175	9	30
14	175	9	60
15	175	9	90
16	175	10	30
17	175	10	60
18	175	10	90
19	200	8	30
20	200	8	60
21	200	8	90
22	200	9	30
23	200	9	60
24	200	9	90
25	200	10	30
26	200	10	60
27	200	10	90

Table shows the output of combination of welding parameters that is generated by using Full factorial Method of general full factorial method in Minitab-21 software.

The run of experiments were carried out as per the above mentioned parameters as shown in table

7.4.2 Welding machine specifications

Fig 7.4.TIG welding machine

Table 7.4: Welding machine specification

Term	Value
Company name	Miller Electric mfg. co.
Model Number	Dynasty 350
Frequency	50/60 Hz
Voltage	208-575 volts
Phase	1 phase or 3 phase
Current	200A-300A
Weight	61.5kg

- In fig TIG welding machine is shown which is situated at P.C.Indutries and manufactured by Miller Electric mfg co.
- This TIG welding machine is used in this entire experimental work.

Fig 7.5 Maintaining root gap in specimen

Fig 7.6 Welding process on specimen

7.5 Welded specimens

The below figure shows that the specimen was welded according to run order which is generated by the Minitab software. Total 27 specimens are prepared by welding.

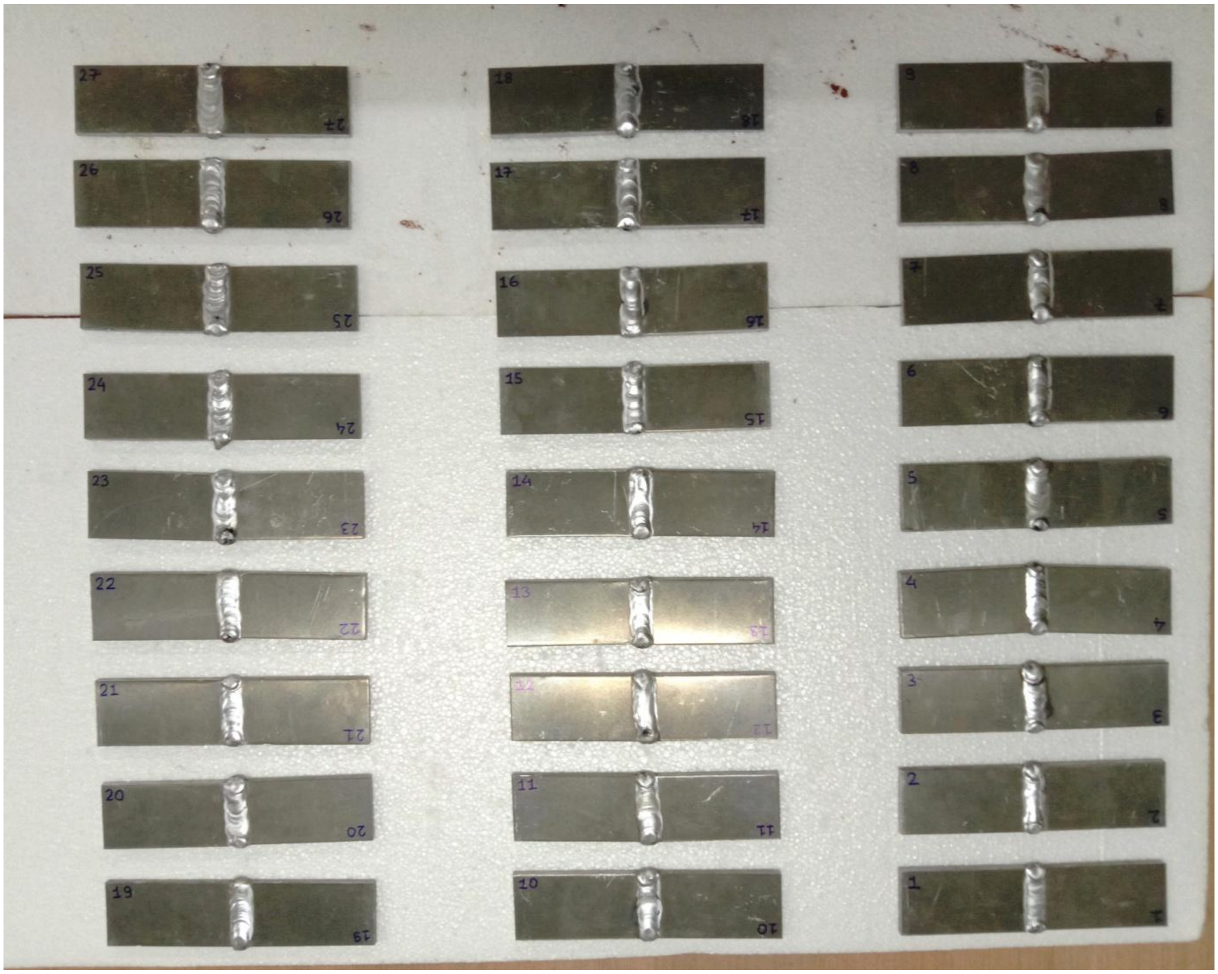


Fig 7.5 Welded specimens

7.6 Liquid Penetrant Test

Liquid Penetrant Test is one of the most popular Nondestructive Examination (NDE) methods in the industry. It is economical, versatile, and requires minimal training when compared to other NDE methods. Liquid penetrant test check for material flaws open to the surface by flowing very thin liquid into the flaw and then drawing the liquid out with a chalk-like developer. It is also known as "Dye Penetrant Test".

Welds are the most common item inspected, but plate, bars, pipes, castings, and forgings are also commonly inspected using liquid Penetrant examination.

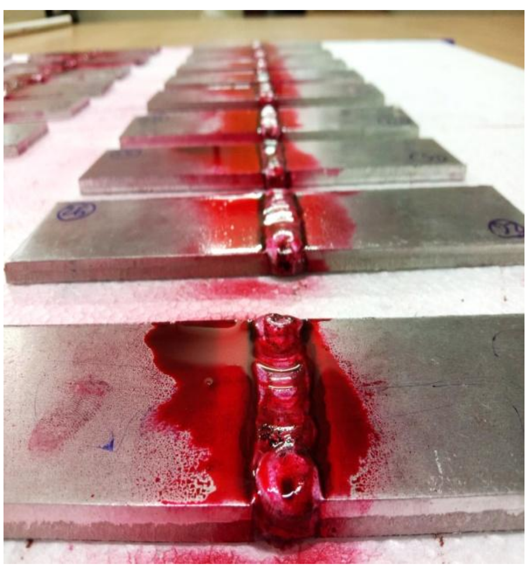
The procedure for doing the DP test find in ASME section V (Non-destructive testing) particularly for finding the surface defects respectively.

Advantages:

- High sensitivity to small surface discontinuities
- Easy inspection of parts with complex shapes
- Quick and inexpensive inspection of large areas and large volumes of parts/materials
- Aerosol spray cans make the process portable, convenient, and inexpensive
- Indications can reveal relative size, shape, and depth of the flaw
- It is easy and requires minimal amount of training

Disadvantages:

- Detects flaws only open to the surface
- Materials with porous surfaces cannot be examined using this process
- Only clean, smooth surfaces can be inspected. (Rust, dirt, paint, oil and grease must be removed.)
- Examiner must have direct access to surface being examined
- Surface finish and roughness can affect examination sensitivity. (It may be necessary to grind surfaces before LPT.)
- Fumes can be hazardous and flammable without proper ventilation



(A)

(B)

Fig 7.7 LPT Equipments

7.7 Inspection steps for LPT

7.7.1 Pre-cleaning :

This is the most important and basic step of the LPT test. The examining surface is cleaned from grease, oil, water, paint, or any other contaminants0. The penetrant must be able to freely enter the discontinuities and weldment. Cleaning of the surface can be done by cotton cloth, solvents, and also alkaline according to the consideration of application.

7.7.2 Apply Penetrant:

This is generally done by spraying penetrant from the aerosol can or applying it with a brush. A dwell time needs to be observed to allow for the penetrant to permeate into cracks and voids. This is typically 5 to 30 minutes but never being long enough for the penetrant to dry.

7.7.3 Excess Penetrant Removal:

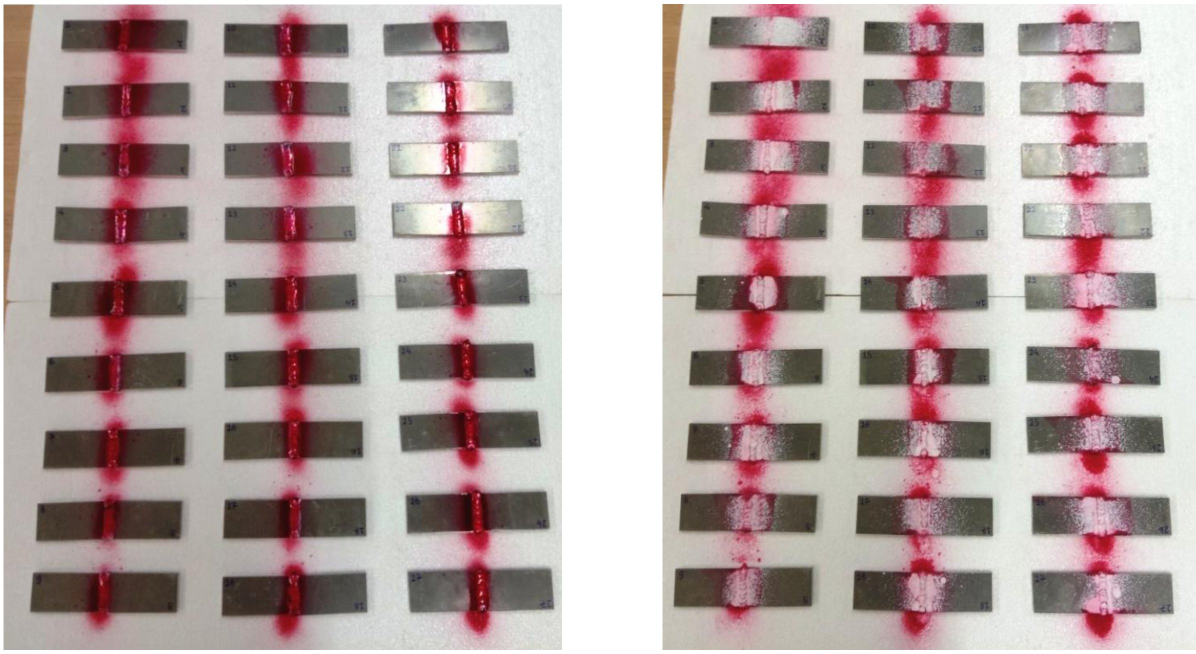
The excess penetrant needs to be removed from the sample surface. Depending on the dye penetrant type. The removal method is selected from water-washable or solvent-removable which is depend on material. The excess penetrant has to be removed thoroughly otherwise, on the application of the developer, it may leave a background in the developed area that can mask indications or defects.

7.7.4 Apply Developer:

The white developer is applied after excess penetrant has been removed. Various types of developers are available like a non-aqueous wet developer, dry powder, water suspendable, and water-soluble. It is based on the compatibility of the penetrant, the developer is selected. The developer draw backs the dye penetrant from the surface defect. Its known as '*bleed out*'.

7.7.5 Inspection:

In the next step using adequate light to inspection is performed. Inspection is by visible light for visible dye penetrant and ultraviolet radiation of adequate intensity for fluorescent penetrant testing.



(A) (B)

Fig 7.8 (A) Apply penetrant (B) Apply developer

7.8 Observation after LPT:

After LPT performing on welded specimens there's no defects were observed in the all specimens. So they have defect free weld joint and good results of weldability.

7.9 Hardness testing:

Fig 7.9 Hardness testing machine

Fig 7.10 Hardness testing

- In above fig 6.8.1 shows the hardness testing machine which is used for hardness test on welded specimen which is situated at our univerity's lab.
- All the experiments for hardness testing is carried out on this machine by the under observation of guide.
- In this rockwell hardness tester has applying load for aluminum is 100KN.
- for hardness test specimen should be in fine and smooth surface so its results is very better.
- The testing results for the all specimens is listed in below table.

7.10 Tensile testing:

- Tensile testing of welded specimen is perfomed at the lab of civil engineering at Darshan University, Hadala-Rajkot.
- For tensile testing the Universal Testing Machine is used.
- The tensile test is carried according to the ASTM standard A370.
- Accoding to the this standard workpiece has been prapared for the tensile test specimen as per stanadard specimen as shown in fig.

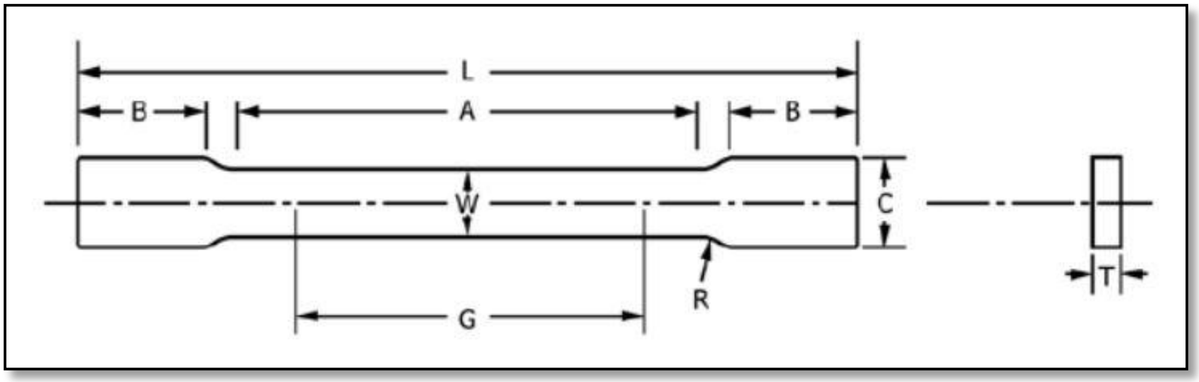


Fig 7.11.1 Tensile specimen ASTM 370

Fig 7.11.2 Plasma cutting of tensile specimen

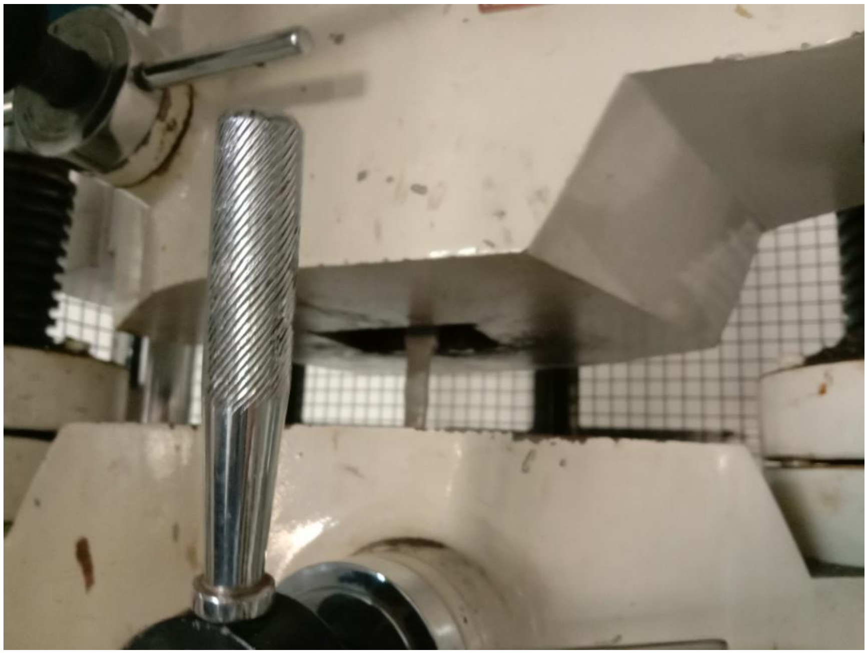


Fig 7.11.3 Tensile testing

- Tensile test specimen is prepared on the plasma cutter machine at Mayur engineering, Shapar whch shown in fig 7.10.2
- Plasma cutter’s gas flame which is cut the material very smoothly.
- Tensile specimen is prepared according to ASTM standard A370 is shown in fig 7.10.1.

Fig 7.11.4 Tensile specimen before testing

Fig 7.11.5 Tensile specimen after testing

7.11 Hardness and distortion results

Table 7.5 Results of specimen

Sr.no	Current(A)	Gas flow rate(LPM)	Included angle(°)	Distortion(mm)	Tensile strength(MPa)	Hardness(HRC)		
						WZ	HAZ	BM
1	150	8	30	0.20	175.66	55	56	57
2	150	8	60	0.44	179.61	56	58	60
3	150	8	90	0.98	174.19	58	58	60
4	150	9	30	0.21	177.65	58	61	62
5	150	9	60	0.64	178.11	59	61	62
6	150	9	90	0.97	179.01	59	62	63
7	150	10	30	0.21	179.61	60	63	64
8	150	10	60	0.65	180.21	63	65	66
9	150	10	90	0.99	182.19	64	66	67
10	175	8	30	0.25	184.02	66	68	69
11	175	8	60	0.64	187.74	72	74	75
12	175	8	90	0.98	188.17	76	75	76
13	175	9	30	0.26	186.29	77	78	79
14	175	9	60	0.51	185.26	79	79	79
15	175	9	90	0.92	189.91	78	80	80
16	175	10	30	0.29	190.61	80	82	83
17	175	10	60	0.52	192.82	82	83	84
18	175	10	90	0.91	201.04	82	84	85
19	200	8	30	0.23	199.42	83	85	86
20	200	8	60	0.42	198.16	84	86	87
21	200	8	90	0.90	194.65	87	89	88
22	200	9	30	0.27	197.43	85	87	86
23	200	9	60	0.43	199.45	89	91	90
24	200	9	90	0.98	210.49	85	87	86
25	200	10	30	0.30	209.99	88	90	89
26	200	10	60	0.66	202.61	95	97	96
27	200	10	90	0.99	201.41	99	98	99

CHAPTER – 8
Results and Discussion

8.1 Regression analysis:

- The main objective of regression analysis is to make an equation by utilizing the statistical techniques in Minitab software, which is used to predict the behavior of a system or output with giving response to the input selected variable.

- It is also used for making the mathematical equation from the observation taken from the experiment and also based on the input which has been given to the particular system. Based on relation regression analysis has two types listed below-
  -Linear Regression
  -Non-linear Regression

- Generally the Linear regression used for giving the linear relationship between output variable and input variable particularly for one selected system to be observed. It is also possible that linear regression may have non-linear terms, but it has only linear relationship shows while giving the result.

- Non-linear regression analysis it gives the relationship between the output and input variable in terms of exponential, quadratic, and also logarithmic etc for doing the statistical analysis of the given system.

- Generally for the linear regression analysis, there may be one or more output parameters was selected on the basis of the number of selected input parameter respectively. There are mainly two types of liner regression analysis shown below-
  - Simple-linear Regression
  -Multiple-linear Regression

- If one can observed the system that has only one input variable that is called Simple-linear Regression and if there are more then on input variable in the system to observe that is called Multiple-linear Regression.

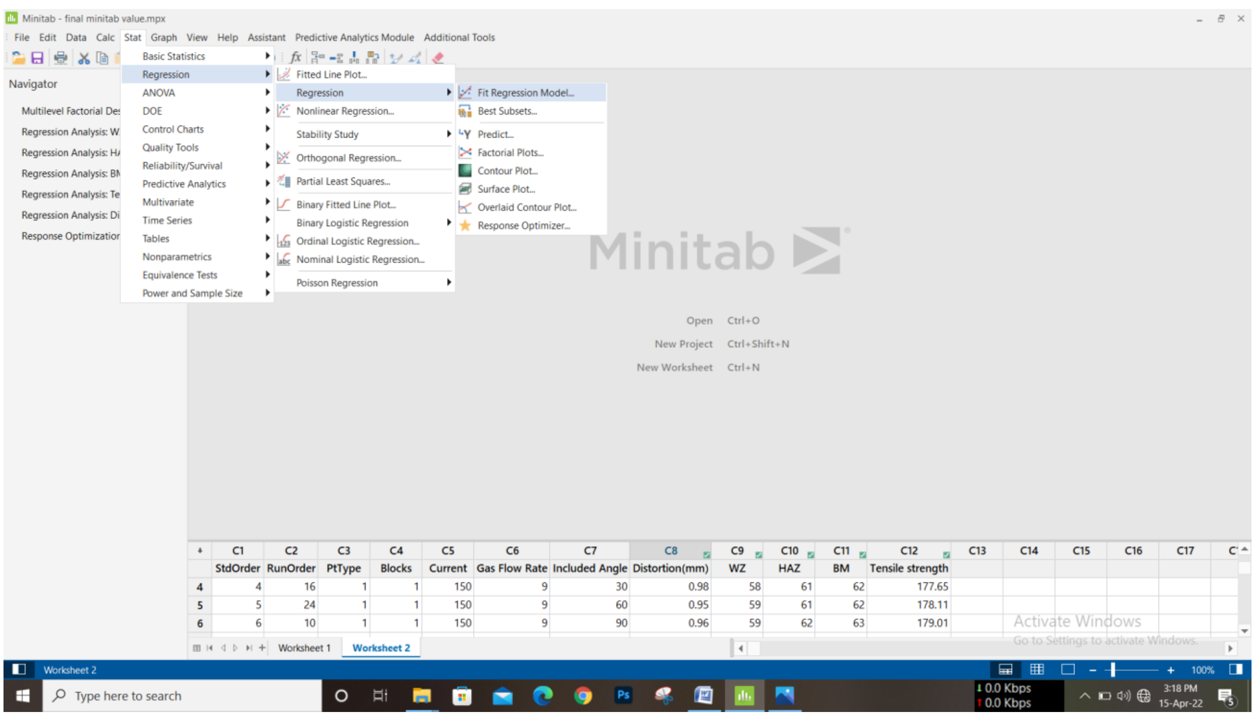
A simple regression analysis formula show cased below:

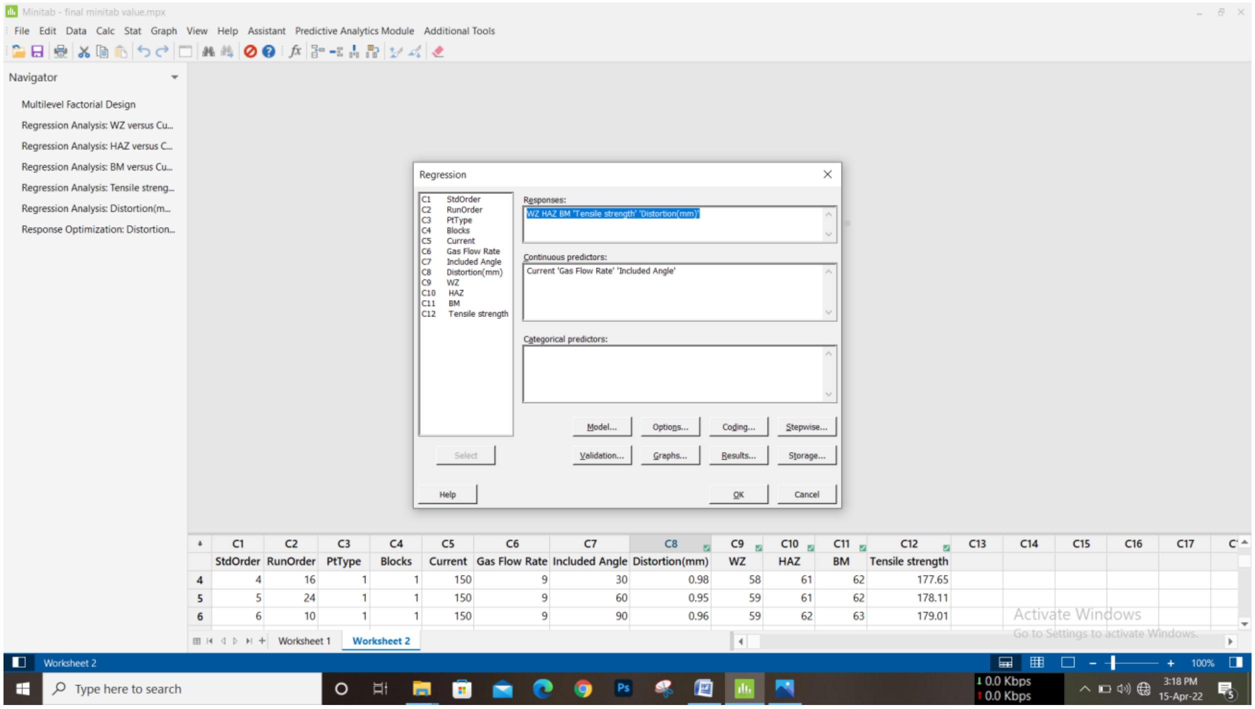
$Y = \alpha + \beta.x\ [n] + \varepsilon$………………………………………………………….. (7.1)
Where, Y = Output Parameter of the system

α =intercept or Constant value or Coefficient β = slope or we can say the input variable coefficient
ε = non-measurable variables, which can't be included in system for analysis or as error of the given system, n= nth variable of the system respectively.

8.2 **Analysis through software:**

Minitab version 21 software for used for the analysis of the result. Go to the Minitab software and click on analyze the Factorial design show on figure.





Form the above Fig.7.2 -After selecting the option the new menu will be open and select the tensile strength as output response for the further step.

Generally the output will be in the form of table with parameter and regression equation, and also the value or R-square, R-prediction, and R-adjacent respectively

8.2.1 Regression Analysis for Distortion

The below listed equation indicates the regression equation of distortion.

Regression Equation
Distortion(mm) = -0.325 - 0.000244 Current + 0.0267Gas flow rate + 0.011852 Included angle

The below listed table shows the coefficients of the regression equations for distortion.

Coefficients					
Term	**Coef**	**SF Coef**	**T-Value**	**P-value**	**VIF**
Constant	-0.0325	0.190	-1.71	0.101	
Current	-0.000244	0.000655	-0.37	0.713	1.00
Gas flow rate	0.0267	0.0164	1.63	0.117	1.00
Included angle	0.011852	0.000546	21.70	0.000	1.00

The below listed summary is of Regression model, here the model summary indicates the value of R-squared which is 95.37% for distortion.

Model Summary			
S	**R-sq**	**R-sq(adj)**	**R-sq(pred)**
0.0695239	95.37%	94.76%	93.87%

The below listed summary is of Analysis of variance for tensile distortion.

Analysis of Variance					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	2.28903	0.76301	157.86	0.000
Current	1	0.00067	0.00067	0.14	0.713
Gas flow rate	1	0.01280	0.01280	2.65	0.117
Included Angle	1	2.27556	2.27556	470.78	0.000
Error	23	0.11117	0.00483		
Total	26	2.40020			

The below listed summary is of fits and diagnostics for unusual observations for distortion.

Fits and Diagnostics for Unusual Observations				
Obs	Distortion(mm)	Fit	Resid	Std Resid
20	0.4200	0.5506	-0.1306	-2.03 R
23	0.4300	0.5772	-0.1472	-2.22 R
R Large residual				

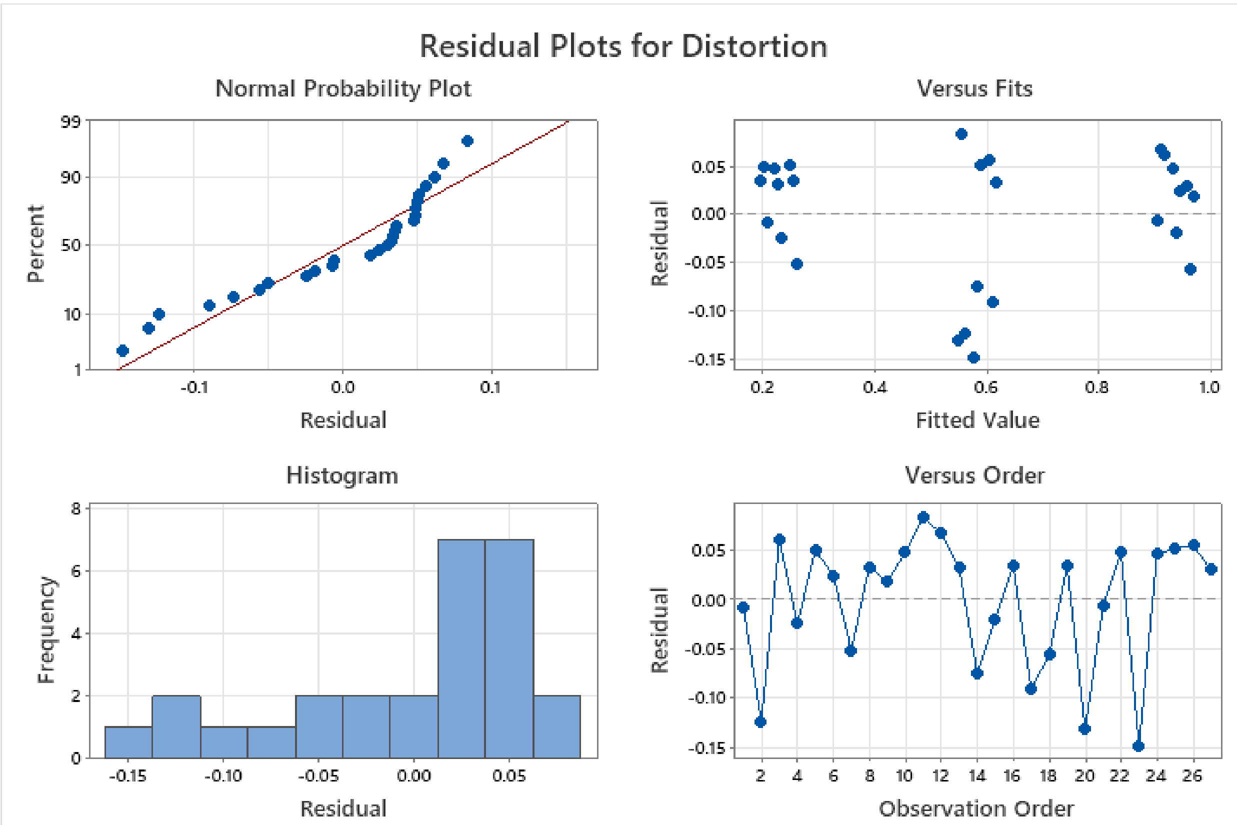


Fig 8.1 Residual plots for Distortion

- The residual plots shows the input parameter and its effect at every points.
- That indicates points effect at various change in values of parameters.
- Fig shows the residual plots for distortion

8.2.2 Regression Analysis of Weld Zone (hardness)

The below listed equation indicates the regression equation of weld zone (hardness).

Regression Equation
WZ = -69.50 + 0.5844 Current + 4.222 Gas flow rate + 0.0667 Included angle

The below listed table shows the coefficients of the regression equations for weld zone (hardness).

Coefficients					
Term	**Coef**	**SF Coef**	**T-Value**	**P-value**	**VIF**
Constant	-69.50	7.59	-9.16	0.000	
Current	0.5844	0.0262	22.34	0.000	1.00
Gas flow rate	4.222	0.654	6.46	0.000	1.00
Included angle	0.0667	0.0218	3.06	0.006	1.00

The below listed summary is of Regression model, here the model summary indicates the value of R-squared which is 95.99% for Weld Zone (hardness).

Model Summary			
S	**R-sq**	**R-sq(adj)**	**R-sq(pred)**
2.77454	95.99%	95.46%	94.54%

The below listed summary is of Analysis of variance for weld zone (hardness).

Analysis of Variance					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	4235.61	1411.87	183.41	0.000
Current	1	3842.72	3842.72	499.18	0.000
Gas flow rate	1	320.89	320.89	41.68	0.000
Included Angle	1	72.00	72.00	9.35	0.006
Error	23	177.06	7.70		
Total	26	4412.67			

The below listed summary is of fits and diagnostics for unusual observations for weld zone (hardness).

Fits and Diagnostics for Unusual Observations				
Obs	WZ	Fit	Resid	Std Resid
24	85.000	91.389	-6.389	-2.49 R
R Large residual				

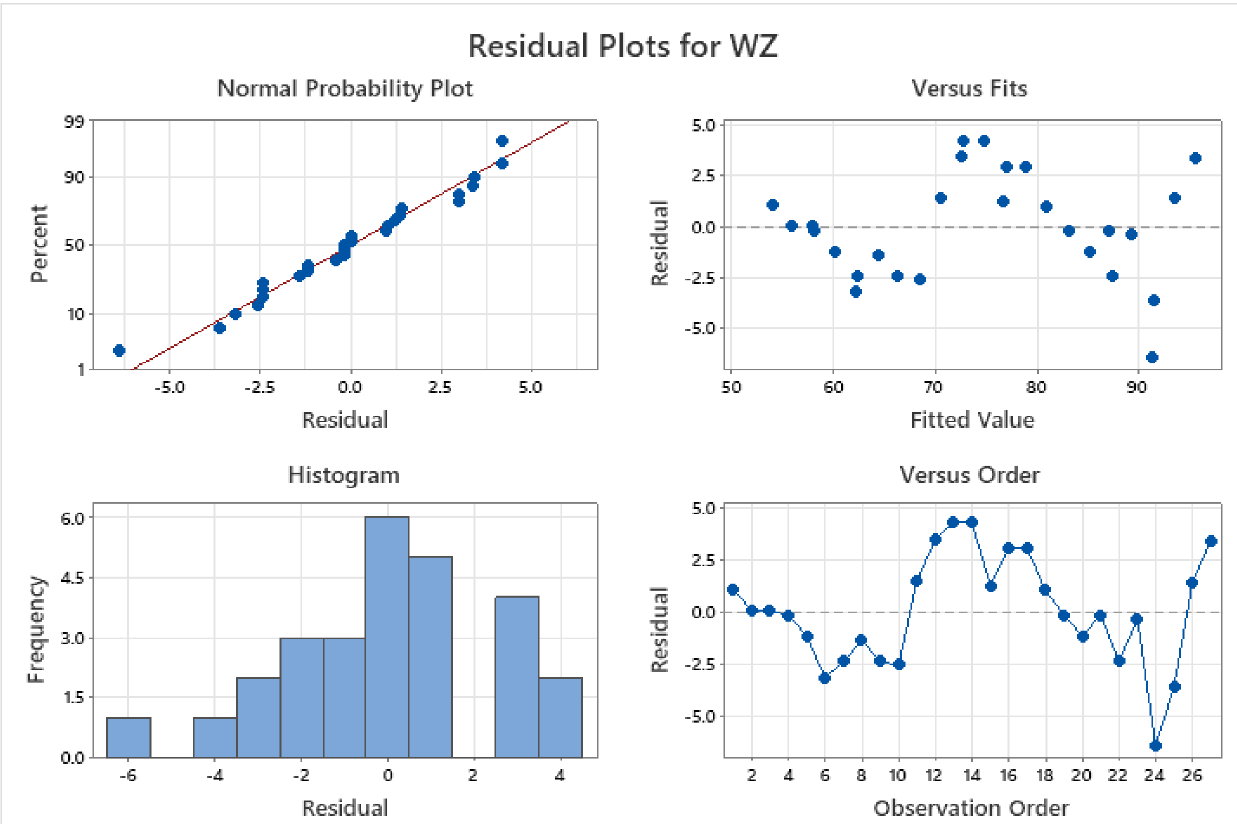


Fig 8.2 Residual Plot for Weld zone (Hardness)

- The residual plots shows the input parameter and its effect at every points.
- That indicates points effect at various change in values of parameters.
- Fig shows the residual plots for weld zone (hardness).

8.2.3 Regression Analysis of Heat affected Zone (Hardness)

The below listed equation indicates the regression equation of heat affected zone (Hardness).

Regression Equation
HAZ = -67.43 + 0.5778 Current + 4.389 Gas flow rate + 0.0537 Included angle

The below listed table shows the coefficients of the regression equations for heat affected zone (hardness).

Coefficients					
Term	**Coef**	**SF Coef**	**T-Value**	**P-value**	**VIF**
Constant	-67.43	6.13	-11.00	0.000	
Current	0.5778	0.0211	27.34	0.000	1.00
Gas flow rate	4.389	0.528	8.31	0.000	1.00
Included angle	0.0537	0.0176	3.05	0.006	1.00

The below listed summary is of Regression model, here the model summary indicates the value of R-squared which is 97.29% for heat affected zone (hardness).

Model Summary			
S	**R-sq**	**R-sq(adj)**	**R-sq(pred)**
2.24110	97.29%	96.94%	96.30%

The below listed summary is of Analysis of variance for heat affected zone (hardness).

Analysis of Variance					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	4149.00	1383.00	275.36	0.000
Current	1	3755.56	3755.56	747.74	0.000
Gas flow rate	1	346.72	346.72	69.03	0.000
Included Angle	1	46.72	46.72	9.30	0.005
Error	23	115.52	5.02		
Total	26	4264.52			

The below listed summary is of fits and diagnostics for unusual observations for heat affected zone (hardness).

Fits and Diagnostics for Unusual Observations				
Obs	HAZ	Fit	Resid	Std Resid
24	87.000	92.463	-5.463	-2.64 R
R Large residual				

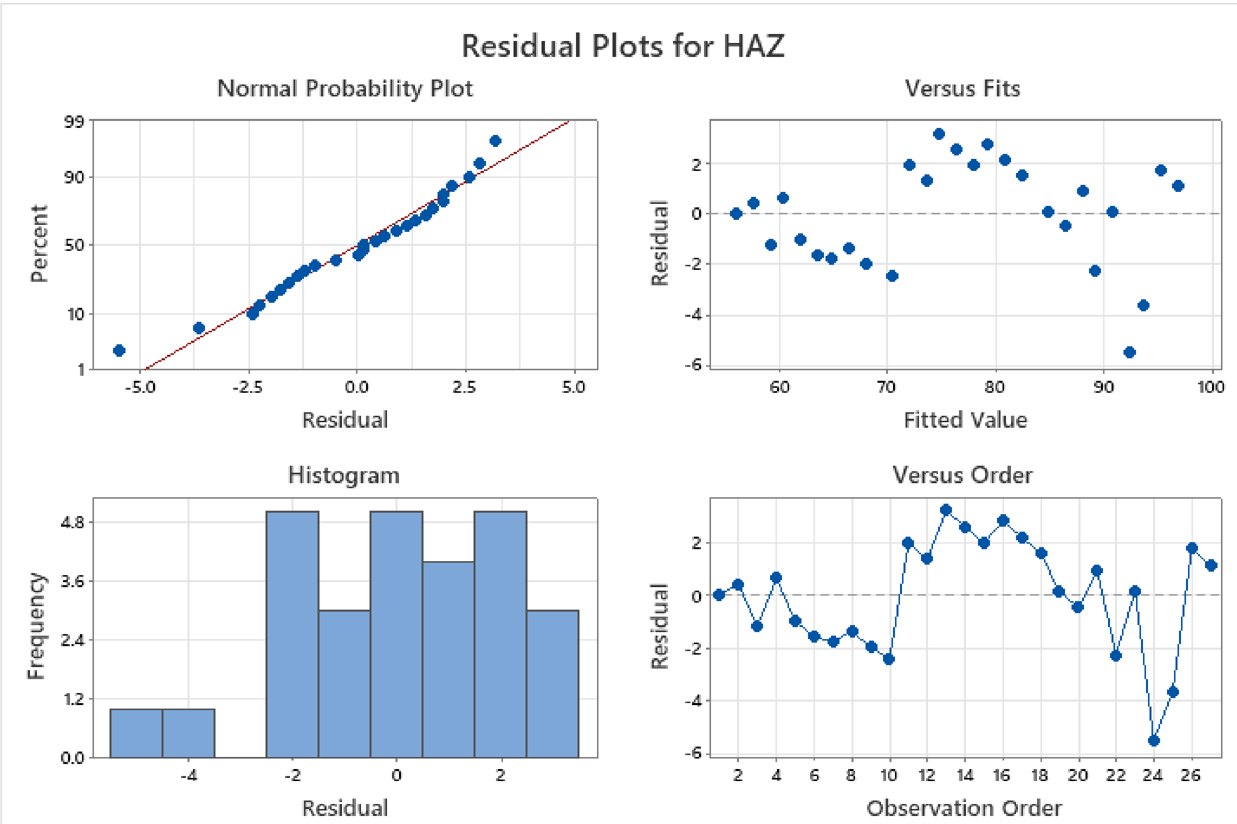


Fig 8.3 Residual plots for heat affected zone (hardness)

- The residual plots shows the input parameter and its effect at every points.
- That indicates points effect at various change in values of parameters.
- Fig shows the residual plots for heat affected zone (hardness).

8.2.4 Regression Analysis of Base metal (Hardness)

The below listed equation indicates the regression equation of Base metal (Hardness).

Regression Equation
BM = -59.43 + 0.5467 Current + 4.167 Gas flow rate + 0.0537 Included angle

The below listed table shows the coefficients of the regression equations for Base metal (hardness).

Coefficients					
Term	**Coef**	**SF Coef**	**T-Value**	**P-value**	**VIF**
Constant	-59.43	6.98	-8.51	0.000	
Current	0.5467	0.0241	0.0241	0.000	1.00
Gas flow rate	4.167	0.601	0.601	0.000	1.00
Included angle	0.0537	0.0200	0.0200	0.013	1.00

The below listed summary is of Regression model, here the model summary indicates the value of R-squared which is 96.13% for Base metal (Hardness).

Model Summary			
S	**R-sq**	**R-sq(adj)**	**R-sq(pred)**
2.55156	96.13%	95.63%	94.65%

The below listed summary is of Analysis of variance for Base metal (Hardness).

Analysis of Variance					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	3721.22	1240.41	190.53	0.000
Current	1	3362.00	3362.00	516.40	0.000
Gas flow rate	1	312.50	312.50	48.00	0.000
Included Angle	1	46.72	46.72	7.18	0.013
Error	23	149.74	6.51		
Total	26	3870.96			

The below listed summary is of fits and diagnostics for unusual observations for Base metal (hardness)

Fits and Diagnostics for Unusual Observations				
Obs	BM	Fit	Resid	Std Resid
24	86.000	92.241	-6.241	-2.65 R
R Large residual				

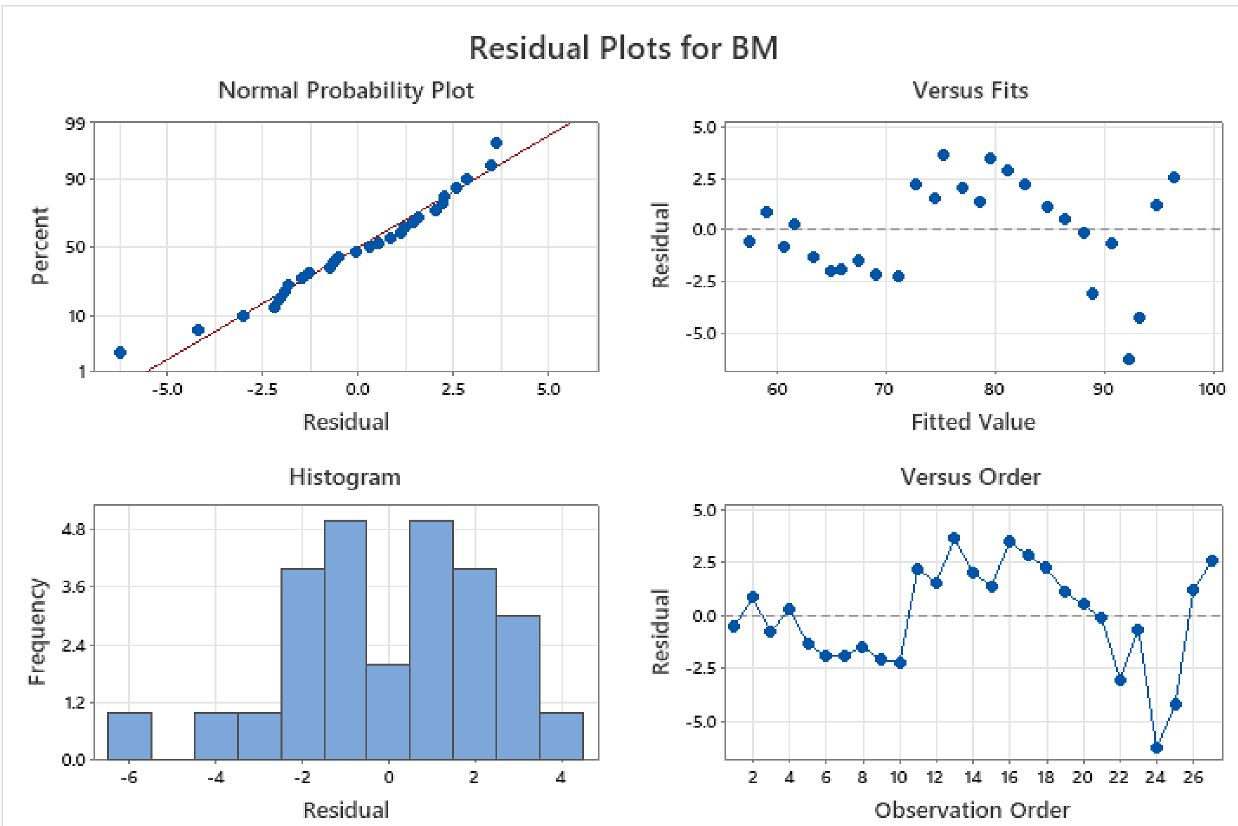


Fig 8.4 Residual plots for BM(hardness)

- The residual plots shows the input parameter and its effect at every points.
- That indicates points effect at various change in values of parameters.
- Fig shows the residual plots for base metal (hardness).

8.2.5 Regression Analysis of Tensile strength

The below listed equation indicates the regression equation of tensile strength.

Regression Equation

Tensile Strength = 77.50 + 0.4608 Current + 3.271 Gas flow rate + 0.0377 Included angle

The below listed table shows the coefficients of the regression equations for tensile strength.

Coefficients

Term	Coef	SF Coef	T-Value	P-value	VIF
Constant	77.50	9.52	8.14	0.000	
Current	0.4608	0.0328	14.05	0.000	1.00
Gas flow rate	3.271	0.820	3.99	0.000	1.00
Included angle	0.0377	0.0273	1.38	0.181	1.00

The below listed summary is of Regression model, here the model summary indicates the value of R-squared which is 90.34% for tensile strength.

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
3.47947	90.34%	89.08%	86.31%

The below listed summary is of Analysis of variance for tensile strength.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	2604.63	868.21	71.71	0.000
Current	1	2389.02	2389.02	197.33	0.000
Gas flow rate	1	192.54	192.54	15.90	0.000
Included Angle	1	23.07	23.07	1.91	0.006
Error	23	278.45	12.11		
Total	26	2883.08			

The below listed summary is of fits and diagnostics for unusual observations for tensile strength

Fits and Diagnostics for Unusual Observations				
Obs	Tensile Strength	Fit	Resid	Std Resid
18	201.04	194.24	6.80	2.12 R
24	210.49	202.49	8.00	2.49 R
25	209.99	203.50	6.49	2.09 R
R Large residual				

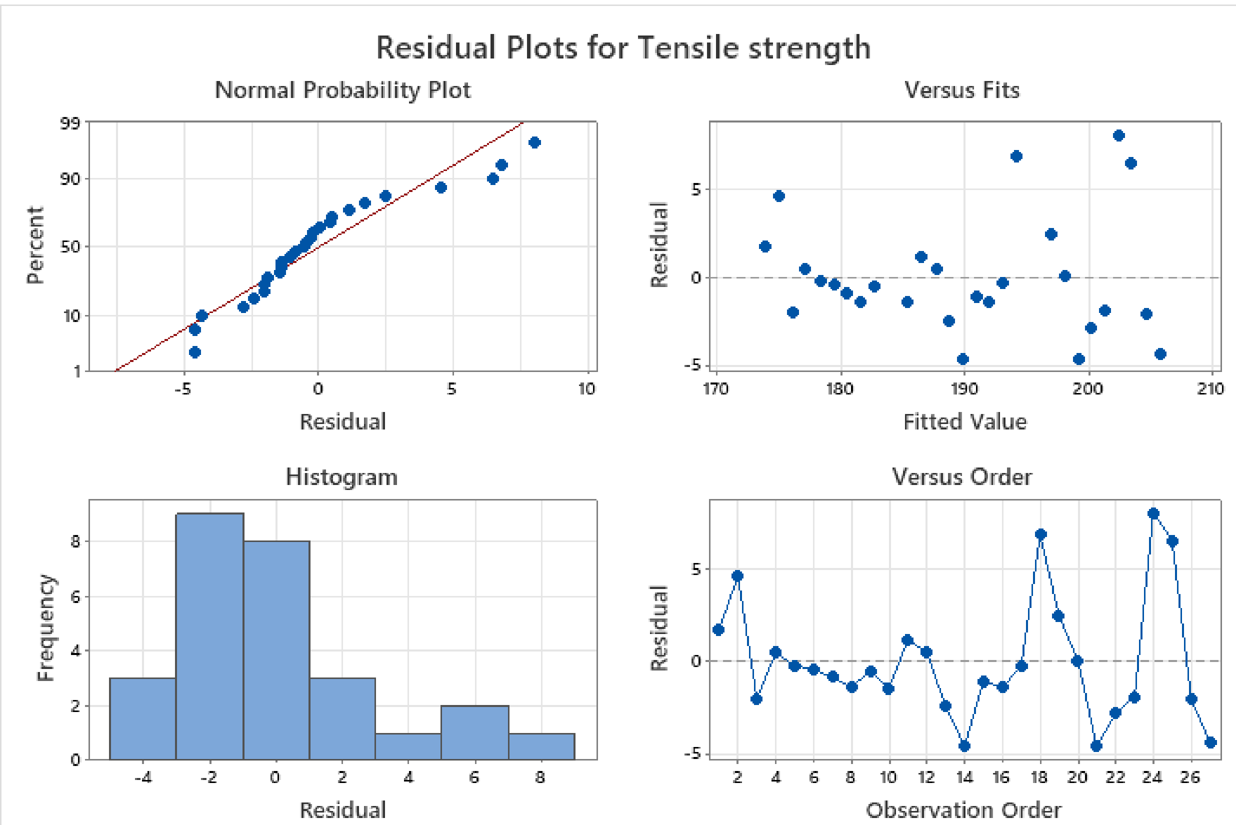


Fig 8.5 Residual plots forTensile strength

- The residual plots shows the input parameter and its effect at every points.
- That indicates points effect at various change in values of parameters.
- Fig shows the residual plots for distortion.

8.3 **Main Effects plot for Distortion:**

The fig.8.5 represents the main effects plot for Distortion

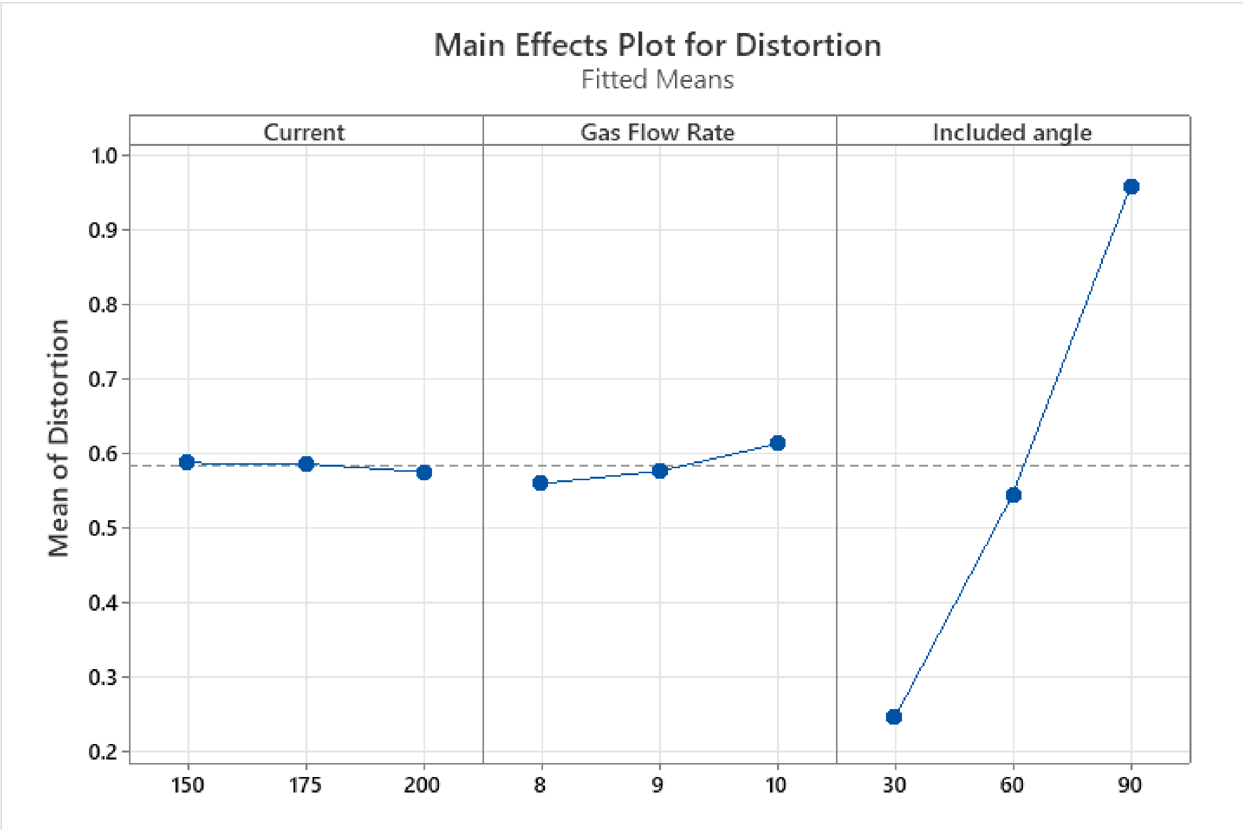


Fig 8.5 Main effects plot for distortion

From above showing graphs is Main effects plot for means and residual plots of distortion(mm) we can conclude that the current as well as gas flow rate and included angle on time effect the most among all the parameter on the output response.

- In main plots shows the three points of effect on by the input parameter.
- It is indicate the minimum, maximum and optimum value of input parameters.
- It shows effects at various points.

8.4 Main effects plots for Hardness for Weld Zone, Heat affected zone and weld zone respectively.

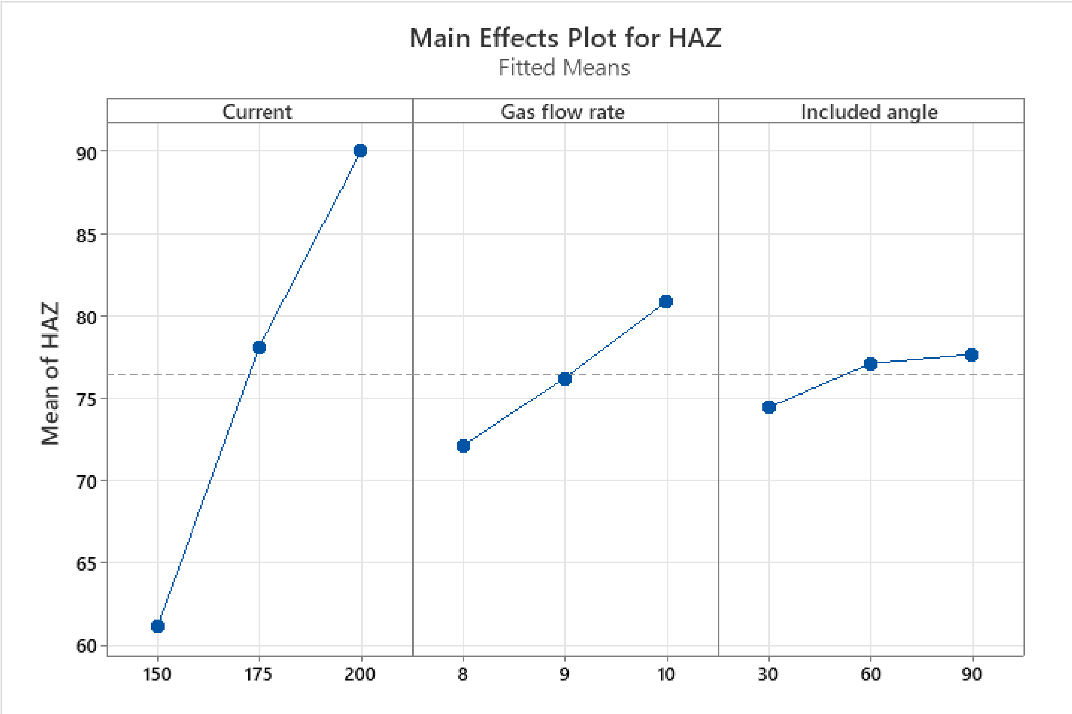


Fig 8.6 Main effects plot for HAZ (Hardness)

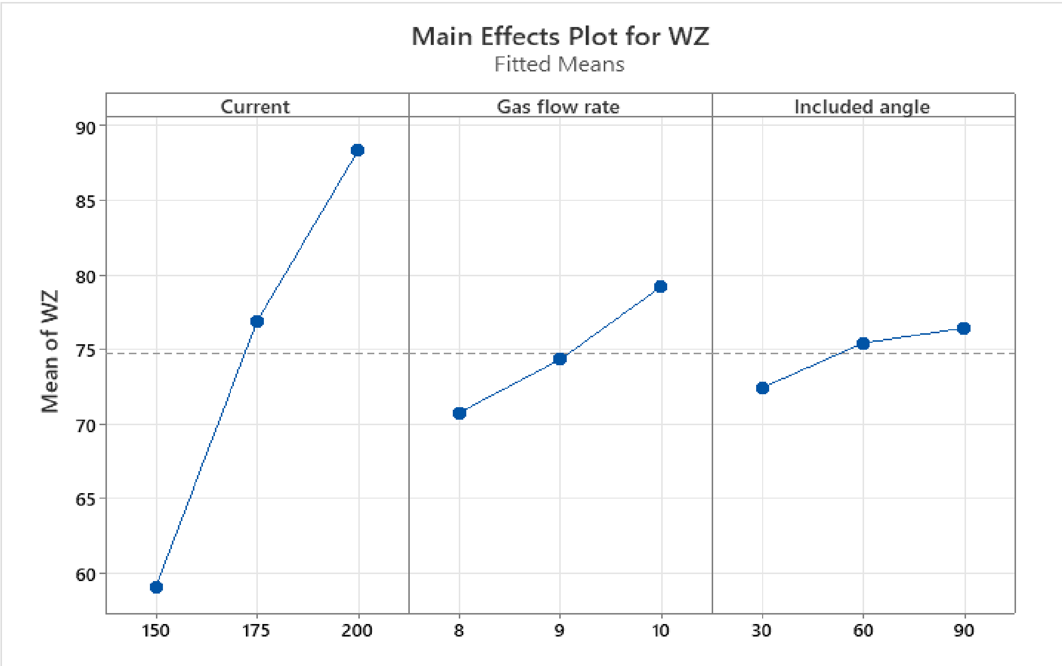


Fig 8.7 Main effects plot for WZ (Hardness)

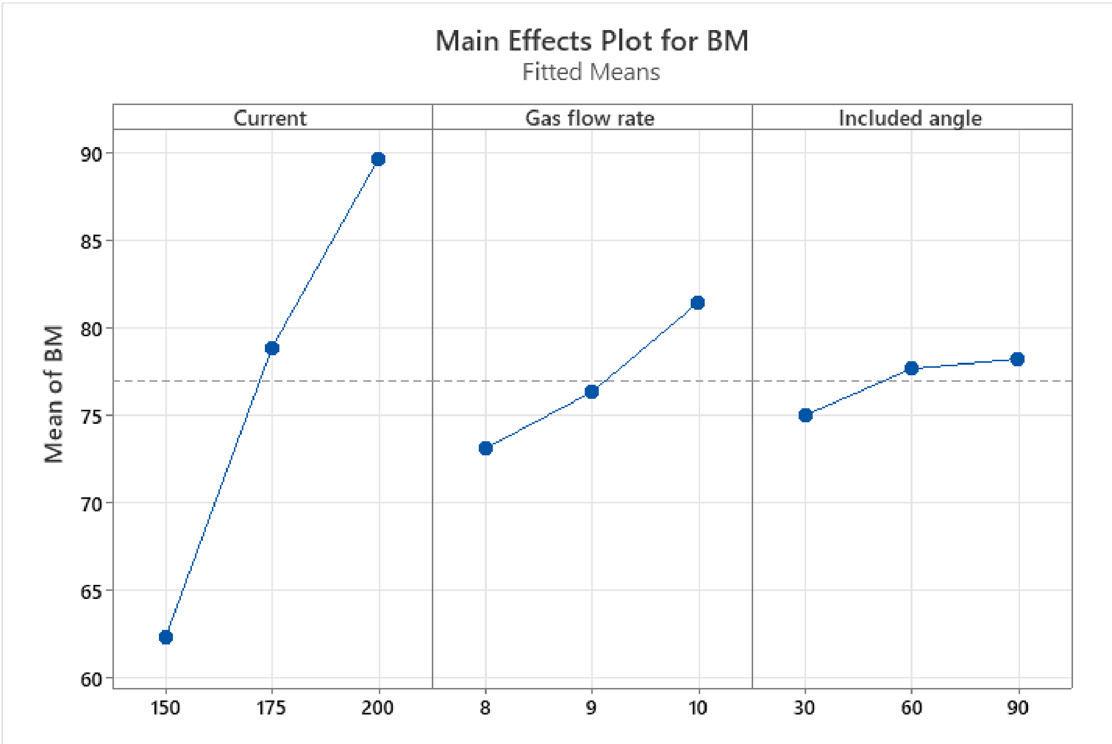


Fig 8.8 Main effects plot for BM (Hardness)

From above showing graphs like Main effects plot for means and residual plots of hardness (BM, WZ, HAZ) we can conclude that the Peak current effect the most among all the parameter on the output response.

- In main plots shows the three points of effect on by the input parameter.
- It is indicate the minimum, maximum and optimum value of input parameters.
- It shows effects at various points.

8.5 **Main Effects plot for Tensile Strength:**

The fig.8.5 represents the main effects plot for Distortion

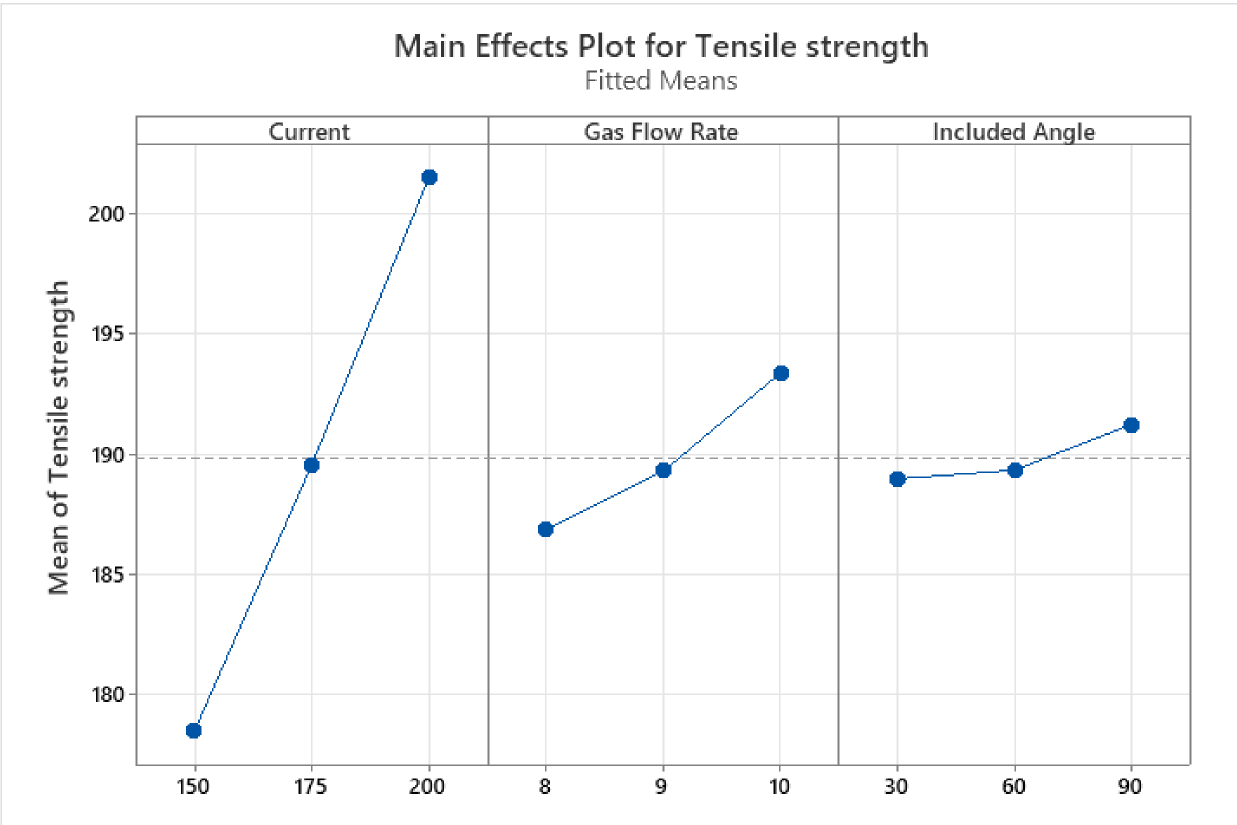


Fig 8.8 Main effects plot for Tensile strength

- In main plots shows the three points of effect on by the input parameter.
- It is indicate the minimum, maximum and optimum value of input parameters.
- It shows effects at various points.

8.6 Response Optimization:

Parameters						
Response	Goal	Lower	Target	Upper	Weight	Importance
BM	Maximum	57.00	99.00		1	1
HAZ	Maximum	56.00	98.00		1	1
WZ	Maximum	55.00	99.00		1	1
Tensile Strength	Maximum	174.19	210.49		1	1
Distortion	Minimum		0.20	0.99	1	1

Solution								
Solution	Current	Gas flow rate	Included angle	BM Fit	HAZ FIt	WZ Fit	Tensile strength fit	Distortion(mm) Fit
1	200	10	30	93.1852	93.6296	91.6111	203.5	0.248333

Solution	Composite Desirability
1	0.865930

Multiple Response Prediction	
Variable	Setting
Current	200
Gas flow rate	10
Included angle	30

Response	Fit	SE Fit	95% CI	95% PI
BM	93.19	1.15	(90.80, 95.57)	(87.39, 98.98)
HAZ	93.63	1.01	(91.54, 95.72)	(88.54, 98.72)
WZ	91.61	1.25	(89.02, 94.20)	(85.31, 97.91)
Tensile Strength	203.50	1.57	(200.25, 206.75)	(195.60, 211.40)
Distortion	0.2483	0.0314	(0.1834, 0.3132)	(0.0905, 0.4061)

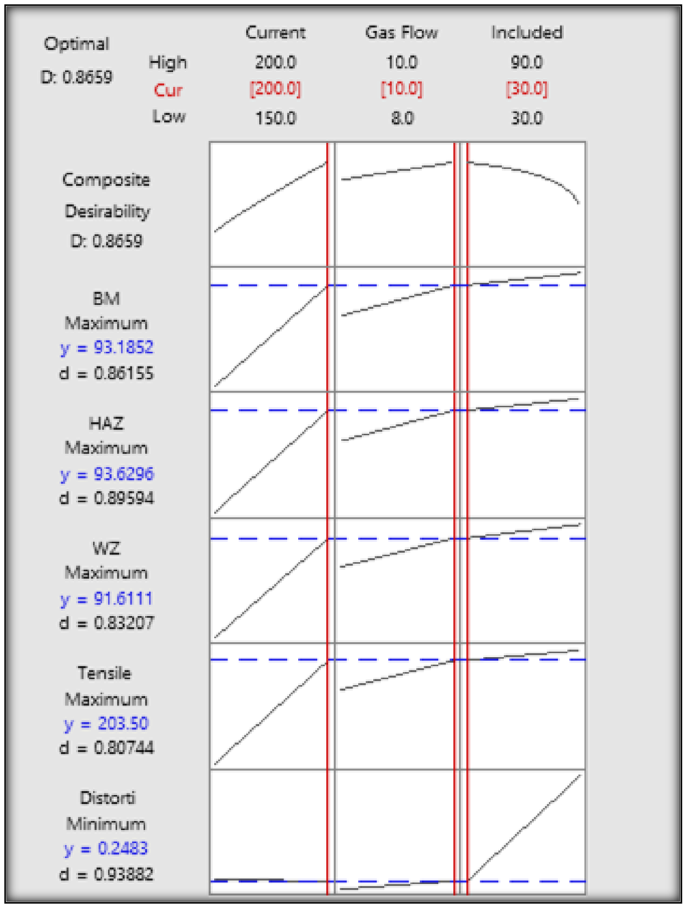


Fig 8.9 Optimized graph

The optimum values of input and output parameters are as follows:

Optimum input parameter	Optimum output parameter
Current(A) = 200	BM hardness = 93.18
Gas Flow Rate (LPM) = 10	HAZ hardness = 93.62
Included angle(°) = 30	WZ hardness = 91.61
	Tensile strength(MPa) = 203.50
	Distortion(mm) = 0.24

8.7 Validation

For the validation of optimized results from the software, experiments were carried out using the optimized input parameters and tensile strength and hardness tests at all zones. The results obtained are as follows:

Table Validation of experimentation

Sr. No.	Element Test	Obtained Value
1	BM hardness	93.18
2	HAZ hardness	93.62
3	WZ hardness	91.61
4	Tensile strength(MPa)	203.50
5	Distortion(mm)	0.2483

Where,
HAZ = Heat Affected Zone
BM = Base Metal
WZ = Weld Zone

It is evident from the below described comparison that the result obtained from the trial experimentation are accurate and précised with software results.

Sr. No.	Parameters	Optimized results	Experimental results	Error between statistical software and experiment results (in %)
1	BM hardness	93.18	92.35	0.89%
2	HAZ hardness	93.62	92.66	1.02%
3	WZ hardness	91.61	90.80	0.88%
4	Tensile strength(MPa)	203.50	205.5	0.98%
5	Distortion(mm)	0.24	0.30	1.5%

CHAPTER – 9

CONCLUSIONS

9.1 Conclusion

Concluding points for the tungsten inert gas welding based on the experimental results and a model created using full factorial method are described as below:

1. Welding current, gas flow rate and included angle are most significant parameters for distortion, hardness and tensile strength.
2. From analysis and experimental results it is conclude that maximum result achieved at welding current of 200A, gas flow rate is 10 LPM and the included angle of 30°.
3. Minimum values of distortion are 0.24 mm and maximum hardness 93.62 HRC.
4. The tensile strength good achieve at 203.50 MPa.
5. Distortion and hardness increase with increasing of current, gas flow rate and groove angle.
6. Optimized range of parameters is welding current of 200A, gas flow rate is 10 LPM and the included angle of 90° gives mechanical sound and defect free welding.
7. From all experiment it is cleared that for better results and welding current is highly effective as compared to gas flow rate.

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Appendix A: Compliance Report

Comments given during Dissertation Phase-1 Review are given below with required actions taken for their fulfillment

- **Comments for Dissertation Phase – 1:**

Sr. No.	Comments Given	Actions
1	Enhance LR by preparing file of Research papers in hard copy.	Total 30 papers are added
2	Give justification of input parameters and it's range selected for project	By collecting the data from research paper. Feedback of craftsman on industry
3	Prepare DOE and perform actual experimentation	DOE prepared and experiment performed
4	Publish a review/research paper before MSD	Paper submitted
5	Identify Validation method	Response optimizer is identified.

APPENDIX – B Material Test Report

R N Laboratory Services

29-30, Samrat Industrial Area,
Nr. P & T Colony, Gondal Road,
RAJKOT - 360004. India (Guj.)
M.: 96649 93801, 98795 23923
E-mail : rnlab08@gmail.com

Chemical Test Certificate

Customer : GAUTAM K MAKWANA — T C No.: RN / 22-23 / 04 / 075

Address: RAJKOT — Heat No:

Sample ID : SAM-G- — Grade A-6061

	Al	Si	Cu	Mn	Mg	Zn	Fe	Cr
Ave	97.08	0.63	0.25	0.10	1.01	0.06	0.46	0.288

	Ni	Ti	Pb	Sn	V	Bi	Zr	B
Ave	0.004	0.023	0.010	0.004	0.012	0.001	< 0.000	0.002

	Ga	Cd	Ag	Sb	P	As
Ave	0.016	< 0.000	< 0.000	0.028	< 0.002	< 0.003

Checked by — 02/04/2022 — Approved by

APPENDIX – C Industry Certificate

Shree Mayur Engineering Company

Manu. of : Investment Casting Machinery

+91 7069040701
smecrajkot@gmail.com
Plot no. 1, survey no 14
near Tip top forging shapar main road,
shapar (Veraval) Rajkot - 360024
(Gujarat) India.
www.shreemayurgroup.com

DATE: 10/04/2022

INDUSTRY CERTIFICATE

To whomever it may concern,

This is to certify that **Mr. Gautam Makwana** from Faculty of Engineering & Technology, Atmiya University, Rajkot has satisfactorily completed his project work on the title **"Investigate the effect of TIG welding process parameters on weld distortion of AA6061"** in time duration from [June 2021] to [April 2022].

During the span of his project we found him law abiding, honest and hard working in his work. The research work carried out by him is useful to our Industry.

Thank you.

With Best Regards.

For Shree Mayur Engineering Company

SHREE MAYUR ENG. CO. RAJKOT

APPENDIX – D Certificate of Publication

Consortium e-Learning Network
Empowering Learners

Certificate of Publication

STM JOURNALS
Scientific Technical Medical

We acknowledge the manuscript

"...Investigate the Effect of TIG Welding Process Parameters on Weld Distortion of AA6061-A Technical Review....

Submitted by

Makwana Gautam

Published in ...Trends in Mechanical Engineering & Technology...

ISSN 2231-1793 Year 2022 Volume 12 Issue 01

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STM JOURNALS

Archana Mehrotra
Director's Signature

APPENDIX- E Welding Procedure Specification

Welding Procedure Specification (WPS)

Sheet 1 of 3

ASME Boiler and Pressure Vessel Code , Section IX

Company Name: www.WPSAmerica.com

Company Address: info@WPSAmerica.com, 1 (877) WPS-WELD

Welding Procedure Specification WPS No.: DEMO-WPS Revision No.: (0) Date: 12,12, 2005
Supporting PQR No. (s): DEMO-PQR Date: 11,12, 2005

BASE METALS (QW-403)

P-No.: 4	Group No.: 1	Material Specification: SA-335	Type or Grade: P11
Welded to			
P-No.: 4	Group No.: 1	Material Specification: SA-234	Type or Grade: WP11, Class 1
OR			
Chem. Analysis and Mech. Prop.	N/A		
Welded to Chem. Analysis and Mech. Prop.	N/A		

Qualified Thickness Range mm (in)	Groove: 5 mm (3/16 in.) to 60 mm (2.36 in.)	Fillet: Unlimited
Qualified Diameter Range mm (in)	Groove: All Sizes	Fillet: Unlimited
Other information: This is a DEMO WPS from www.WPSAmerica.com		

	FIRST PROCESS	SECOND PROCESS
Welding Process (es):	Gas Tungsten Arc Welding (GTAW)	Shielded Metal Arc Welding (SMAW)
Type (s):	Manual	Manual
FILLER METALS (QW-404)		
AWS Classification Electrode-Flux Class (SAW)	ER80S-G (see sheet 3)	E8016-B2 (see sheet 3)
SFA Specification	SFA 5.28	SFA 5.5
Filler Metal F-No.	6	4
Weld Metal Analysis A-No.	_	3
Size of Filler Metals mm (in)	2.0 mm (see sheet 3)	3.25 mm (see sheet 3)
Filler Metal Product Form	Solid copper coated wire	Iron powder low hydrogen
Max. Weld Pass Thickness mm (in)	1/8 in.	3/16 in.
Qualified Weld Metal Range: Groove mm (in)	10 mm (3/8 in.)	60 mm (2.36 in.)
Qualified Weld Metal Range: Fillet mm (in)	Unlimited	Unlimited
Weld Deposit Chemistry	_	_
Flux Trade Name and Flux Type (SAW)	N/A	N/A
Consumable Insert, Class and Size	_	_
Other information: This is a DEMO WPS from www.WPSAmerica.com		
POSITIONS (QW-405)		
Position (s) of Groove	ALL Position	ALL Position
Welding Progression	Up	Up
Position (s) of Fillet	ALL Position	ALL Position
PREHEAT (QW-406)		
Preheat Temp. °C (°F)	150 °C	150 °C
Interpass Temp. Max. °C (°F)	280 °C	280 °C
Preheat Maintenance °C (°F)	New Joint	New Joint
GAS (QW-408)		
Shielding Gas Type (Mixture)	100% Ar	N/A
Flow Rate lt/min. (CFH)	7 to 9 lt/min.	_
Trailing Gas Type (Mixture)	N/A	N/A
Flow Rate lt/min. (CFH)	_	_
Gas Backing (Mixture)	N/A	N/A
Flow Rate lt/min. (CFH)	_	_

POSTWELD HEAT TREATMENT (QW-407)

Holding Temperature Range °C (°F): 680 °C + or - 10 °C	Holding Time Range: 1 hr/ in. (15 minutes Min.)
Heating Rate °C/hr (°F/hr): 120 °C/hr	Method: Furnace
Cooling Rate °C/hr (°F/hr): 120 °C/hr	Method: Open Air

WPS No. DEMO-WPS Rev. (0) Sheet 2 of 3

ELECTRICAL CHARACTERISTICS (QW-409)

Following data may also shown on Table below in this sheet	FIRST PROCESS	SECOND PROCESS
Current/ Polarity	DCEN	DCEP
Amps (Range)	90 to120	100 to 130
Volts (Range)	18 to 25	20 to 28
Wire Feed Speed (Range) mm/min (in/min)	_	_
Travel Speed (Range) mm/min (in/min)	Manual control	Manual control
Mode of Metal Transfer for GMAW (FCAW)	N/A	N/A
Tungsten Electrode Size mm (in)	2.5 mm	_
Tungsten Type	SFA 5.12 EWTh-2	

TECHNIQUE (QW-410)

String or Weave Bead	String Bead	String and Weave Bead
Multiple or Single Electrodes	Single	Single
Multiple or Single Pass (per side)	Multiple	Multiple
Orifice or Gas Cup Size	5/8 in. Nozzle Size	_
Contact Tube to Work Distance mm (in)	_	_
Initial and Interpass Cleaning	Brushing	Brushing and Grinding
Method of Back Gouging	n/a	n/a
Oscillation	_	_
Peening	Not Required	Not Required

Other information: Clean each layer before start welding new passes/layers

JOINTS (QW-402)

Joint Design: Groove Design Used Backing Type: Metal Backing Material (Refer to both backing and retainers.): Same as base metals

Joint Details/ Sketch: Groove Details (or as per production drawing): Root Opening G: _ Root Face RF: _ Groove Angle: _ Radius (J-U): _

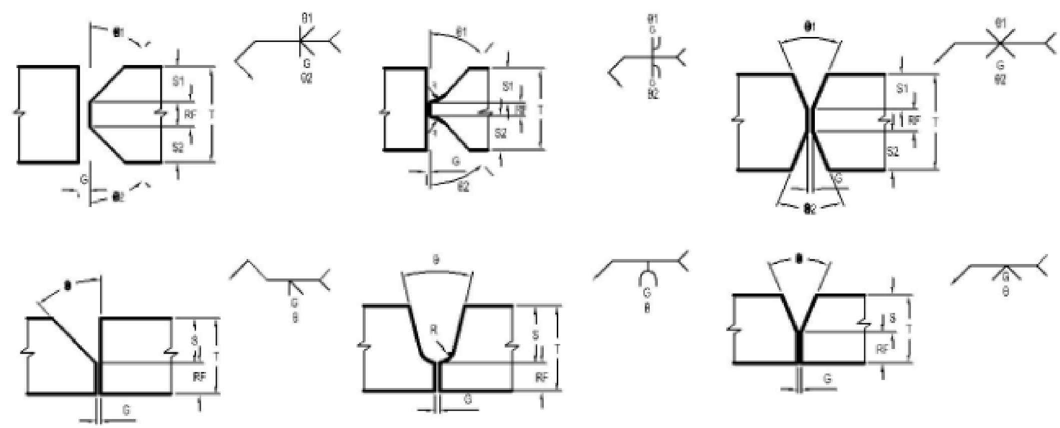

Table for recorded welding parameters; Refer to QW-409

Weld Layer(s)	Pass No. (s)	Process	Filler Metal Classification	Filler Size Diameter mm (in)	Current Amps Range	Current Type & Polarity	Wire Feed Speed Range mm/min (in/min)	Volts Range	Travel Speed Range mm/min (in/min)	Max. Heat Input kJ/mm (kJ/in) Or Remarks
1	1	GTAW	ER80S-G	2.0 mm	90-120	DCEN	N/A	18-25	_	Root Pass
2	2 to 3	GTAW	ER80S-G	2.0 mm	90-120	DCEN	N/A	18-25	_	
3 to n	4 to n	SMAW	E8016-B2	3.25 mm	100-130	DCEP	N/A	20-28	_	Fill and Cap Passes

Additional Notes: This is a DEMO-WPS prepared by online welding software of www.WPSAmerica.com

Manufacturer or Contractor's Welding Engineer:

Name: *Jim Clark*

Signature: *J.C.*

Title: *Welding Engineer*

Date: *12, 12, 2005*

Authorized by:

Name: *John Smith*

Signature: *J.S.*

Title: *QA Manager*

Date: *12,12, 2005*

Heat Treatment (ASME Code's Guideline):

PREHEAT TABLE:
ASME Section I: Preheating from Appendix A (A-100)
(a) 250 °F (120 °C) for material which has either a specified minimum tensile strength in excess of 60,000 psi (410 MPa) or a thickness at the joint in excess of 1/2 in. (13 mm):
(b) 50 °F (10 °C) for all other materials of P-No. 4 group.

POSTWELD HEAT TREATMENT TABLE:
ASME Section I: Mandatory Requirements for PWHT of Table PW-39
Min. Holding Temperature: 1,200 °F (650 °C)
Min. Holding Time for Weld Thickness (Nominal):
Up to 2 in. (50 mm): 1 hr/in. (2 min/mm), 15 min Min.
Over 2 in. (50 mm) to 5 in. (125 mm): 1 hr/in. (2 min/mm)
Over 5 in. (125 mm): 5 hr plus 15 min for each additional inch over 5 in. (125 mm)
Heating rate: The weldment shall be heated slowly to the holding temperature, Min. 100 °F (55 °C)/hr
Cooling rate: Cool slowly in a still atmosphere to a temperature not exceeding 800 °F (425 °C)
For Non-Mandatory conditions of PWHT, See Notes (1), (2) of Table PW-39

WPS Qualified Range (ASME IX Guideline):

Qualified Positions (Groove, Fillet): All Positions for Plate or Pipe. Unless specifically required otherwise by the welding variables (QW-250), a qualification in any position qualifies the procedure for all positions. The welding process and electrodes must be suitable for all positions permitted by the WPS (ASME Section IX, QW-203). (For impact test application, there are some restrictions for welding in vertical-uphill progression position; See ASME Section IX, QW-405.2)

Qualified Thicknesses (Groove, Fillet): 3/16 in. (5 mm) Min., 2T Max. (Plate or Pipe)
[For GMAW-Short Circuit Arc, when T is less than 1/2 in. (13 mm): 1.1T Max. ASME IX, QW-403.10]
[For impact test application, except ESW process: Min. Qualified Thickness is either T or 5/8 in. (16 mm), whichever is less; This variable does not apply when a WPS is qualified with a PWHT above the upper transformation temperature or when an austenitic material is solution annealed after welding. ASME IX, QW-403.6]
[For ferrous base metals other than P-No. 7, 8 and 45 (when test coupon receives a PWHT above the upper transformation temperature): 1.1T Max. ASME IX, QW-407.4]
[For any weld pass greater than 1/2 in. (13 mm) thick: 1.1T Max. (Except GTAW process). ASME IX, QW-403.9]
T: Thickness of Test Plate or Pipe Wall in PQR (ASME Section IX, Table QW-451.1)

Qualified Diameters (Groove, Fillet): All Nominal Pipe (Tube) Sizes, within Qualified Thicknesses in PQR

WPS Base Metal P-Numbers Allowed by PQR: Any metals of the same P-No. 4, plus combination between any metal from P-No. 4 to any metal from P-No. 3 or P-No. 1 (ASME Section IX, QW-424)

Qualified WPS Filler Metal Allowed by PQR: Only Filler Metal categories with the same F-number and same A-number tested in PQR. Any electrode diameter sizes can be used in WPS, as it is not an essential variable for the most process and conditions. For Non-impacted test applications only, filler metal classification within an SFA specification, with the same F-number and the same A-number and the same minimum tensile strength and the same nominal chemical composition can be used in WPS. (ASME Section IX, QW-250)