Study and analyses of Arc Length Correction and Mechanical Properties on Weld Bead Geometry for AA6061T6 by Cold Metal Transformation Process.

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE AWARD OF THE DEGREE

OF

MASTER OF TECHNOLOGY

IN

PRODUCTION ENGINEERING

Submitted by:

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AUGUST 2021

CANDIDATE’S DECLARATION

I, DESH RAJ, 2K18/PIE/501 student of M. Tech. (Production Engineering), hereby declare that the project Dissertation titled “**Study and analyses of Arc Length Correction and Mechanical Properties on Weld Bead Geometry for AA6061T6 by Cold Metal Transformation Process”** which is submitted by me to the Department of Mechanical Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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(2K18/PIE/501)

CERTIFICATE

I hereby certify that the Project Dissertation titled "**Arc Length Correction and Mechanical Properties on Weld Bead Geometry for AA6061T6 by Cold Metal Transformation Process**" which is submitted by DESH RAJ, 2K18/PIE/501, Department of Mechanical Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge, this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi (**Prof. Ranganath M. Singari and Prof. Vipin)**

Date: SUPERVISOR

DEPARTMENT OF MECHANICAL ENGINEERING

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DATE:

PLACE:

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ABSTRACT

Welded aluminium AA6061T6 joints have a wide range of industrial applications due to their low cost, lightweight, and excellent efficiency. In the automation industry, thin aluminium AA6061T6 of various thicknesses is widely utilized. Traditional welding procedures have always had issues with burn-through and distortion when welding these light aluminium AA 6061T6 joints due to their high heat input and large spatters. Because of its low distortion rate and low heat input, the CMT welding technique is an excellent choice for attaching thin sheets. In this study, Aluminium AA 6061T6 joints of grade 6000 series welded using the CMT welding process, and the mechanical properties of the joints investigated. The Taguchi L9 optimization technique was utilised to determine the best process factors for achieving the highest tensile strength. The maximum tensile strength of Aluminium 6061T6 joints welded at 100 A current, 6 mm/s welding speed, and a -10 percent Arc length correction factor was determined to be 206 MPa. The weld zone obtained its maximum micro-hardness value of 81.05 HB, but the heat-affected zone had a lower value (HAZ). The residual stresses of the welded junction detected using the X-ray diffraction (XRD) technique. In the weld zone and base plate, residual stress was compressive, while in the heat-affected zone, it was tensile (HAZ). The CMT welding procedure may use to create high-strength aluminium 6061T6 joints of various thicknesses.

Keywords:

CMT (Cold metal Transformation), ARC (Arc length correction), HAZ (heat-affected zone).

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CHAPTER 1: INTRODUCTION

Among the different manufacturing technologies, fusion welding regarded as one of the most significant and greatest technologies for enhancing sustainable manufacturing. Due to technological limits, manufacturing any product without using the joining process is extremely difficult. Several components of the goods usually assembled, and fusion procedures primarily aid in the fabrication and improvement of process proficiency. [Tseng et.al. (2014)]. joining multiple metals is favoured because it allows for the benefits of diverse materials to use to provide unique solutions to various technical needs. [Taban et.al. (2010)]. One of the primary benefits of fusing diverse materials is the reduction in weight and cost of the product without compromising structural standards or safety.

Many joining procedures for dissimilar materials have gotten a lot of attention in the last few years. For the junction to be successful within the weld, the dissimilar fusion weld must have appropriate tensile and ductility test results. [Ghosh et.al. (2017)]. Similar metal joints are utilised in a variety of engineering-related applications such as vehicle fabrication, power plants, boilers, railways, aerospace industries, and so on. [Ghosh et.al. (2017) and Chaudhary et.al. (2014)]. As a result, the combining of dissimilar metals has received a lot of attention in recent years.

Gas metal arc welding (GMAW), Metal Inert gas welding (MIG), Shielded metal arc welding (SMAW), Pressure Welding, Brazing, Soldering, and other welding operations that entail fusion joining of incompatible materials have been used until now. Large heat-affected zones and filler material selection are important challenges in these fusion-welding procedures of aluminium metals. The vast heat affected zone causes brittle intermetallic compounds to form, which might cause a fracture. As a result, HAZ is primarily a fracture zone. Also selecting suitable filler material is most important as it controls the mechanical properties and microstructure characterization in the weld zone.

Due to its superior weldment qualities, GMAW/MIG is the most commonly utilised technique for connecting ferrous and non-ferrous metals among the several processes discussed above. [Ibrahim et.al. (2012)]. GMAW is a specialised technology that readily covers up the loss of alloys created during welding, in addition to gap bridging expertise. [Hu et.al. (2016)]. this approach is particularly well suited to applications in the automotive industry. In any case, new grades of Aluminium currently used for fabrications because of these industries' recent shift towards environmental sustainability and passenger safety. Because thin sheet alloys have a high coefficient of heat conductivity and thermal expansion, they can cause problems during arc welding, such as burn through and deformation. Welding similar materials of varying thicknesses with a traditional welding method has always been difficult due to excessive heat input and spatters. To avoid such difficulties, a controlled heat input is required. [Tseng et.al. (2014) and Gungor et.al. (2014)]. As a result, there is a need for a welding technology that can be utilised to combine thin sheets and solve these issues. CMT approaches help to mitigate these issues largely. When compared to other techniques, properties like as narrow HAZ, higher productivity, and narrow distortion make cold metal transfer welding (CMT) approach suitable for attaching thin plates. [Ghosh et.al. (2017)].

Cold Metal Transfer (CMT) is a relatively new method of connecting thin sheets based on the "Fronius of Austria" technique of conventional short-circuiting (CSC). Due to its unique feature known as low heat input, it is a technological advancement of the Gas Metal Arc Welding (GMAW) technique and is far superior to GMAW in terms of spatter, distortion, burn through, and welding cost. It also has a strong gap-bridging capability, which is ideal for automation. CMT welding is an automatic welding process that involves the controlled deposition of material during the short-circuiting of a work piece to an electrode. It well known for its ability to function with little heat input. [Feng et.al. (2009)]. As a result, the base metal suffers less damage, distortion, and residual stress. The filler wires in a traditional arc welding technique travel constantly in the outer direction until a short circuit occurs. The filler wire in a CMT process is both pushed and retracted during welding, earning it the name "intelligent system." The movement of the feeding wire with an oscillating frequency of up to 70 Hz is commonly utilised in this operation. [Pickin et.al. (2011)].

1.1 Cold Metal Transfer Process

CMT is a meticulous process that uses a digitally controlled wire feeding system to deposit material at a lower heat input. [Pickin et.al. (2011)]. Beginning the arc, the electrode advances toward the weld puddle in this newly developed welding method. A quenched as the electrode tip interacts with the molten metal in the weld pool. The value of current drops dramatically to a non-zero number, effectively eliminating the possibility of splatter. The reduction in welding current results in a significant reduction in thermal heat input. As a result, the most favourable conditions and a practical approach for welding thin sheets with no or very little distortion, a lower rate of dilution, and lower stresses in the weld zone are established. [Cao et.al. (2013), Cao et.al. (2014), Wang et.al. (2008), Lorenzin et.al. (2009) and Lin et.al. (2013)]. the wire reverses its motion, which digitally controlled by a synergic power source that supports the separation of the weld drop during short-circuiting [Yang et.al. (2013)]. the feed wire action is reversed, and the operation is repeated from the beginning. [Gungor et.al. (2014)]. Because of its low thermal heat input feature, which reduces the heat-affected zone, the CMT method has become a well-known and dependable welding technique (HAZ). A CMT welding electrical cycle signal is the time it takes for a droplet from an electrode to deposit in this molten state weld pool. The entire process, from droplet detachment to energy distribution, takes place in stages and requires the analysis of current and voltage waveforms.

Fig.1.1.Depicts the current and voltage waveforms and studying them is necessary for understanding the energy dissipation in various stages throughout the droplet transfer process. The three different phases in the CMT cycle are as follows: -

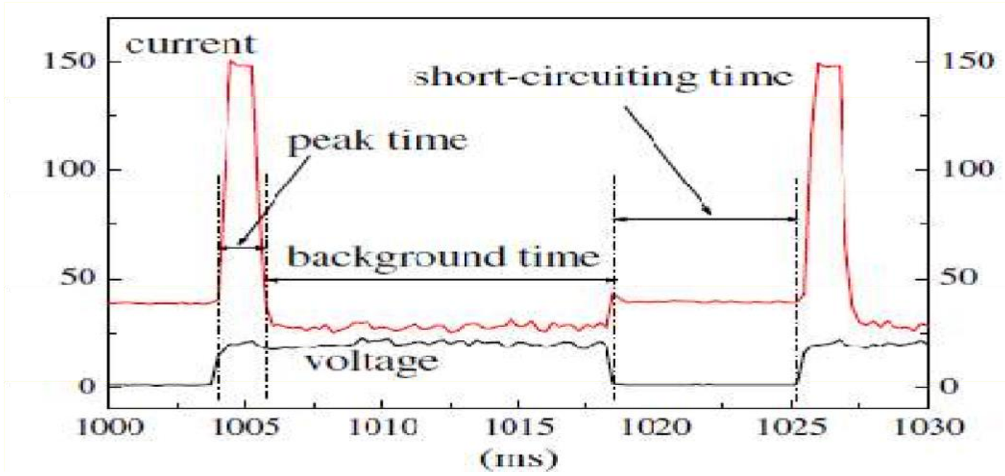


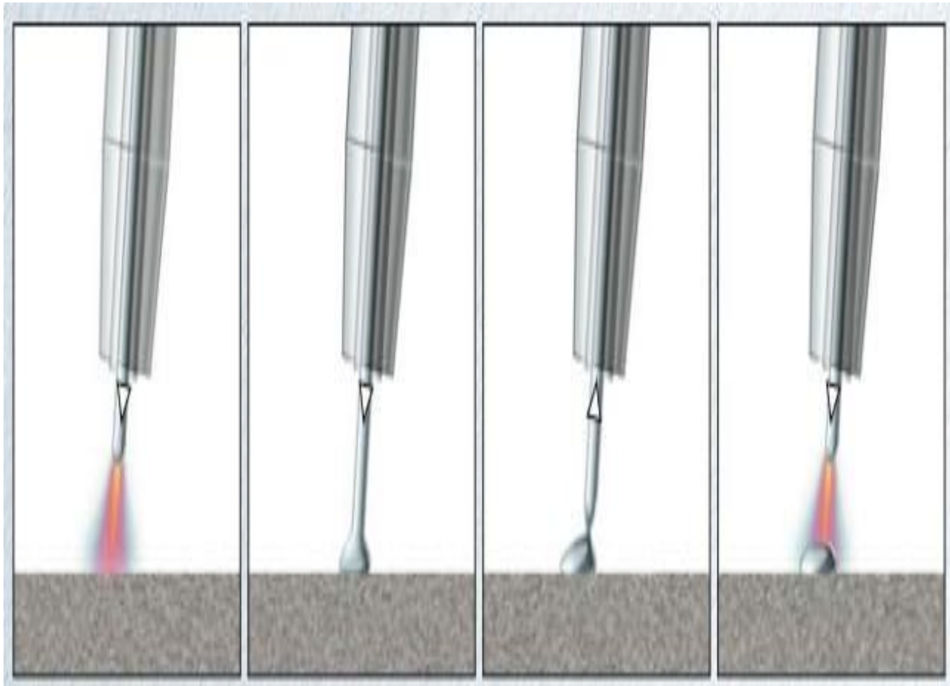
Fig. 1.1. Current and Voltage waveforms of CMT process [Feng et.al. (2009)]

The Peak current phase: It is a 'constant arc voltage' (CAV) that corresponds to a strong current pulse for a short time, easily igniting the welding arc and melting the electrode wire to form a droplet

I. The Background current phase: This phase has resulted in a decrease in current value. As the liquid droplet forms on the wire tip during the peak current phase, the current decreased to a non-zero value to prevent globular transfer and spatter formation. This phase lasts until the circuit is short-circuited.

II. The Short-circuiting phase: A zero arc voltage corresponds to this phase. As the wire meets the weld pool, the arc voltage drops to zero. Similarly, the retractor mechanism supplied by ‘Digital Process Control' (DPC) to the wire feeder, which provides the wire with a back-drawing effort, aids in the liquid bridge fracture and material transfer into the weld pool. The arc then re-ignited, and the sequence repeated once again. [Feng et.al. (2009)].

The welding current and reverse feeding of filler electrode wire have a complicated waveform that mechanically enforces metal movement, making it difficult to recognise the relationship between welding parameters, metal, and heat transfer. A CMT welding method, on the other hand, becomes an ideal approach for industrial applications by keeping perfect arc duration management and higher edge tolerance, thereby overcoming the constraints of other traditional welding procedures. A CMT arc-welding can demonstrated in the following steps as shown in Fig.1.2.



(a) (b) (c) (d)

Fig. 1.2. Demonstration of CMT welding arc [Merkler M. (2004)]

a) During welding, molten metal on the electrode tip travels towards the weld pool.
b) When the filler electrode wire dipped in the weld pool, the arc extinguished. The current value decreases.
c) Because the backward movement of the filler wire aids in the detachment of the d roplet during short-circuiting, it kept at a low value. The wire movement reversed, and the procedure repeated.

1.2 Welding Parameters

I. **Current:** It is one of the most critical criteria that significantly affect the welding process. It also has an impact on penetration, along with the macrostructure of the weld bead. Increases in the current value enhance the width of the weld bead as well as the depth of penetration, according to several studies and literature. When the current reduced, the penetration depth reduced, and the weld breadth narrows. [Little (1994)].

II. **Voltage** – In this welding technique, a constant voltage arc usually maintained. The operator sets the needed voltage, which the machine then maintains throughout the welding process. [Little (1994)].

III. **Welding Speed** – It refers to the rate at which the welding nozzle passes across the plates. It regulates the metal transfer mode and weld bead penetration.

IV. **Wire feed Rate** – It refers to how quickly the feed wire passes through the nozzle on its way to the weld bead. It regulates both the form of the bead and the amount of metal deposited in the weld bead. [Little (1994)].

V. **Shielding Gas Flow Rate-** It is the flow rate of the shielding gas. A shielding gas shields the welding arc from pollutants in the environment, allowing for a defect-free weld. For processes, a constant flow rate is desirable since a lower flow rate results in insufficient shielding and a greater flow rate interferes with arc stability. [Zhang et.al (2013)].

VI. **Arc length Correction factor-** The distance between the end of the filler wire and the work piece material measured in arc length. Apart from heat input and welding speed, an Arc length correction factor is a crucial element in determining tensile strength. A longer positive arc length means more strength and penetration. [Kannan et.al. (2019)].

VII. **Contact tip to work-piece distant (CTWD**) – It is the distance between the filler wire's contact tip and the work piece surface. The welding current and penetration both decrease as the CTWD is increased.

1.3 Aluminium

Aluminium is a chemical element with the atomic number 13 and the symbol Al. Aluminium has a lower density than most other common metals, about one-third that of steel. When exposed to air, it has a strong affinity for oxygen and creates a protective coating of oxide on the surface. Aluminium has a hue that is similar to silver and has a high propensity to reflect light. It is ductile, soft, and non-magnetic. There is only one stable isotope in it. Aluminium is the tenth most abundant element in the universe because of this isotope's abundance. In radio dating, the radioactivity of 26Al employed.

Aluminium is a chemically weak metal in the boron group, and it forms compounds largely in the +3-oxidation state, as is typical of the group. Al3+, the aluminium cation, is a tiny and highly charged cation.

Some of the major advantageous properties of Aluminium are:

1. Corrosion-resistant
2. Light Weight
3. lower density than most other common metals
4. It is ductile
5. It is a soft
6. Non-magnetic

1.3.1 Types of Aluminium and Its alloys: -

Aluminium 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. Aluminium has a density of 2.7 g/cm3, which is about one-third that of steel (7.83 g/cm3). A cubic foot of steel weighs approximately 490 pounds, while a cubic foot of aluminium weighs just about 170 pounds.

Such light weight, combined with the high strength of some aluminium alloys (which exceeds that of structural steel), allows for the design and construction of strong, lightweight structures that are especially useful for anything that moves—spacecraft and planes, as well as all types of land- and water-based vehicles.

Aluminium is resistant to the kind of oxidation that causes steel to corrode. Aluminium's exposed surface reacts with oxygen to generate an inert aluminium oxide film a few ten-millionths of an inch thick that prevents further oxidation and unlike iron rust, aluminium oxide does not corrode. The film does not flake off, exposing a new surface to oxidation. In the event that the

If the protective layer of aluminium scratched, it will automatically reseal. The thin oxide coating adheres to the metal strongly and is colourless and transparent to the human eye. Aluminium not rust and not tarnish or flake as iron and steel do. Aluminium, when alloyed and treated properly, can withstand corrosion from water, salt, and other environmental variables, as well as a variety of chemical and physical agents. Aluminium's corrosion characteristics. The section "Effects of Alloying on Corrosion" looks at alloys. In this article, the term "behaviour" is used.

Aluminium surfaces can reflect a lot of light. While anodised and dark anodized surfaces can be reflective or absorbent, they efficiently reflect radiant energy, visible light, radiant heat, and electromagnetic waves.

Polished aluminium's ability to reflect light over a wide range of wavelengths makes it ideal for a variety of ornamental and utilitarian applications. Although aluminium has great electrical and thermal conductivity, special alloys with high electrical resistivity have created. These alloys are helpful in high-torque electric motors, for example. Aluminium is frequently used because of its electrical conductivity, which is roughly double that of copper in terms of weight. Long-line, high-voltage, aluminium steel-cored reinforced transmission cable may meet the requirements for high conductivity and mechanical strength. Heat exchangers, evaporators, electrically heated appliances and utensils, and automotive cylinder heads and radiators benefit from aluminium alloys' thermal conductivity, which is around 50 to 60 percent that of copper. Aluminium is no ferromagnetic, which is a desirable feature in the electrical and electronics sectors. It is non-pyrophoric, which is significant in applications involving the handling or exposure of flammable or explosive materials. Aluminium is also non-toxic and commonly used in food and beverage containers. Its natural finish, which can be smooth and lustrous, offers an appealing appearance. One of aluminium's most valuable advantages is the ease with which it be manufactured into any shape. It can often outperform lower-cost materials with a lower degree of workability. Foundry men can use any method to cast the metal. It can be rolled to any thickness, including foil that is thinner than paper. Stamping, drawing, spinning, and roll forming are all options for forming aluminium sheet. The metal can either be forged or pounded. Draw aluminium wire stranded into cable of any size and type from rolling rod. The number of different profiles (shapes) in which metal extruded is practically limitless. Solution heat treatment, quenching, and precipitation, as well as ageing and hardening, are examples of these treatments. Such alloys described as heat treatable for either casting or wrought alloys. For property development, vast varieties of different wrought compositions rely on work hardening through mechanical reduction, usually in combination with various annealing procedures.

Work alloys are what they called. Hardening. Some casting alloys are not heat treatable and are only utilised in as-cast or thermally modified situations that not affected by solution or precipitation effects. There are now nomenclatures for cast and wrought alloys.

1.4 Properties and Applications of AA6061T6 Aluminium

Aluminium grade 6000 Series is a popular alloys material 6061T6 it is a lightweight material it is a good corrosion resistance, Strong, High strength-to-weight ratio, and Ductile at low temperatures.

1.4.1) Chemical Composition

Chemical Composition

Al	95.85-98.56
Mg	0.8-1.2
Si	0.40-0.8
Fe	0.0-0.9
Cu	0.15-0.40
Cr	0.04-0.35
Zn	0.0-0.25
Ti	0.0-0.25
Mn	0.0-0.15
Remainder	0.15to 0.15 total

1.4.2) Mechanical Properties

Tensile Strength	310MPa
Yield Strength	276 MPa
Elastic Modulus	68.9 GPa
Poisson's Ratio	0.33
Elongation at breaking-	17%
Brinell Hardness	95
Rock Hardness	40
Ultimate Bearing strength	607 Mpa
Fatigue Strength	96.5 Mpa
Fatigue toughness	29 Mpa
Machinability	50%
Density	2.70g/cm²
Melting point	650 ℃

1.4.3) Electrical Properties

Electrical Resistivity 3.99-0.06 ohm-cm

1.4.4) Thermal Properties

CTE, linear(68°F)	23.6µ/m-℃
CTE, linear (250 ℃)	25.2µ/m-℃
Specific Heat Capacity	0.896J/g- ℃
Thermal Conductivity	167w/m-K
Melting Point	582-652℃
Solidus	582℃
Liquids	652℃

1.4.5) Manufacturing Process

We take great satisfaction in producing the highest-quality aluminium ramps in the business, which are made of AA6061 aluminium. At Copper alloy, all of our aluminium ramps start as raw Bauxite, a clay-like dirt found a few metres deep in layers around the equator. Alumina, or aluminium oxide, recovered from bauxite using caustic soda and lime in a refining process. This combination boiled and filtered until it has the consistency of a white powder. The refined alumina converted into aluminium in metal facilities around the United States. AA6061-T6 aluminium is a precipitation-hardened aluminium that developed in 1935. High temperatures used in precipitation hardening to increase the yield strength of aluminium. Precipitation hardening reduces the flexibility of aluminium and converts it to AA6061-T6.

Aluminium AA6061-T6, three different raw materials are required:

- Aluminium oxide
- Electricity
- Carbon

Electricity passed between negative and positive carbon anodes, which react with the oxygen in the alumina to produce CO2.

Aluminium obtained from the resulting liquid, which subsequently tapped from the cells. Sheet ingots or foundry alloys made from liquid aluminium. That is where we can help. We make the most excellent quality aluminium yard ramps. A ramp, twin lock, and stage ramps on the market today in our state-of-the-art facilities.

What Is The AA6061-T6 Aluminium Blend?

Aluminium density of 2.70 g/cm3 (0.0975 lb/in3) and is remarkably pure, with aluminium content ranging from 95.85% to 98.56 percent. Other elements (by weight) that increase hardness and durability are:

- Silicon 0.4%- 0.8%
- Iron no minimum, maximum 0.70%
- Copper 0.15%- 0.40%

- Manganese no minimum, maximum 0.15%
- Magnesium 0.8%- 1.2%
- Chromium 0.04%- 0.35%
- Zinc no minimum, maximum 0.25%
- Titanium no minimum, maximum 0.15%
- Other elements 0.05%- 0.15% total

Is there anything unique about machining 6061-T6 aluminium?

Tungsten inert gas welding (TIG) or metal inert gas welding is excellent welding AA6061-T6 (MIG). At a higher temperature, aluminium creates a thin layer of aluminium oxide, which melts. This oxide must remove before welding by heating the 6061-T6 to 350 degrees Fahrenheit (176 degrees Celsius). When AA6061-T6 is hotter than room temperature, it is also much easier to weld. Welding AA6061-T6 without preheating not recommended. Prior to any welding, our AA6061-T6 aluminium ramps are treated with acetone, rinsed in clean water, dried, and cleaned with a stiff, stainless steel brush – it's time-consuming, but it's the right way to do it, and it makes our ramps some of the best in the market.

Why Do We Use Aluminium AA6061-T6 for Our Yard Ramps?

Even though they are lighter, AA6061-T6 aluminium yard ramps still have a typical capacity of up to 25,000 pounds and steel grating for superior traction. Copper alloy AA6061-T6 aluminium yard ramps are the way to go if you need a weight limit and mobility for your job. For our leading-edge yard ramps, we employ AA6061-T6 aluminium since it is a very stable and mobile working material. It is non-toxic, environmentally friendly, and easy to clean, thanks to its anodic coating. 6061-T6 aluminium is remarkable in that it is 100 percent recyclable with no loss of quality. Only 5% of the energy used to make AA6061-T6 aluminium used in the recycling process.

1.4.6) Applications of 6061 Aluminium Alloy:

Aluminium alloy 6061 is a popular grade aluminium alloy that comes in a variety of Shapes, sizes, May utilized in a variety of applications 6061 aluminium plate, 6061 aluminium tooling plate, and 6061 aluminium bar or extrusions are examples of this. It is frequently the alloy of choice for applications, including furniture, yachts, and general engineering. Howard Precision Metals is your source for a wide range of aluminium alloys, including 6061 aluminium that enables our customers to meet their commercial and industrial needs. To ensure you get the items you need, we maintain a wide range of industrial contacts with leading extruders in the aluminium and metals industries. What makes 6061 aluminium so adaptable to a wide range of uses? The metals adaptability is due to the elements that make it up. Magnesium and silicone, at 1.0 percent and 0.6 percent, respectively, are the primary alloying components in 6061. These constituents offer 6061 remarkable stress, fracture, and corrosion resistance, as well as weld ability and formability. Aluminium alloy 6061 is a heat-treatable medium to high-strength alloy with a strength level higher than that of alloy 6005A. It has a mild fatigue strength. Even though its strength reduced in the weld zone, it possesses excellent weld ability and corrosion resistance.

An Extensive Range of Industrial Application

Aluminium 6061 often used in certain heavy-duty structural applications that involve:

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

- Bridges and Military Bridges
- Pylon Towers
- Motorboats

Aluminium 6061, including 6061 aluminium plate, is widely utilized in the automotive industry, where jig and fixtures are required in mass production lines, marine fittings, lenses camera, yachts, motorcycles, bicycle frames, brake parts, couplings and valves, fishing reels, and electrical fittings, and diving tanks are just a few of the elements and products made from 6061 alloys.. This aluminium-magnesium silicon alloy commonly utilized in the construction of large span roof structures like bridge decks and arenas.

Aluminium 6061 is one of the most regularly utilized and adaptable alloys for extrusion.

It often referred to as structural aluminium because of its high strength, which makes it ideal for various structural applications. It is best to include generous corner radii when developing a custom extruded shape for a structural purpose, both to boost the design's strength and extrudability. Because of the chemical characteristics of this 6061 alloy, use it in a wide range of applications, including unique extrusion shapes. Hot forging is a standard procedure for aluminium 6061, which includes 6061 aluminium plate and extruded bar. Billets heated and forged in a closed due process using an induction furnace.

6061 Aluminium Sheet

Aluminium alloy 6061 T6 sheet is one of the most widely used materials on the planet. The T6 in this designation refers to the alloy's temper (or degree of hardness) achieved by a precipitation-hardening process. Heat-treatable and with an excellent strength-to-weight ratio, this alloy is a good choice. This aluminium alloy utilized in furniture, yachts, and other applications because of its exceptional weld ability and formability.

6061 Aluminium Bar

Aluminium 6061bar is one of the most versatile and widely used aluminium alloys. This type of 6061 aluminium used in a variety of industrial applications. The severe aluminium alloys of the year 2000, on the other hand, are more Machin able.

Cold finished hexes and rounds match ASTM B211 and AMS QQ-225/8, while extruded rectangles, squares, and rounds match ASTM B221 and AMS QQ-A-200/8. Extruded 6061 square bar is simple to cut, process, and weld for various demanding applications because it is require a high level of corrosion resistance and strength-to-weight ratio. For screw machine applications, many extruded rounds under 2.0” dia. of 6061 aluminium are manufactured to tight diameter tolerances.

6061 Aluminium Plate

Aluminium 6061is one of the most versatile heat-treated or sometimes referred to as wrought alloys. This alloy utilized for stairways, ramps, and flooring because of its high corrosion resistance, weld ability, machinability, and strength. This alloy is used for stairways, ramps, and flooring.

6061 Aluminium Angle

The 6061 aluminium alloy angle is one of the most regularly utilized shapes in structural applications. This 6061 aluminium alloy is good for welding and has a high strength-to-weight ratio.

Whether it is a 6061 aluminium tooling plate or another grade of aluminium, our staff at Howard Precision Metals is here to assist you to select the right alloy for your purpose. We are dedicated to assisting you in meeting your project requirements by providing the appropriate aluminium alloy products.

Our experts at Howard Precision Metals have you covered if you require one or more grades of aluminium alloy, such as 6061 or others, for a current or forthcoming project or application.

Common alloying elements

Iron (Fe)

Iron commonly regarded as an impurity element. Because producing aluminium without Iron contamination is difficult and expensive, it considered an alloying element. It harms the ductility and corrosion resistance of the alloy. Fe forms a common Inter metallic when manganese is present. Is the Al6 (Mn,Fe)-phase [18, 22].

Manganese (Mn) and Chromium (Cr)

To compensate for the corrosive effects of iron, manganese added as an alloying element. It will also boost the recrystallization's strength and control. During solidification, manganese produces massive components. Chromium has a similar but more substantial effect on the alloy. It frequently combined with Mn. [18, 22].

Copper (Cu)

It added to increase strength and resistance to fatigue. Copper, on the other hand, reduces corrosion resistance and weld ability. Thus, it typically only used in limited amounts. (0-5wt %) [18, 22]

Magnesium (Mg)

The principal alloying element in the 5xxx series alloys is magnesium. It is used to improve the when Mg is added, only modest amounts (0-2wt %) are normally used. [18, 22]

Titanium (Ti)

The addition of titanium acts as a grain refiner. It creates intermetallic phases when combined with aluminium.

Silicon (Si)

Silicon is the primary alloying element in the 4xxx series alloys; however, it frequently regarded as an impurity in the 5xxx series alloys. It purposely added to some kinds of the 5xxx series alloys to promote fluidity, which is the general goal of silicon addition in all alloys.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The literature scrutinized in the previous experimental work. Its result in various researchers is a clear picture in work done in a field in CMT welding processes in joining in similar metal.

[Yan et.al. (2010)] He observed that a lower welding speed could increase heat input and improve fluidity in his research on the effects of the CMT welding process on aluminium. [Varghese et.al. (2019)] He discovered a relation between heat input and the welding current during his experiments with the Aluminium AA6061T6 CMT welding method. [Sathiya et.al. (2005)] He discovered that when the friction pressure increased, the tensile strength increased and the toughness reduced in his studies on the metallurgical properties of friction welded aluminium.

[Mishra et.al. (2014)] He determined that with TIG and MIG welding, the welded joints produced the best tensile strength value in his investigation into aluminium-welded strength using various aluminium classes. According to the findings of a study on the physical parameters of welding with AA6061T6, similar welding produces stronger tensile strength than the base AA6061T6 metals. [Ramkumar et.al. (2017)]. According to investigations and analyses (HAZ) [Joseph et al. (2005)], the bulk of the failures occurred in the heat-affected zone. According to the research paper, AA6061T6 is the best filler wire for connecting ER4043. This filler wire is perfect for applications that require a lower temperature. [Dupont et.al. (2007)]. the experimental results show that arc length correction must be non-linear while joining. As a result, the welding zone diluted in a controlled manner, which is beneficial when attaching sheets. [Cai et.al. (2017)]. the majority of welding research done on sheets or plates with similar thicknesses. Although the overwhelming of the welding required between car parts happens between materials of differing thicknesses. [Williams’s et.al. (2005) and Zhang et.al. (2005)]

The mechanical properties of CMT welded identical aluminium 6061T6 of different thickness plates, such as hardness, tensile strength, and residual stresses, discovered in this study. Internal strains that remain in bodies when exposed to unequal or non-uniform temperature conditions when no external load is applied referred to as residual stresses. [Okumura et.al. (1982), Withers et.al. (2001), Wan et.al. (2007) and Vieira et.al. (2013)]. the measurement of residual stress is crucial for understanding the mechanical behaviour of materials. Easily predict the tensile and fatigue properties of specimens if we know the distribution and location of residual stresses and types of stress in the material. [Mishra et.al. (2014) and Gupta et.al. (2019)]. For examining mechanical structures whose static behaviour may be investigated from a microscopic and macroscopic range, the X-ray diffraction method for quantifying these stresses is frequently used. [Withers et.al. (2008)]. Summary of literature review exhibited as in Table 2.1.

Table 2.1. Literature Review

Sl. No	Author	Process	Material and Filler Metal	Process Parameters	Key Results
1	Peng-Cheng Huan. et.al. (2020)	Cold Metal Transfer welding	6063 aluminium alloy ER4047 and ER5183	High current time correction-6.0 Low energy period-6.0 Low energy regulation-(-6.0) Duty cycle (%)-60 Peak arc length correction-(-3.0) Valley arc length correction-(-1.5) Total energya Q(kJ)-39.4	1) The surface tensions of the molten pools differed due to the various compositions. (the difference was 33.2 MN/M). 2) The thermal conductivities of the molten pools differed due to the varied compositions (the difference at 540 C was 15.7 W/ (m. K)). The porosity of the molten pool and the release of hydrogen gas was barely 0.01 percent.

2	Shuhai Chen. et.al(2019)	laser-CMT	Q235 low carbon steel and 5052 aluminium alloy with the size of 150 mm × 75 mm×2 mm	laser power was fixed in 3kw 1 Wire feed speed- 1.5 m/min. 2 Welding speed- 1.5 m/min. Beam offset.- 3.1 m/min.	1) Butt welding-brazing with a laser-CMT Arc hybrid heat source improves weld form and interfacial reaction inhomogeneity. 2) Fe2Al5 and Fe4Al13 make up the interfacial IMCs layers between steel and aluminium alloy. The thickness of the IMCs was limited to 3- 5 m. The -Al and Al3Mg2 welded together. 3) The joint's strongest weld strength was 83.4 MPa. The joint ruptured in the weak zone of the joint, the interfacial IMCs layer.
3	S. Selvi.et .al (2018)	Cold metal transfer (CMT) technology	Aluminium AA6061 alloy ER4043 as filler metal.	Review paper	1. The retraction of the wire during the short circuiting phase is critical because it prevents spatter formation and improve the aesthetics of the weld bead. 2. The post weld Heat Treatment (PWHT) had a favourable effect on the welds by uniformly dispersing the fine sediments. Still, the Nitro-oxidation

					treatment of the base metal before welding caused a rise in porosity, resulting in a significant increase in the weld's micro hardness.
4	R. Ahmad. et.al(2011)	fect of a post-weld heat treatment on the mechanical and microstructure	AA6061	Current (A)-210 Voltage (V) -24 Feeding speed (mm/ s) -190 Heat input (mm /s)-1.4 Travel speed (mm /s) -3.6 Air flow -23.6 (min)	Tensile strength improved by 3.8 percent, hardness strength increased by 25.6 percent, and elongation increased by 21.5 percent after PWHT used. PWHT was able to improve the hardness strength and tensile qualities of AA6061 welded joints utilizing the GMAW CMT method, according to the findings. 2) PWHT generates a fine and uniform distribution of precipitates at the weld joints, resulting in higher hardness, tensile strength, and elongation values. The benefits of the GMAW CMT process, which creates weld joints with spatter-free welding, excellent gap bridging capabilities, and minimal heat input, also considered.

					3) A smaller particle size means a smaller gap, according to SEM fractographs. There were spaces between the grains and they were relatively small. In the case of the PWHT joints, These characteristics contributed to the better tensile strength. When compared to an as-welded junction, the qualities of the welded joint are better.
5	haitanya Gandhi. et.al.(2017)	CMT Process	AA7075(6 mm thick) ER5356	Current (A)-120 Initial Final Voltage (V) -125 Initial Final Wire - 14.6 Feed Rate - 17.7(m/min) Welding speed (mm/min)-600	1) The CMT welded beads have a uniform convex face that supports consistent weld material distribution and linearity, according to visual inspection. 2) Fractographs examination reveals a fracture at the welded section, indicating that the weld failed with a brittle fracture failure mechanism, lowering ductility and strain rate. 3) Due to non-uniform penetration tensile testing, the ultimate tensile strength reduced by

					68 percent, and the impact energy efficiency recorded as 48.6% of the work piece due to a lack of mechanical bonding.
6	Yashwant Koli1.et.al. (2019)	CMT, MIG pulse synergic and MIG welding	AA6061-T6-3.18mmThickness ER4043 (AlSi5%)-1.2mm	Current (80 A, 100 A and 120 A) and welding speed (7.5, 10.5 and 13.5 mm sec−1)	1) In comparison to MIG pulse synergic and MIG manual, CMT has lesser penetration for the same current and welding speeds, which makes it easier to weld thin sheets. 2) High heat input and quick cooling in the molten pool result in high residual stresses visible on the bead's surface in the form of cracks, reducing joint strength.
7	Yashwant Koli1.et.al. (2020)	Multi-response Mathematical Modelling	AA6061-T6 ER4043 (AlSi5%)	Current (80 A, 100 A and 120 A) and welding speed (7.5, 10.5 and 13.5 mm sec−1)	1) The weld bead geometry, mechanical characteristics, and microstructural analyses all influenced by process parameters like current and welding speed. 2) Although the optimal process parameters for CMT are lower than for MIG P and MIG M, it still produces a good penetration depth that is almost identical to

					MIG P and MIG M while using less heat.
8	S. Venukumar.et.al. (2019)	Cold Metal Transfer (CMT) Welding	Al 5183 and Al 5087 to join 6082-T4 and 5182-O aluminium	Review Paper	1) The cold metal transfer has used to effectively fuse incompatible alloys together. 2)Intermetallic compounds are formed, which are common in traditional fusion welding methods. The CMT procedure is used to keep everything under control.
9	Krishna P. Yagatiet.al. (2019)	CMT Weld Brazing	6061-T6 aluminium150 mm x 100 mm (4043(Al–5%Si) and 4047 Al–(12%Si)) filler wires1.2mm	Tandoff distance (mm) 6 6 Torch angle 80–85 80–85 Argon gas flow rate (GFR, L/min) 18–20 18–20 Wire position 60% on Al side 60% on Al side Wire feed rate (WFR, m/min) 3.5, 4 3.5, 4 Processing speed (S, m/min) 1, 1.2 1, 1.2 Current (A) 55–69 61–87 Voltage (V) 11.4–12 14.6–16.5	1) The nature of intermetallic compounds at the Al/steel interface was influenced by the filler wire composition (Al–5% Si and Al–12% Si) and CMT modes (with and without pulsing). Overall, joints manufactured with the CMT method outperformed joints made with the pulsed CMT technique, and joints made with 4047 filler outperformed joints made with 4043 filler in terms of fracture loads.

10	Jair Carlos Dutra.e t.al. (2015)	Cold Metal Transfer (CMT) Welding	5083 Aluminium alloy 6.0-mm-thick plates	The power source was a Fronius TPS3200 Torch Angle -5° Pure argon was applied as shielding gas at a flow rate of 15 l/min, Contact tip to work distance - 15.0 mm. Arc height −5 (Fronius TPS3200 CMT parameter). Wire feed speed -7.0 m/min. Current - 106 A welding speed - 40 cm/min Weaving amplitude of 3.5 mm ,4.0-Hz frequency. Wire feed speed - 7.0 m/min welding speed -30 cm/min	CTOD tests results indicate that the applied combinations (under matching) of base and feed material yield good cracking resistance characteristics. Residual stress in a body depends upon the Eigen strain and the mechanical properties of the material. 2) Visual inspection and SEM demonstrated a higher incidence of pores with the 5183 wire electrode. Still, the X-ray results indicate that both feed materials yield acceptable results using this process (CMT) and producers.
11	Pengli Jinet.al. (2021)	CMT welding-brazing	AlSi5 alloy 200mmx100 mm×3mm. ER4043 - 1.2mm	Wire feed speed of 6.0 mmin−1 Current- (127A) Pure argon gas(99%)Gas Flow rate - 20 l min−1 Welding Speed- 20mm/s	1) The spreading process influenced by the wetting conditions, which leads to the formation. 2) Discrepancies in the intermetallic compound layer and the zinc-rich zone. Current is the most important parameter that has an impact approx. 66.94% on the

					strength of dissimilar weld produced.
12	Zhibin Xin 1 et.al. (2019)	Cold Metal Transfer (CMT) Welding	AA6082-T6 200 mm × 150 mm × 6 mm. R5356-1.2mm	Shielding gas- Argon Gas flow rate – 6 Ltr/min Current-205 A Volt-23 Welding speed- 0.1 m/min Wire feed rate- 12m/min	The laser-CMT and plasma-CMT welds had good overall quality. The laser-CMT hybrid weld seemed "funnel shaped" and had a superior surface than the plasma-CMT weld. Materials 2019, 12, 3300 forming quality 9 out of 10 the laser-CMT hybrid welding technology required a higher weld penetration to get the same results. 2) The micro hardness values of the fusion zone and the heat-affected zone decreased in both hybrids welded joints compared to the base material, and two separate softening zones detected in the heat-affected zone. 3) The laser-CMT hybrid welded joints had higher tensile strength than the plasma-CMT hybrid welded joints, which could reach up to 79.4% and 73.7 percent of the basic materials, respectively.

13	Giovanna Cornacchia et.al. (2020)	CMT Welding	EN-AW 6181-T6, EN-AW 6082-T6, and EN AC 42100-T6 3 mm X 100 × 25 mm,	current 130–140 A welding voltage -18–20 V wire feeding rate of 6–8 m/min CMT. The gas flow rate- 14.5, 15, and 20 l/min for MIG, CMT	1) The typical faults of welded aluminium alloys, such as porosity and partial penetration, mostly noticed in the frame welds from a quality standpoint. Then, only the frame joints developed fractures, owing to greater difficulty in heat dissipation for higher thicknesses and geometries that are more complex. Typical casting flaws, such as shrinkage voids, also discovered. The Micro-Hardness obtained was highest for the welded joint with SS 308 filler wire due to proper fusion. In terms of macrostructures, the fibre laser joint found to be of higher quality. The microstructures of the FZ, PMZ and HAZ then examined. Tiny dendrites characterized the weld seam, and all joints showed similar FZ microstructures.
14	Ban gjia n	CMT repairing welded	7075-T651 aluminium(A	Welding torch tile angles (°)-80	. Tensile strength improved by 3.8 percent, hardness

	Yan g.et. al. (2021)		l) alloy ER5356 -1.2 dimeter mm	Stick out (mm) - 15 Shielded gas Gas-99.99 flow rate (L/min)-25 Welding speed (mm/s) -6.5 Wire feed speed (m/min) -12	strength increased by 25.6 percent, and elongation increased by 21.5 percent after PWHT. 2. PWHT was able to improve the hardness strength and tensile qualities of AA6061 welded joints utilizing the GMAW CMT method, according to the findings.
15	Eriel Pe´rez Zapico. et.al. (2017)	Cold Metal Transfer Welding	3-mm-thick AA5754 Al–Mg	Shielding Gas-Argon (98%) + Carbon-di-oxide (2%) Gas Flow Rate- 20 L/min Current- 105 A Voltage- 12.5 V Welding Speed- 350 mm/min Arc Length Correction- -20% to 20%	1) Temperature measurements from thermocouples and microscopic examination of the fusion zone used in experiments to demonstrate the model's validity. The Arc length correction factor controls the tensile strength of the welded austenitic steel to some extent. The obtained strength is more for positive Arc length correction factor. The method, which includes melting and fluid movement, will almost certainly result in better alignment between experimental and theoretical conclusions; but in this situation, a simpler approach adopted to

					make understanding and applicability of results easier.
16	C. G. Pickin. et.al. (2012)	cold metal transfer	3 mm thick AA 6111 1.2 mm 4043 filler wire	Current- (92 A) welding speed of 1 m min21 torch travel angle of 10° pure argon shielding	With an increase in short circuit duration, weld bead penetration decreases while the volume of weld material deposited decreases only slightly.
17	R. Pramod et.al. (2020)	Cold Metal Transfer Welding	AA6061-T6 145 mm diameter (Ø) and 11 mm height ER4043 filler wire	Plus Synergic 4000 CMT Argon (99.9% purity) provided at a gas flow rate of 20 L/min. Welding current -77 voltage -11.3 Rotational speed (RS)-2.5 Wire feed speed - m/min_ALC %-10 Heat input (HI) - 0.041kJ/mm Linear welding speed -1138 Mm/min	Welding bigger material sections with improved weld bead aesthetics while maintaining control over-penetration is possible. CMT appears to be a highly competitive welding method for automated welding of aluminium parts due to these properties.
18	Gulshan et.al. (2015)	Resistant Spot Welding	Low Carbon steel (Thickness 1.51 mm) and Austenitic Stainless Steel (1.48 mm)	Current – 3-9 kA Voltage- 5 kVA Frequency- 50 Hz Cooling water flow rate- 6 L/min Holding time- 5 cycles Weld Force- 4 KN	1) Asymmetrical weld nuggets generated in a dissimilar welded connection. 2) The size of the nugget grows in proportion to the current value. 3) The joint's strength is greatest when the maximum current is applied.

					The weld zone yields the highest hardness value.
19	Raghuram et.al. (2019)	Tungsten Inert Gas (TIG) Welding and Metal Inert Gas (MIG) Welding	SS 202 and SS 304 of thickness 6 mm		1) The best filler wire for welding Austenitic stainless steel grade 304 is SS 308. 2) The base metal of both welded joint materials has an austenitic microstructure, but the grain size in the heat-affected zone increases coarser.
20	Triyono et.al. (2011)	Resistance spot welding	Austenitic Stainless steel 304 of thickness mm3 and 1mm	Welding Current- 4.7 kA Welding Time- 20 Cycles Electrode force- 6 kN	1) The different thickness causes an uneven distribution of heat balance, resulting in more thermal heat created on the thicker plate, resulting in nearly 100% penetration. 2) The different thickness of the joining plates has little effect on the joint's hardness. 3) The crack begins in the thinner portion and spreads until it fractures. The majority of the fracture occurs in the narrow section's HAZ.

21	Bhushan Y Dharmik et.al. (2020)	Cold metal transfer Welding	Cold Rolled Noon-oriented (CRNGO) Electrical Steel (Grade M-45) of thickness 0.5 mm		1) Following analysis, it discovered that CMT caused fewer losses in the welded junction than MIG or GTAW. 2) Because of the short- -circuiting of CMT welding ,less heat accumulates on the material , resulting in fewer coarse grains.
22	Madhavan et.al. (2017)	Cold Metal transfer welding	Aluminum 1060 (Thickness 1 mm) and Zncoated steel (Thickness 0.6 mm) Al-Si alloy wire of thickness 1.20 mm	Shielding Gas- Argon (100%) Gas Flow Rate- 15 dm^3/min	1) A higher heat input results in a higher tensile strength value, while a high welding speed results in a small heat-affected zone. Because the fusion zone is directly proportional to heat input, the breadth of the fusion zone expands as the heat input rises and the fusion zone directly impacts joint strength.
23	Zhang et.al. (2009)	Cold Metal Transfer Welding	Aluminum 1060 (Thickness 1 mm) and Zncoated steel (Thickness 0.6 mm)	Shielding Gas- Argon (100%) Gas Flow Rate- 15 dm^3/min	1) Using the CMT technology, it is feasible to fuse different materials such as aluminium alloy and steel sheet without any fractures. The Inter-metallic Layer (IML) between

			Al-Si alloy wire of thickness 1.20 mm		the steel and weld metal interface is made up of Fe_2Al_5 and $FeAl_3$ phases and has a thickness of less than 5 m.
24	D. Delberg ue et.al. (2016)	X-Ray Diffraction Technique	Martensitic Steel of thickness 0.798 mm	Proto iXRD diffractometer- $\sin^2\psi$ method Pulstec μ-X360 apparatus - cos α method X-Ray Tube Voltage 30 kV	1) The Elastic constants of X-Ray linearly related to the stresses determined by X-Ray diffraction. 2) The Cos approach, which is a 2D detector methodology, produces better results than the sin2 method. This device is also simpler and lighter than the one that uses the latter method.

2.2 Heat Input Calculation

The qualities of the weldment created mostly determined by the heat input, which also determines the pace of cooling, which affects the microstructure developed. [Irizalp et.al. (2016)]. the heat input can be easily calculated from equation one below [Cook et al. (1985)]. A process said to be efficient if it produces a more robust joint with a lesser heat input [Mandez et.al. (2001)].

$$Q = \eta \frac{V.I.60}{S.1000}$$

Where Q is the heat input (KJ/mm)

V is the voltage (V)

I is the current (A)

S is the welding speed (mm/min)

2.3 Summary of Literature Review

The numerous welding procedures, their process parameters, material welding combinations, and various researchers' mechanical and microstructural studies of welded connections discussed. Interferences derived from the most notable results of Table 1 Are: -

1. In CMT, the filler wire's reactive movement during the short circuit plays an essential role in reducing spatter formation, obviating the need for post-weld machining and resulting in a high-quality weld.
2. The best process parameters determined by a variety of criteria, including the type of material used, the filler wire metal used the arc correction factor, and other environmental factors.
3. The wire feed rate and welding speed have a significant impact on the heat input as well as the penetration in the fusion zone. Increased heat input and a weld bead with higher penetration are obtained with a faster wire feed rate and a slower welding speed.
4. Compared to Pulsed arc mode and Standard arc mode, CMT arc mode provides the best bead stability, spatter-free weld, and most minor heat impacted zone.
5. Filler wire selection is also vital for achieving superior CMT welding results. Compared to the base material, the filler wire should have chemical and mechanical qualities that are compatible.
6. 7. Shielding gas selection is also an essential factor in CMT welding. The molten weld pool shielded from ambient gases by shielding gas. Shielding gas should selected based on the base material, and a sufficient gas flow rate should give. Gas porosity and other flaws reported in the absence of shielding.
7. Taguchi design arrays are utilised to obtain the best parametric combination and Taguchi S/N ratios employed to optimise the response value.

2.4 Research Gaps

1. There is relatively little research in combining thin Aluminium 6061T6, and it has to research.

2. Researchers have yet to investigate connecting Aluminium 6061T6 of various thicknesses using the CMT welding technology.

3. Although numerous authors have explored many different types of work-piece materials, filler wires, and arc length correction factors of various levels, none of these parameters been researched together for welding Aluminium 6061T6.

4. The literature evaluation reveals that industrial application-based research on Aluminium 6061T6 has yet to carry out.

CHAPTER 3: EXPERIMENTAL PROCEDURE

3.1 Material and Methods

Welding of Aluminium 6060T6 of different thicknesses of 3.18 mm, respectively, done in the present experimental study using the CMT welding technique, as shown in Table 3.2 ER4043 (AlSi5%) As filler material for welding wire, with a thickness of 1.2 mm diameter used. Tailor welded blanks (TWB), which are manufactured from single sheets of aluminium of varying thickness and strength that are welded together, have found a number of applications in modern industry. This manufacturing technique allows for flexible part designs and ensures that the proper amount of material used at the right time. In this experiment, the shielding gas is a mixture of 98 percent argon and 2% carbon. Throughout the procedure, the shielding gas typically interacts with the filler metal during the welding process, causing microstructure advances and influencing the weld deposits' mechanical and corrosion resistance qualities. Increased spatter rates and decreased ferrite numbers result from increasing the CO2 percent in the Argon + CO2 combination. It also improves molten filler wire wettability and fusion volume. 6061T6 aluminium plates cut to sizes of 100 mm x 50 mm x 3.18 mm respectively, for the experiment. Tables 3.1 the weight percentage composition of 6061T6 sheet respectively.

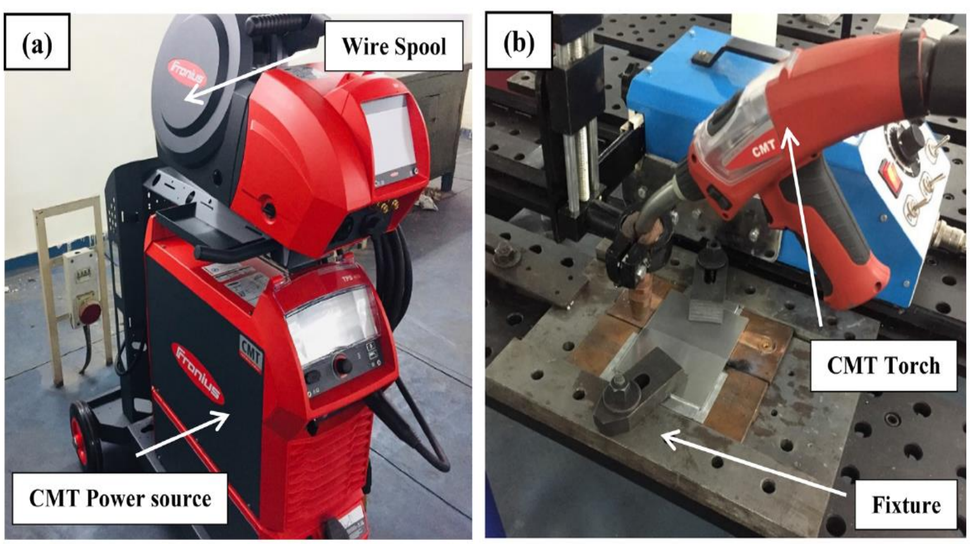


Fig. 3.1 CMT Welding Machine

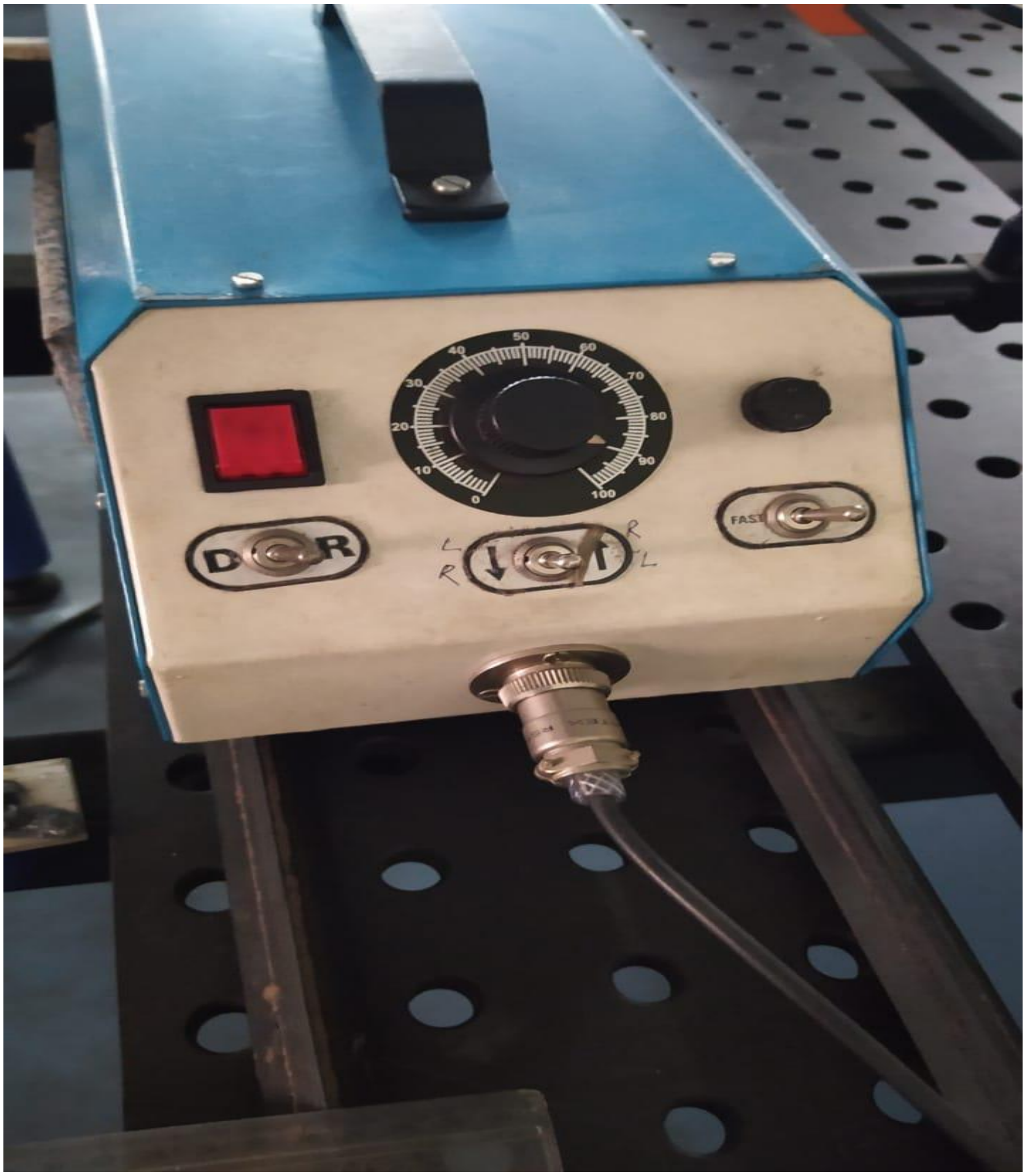


Fig.3.2 Welding Torch Speed Contral unit.

Table 3.1. Chemical Composition of 6061T6

Al	Si	Fe	Zn	Cu	Ti	Mg	Mn	Cr
97.75	0.665	0.253	0.0226	0.153	0.0225	0.840	0.05	0.05

Table 3.2 Welding Electrode Chemical Composition (ER4043)

Al	Si	Fe	Zn	Cu	Ti	Mg	Mn	Cr
93.03	5.6	0.8	0.10	0.3	0.02	0.05	0.05	0.05

3.2 Taguchi Optimization Technique

Several experimental experiments are required to produce high-quality weld bead. The Design of Experiments (DOE) is a technique for selecting parameters based on trials and evaluations. Then, with these values, tests done to produce a set of optimal parameters and their relationships. [Shanmugasundar et al. (2019)]. While running this set of designed experiments, any changes made to the input parameters reflected in changes to the output parameters. When there are multiple variables, the Taguchi L9 approach reduces the number of tests required to reach a result. The Taguchi L9 method reduces the total number of tests that must completed. The technique decreases the number of tests needed to obtain a conclusion. The Taguchi L9 approach decreases the total number of tests required to reach a result when there are several variables. The Taguchi method entails identifying and evaluating the input elements and their interactions to optimize using variables. To conduct the tests, the input variables assigned to orthogonal array arrangements. Table 3.3 lists the welding process parameters, as well as their three levels. This design technique used to determine the impact of input parameters on output response values such as tensile strength, elongation, and hardness. The main effect plot and S/N main effect plots generated, demonstrating the effect of each parameter on the output response and the optimum ideal parameter for producing the best output.

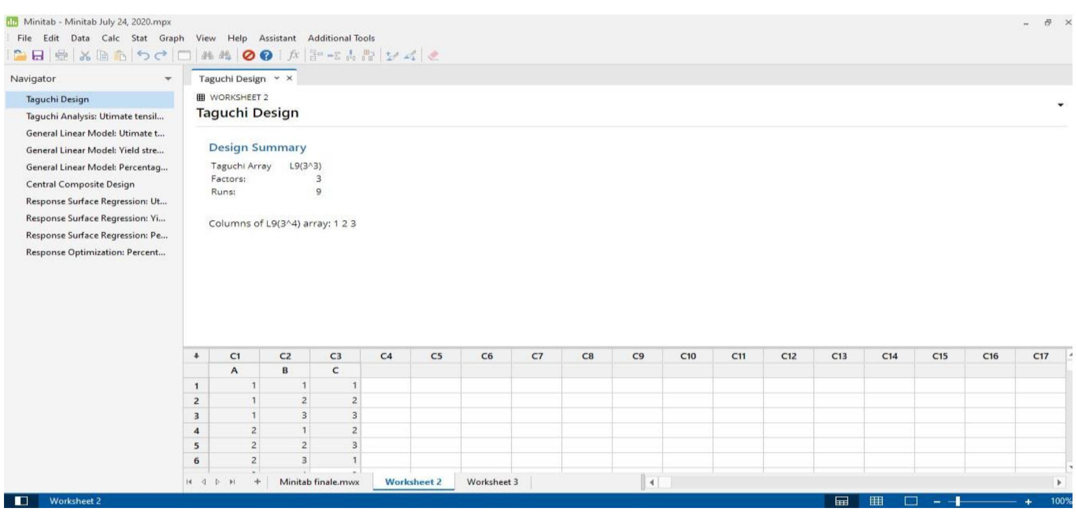


Fig.33 Taguchi L9 Design of experiment Interface on Minitab 19 Software

Table 3.3. Working range of Process Parameters

Sample No.	Welding Process Parameters		
	Welding Current (A)	Welding Speed (mm/sec)	Pulse Dynamic Correction Factor (PDC)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 3.4. Welding Process Parameters

Factors	Process Parameters	Units	Levels		
			1	2	3
A	Welding Current	(Amps)	80	90	100
B	Welding Speed	(mm/s)	6	9	12
C	Arc Length Correction Factor	(%)	0	-5	-10

3.3 Welding Parameters

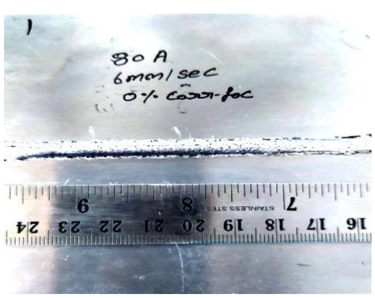
A variety of preliminary experiments and testing conducted to determine the best current, welding speed, and Arc length correction factor. The parameters chosen such that the plates properly welded without damaged or burning through. The thickness ratio of the two plates is 3.18 mm, which could cause local stress concentration and a shift in the neutral axis, making clamping difficult. The Taguchi L9 Optimization technique used to obtain a set of optimal parameters for the process, namely the design of trials.

Based on the acquired design of experiments (DOE) by L9 Taguchi's orthogonal array approach utilizing the MINITAB 19 software, three different welding current levels, welding speed, and Arc length correction factor used to make nine other welded specimens. Table 3.4 displays the process parameters used during the CMT process, with three levels of current, welding speed, and Arc length correction factor, while keeping the shielding gas flow rate and contact tip to work piece distance (CTWD) constant all samples. Table 3.4 depicts a welded piece with all of the parameters.

Table 3.5 Welded Samples with different Process Parameter

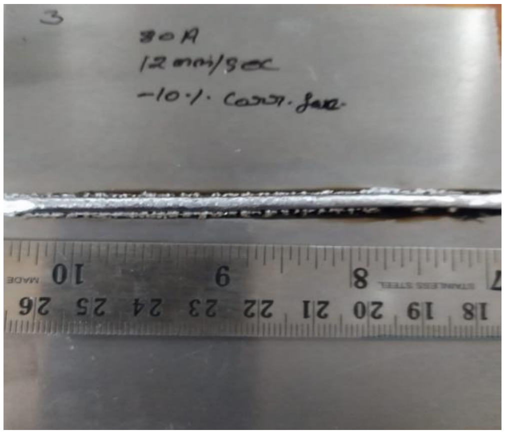
Sample No.	I (A)	W.S (mm/s)	A.C.F (%)	CTWD (mm)
C 1	80	6	0	10
C2	80	9	-5	10
C3	80	12	-10	10
C4	90	6	-5	10
C5	90	9	-10	10
C6	90	12	0	10
C7	100	6	-10	10
C8	100	9	0	10
C9	100	12	-5	10
I = Current, W.S = Welding Speed, A.C.F = Arc Correction Factor, Flow Rate Of Shielding Gas = 15 Ltr/Min				

3.4 Experimental Works



C-1

C-2

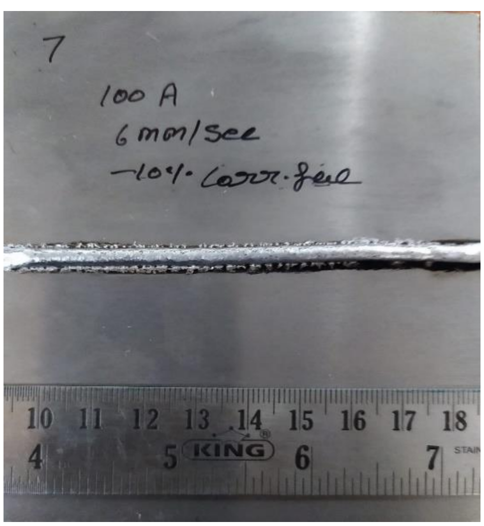


C-3

C-4

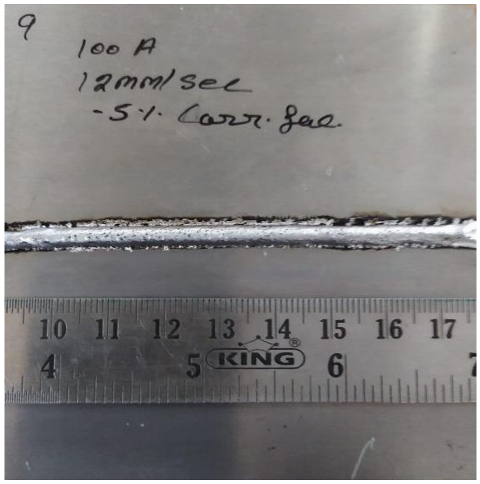
C-5

C-6



C-7

C-8



C-9

CHAPTER 4: TESTING METHODS

4.1 Tensile Strength Testing

Any material's use in an engineering application determined by its mechanical qualities. Such as tensile strength, elongation, and so on. These properties can be determined through tensile testing any new joint that is established must documented since it stabilises the new joint combination. As compared to what is currently on the market the tensile strength of a substance only assessed by conducting tests on it. A Universal Testing Machine used to determine the tensile strength of a material (UTM).

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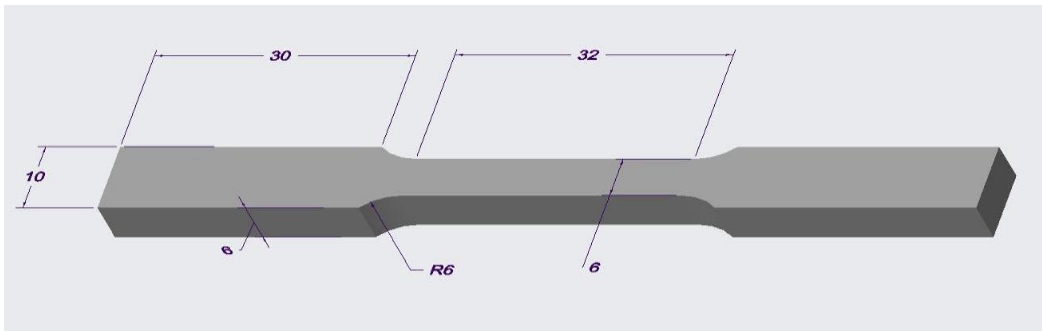


Fig. 4.1. Tensile testing specimen as per ASTM E8 std.

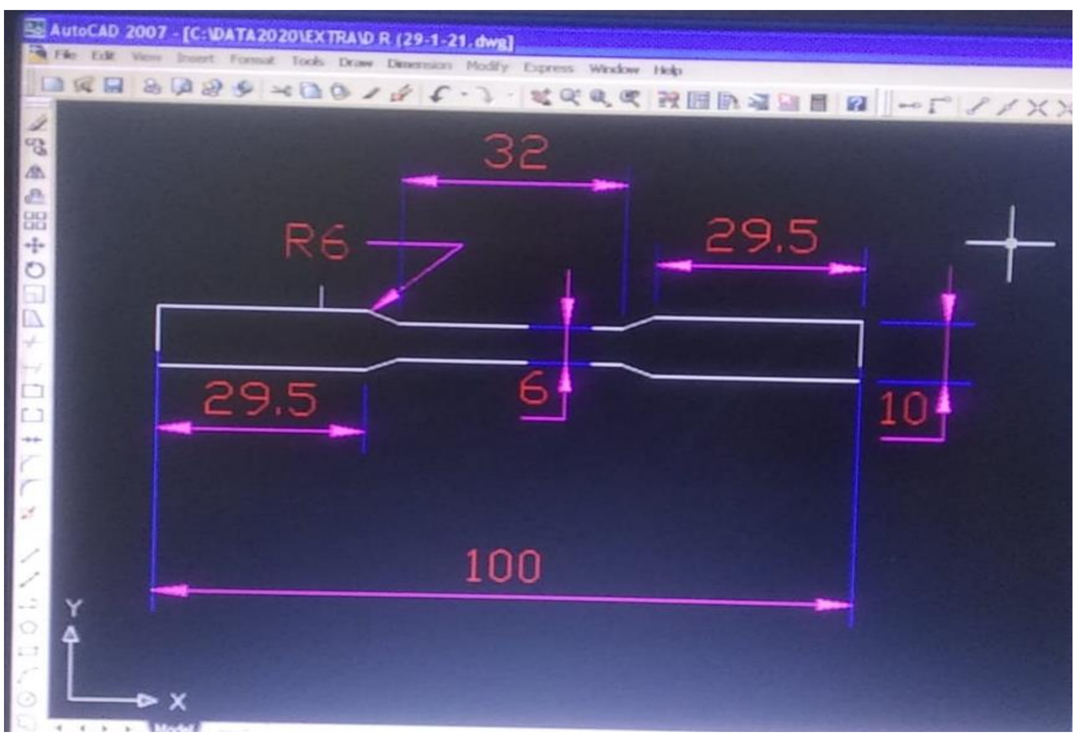


Fig .4.2 CNC Wire Cutting Programing Sub Sam pal as Per Tensile testing Specimen as per ASTM stander

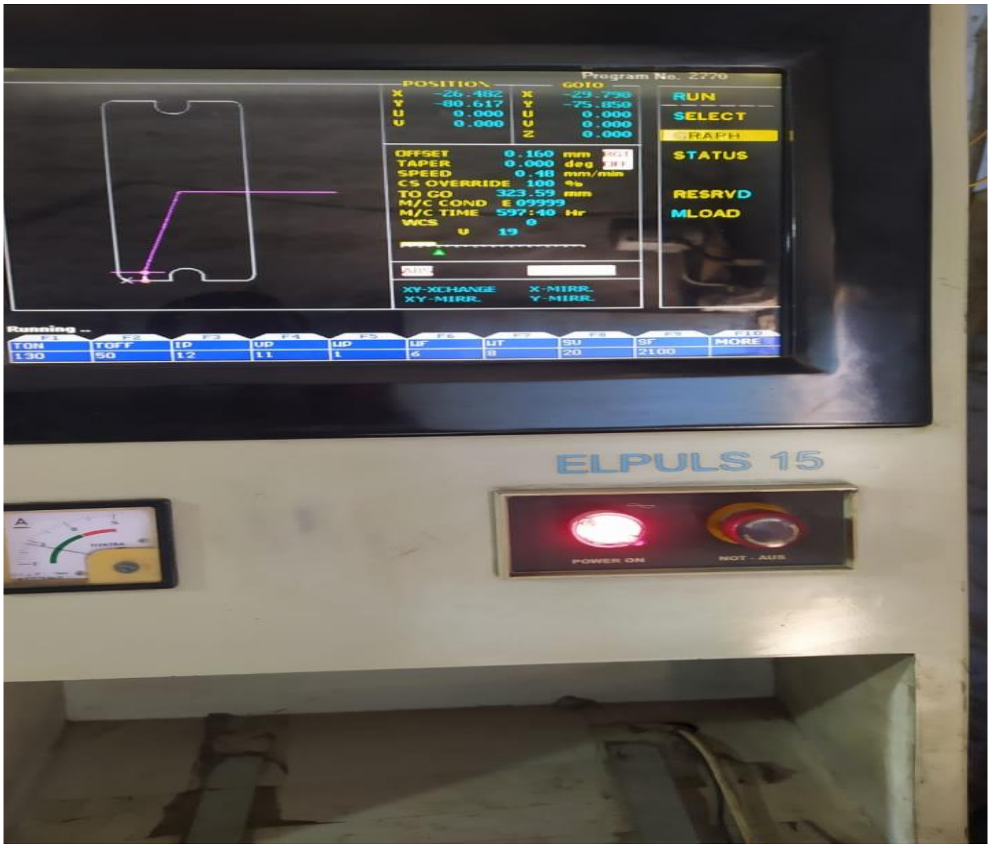


Fig. 4.3 Control Panel CNC EDM wire cutting Machine

Fig.4.4 EDM Wire Cutting under Process.

The wire EDM procedure used to cut the specimen for tensile testing according to ASTM standards, as shown in Fig. 4.1 the welded plates from which the specimens cut according to specifications shown in Fig.4.2. The sub-size 100 mm tensile specimen had a gauge length of 32 mm and a gauge width of 6 mm.

Fig.4.5. Tinius Olsen Ultimate Testing Machine

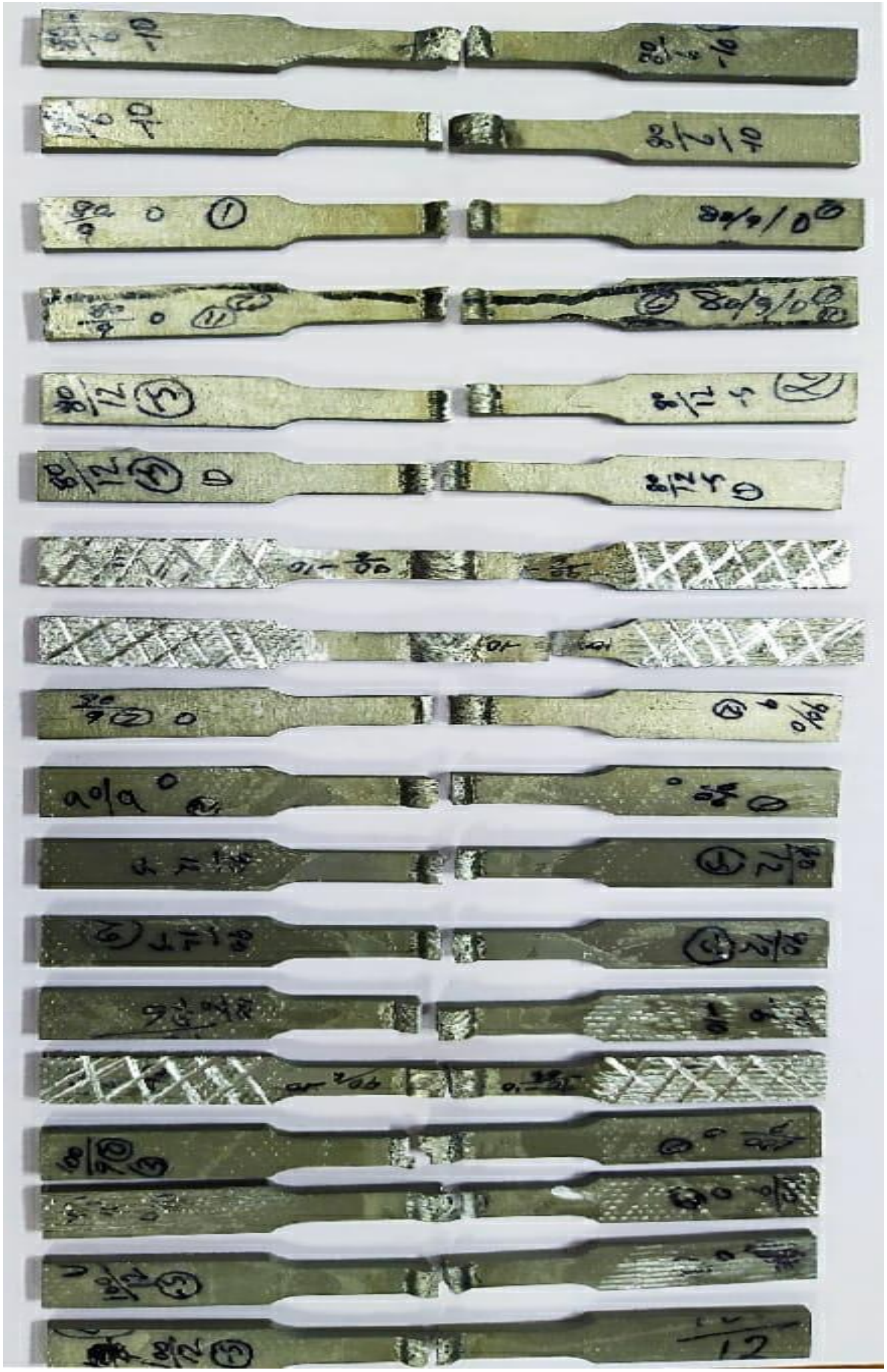


Fig.4.6 Sapsimans after Braking in UTM Machine

The specimens put through their paces across a variety of metrics in order to determine their strength. The mechanical strength was determined at a strain rate of 1 mm per minute at room temperature using a Tinius Olsen Ultimate Testing Machine H50KS with a 50 KN capacity, as illustrated in Fig. 4.5. The yield stress and ultimate tensile stress, as well as other conventional tensile parameters, were determined. As per show in fig No.4.8 UTM and current graph, the maximum UTM is 206Mpa.

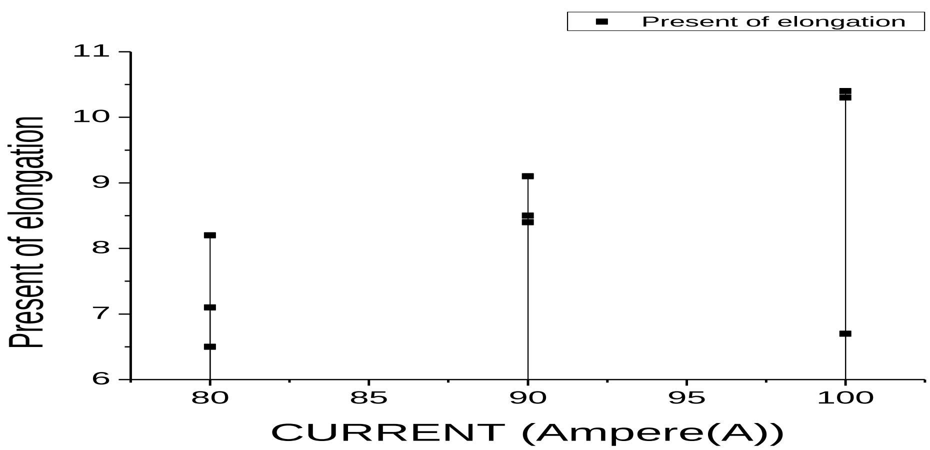


Fig.4.7 Present of elongation V/S Current Graph.

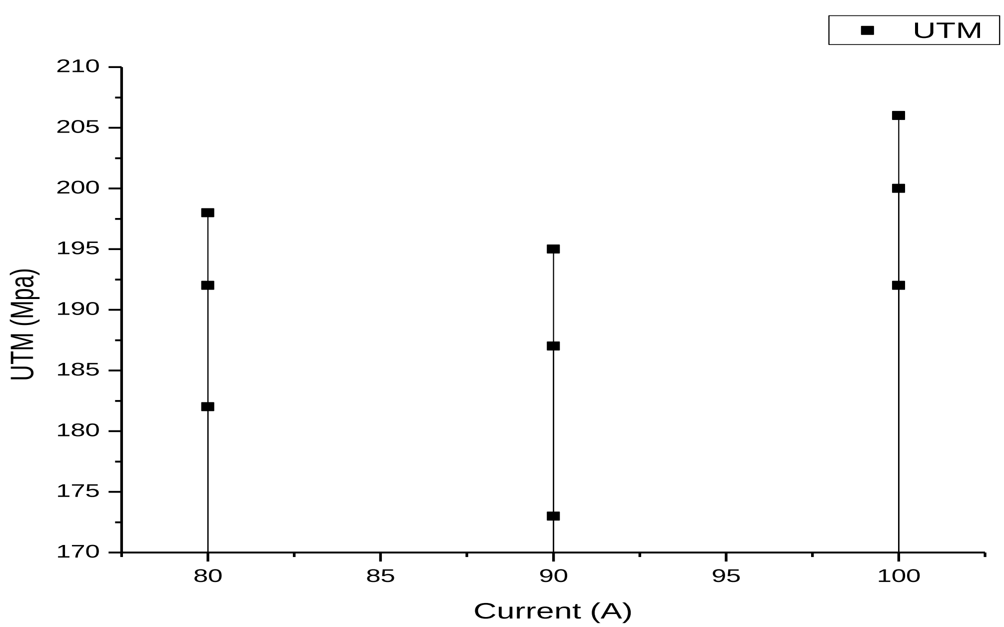


Fig.4.8 UTM V/S Current Graph.

4.2 Micro-Hardness Testing

The hardness of a joint surface determined by micro-hardness testing, which is a measurement of the surface's resistance to indentation or penetration. Micro hardness in a welded joint measured over a small test sample or a small region to determine the hardness of the welded surface. During Micro hardness testing, a Vickers diamond indenter pushed into the surface of the welded part using a penetrator and a slight stress. When a bag is placed on a surface, it indents, causing a lasting deformation and leaving an imprint of the shape of the indenter. The applied pressure monitored, and the test conducted under controlled settings for a set period, yielding the following results, the surface has a square form in the shape of the indenter. The Vickers hardness value calculated using the formulas after measuring the diagonal. The Micro hardness test carried out using an instrumented indentation tester, as shown in Fig.4.10.

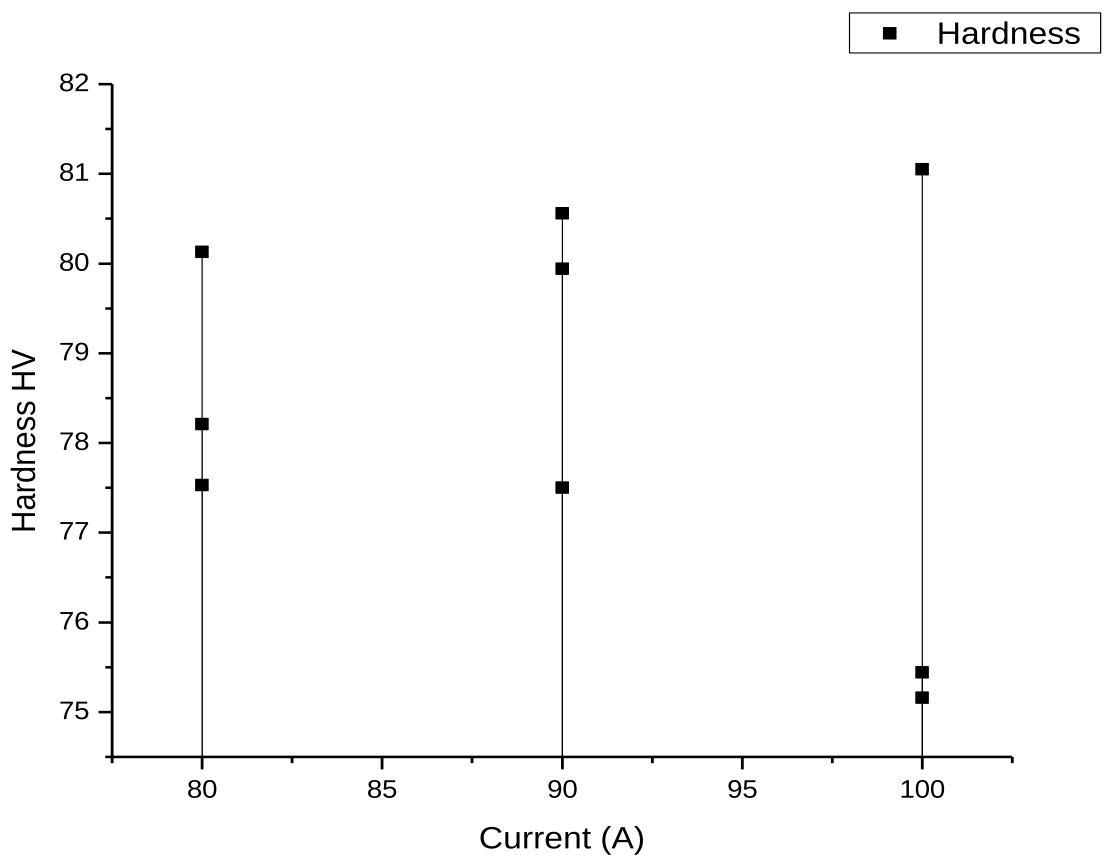


Fig.4.9 Hardness V/S Current Graph.

The welded portion cut into 10mm x 10mm pieces and tested for micro-hardness in the cross-sectional view. 120, 180, 240, 600, 800, 1000, 1200, 1600, 1800, and1800 grit emery paper in various sizes were used to dry polish it. Specimens were ground correctly for around 2-3 minutes for each grade.

After that, the polishing done wet, with a steady water supply to reduce friction and ensure a scratch-free surface. The surface polished using alumina powder and a velvet cloth. To create a sparkling mirror-like surface, alumina powder utilized. A micro hardness show in a fig.4.9. Hardness V/S Current Graph show Variable current its variable hardness.

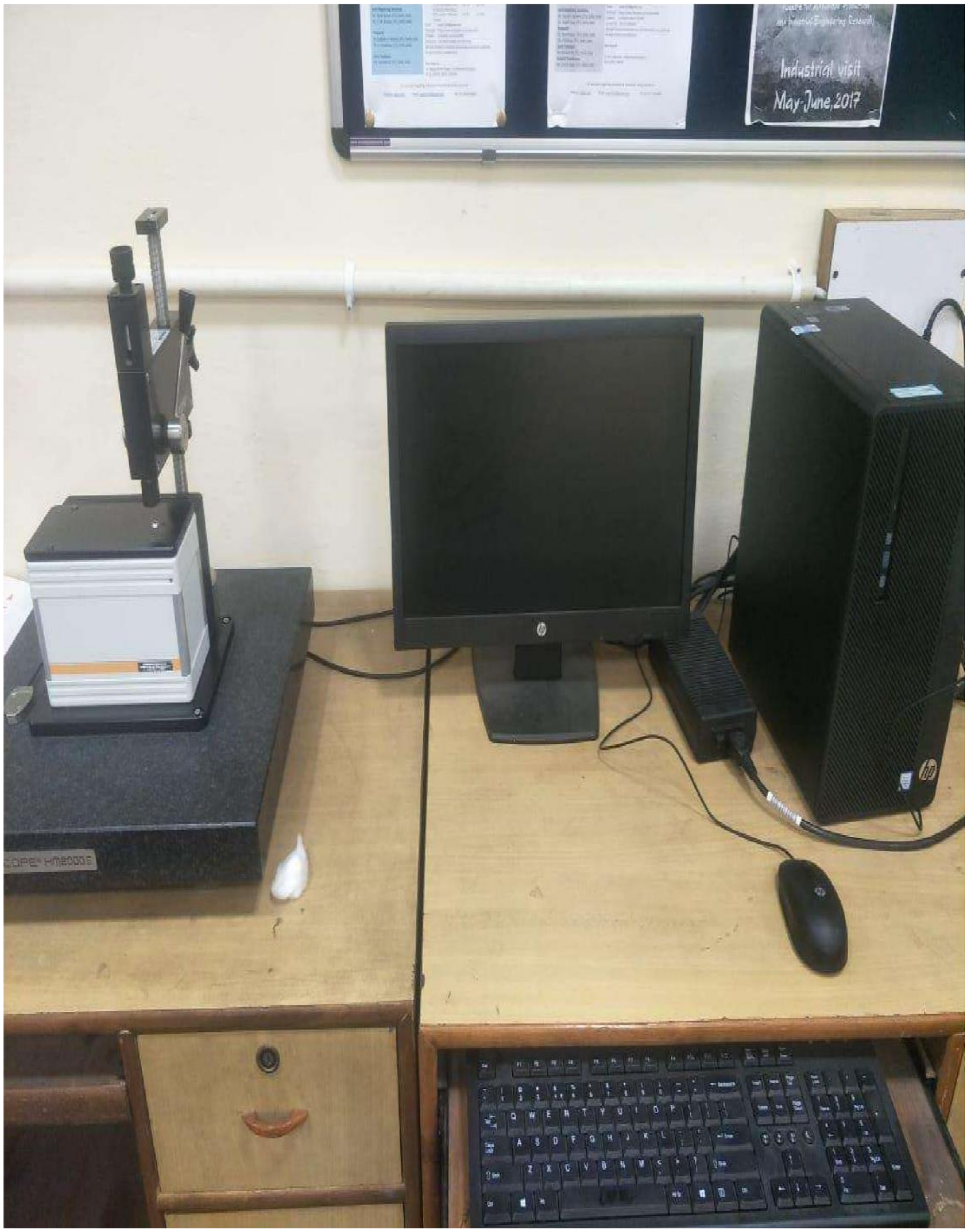


Fig.4.10. micro hardness analyser

4.3 Residual Stress Measurement

A -X360s X-ray residual stress analyser used to calculate the residual stress, which is the internal stresses that occur owing to non-uniform temperature distribution, as illustrated in Fig.4.10 a sensor unit connected to a computer for output results, as well as a power system. The residual stress is calculated by the sensor unit using the cos alpha method.

Fig.4.11. μ-X360s X-ray residual stress analyser

Although several non-destructive techniques for evaluating residual stresses, X-ray diffraction is ideal for thin plates due to its penetration of around 10m and spatial resolution of 10m to 1mm. On both plates, some positions designated, including the base plate (BM), heat affected zone (HAZ), and weld zone (WZ). Along with the weld bead, several spots also noted. X-ray irradiation used to obtain a complete debye-Scherrer ring at each point. These rings estimated the strain, and the residual stress value at each place calculated as a result. As shown in Fig.4.11, residual stress calculated at five points for all samples. Shown in the Fig. 4.13 Resldjal StressV/S Current Graph the variable current are variable Resldjal Stress.

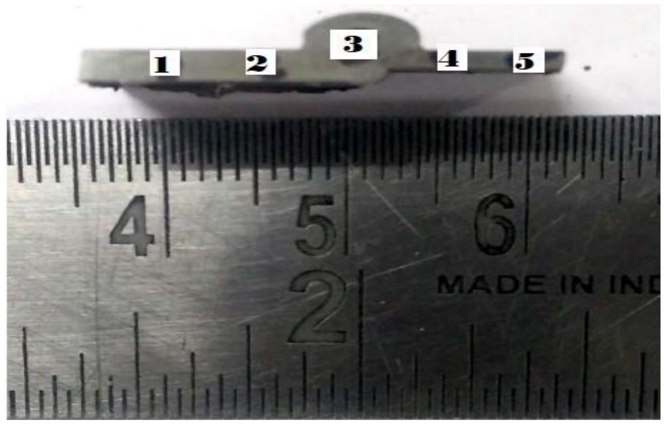


Fig.4.12. Sample for Residual Testing

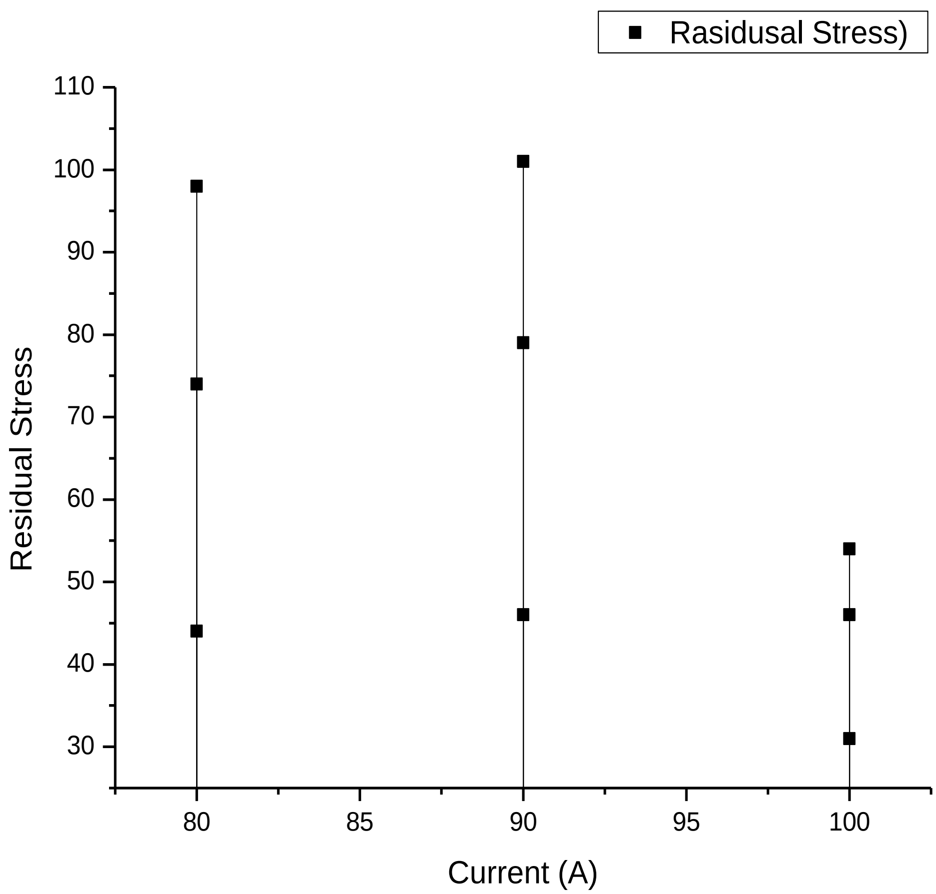


Fig.4.13 Resldjal StressV/S Current Graph

CHAPTER 5: RESULT AND DISCUSSIONS

5.1 Tensile Strength

The evaluation of the optimal joint aided by testing each sample at various parameters. Table No. 3.5 Displays the specimens for tensile testing following EDM wire cutting, and Table No.5.1.Shows the specimen's breaking point after the ultimate tensile strength is determined. Welding is the process of melting and solidifying the base metal.

Welding of aluminium 6061T6 materials entails the fusion of two materials with differing rates of solidification. In this turn, microstructure alters and grain size. Because of the alloy genesis, the weld zone bead has high strength. The filler wire and the base of molten metal form this alloy, and it is the most durable. Table 5.1 shows the tensile strength and elongation response data for the welded sample produced using the L9 orthogonal array. At 206 MPa, the maximum tensile strength obtained. [Prakash et.al. (2017)] The tensile strength of sample Aluminium 6061T6 and 3.18 mm sheets spot welded specimen was 206 MPa, according to the study. Maximum tensile strength of 206 MPa has achieved in this study. With a welding Current 100(A), welding speed of 6 mm/s and a -10 % arc length correction factor, the strength was reached. The distance between the end of the filler wire and the work piece material measured in arc length. An arc length correction factor also an important process parameter to determine and maximize the tensile strength of welded material. Show that samples C2, C3, C4, C5, C7, and C7 with Negative arc length correlation have a considerable improvement in strength. The response of variables used to create main effect plots. The main effect plots show the impact of input variables on the variation of individual output responses. The input parameters at various levels displayed on the x-axis, while the mean average of the responses was on the y-axis in the main effect plots. The mean effect plot derived by the shown in Fig.5.1 It demonstrates an increase in the trends or values for which the highest quality response received; with an increase in the current value and a drop in the welding speed, the maximum strength, and hardness increase.

Table 5.1. L9 Orthogonal array with Response Variables.

SAMPLE NO.	I (A)	W.S (mm/s	A.C.F (%)	TENSILE STRENGTH (MPa)	ELONGATION (%)	Hardn ess HV	R.S
C1	80	6	0	192	8.2	78.21	98
C2	80	9	-5	182	6.5	77.53	74
C3	80	12	-10	198	7.1	75.16	44
C4	90	6	-5	173	8.4	80.13	-46
C5	90	9	-10	187	9.1	79.94	101
C6	90	12	0	195	8.5	79.54	79
C7	100	6	-10	206	10..43	80.56	54
C8	100	9	0	200	6.7	73.50	31
C9	100	12	-5	192	10.3	75.44	-46

A negative Arc length correction factor produces a high-quality weld bead.

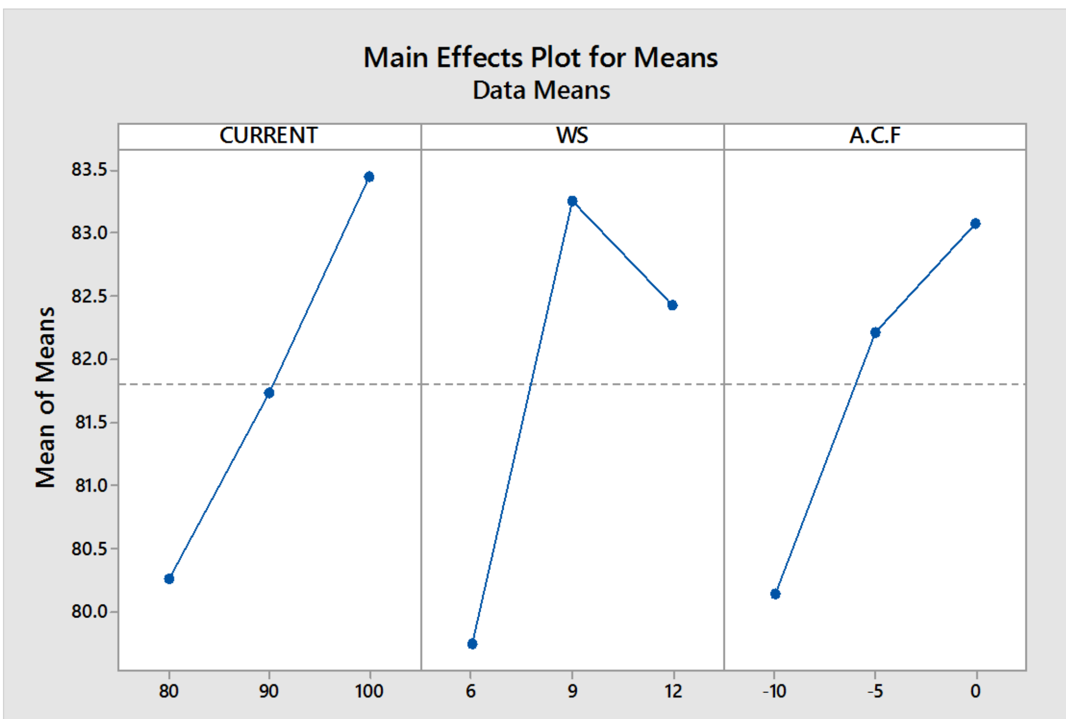


Fig.5.1 Main Effects Plots for Response Variables

An S/N ratio primary effect graphic has also generated, revealing the best settings for achieving the best result. The S/N ratio is a way of determining a character's ability to influence external or uncontrollable noise components. The effect of the S/N plot on the replies depicted in Figure 5.2. According to the plot, the best quality weld is created with 100 A current, 6 mm/s weld speed, and a -10 % arc length correction factor.

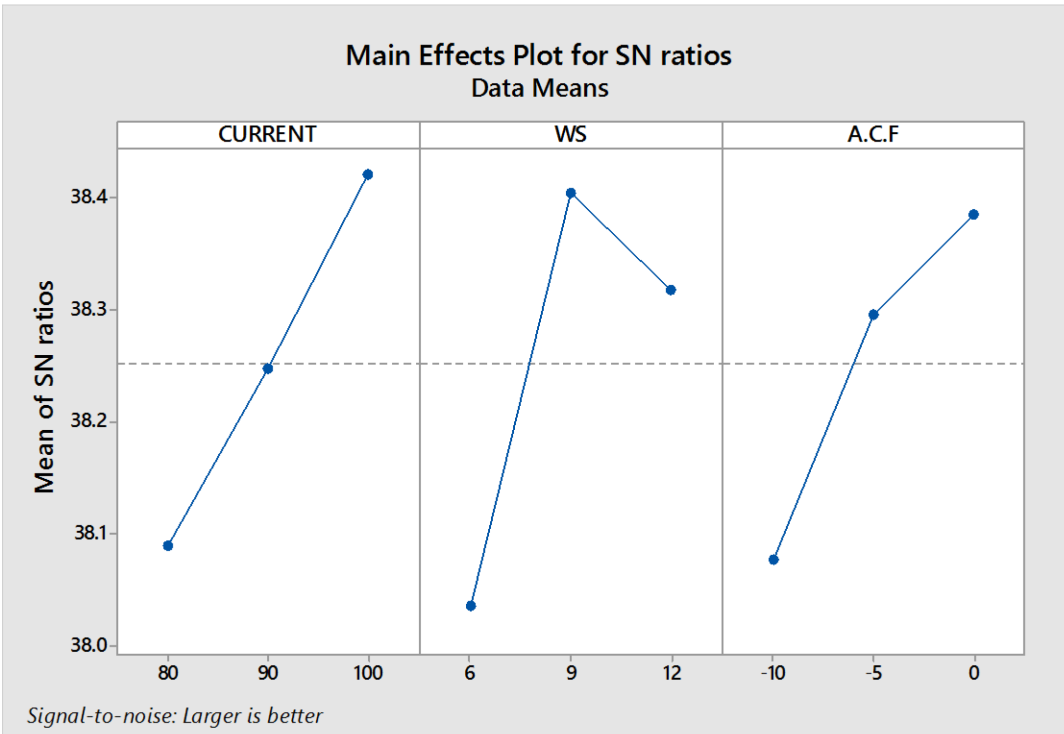


Fig. 5.2 S/N Plot for the Optimal Parameter

When necking or surface slip occurs, the tensile fracture of the welded specimen clearly displays the creation of a cup-cone configuration. When similar material thicknesses joined, heat distribution is equal, and thicker sheets receive more heated than thinner sheets. Because of these findings, the greatest penetration occurs in thicker plates and less occurs in thin sheets. [Hasanbasgolu et.al. (2007)] and [Marashi et.al. (2008)] Necking of lower thickness sheets seen during spot welding of similar thickness materials. Due to reduced force, the thinner sheets suffer from severe necking. Due to plastic deformation in the thinner region, the finite element results revealed a concentration of stress in the thinner section. [Darwish et.al. (2004)]. because all of the failures occurred in the heat-affected zones (HAZ) of the thinner segment of the aluminium 6061T6 material, the welded joint's efficiency was 100 percent. These findings demonstrated that CMT welding has low heat input characteristics, resulting in stronger connections for similar thicknesses.

5.2 Micro-Hardness (HV)

with regard to the locations, displays the micro-hardness variations for the welded at 100 A current, 6 mm/s welding speed, and -10 % arc length correction factor. For aluminium 6061T6 sheets, a higher hardness value observed in the welded region and a decreasing trend in the base metal (BM) and heat-affected zone (HAZ). The micro-hardness of aluminium 6061T6, respectively, is 80.56 HV. In the heat-affected zone (HAZ), the micro-hardness of Aluminium, 6061T6 drops to 95 HV and 80.56 HV, respectively. Friction stir welding of 6061T6 softens HAZ due to the recovery of more refined grains, according to [Sabooni et al. (2015)]. The hardness and strength of a material connected with grain size, according to the hall-petch connection. The coarser granules in HAZ cause a drop in micro-hardness. The tensile qualities of the material related to the hardness of the material. During tensile testing, the poor hardness of HAZ played a major role in the development of cracks and fractures in this area.

The hardness begins to build as you move closer to the weld. The enhanced refining grains of aluminium 6061T6 are responsible for the rising trend between HAZ and WZ. Less heat input leads to a more difficult rise in the weld zone. The hardness of the weld zone increased by the diffusion of chromium between the two stainless steel sheets. The C7 sample, which was welded at the greatest current (100 A), moderate welding speed (6 mm/s), and a -10% negative arc length correction factor. Results that are similar for samples C2, C3, C4, C5, C7 and C9.

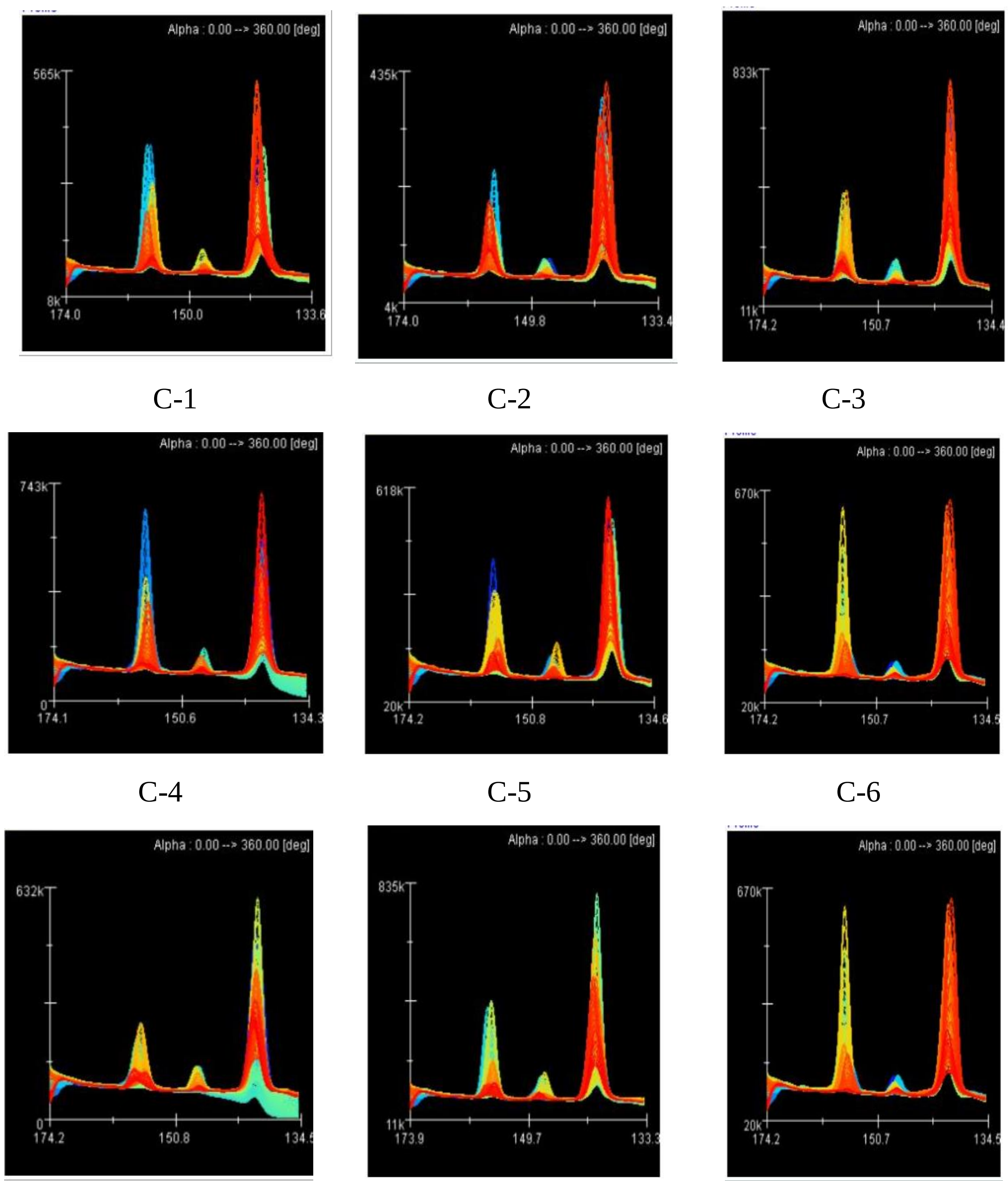
5.3 Residual Stress (MPa)

Shows position 3 under the X-ray diffract or. Standard chromium (Cr) material X-ray tube used having collimator size of 1mm diameter with 30kV and 1mA specification.

Fig.5.3 Sample C7 under X-Ray Diffractor

Residual stress variation at different zones of sample C7 welded at 100 A, 6 mm/s welding speed and -10 % arc length correction factor.

In the absence of temperature gradients or external loads, residual stresses are the stresses that remain within a body or a material after manufacturing and material processing [Wan et al. (2017)]. The obtained residual stress values for the C7 welded sample. In the base plate and weld zone, compressive residual stress created. In the heat-affected zone, tensile residual stress created (HAZ). Because of the low heat input during the CMT process, the upper and lower weld zone surfaces solidify faster than the material within the weld pool and the heat-affected zone due to rapid cooling (HAZ). The differential thermal distribution caused by the uneven rate of cooling causes expansion in the heat impacted zones and contraction in the weld zone. Because of the contraction of the grain size, residual stress in the weld zone tends to become negative (compressive) (fine grains). In specific ways, compressive stress is good since it helps to prevent the creation of fractures and notches. In the weld zone, there was also relief from stress corrosion cracking. The heat-affected zone (HAZ) has a positive or tensile residual stress due to the sluggish cooling and coarser grains. This tensile residual stress, which exists in the heat-affected zone, is harmful and causes fatigue failure. There is a risk of fracture initiation, and as a result, the material fails most of the time in this area, resulting in mechanical property degradation.



C-1 C-2 C-3

C-4 C-5 C-6

C-7 C-8 C-9

Fig.5.4 Residual stress profile VS alpha an angle for Variable Process Parameters and Base metal.

Figure 5.3 depicts the residual stress profile for CMT welding processes at different process parameters show in Table 3.5 All of the samples' residual stress peaks are between 155 ° to 160 °. The fusion zone and weld bead have red shade peaks, indicating a more significant concentration of residual stresses. The presence of blue shade peaks indicates that there are no leftover tensions.

CHAPTER 6: CONCLUSIONS

The paper investigates the mechanical characteristics of welded joints of similar aluminium AA6061T6 thin sheets by cold metal transfer welding technique. The below mentioned the conclusions drawn from this experimental study: -

1) CMT welding is a suitable technique for welding thin aluminium plates of similar grades and same thick ness.
2) The highest strength equal to 206 MPa and highest hardness 80.56 HV achieved at 100 A current, 9 mm/s welding speed, and -10 % arc length correction factor.
3) The results obtained by the experimental work is analysed and it validates the result obtained by Taguchi L9 optimization technique.
4) Low heat input and rapid cooling in CMT welding results in compressive (negative) residual stress in the weld zone making it the strongest and hardest zone.
5) The HAZ is the most affected portion of the joint due to coarser grains and tensile residual stress because of the slow cooling here thus making it a hotspot for failure. The necking starts in the thinner section and results in cup-cone shaped fracture.

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