بسم الله الرحمن الرحيم

Sudan University of Science and Technology

Faculty of Engineering

Aeronautical Engineering Department

Study of Using Plasma Welding techniques in A/C Parts Instead of Riveting

Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Bachelor (BSc Honors) in Aeronautical Engineering

Prepared by:

1. Elhibir Rahmtalla Abdelgadir Elamin
2. Khalid Salah-Eldeen Sir-Elkhatim Seidahmed
3. Mohamed Faroog Mohamed Bushara

Supervised by:
General Eng. Abdulraheem Saad Omer

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الآية

﴿ لَقَدْ أَرْسَلْنَا رُسُلَنَا بِالْبَيِّنَاتِ وَأَنْزَلْنَا مَعَهُمُ الْكِتَابَ وَالْمِيزَانَ لِيَقُومَ النَّاسُ بِالْقِسْطِ وَأَنْزَلْنَا الْحَدِيدَ فِيهِ بَأْسٌ شَدِيدٌ وَمَنَافِعُ لِلنَّاسِ وَلِيَعْلَمَ اللَّهُ مَنْ يَنْصُرُهُ وَرُسُلَهُ بِالْغَيْبِ إِنَّ اللَّهَ قَوِيٌّ عَزِيزٌ ﴾

سورة الحديد – الآية 25

Abstract

This research aimed to study the plasma welding technology in aircraft structure instead of riveting, and prove that using plasma welding leads to noticeable reduction in aircraft weight, and offers better strength properties when compared with rivets.

This research followed the analytical and experimental approaches to prove that the plasma welding has better strength properties than riveting.

Two models of passengers' compartment were fabricated once by fitting the skin to the frames by using rivets and other by using plasma welding and then the strength properties of two models were compared.

It had been proved that the plasma welded model had much higher strength properties than riveted model through destructive tests for riveted and plasma welded samples.

مستخلص البحث

هدف هذا البحث هو دراسة إستخدام تكنولوجيا لحام البلازما في هياكل الطائرات بدلاً عن البرشام ، وإثبات أن إستخدام لحام البلازما يقود إلى تقليل ملحوظ في وزن الطائرة ، ويوفر خصائص متانة أفضل مقارنة بالبرشام.

إتبع هذا البحث المنهج التحليلي والتجريبي لإثبات أن لحام البلازما له خصائص متانة أفضل من البرشام .

تم تصنيع نموذجين لمقصورة الركاب مرة بتثبيت الغطاء الخارجي لمقصورة الركاب مع دعامات الهيكل بإستخدام البرشام ، ومرة أخرى بإستخدام لحام البلازما ، وتمت مقارنة خصائص المتانة للنموذجين.

تم إثبات أن النموذج المثبت بلحام البلازما له خصائص متانة أفضل من النموذج المبرشم من خلال الإختبارات الإتلافية لعينتين إحداهما بإستخدام لحام البلازما والأخرى بإستخدام البرشام .

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- Technical Sergeant. Mohamed Hassan Abdulraheem.
- Technical Sergeant. Mohamed Hussien Abdulraheem.

We are outstandingly indebted and extremely grateful to anyone who encouraged us.

Dedication

To our loving mothers … fathers

our brothers …

faithful friends ...

and honorable teachers ...

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List of abbreviations

A\C	Aircraft
DC	Direct Current
DT	Destructive Test
EBW	Electron Beam Welding
FRW	Friction Welding
FSW	Friction Stir Welding
FW	Flash Welding
GMAW	Gas Metal Arc Welding
GTAW	Gas Tungsten Arc Welding
HAZ	Heat Affected Zone
LBW	Laser Beam Welding
NDT	Non Destructive Test
PAW	Plasma Arc Welding
RSW	Resistance Spot Welding
TIG	Tungsten Inert Gas

List of symbols

Symbol	Description
A	Cross-sectional area of rivet
D	Diameter of rivet
ed	Edge distance
Fb	Bearing strength of metal
Fs	Shear strength of rivet
Fw	Weight of single fastener
N	Number of rivets
N f/s	Number of fasteners per stringer
N p/s	Number of panels per section
N s/f	Number of sections per fuselage
N s/p	Number of stringers per panel
P	Load leading to failure
t	Thickness of the material
W	Total weight reduction of aircraft
W s/s	Weight of sealant per stringer
Wf1	Weight of rivet reduction
Wf2	Weight of high lock reduction
Ws	Weight of sealant reduction

CHAPTER ONE

INTRODUCTION

CHAPTER ONE: INTRODUCTION

1.1 Overview

This era is characterized by domination of modern science on all aspects of life and on the fate of the Nations. plasma technology considered as the key of development of era technology either in plasma of materials or Laser plasma.

Definitely the progress in plasma technology will lead the world countries-especially Arab countries-to shed lights on this relatively recent technology. Whereas the plasma technology is globally recognized as a clean and safe source of energy.

The current researches tend toward making this source more economically. The plasma technology has a variety of applications such as Painting and cleaning the metal surfaces, cutting and welding of metals, television screens, the preservation of the environment, welding of aircraft structure, and other industrial applications.

1.2 Aims and Objectives

1.2.1 Aims

Getting good grasp of welding technologies and improve them to develop cheaper, long lifetime, and reliable welding techniques.

1.2.2. Objectives

- Reduction of A/C weight by using plasma welding instead of Riveting.
- Prove that the plasma welding has better rigidity and solidity characteristics than Riveting.

1.3 Problem Statement

Study the reduction of aircraft weight by using plasma welding instead of riveting, and maintaining the aircraft structure from buckling which resulting from using riveting.

1.4 Proposed Solution

Using plasma welding technology to reduce aircraft weight.

1.5 Research Methodology

Passengers' compartment riveting model and plasma welding model had been designed by Catia software then fabricated, then strength properties of the two models had been compared as a case study

1.6 Research Outline

- **CHATER ONE INTRODUCTION:**
  Consists of overview, aims & objectives, problem statement, proposed solution, and research methodology.
- **CHAPTER TWO LITERATURE REVEIW:**
  Consists of aircraft rivets, metal bonding, welding of aircraft structure especially plasma welding.
- **CHAPTER THREE RESEARCH METHODOLOGY:**
  Consists of design & fabrication of riveting and plasma welding models, weight of rivets for selected aircraft, and strength of riveted joint.
- **CHAPTER FOUR RESULTS AND DISCUSSION:**
  Consists of results and discussion obtained from chapter three.
- **CHAPTER FIVE CONCLUSION AND RECOMMENDATIONS.**

CHAPTER TWO
LITERATURE REVIEW

CHAPTER TWO: LITERATURE REVIEW

2.1 Techniques of joining aircraft structure

The aircraft structure is composed of sheets of metals fastened together by several methods such as riveting, bonding, and welding. Riveting is the most common joining technique used in aircraft, but it encountered with various problems such as increasing the weight of A/C and concentration of stresses in particular points, so that to overcome these problems, bonding and welding techniques were developed to join A/C structure.

2.2 Aircraft Rivets

A rivet is a metal pin with a formed head on one end. The shank of the rivet is inserted into drilled hole then deformed by a hand or pneumatic tool. Aircraft rivets are manufactured to much higher standards and specifications than rivets manufactured for general use for securing fittings to various parts of the aircraft.

The rivets may be made from very different materials according to the type of material being riveted, hence the material used for the majority of aircraft rivets is aluminum alloy. Rivets are classified into several types, but two of the major types of rivets used in aircraft are the common solid shank type, and special (blind) rivet type.

2.2.1 Solid Shank Rivets

Solid shank rivets are one of the oldest and most reliable types of fastener widely used in the aircraft manufacturing industry, they are relatively low-cost, permanently installed fasteners.

Solid shank rivets are available in several head shapes, but the universal and the countersunk head are the most commonly used in aircraft structures.

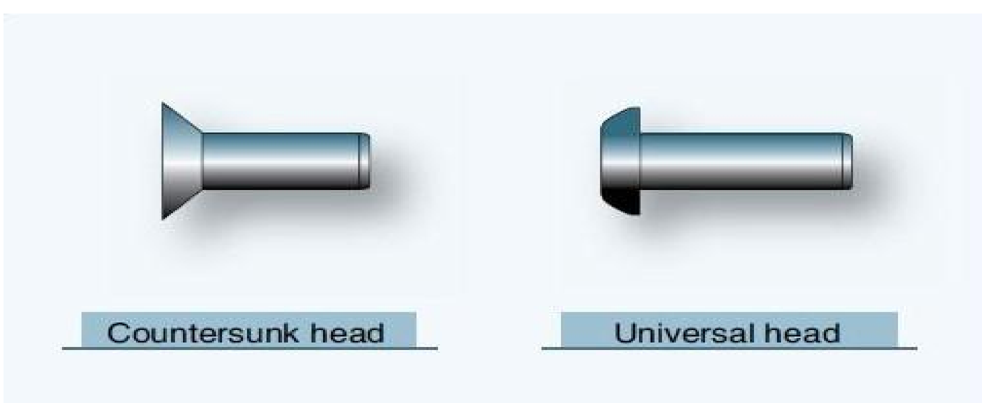

Figure 2-1 Solid Shank Rivet Styles

2.2.2 Blind Rivets

There are many places on an aircraft where access to both sides of a riveted structure is impossible, or where limited space will not permit the use of a bucking bar. Also, in the attachment of many nonstructural parts, such as aircraft interior furnishings, flooring, where the full strength of solid shank rivets is not necessary.[1]

2.2.3 Disadvantages of Rivets

Rivets have many disadvantages as follows:

1- Concentration of stresses in particular points which weakens the structure of matter.
2- Heavy weight.
3- The drilled holes weaken the structure of matter.
4- Exposure to corrosion.

The failure modes of rivets are:

- Tensile failure.
- Shear failure.
- Bearing failure.
- Tear-out failure.

2.3 Metal Bonding

2.3.1 Bonded Fuselages

Bonding of aircraft structural components is a process of joining parts by using adhesive rather than a mechanical fastener. Safety authorities will often require that adhesively bonded Structures, particularly those employed in primary load-bearing applications, include mechanical fasteners (e.g. bolts) as an additional safety precaution. Adhesively bonded joints have excellent fatigue properties. Adhesives are used extensively for secondary (not main load-bearing frame) aircraft and automotive parts, and in some cases primary parts of aircraft. This method of joining is particularly attractive for joining relatively thin skinned or walled structures, particularly where fatigue is a problem. The success of adhesive bonding depends strongly on the surface treatment of the adherents, which needs to be optimized to ensure that structural integrity is maintained under service conditions for the required life of the component. Adhesively bonded structure may in many cases be the more economic option, despite the high tooling and process costs.

Bonding has many advantages over conventional mechanical fasteners represented as follows:

1- Higher strength and longer fatigue life than conventional riveted joints.
2- More economical than rivets.
3- Low stress concentrations in adherents.
4- Lightweight.
5- Stiff connection.

[1] Aviation Maintenance Technician Handbook - General, FAA.

6- No fretting problems.
7- Smooth surface contour.
8- Damage tolerant.

In spite of the mentioned advantages of bonding, but it has some problems include:

1- the need for special inspection processes and specialized repair considerations.
2- Difficulty in bonding thick sections.
3- Difficult to inspect.
4- Prone to environmental degradation.
5- Sensitive to peel and cleavage stresses.
6- Cannot be disassembled.
7- High quality control required.
8- Difficulties in recycling materials.

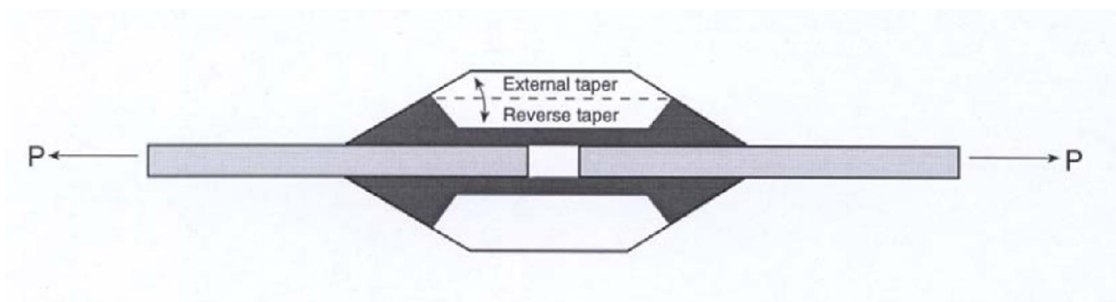

Figure 2-2 Metal bonding

Increasing the bond thickness spreads the strain over a larger volume, resulting in lower strain in the adhesive and therefore, a lower stress concentration In design of adhesively bonded joints should be given to the adherents geometry and material properties, adhesive, actual and potential failure modes, thermal properties, magnitude and nature of loading involved, and environmental conditions. [2]

There are a number of potential failure modes for bonded joints, including:

• Tensile, compressive or shear failure of the adherents.
• Shear or peel in the adhesive.
• Shear or peel in the composite near surface plies.
• Shear or peel in the resin-rich layer on the surface of the composite.
• Adhesive failure at the metal/adhesive or composite/adhesive interface.

[2] K. M. M.M.Krishna, "DESIGN AND EXPERIMENTAL ANALYSIS OF ADHESIVELY BONDED SINGLE RIVETED LAP JOINT," *INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY,* p. 8, january 2015.

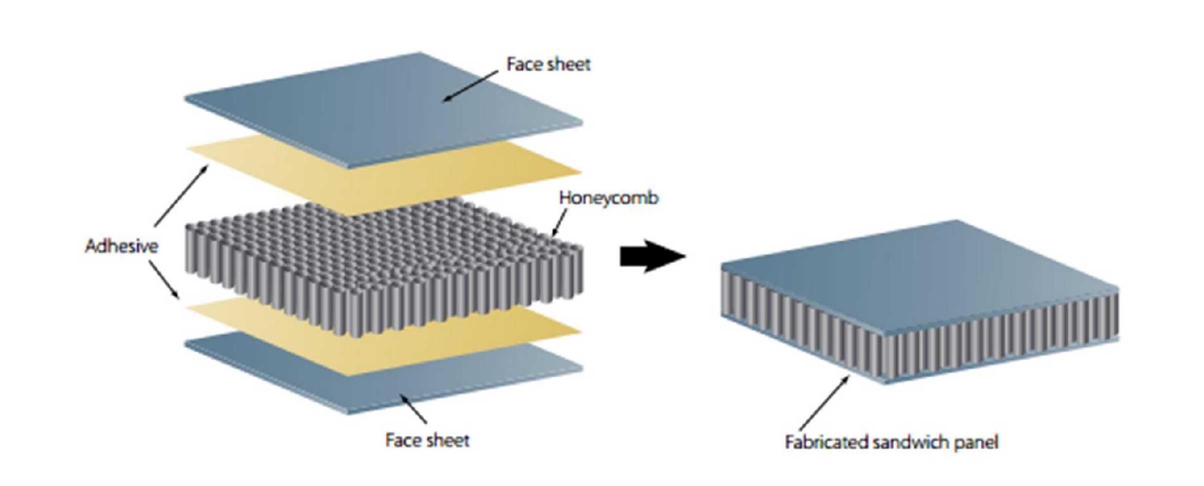

Figure 2-3 Bonding of sandwich structure

2.4 Welding of Aircraft Structure

welding is defined as a process that joins metal by melting or hammering the work pieces until they are united together, With the right equipment and instruction. Welds are replacing rivets in a variety of components in both military and civil airplanes, to improve both cost and structural integrity.

Welding has many advantages over conventional rivets represented as follows:

1- Materials saving.
2- Reduction of production duration.
3- Less noise.
4- Lower cost.
5- It is not restricted by specific thickness.
6- High efficiency for fastening.

Disadvantages of welding:

1- Difficulty of inspection by using nondestructive tests (NDT).
2- Occurrence of residual stresses & distortion.

Types of welded joints:

[1] Butt joints:

A butt joint is made by placing two pieces of material edge to edge, without overlap, and then welding. The butt joints are classified into flanged butt joint, plain butt joint, single bevel butt joint, and double butt joint.

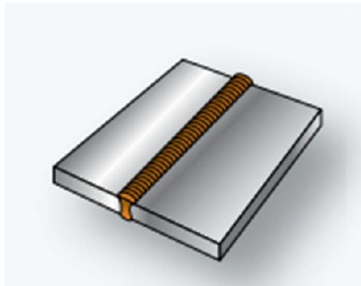

Figure 2-4 Butt joint

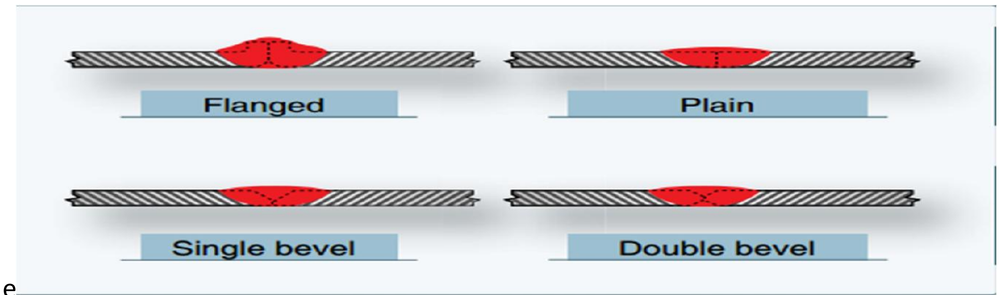

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Figure 2-5 Types of butt joints

[2] Tee joints:

A tee joint is formed when the edge or end of one piece is welded to the surface of another. These joints are quite common in aircraft construction, particularly in tubular structures. The tee joints are classified into plain tee joint, single bevel tee joint, and double bevel tee joint.

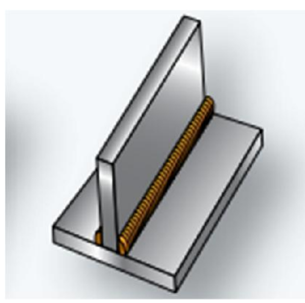


Figure 2-6 Tee joint

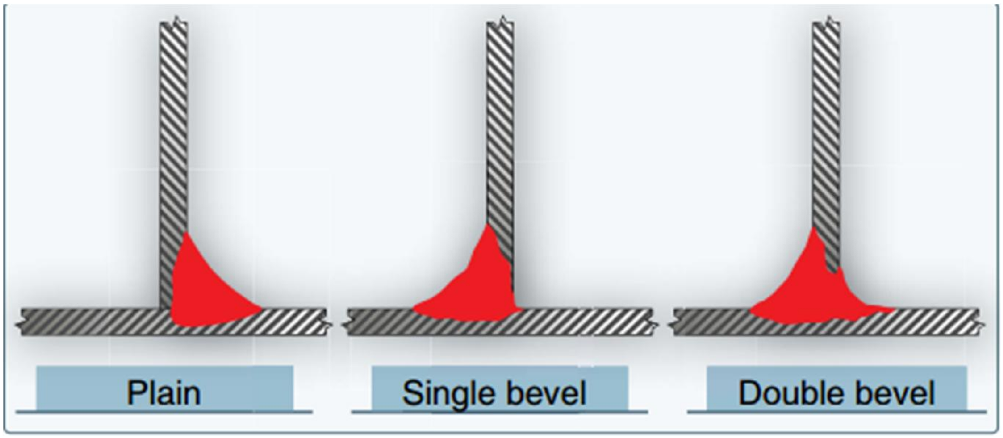
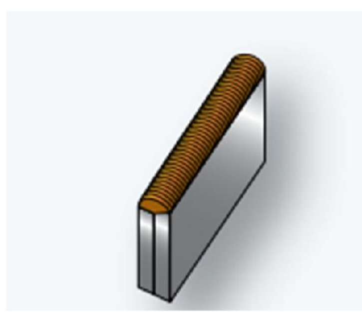


Figure 2-7 Types of tee joints

[3] Edge joints:

An edge joint is used when two pieces of sheet metal must be fastened together and load stresses are not important. Edge joints are usually made by bending the edges of one or both parts upward, placing the two ends parallel to each other, and welding along the outside of the seam formed by the two joined edges. [3]



`Figure 2-8 Edge joint

[3] Aviation Maintenance Technician Handbook - General, FAA.

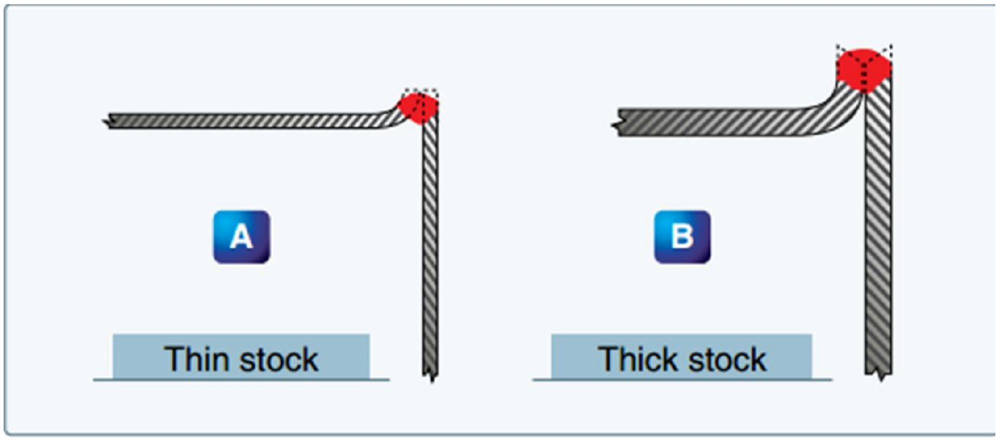


Figure 2-9 Types of edge joints

[4] Corner joints:

A corner joint is made when two pieces of metal are brought together so that their edges form the corner of a box or enclosure. The corner joints are classified into open type, closed type, and braced type.

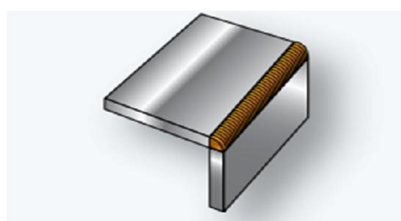


Figure 2-10 Corner joint

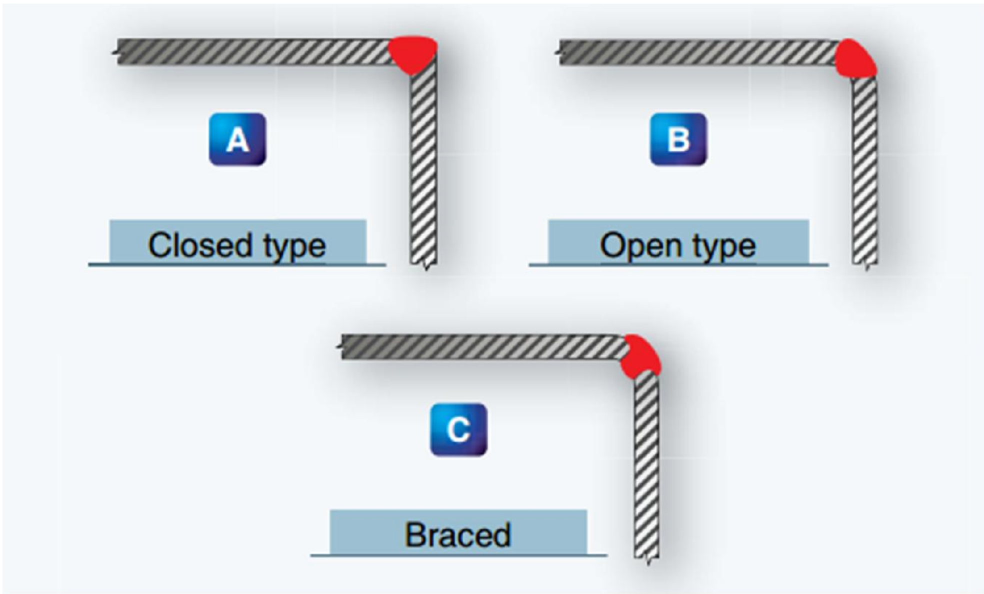


Figure 2-11 Types of corner joints

[5] Lap joints:

The lap joint is seldom used in aircraft structures, The single lap joint has very little resistance to bending, and cannot withstand the shearing stress to which the weld may be subjected under tension or compression loads. The double lap joint offers more strength, but requires twice the amount of welding required on the simpler, more efficient butt weld.

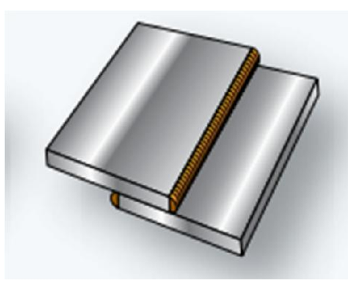


Figure 2-12 Lap joint

Figure 2-13 Types of lap joints

Characteristics of a Good Weld:

A completed weld should have the following characteristics:

1- The seam should be smooth, the bead ripples evenly spaced, and of a uniform thickness.
2- The weld should be built up, slightly convex, thus providing extra thickness at the joint.
3- The weld should taper off smoothly into the base metal.
4- No oxide should be formed on the base metal close to the weld.

5-The weld should show no signs of blowholes, porosity, or projecting globules.
6-The base metal should show no signs of burns, pits, cracks, or distortion.

2.4.1 Trends in Welding in The Aeronautic Industry

New discoveries and the availability of electric energy in 19th century leads to a huge revolution in welding technology. Welding processes are now classified by the intensity of the heat source, as indicated in Fig 2.14.

The classification in figure 2.14 leads to important trends as follows:

a) The penetration measured as the ratio of depth to width (d/w) of the weld cross section increases dramatically with the intensity of the heat source. This makes the welding process more efficient and allows for higher welding speeds.

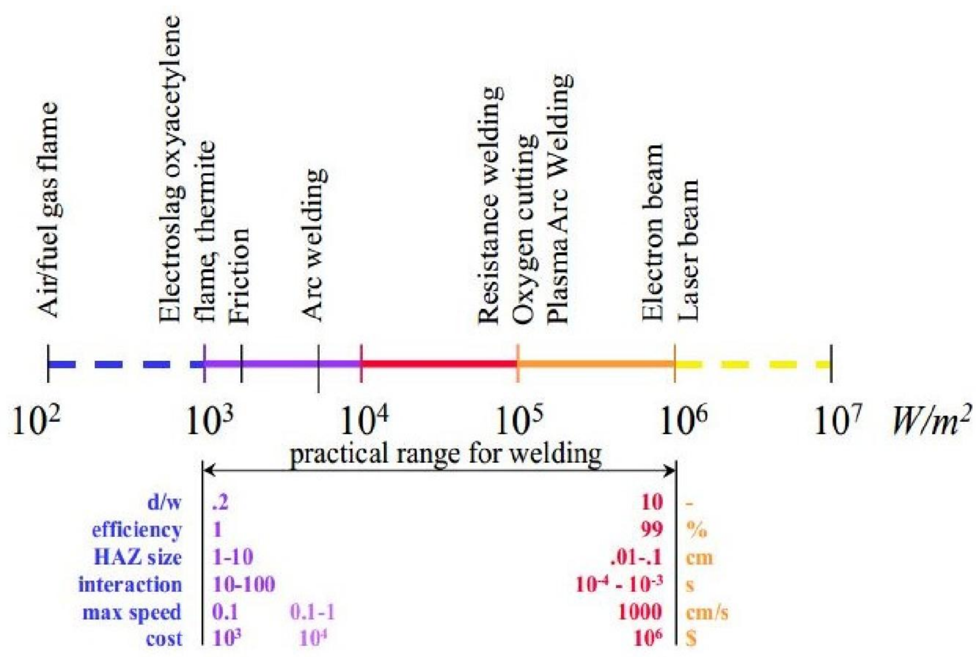


Figure 2-14 Welding processes ordered according to heat source intensity

b) A more efficient process requires less heat input for the same joint, resulting in a stronger weld, as shown in figure 2.15.

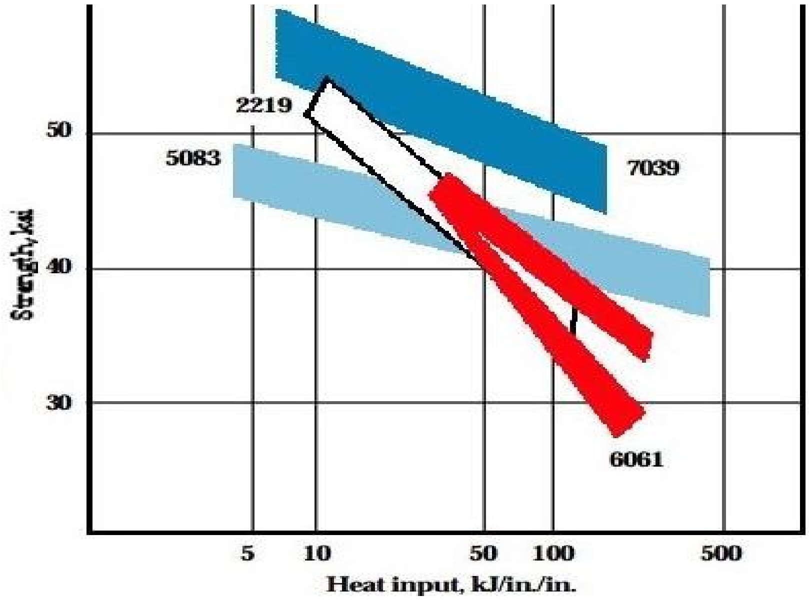


Figure 2-15 Relationship between the effective heat &the resulting weld strength

c) A smaller heat source moving at a faster speed also implies a much-reduced dwell time at any particular point. If the dwell time is too short, the process cannot be manually controlled and must be automated. The minimum dwell time that can still be controlled manually corresponds to arc welding (approximately 0.3 seconds). Heat sources more intense than arcs have shorter dwell times; therefore, they must be automated as shown in figure 2.16.

d) Welding processes with a more concentrated heat source create a smaller heat affected zone (HAZ) and lower weld distortions, However the capital cost of the equipment is roughly proportional to the intensity of the heat source.

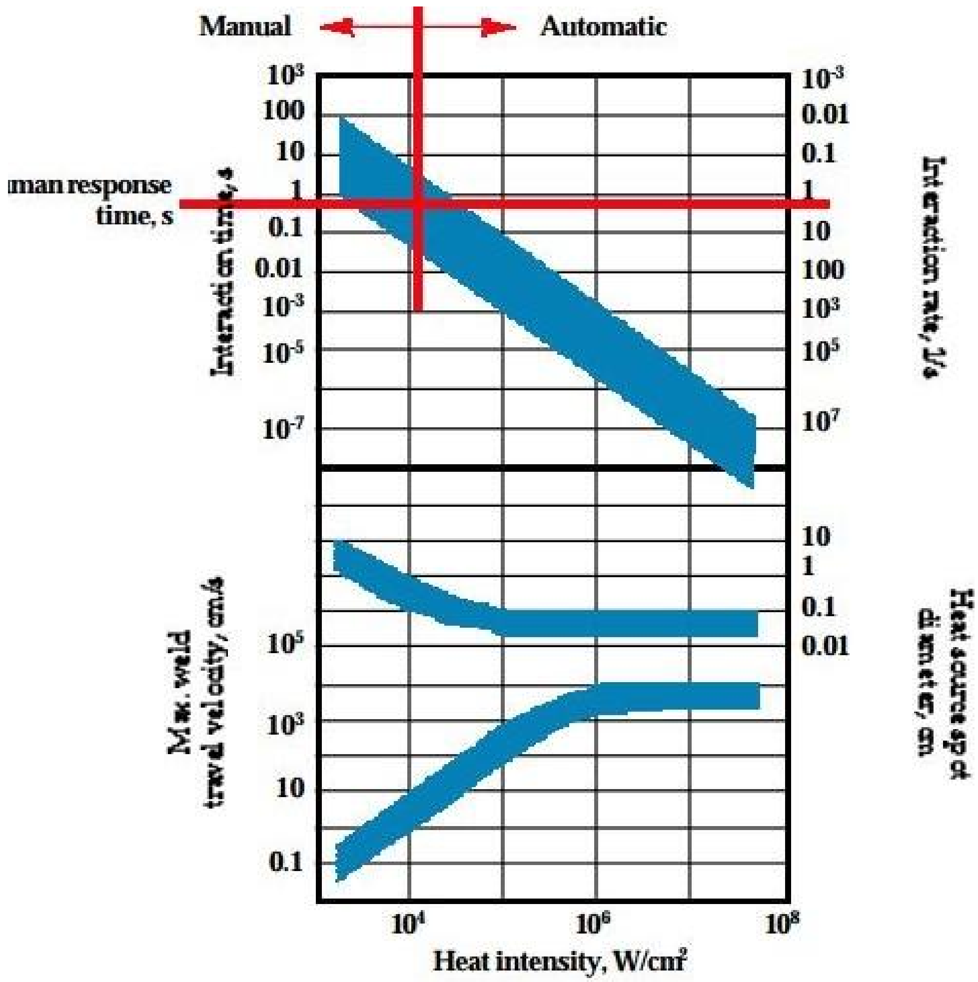


Figure 2-16 Maximum weld travel velocity, heat source size as a function of intensity of the heat source

2.4.2 Friction welding (FRW)

In this process, metals are joined through mechanical deformation without melting them, and strong unions can be obtained. This process can join components having relatively simple cross sections, especially circular. It is preferred for the joining of turbine shaft and case components, and is occasionally selected for the joining of aluminum landing gear components. This process adopted by General Electric and Pratt & Whitney as an alternative for the manufacture and repair of high-temperature alloys for jet engines. [4]

2.4.3 Friction stir welding (FSW)

This process invented by The Welding Institute, Cambridge, England in 1991. It is a solid-state process in which metals are joined through mechanical deformation.
This process can be used to weld aluminum alloys such as the 2xxx and 7xxx series, which were previously considered to be non-weldable in aircraft structures. The e strength of the weld is 30%

[4] P. F. Mendez, "NEW TRENDS IN WELDING IN THE AERONAUTIC INDUSTRY".

to 50% greater than with arc welding, and fatigue life is identical to that of riveted panels. This process has been used by Boeing to weld the booster core tanks of space launch vehicles.

2.4.4 Flash welding (FW)

FW is a melting and joining process in which joint is welded by the flashing action of a short arc and by the application of pressure. It provides strong welds. This process can weld aluminum and temperature resistant alloys without special surface preparation. Also It can join sections with complex cross-sections.

2.4.5 Resistance spot welding (RSW)

In this process, sheets of metal are joined by the heat generated by resistance to the current flow from electrodes which press the metal sheets at the welding spot. This process is seldom applied in the aeronautic industry due to its lack of reliability and its restriction for joining aluminum alloys. This process was adopted and developed by General Electric to join afterburners of military aircraft.

2.4.6 Gas metal arc welding (GMAW)

This process is not commonly used in aircraft due to its large size of the heat source which causes the welds to have poor mechanical Properties.

2.4.7 Gas tungsten arc welding (GTAW)

Gas–tungsten arc welding (GTAW) is a process that melts and joins metals by heating them with an arc established between a non-consumable tungsten electrode and the metals, it used to weld stainless steel, magnesium, and most forms of thick aluminum.

2.4.8 Laser beam welding (LBW)

This process provides concentrated heat source for welding, higher accuracy, and higher quality welding that with minimum distortions. [5]

2.4.9 Electron beam welding (EBW)

This process presents an advantage over LBW, whereas it has no problems with beam reflection on the molten metal; however, it must operate in a vacuum. This characteristic makes this process especially suitable for the welding of titanium alloys that cannot be welded in an open atmosphere.

2.5 Plasma welding

2.5.1 Definition of Plasma

plasma is a hot ionized gas consisting of approximately equal numbers of positively charged ions and negatively charged electrons. The characteristics of plasma are significantly different from those of ordinary neutral gases so that plasma is considered a distinct fourth state of matter.

[5] P. F. M. &. T. W. Eagar, "Welding process for aeronautics".

Plasma representing 99% of the universe substance, whereas galaxies and stars are composed of Plasma.

Plasma can be naturally found in earth in the ionosphere layer due to ionize of ambient air, which caused by ultraviolet radiation. Otherwise the plasma can be produced in laboratories by heating a Gas till its kinetic energy equal to or greater than ionization energy of Gas molecules. Plasma is found at very high temperatures so that it is difficult to confine it into an ordinary vessel, hence a magnetic field are used to confine it.

2.5.2 Applications of Plasma

1- In Nuclear reactors as a source of power.
2- In rockets as a source of power.
3- Manufacturing of Screens (Plasma screens).
4- Manufacturing of computer integrated circuits.
5- Maintaining the cleanliness of the environment.
6- Metals welding and cutting.

2.5.3 Plasma Arc welding (PAW)

Plasma arc welding (PAW) was developed in 1964 as a method of bringing better control to the arc welding process. PAW provides an advanced level of control and accuracy using automated equipment to produce high quality welds, Furthermore, PAW is equally suited to manual operation. Plasma gas is normally argon, the torch also uses a secondary gas, such as argon/helium or argon/nitrogen, that assists in shielding the molten weld puddle and minimizing oxidation of the weld. Plasma arc welding is similar to TIG welding. The difference is that in plasma welding, the arc is sharply constricted by a cooled gas nozzle through which a flow of plasma gas is directed. The concentrated arc results in maximum energy, leading to a deep-penetration effect in the work piece. Also, the welding speed is as much as 20 % faster than in mechanized TIG welding.

The plasma welding advances TIG welding by the following:

1-No weld-seam preparation.
2-less filler metal required.
3-Higher availability of wearing parts.
4-Less distortion occurrence than in TIG.

2.5.3.1 Plasma Arc Welding with Non-Transferred Arc

The arc burns between the tungsten electrode (- pole) and the plasma gas nozzle (+ pole) .it is mainly used for metal-spraying and for the welding of metal.

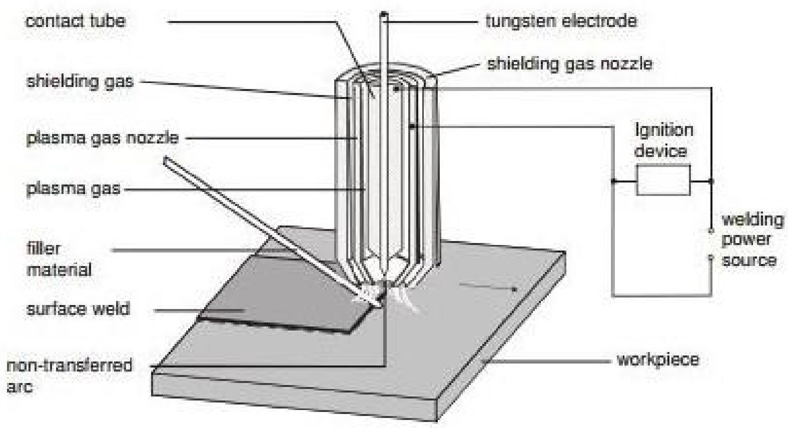


Figure 2-17 Plasma Arc Welding with non- transferred Arc

2.5.3.2 Plasma Arc Welding with Transferred Arc

The arc burns between the tungsten electrode (-pole) and the work piece (+ pole), this process used for welding of joints.

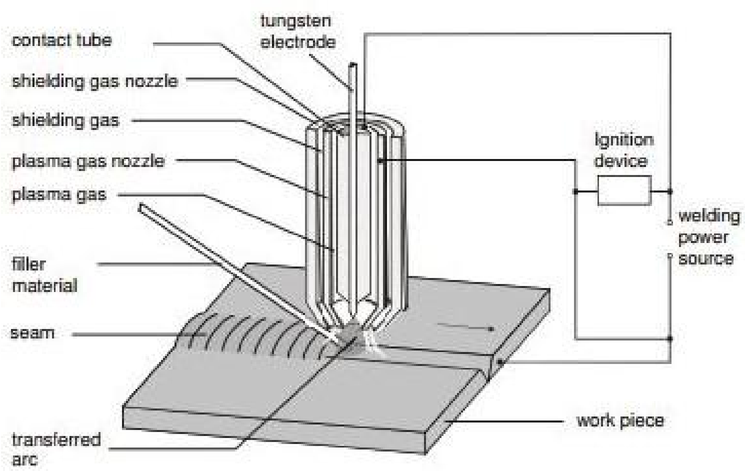


Figure 2-18 Plasma Arc Welding with transferred Arc

2.5.3.3 Plasma Arc Welding with Semi-Transferred Arc

It is a combination of both plasma arc welding with transferred arc & plasma arc welding with non-transferred arc.

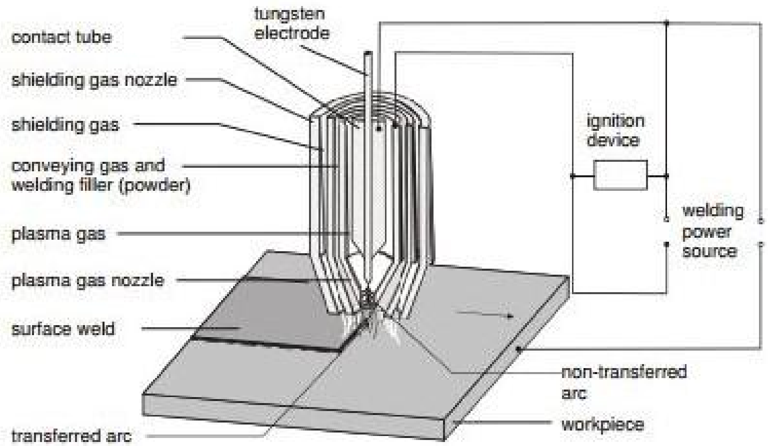


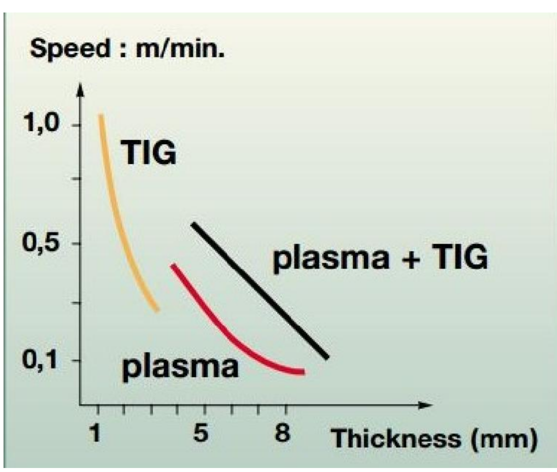
Figure 2-19 Plasma Arc Welding with Semi –Transferred Arc

2.5.4 Advantages of plasma welding

1-Rapidity of operation and low Deformation which eliminate polishing procedures.
2- Excellent visual appearance.
3-Reduction in welding time.

2.5.5 Plasma and TIG welding

It is an integration between plasma welding and TIG welding into a single installation which can improve productivity by 30-50 %. [6]



Welding speed (cm/min.)

Thickness (mm)	plasma	plasma + TIG
3	50	65
4	35-40	50-60
6	25-30	40
8	15-20	25

Figure 2-20 Comparison in welding speed between plasma welding &Plasma +TIG

[6] "Plasma and TIG processes automatic welding application," WWW.airliquid.com.

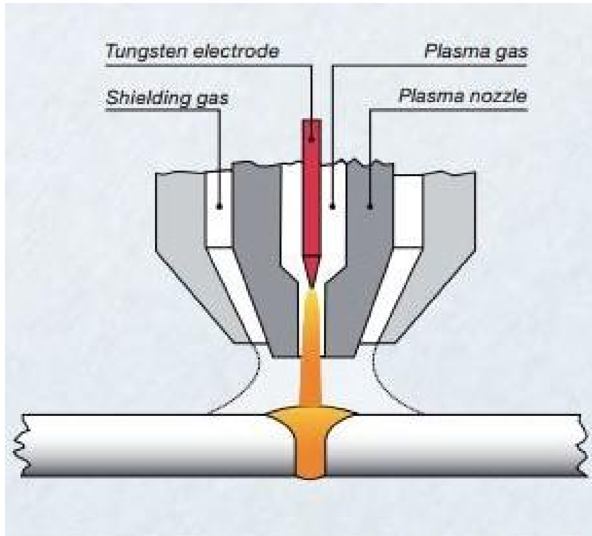


Figure 2-21 Plasma &TIG Welding

2.5.6 Advantages of the plasma & TIG welding

1- High quality welding.
2- Significance increase productivity.
3-The plasma + TIG process works on thicknesses between (2- 8) mm, also thicknesses less than 3 mm can also be welded perfectly.

2.5.7 Equipment for plasma welding

The equipment needed in plasma arc welding along with their functions are as follows:

Power supply:

A direct current power source (generator or rectifier) having drooping characteristics and open circuit voltage of 70 volts or above is suitable for plasma arc welding. Rectifiers are generally preferred over DC generators. Working with helium as an inert gas needs open circuit voltage above 70 volts. This higher voltage can be obtained by series operation of two power sources; or the arc can be initiated with argon at normal open circuit voltage and then helium can be switched on.

Typical welding parameters for plasma arc welding are as follows:

Current 50 to 350 amps, voltage 27 to 31 volts, gas flow rates 2 to 40 liters/minute (lower range for orifice gas and higher range for outer shielding gas), direct current electrode (negative) is normally employed for plasma arc welding except for the welding of aluminum in which cases water cooled electrode is preferable for reverse polarity welding.

High frequency generator and current limiting resistors:

A high frequency generator and current limiting resistors are used for arc ignition. The arc starting system may be separated or built into the system.

Plasma torch:

It is either transferred arc or non-transferred arc type. It is hand operated or mechanized. At present, almost all applications require automated system. The torch is water cooled to increase the life of the nozzle and the electrode. The size and the type of nozzle tip are selected depending upon the metal to be welded, weld shapes and desired penetration depth.

Shielding gases:

Two inert gases or gas mixtures are employed. The orifice gas at lower pressure and flow rate forms the plasma arc. The pressure of the orifice gas is intentionally kept low to avoid weld metal turbulence, but this low pressure is not able to provide proper shielding of the weld pool. To have suitable shielding protection same or another inert gas is sent through the outer shielding ring of the torch at comparatively higher flow rates. Most of the materials can be welded with argon, helium, argon+hydrogen and argon+helium, as inert gases or gas mixtures. Argon is very commonly used. Helium is preferred where a broad heat input pattern is desired without key hole mode weld.

A mixture of argon and hydrogen supplies heat energy higher than when only argon is used, and thus permits keyhole mode welds in nickel base alloys, copper base alloys and stainless steels.

For cutting purposes a mixture of argon and hydrogen (10-30%) or that of nitrogen may be used. Hydrogen, because of its dissociation into atomic form and thereafter recombination generates temperatures above those attained by using argon or helium alone. In addition, hydrogen provides a reducing atmosphere, which helps in preventing oxidation of the weld and its vicinity.

Voltage control:

Voltage control is required in contour welding. In normal key hole welding a variation in arc length up to 1.5 mm does not affect weld bead penetration or bead shape to any significant extent and thus a voltage control is not considered essential.

Current and gas decay control:

It is necessary to close the key hole properly while terminating the weld in the structure.

Fixture:

It is required to avoid atmospheric contamination of the molten metal under bead.

2.5.8 Plasma arc welding process

Technique of work piece cleaning and filler metal addition is similar to that in TIG welding. Filler metal is added at the leading edge of the weld pool.

Making a non-key hole weld: The process can make non key hole welds on work pieces having thickness 2.4 mm and under.

Making a keyhole welds: An outstanding characteristics of plasma arc welding, owing to exceptional penetrating power of plasma jet, is its ability to produce keyhole welds in work piece having thickness from 2.5 mm to 25 mm. A keyhole effect is achieved through right selection of current, nozzle orifice diameter and travel speed, which create a forceful plasma jet to penetrate completely through the work piece. The major advantages of keyhole technique are the ability to penetrate rapidly through relatively thick root sections and to produce a uniform under bead without mechanical backing. Also, the ratio of the depth of penetration to the width of the weld is much higher, resulting narrower weld and heat-affected zone. As the weld progresses, base metal ahead the keyhole melts, flow around the same solidifies and forms the weld bead. Key holing aids deep penetration at faster speeds and produces high quality bead. While welding thicker pieces, in laying others than root run, and using filler metal, the force of plasma jet is reduced by suitably controlling the amount of orifice gas.

Plasma arc welding is an advancement over the GTAW process. This process uses a non-consumable tungsten electrode and an arc constricted through a fine-bore copper nozzle. PAW can be used to join all metals that are weldable with GTAW.

The design of a joint (rivet ,bonding, welding) should satisfy the following conditions :

• Allowable shear stress of adhesive not exceeded.
• Allowable tensile (peel) stress of adhesive not exceeded.
• Allowable in-plane shear stress of adhered not exceeded.
• Allowable through-thickness tensile stress of adhered not exceeded.

The choice of joining technique is dependent on several factors including:

• Materials to be joined.
• Design of joint region.
• Joining process used.
• Joint strength and/or stiffness – dependent on:
o Arrangement of parts to be joined.
o Properties and geometry of materials to be joined.
o Load-transfer path between parts.
o Joining process and process control.
• Need to disassemble.
• Durability.
o Absences of crevices, traps for moisture & other chemicals.

- o Contact between materials, galvanic corrosion.
- o Sharp corners, holes/notches: stress raisers.

CHAPTER THREE RESEARCH METHODOLOGY

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Design & fabrication of riveting & plasma welding models

Two models were designed by using computer based program named Catia VR5, one of them for riveted passengers' compartment, and the other for plasma welded passengers' compartment. The design is carried out through using mechanical part design & then constructing the basic geometry of the intended parts, after that the parts were assembled together to form the final shape of the component "passengers' compartment".

The fabrication stage started with sizing the sheet metal, then using power squaring shear machine for cutting the sheet metal.

Figure 3-1 Power squaring shear machine

The stretching & shrinking machine is then used to form the sheet metal to obtain the curved shape of the frames.

Figure 3-2 Stretching &shrinking machine

The cornice brake machine is then used for turning or bending the edges of sheet metal. Then the stringers were fitted to the frames and then covered with sheet metal once by using rivets and other by using plasma welding.

Figure 3-3 cornice brake machine

3.2 Weight of rivets for selected aircraft

Stringer – skin joint

Formula:

$$W = Wf1 + Wf2 + Ws \quad \ldots\ldots (3.1)$$ [7]

Where:

W: is the total weight reduction of aircraft.

Wf1: is the weight of rivet reduction.

Wf2: is the weight of high lock reduction.

Ws: is the weight of sealant reduction.

$$Wf = (Fw * Nf/s) * (Ns/p * Np/s * Ns/f) \quad \ldots\ldots (3.2)$$

$$Ws = Ws/s * (Ns/p * Np/s * Ns/f) \quad \ldots\ldots (3.3)$$

Where:

Fw= is the weight of a single fastener.

Nf/s= is the number of fasteners per stringer.

Ns/p=is the number of stringers per panel.

Np/s= is the number of panels per section.

Ns/f = is the number of sections per fuselage.

Ws/s=is the weight of sealants per stringer.

[7] Using plasma welding in A/C structure, page 65, BSC Thesis, University of Khartoum, Mechanical Eng. Dept., issued 2001, supervised by General Eng. Abdulraheem Saad Omer

Data:

Table 3-1 number of fasteners & their weight for selected aircraft

A/C type	Fastener type			Ws/s	Ns/p	Np/s	Ns/f
	Rivet	High lock					
		Steel	Titanium				
B-707	180	20	-	100g	10	5	8
B-737	150	20	-	90g	8	5	6
A-300	180	20	40	120g	12	5	10

Fw (rivet) (Aluminum alloy) =2g

Fw (High lock) (steel)=20g

Fw (High lock) (Titanium)=12g

B-707 (Medium and long range A/C) Narrow body:

Wf1= (2*180) *400=144000 g =144kg

Wf2= (20*20) *400=160000g =160kg

Ws=100*400 =40000g =40kg

W = 344000g =344kg

B-737 (small and medium range A/C) Narrow body:

Wf1= (2*150) *240=72000g=72kg

Wf2= (20*20) *240 =96000g =96kg

Ws=90*240=22000g=22kg

W=190000g =190kg

A-300 (medium and long range A/C) wide body:

Wf1 = (180*2) *600=216000g =216kg

Wf2 = {(20*20) +(40*12)} *600=528000g=528kg

Ws = 120*600=72000g =72kg

W = 816000g =816kg

3.3 Strength of riveted joint

Here the strength of riveted joint was calculated for two riveted plates having the following data:

Table 3-2 Data of joint

Parameter	Amount
Length of the plate	0.15 m
Width of the plate	0.1 m
Thickness of the plate	0.002 m
Number of holes	8
Diameter of each hole	0.005 m
Ft	483 Mpa
Fs	220 Mpa
Fb	586 Mpa
ed	0.0375 m / 0.0125m

A rivet will fail for one of the four reasons:

[1] Tensile failure:

Is related to tensile strength of the material.

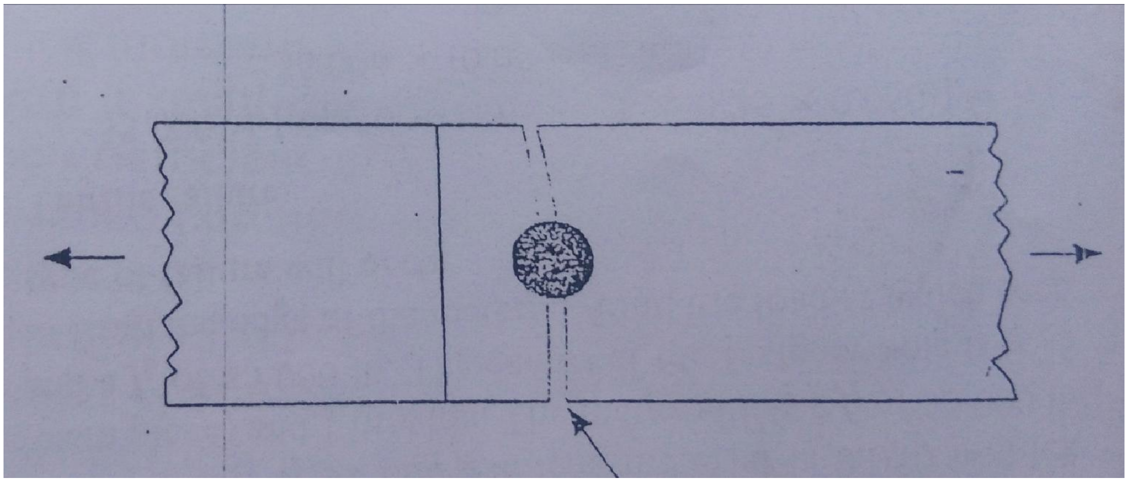


Figure 3-4 Tensile failure mode

The tensile strength is calculated by the following equation:

$$P\ tensile\ failure = ft\ \times [\mathrm{A} - \mathrm{N}(\mathrm{t} \times \mathrm{D})] \ldots\ldots\ldots\ldots\ldots (3.4)$$ [8]

Where:

P = load leading to failure.

Ft = tensile strength of the material.

A = cross-sectional area of the material.

N = number of rivets.

t = thickness of the material.

D = diameter of the rivet.

P = 483 × 10^6 [(0.002 × 0.1)-8(0.002 × 0.005)] = 57960 N

[2] Shear failure:

A joint will experience shear failure when a load applied as shown in figure 3.5 .

[8] Aircraft Basic Science, eighth edition, page 180

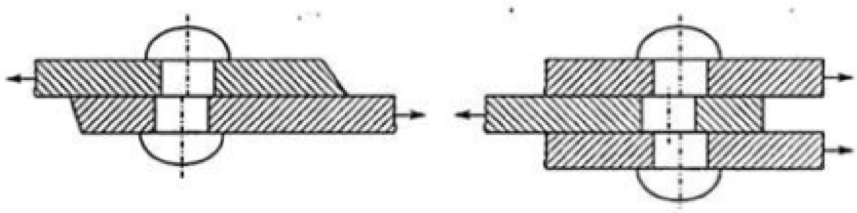


Figure 3-5 shear failure mode

The shear failure is calculated by the following equation:

$$P\ shear\ failure = fs \times A \times N \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.5)$$ [9]

Where:
P = load leading to failure.
fs = shear strength of the rivet.
A = cross-sectional area of the rivet.
N = number of rivets.
$A = \frac{\pi}{4} D^2 = 0.00002\ m^2$

$P = 220 \times 10^6 \times 0.00002 \times 8 = 35200$ N

[3] Bearing failure:
A bearing failure is a type of compressive failure from the fastener pushing or bearing against the sheet.

[9] Aircraft Basic Science, eighth edition, page 180

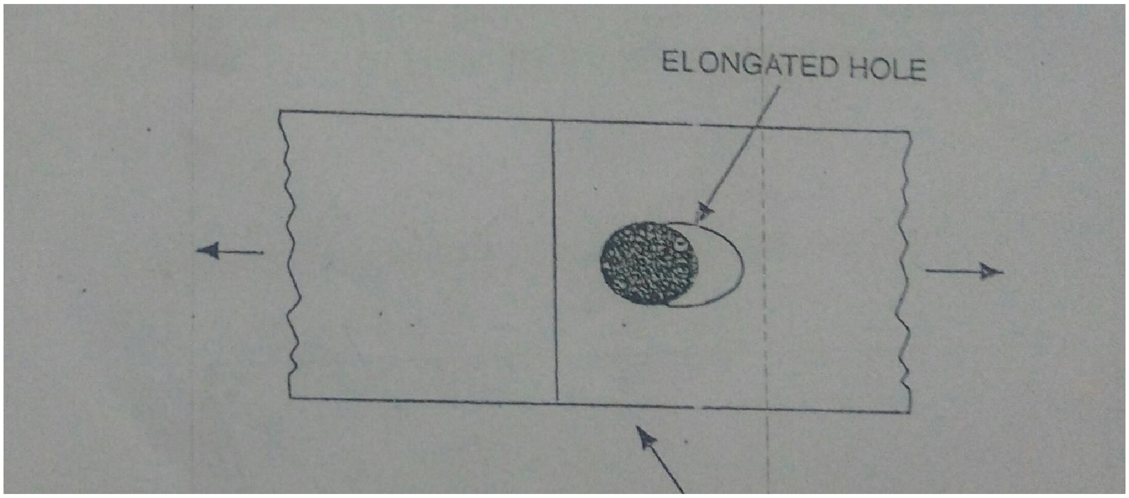


Figure 3-6 Bearing failure mode

A bearing failure is calculated by the following equation:

$$P\ bearing\ failure = fb\ \times t\ \times D\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.6)$$ [10]

Where:
P = load leading to failure.
Fb = bearing strength of the material.
t = thickness of the material.
D = diameter of the rivet.

$P = 586 \times 10^6 \times 0.002 \times 0.005 = 5860$ N

[10] Aircraft Basic Science, eighth edition, page 180

[4] Tear-out failure:

Results from placing fasteners too close to the edge of the sheet.

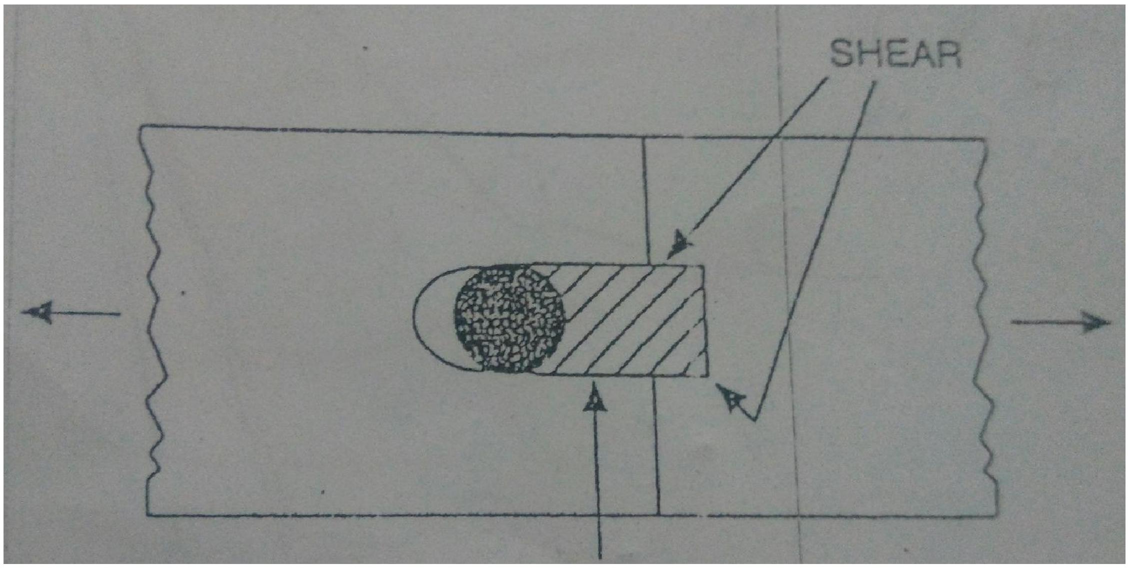


Figure 3-7 Tear- out failure mode

Tear-out failure is calculated by the following equation:

$$P\ tear-out\ failure = 2 \times fs\ \times t\ \times ed \ldots\ldots\ldots\ldots\ldots\ldots\ (3.7)$$ [11]

Where:

P = load leading to failure.

fs = shear strength of the material.

t= thickness of the material.

ed = edge distance (distance from the center of the hole to the edge of the sheet).

- Tear-out when distance from the hole center to the edge of the sheet equal 0.0375 m:
  $P = 2 \times 220 \times 10^6 \times 0.002 \times 0.0375 = 33000$ N
- Tear-out when distance from the hole center to the edge of the sheet equal .0125 m:

  $P = 2 \times 220 \times 10^6 \times 0.002 \times 0.0125 = 11000$ N.

[11] Aircraft Basic Science, eighth edition, page 180

3.4 Destructive test (DT) for riveted joint

A riveted joint has the dimensions as illustrated in Table 3.2 was subjected to destructive test by applying various loading conditions to determine the point of failure.
The tensile failure value was equal 58370 N. And the shear failure was equal 36097 N.

3.5 Destructive test (DT) for plasma welded joint

Plasma welded joint has the dimensions as illustrated in Table 3.2 was subjected to destructive test by applying various loading conditions to determine the point of failure.
The tensile failure value was equal 93020 N. And the shear failure was equal 56498 N.

3.6 Nondestructive test (NDT) for plasma welding sample

NDT is carried out through using X-ray test to ensure the quality of plasma welding, and it had been found that plasma welding provides excellent welding.

CHAPTER FOUR RESULTS AND DISCUSSION

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Results

4.1.1 Weight of rivets for selected aircraft

Table 4-1 Total Weight of rivets for selected aircraft

Type of aircraft	Total weight of used rivets
B-707	344 kg
B-737	190 kg
A-300	816 kg

4.1.2 Strength of riveted joint as estimated by calculation

Table 4-2 Strength of riveted joint as estimated by calculation

Failure mode	Amount
P tensile failure	57960 N
P shear failure	35200 N
P bearing failure	5860 N
P tear- out when (ed)= 0.0375m	33000 N
P tear-out when (ed) = 0.0125 m	11000 N

4.1.3 Strength of riveted joint as estimated by destructive test

Table 4-3 Strength of riveted joint as estimated by destructive test

Failure mode	Amount
P tensile failure	58370 N
P shear failure	36097 N

4.1.4 Strength of plasma welded joint as estimated by destructive test

Table 4-4 Strength of Plasma welded joint as estimated by destructive test

Failure mode	Amount
P tensile failure	93020 N
P shear failure	56498 N

4.2 Discussion

Using of plasma welding leads to reduce the total weight of aircraft as extrapolated from table 4.1 which in turn leads to increase of payload, improve A/C engine performance, and then an economic operation can be achieved.

The results obtained for strength of joint for both riveting & plasma welding were nearby to each other when estimated by calculation and by experiment (Destructive test).

The plasma welded joint has better strength properties than riveted joint (1.5 stronger than riveted joint).

CHAPTER FIVE
CONCLUSION AND RECOMMENDATIONS

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The main objectives of this research were reduction of aircraft weight by using plasma welding techniques in aircraft parts instead of riveting, and prove that the plasma welding has better rigidity and strength properties than riveting.

All the objectives of this research had been met through fabrication of plasma welding and riveting model of passengers' compartment and then destructive tests for shear and tension had been carried out for samples of both models.

The quality of plasma welding was tested through non- destructive test (NDT) for plasma welded sample.

The minor difference comes from using Plasma welding for Aluminum alloy 4047 which is normally used in A/C Plasma welding instead of Aluminum alloy 2024.

5.2 Recommendations

- carry out stress analysis for plasma welded and riveted joint by using computer software i.e Catia V5 & ANSYS.
- Using Aluminum Alloy (4047) for plasma welding due to its excellent strength for fabrication of models.

5.3 **References**

[1] Aviation Maintenance Technician Handbook - General, FAA.

[2] P. F. M. &. T. W. Eagar, "Welding process for aeronautics".

[3] P. F. Mendez, "NEW TRENDS IN WELDING IN THE AERONAUTIC INDUSTRY".

[4] U. o. W. sindo Kou professor and chair department of material science and engineering, Welding metallurgy, John Wiley & Sons, Inc., Hoboken, New Jersey, 2003.

[5] M. products, Welding handbook , Welding and related processes for repair and maintenance onboard.

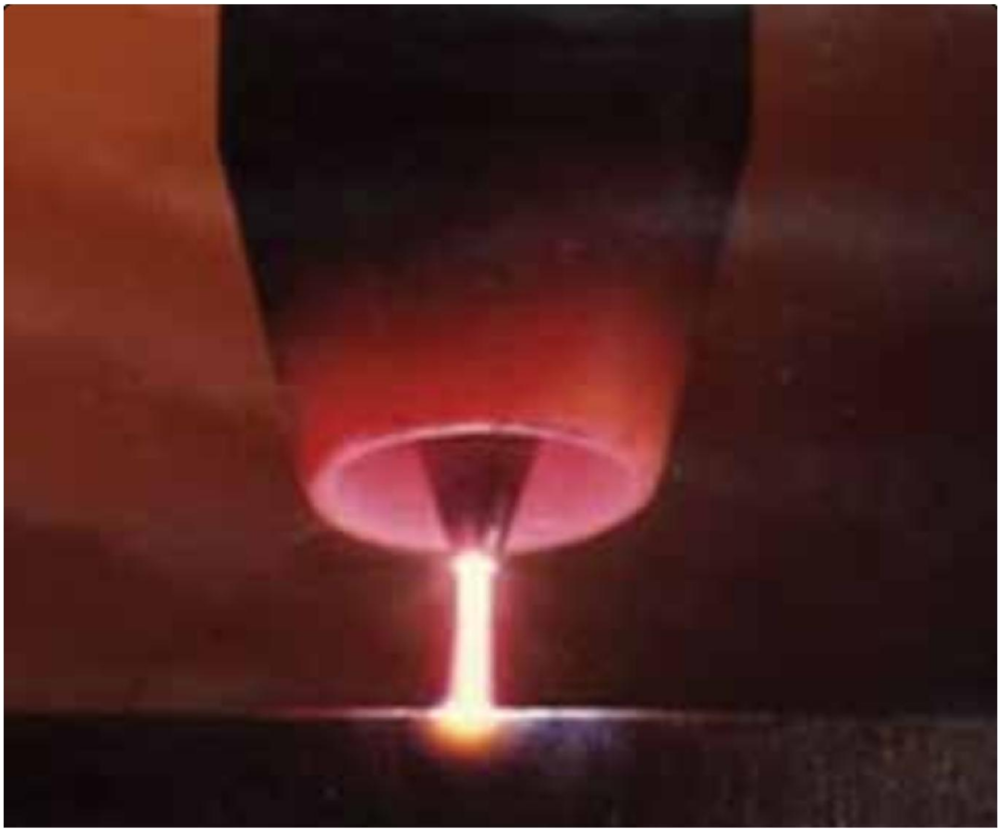
[6] "Plasma and TIG processes automatic welding application," WWW.airliquid.com.

[7] L. E. C. a. M. R. L. G. W R Broughton, Design Requirements for Bonded and Bolted Composite Structures, NPL Materials Centre & National Physical Laboratory Teddington, Middlesex TW11 0LW, UK.

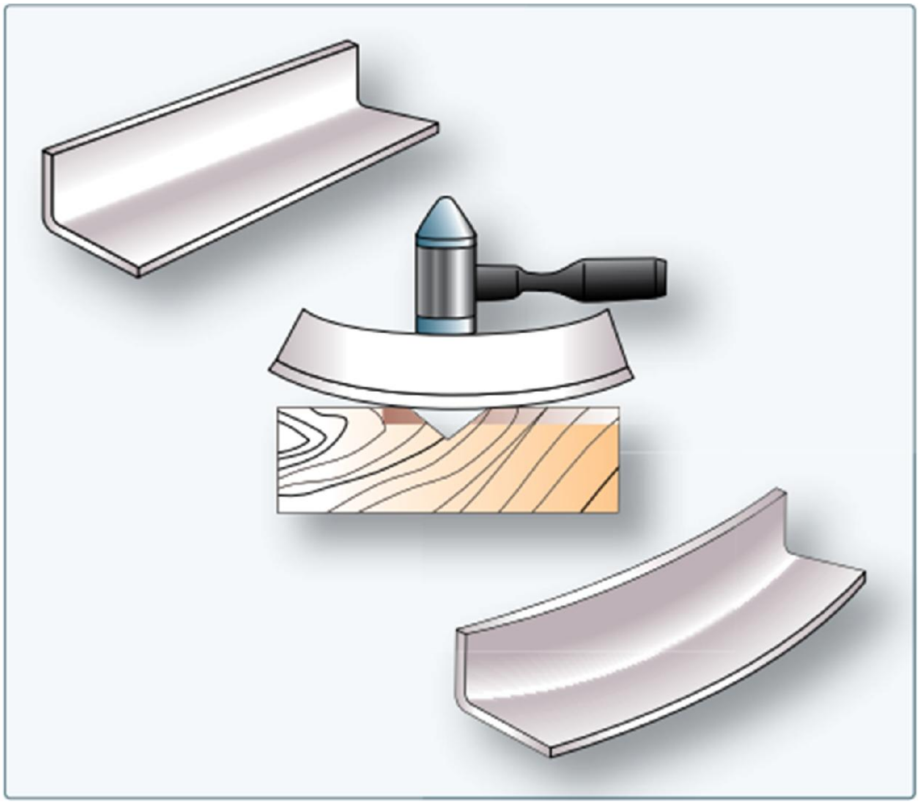
[8] K. M. M.M.Krishna, "DESIGN AND EXPERIMENTAL ANALYSIS OF ADHESIVELY BONDED SINGLE RIVETED LAP JOINT," *INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY,* p. 8, january 2015.

APPENDICES:

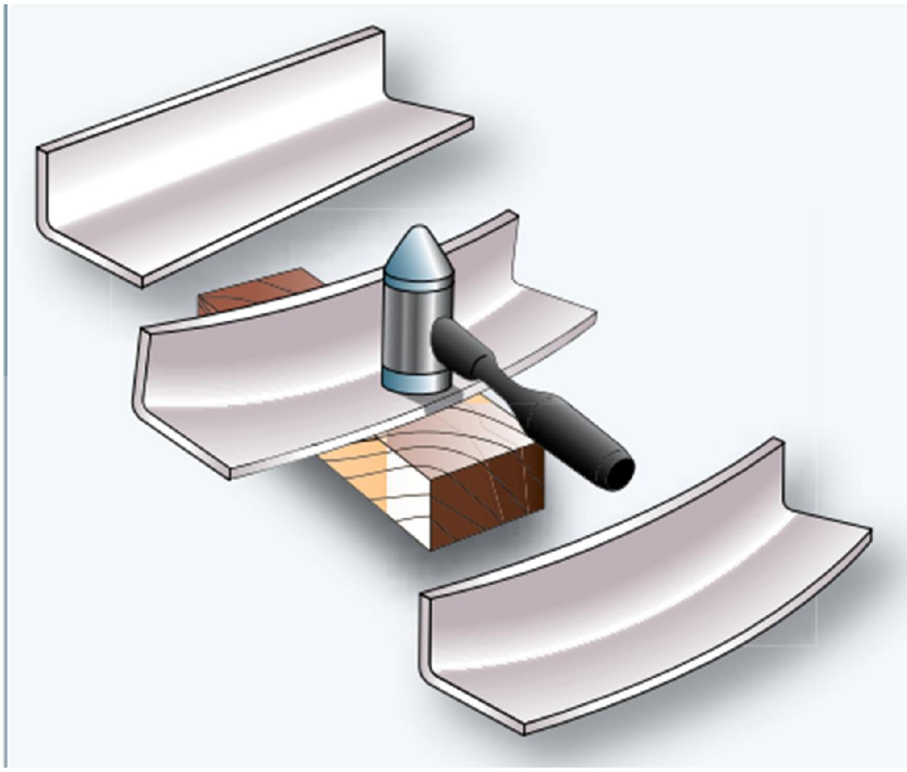
APPENDIX (A): Plasma Arc



APPENDIX (B): SAHRINKING & FORMING METAL

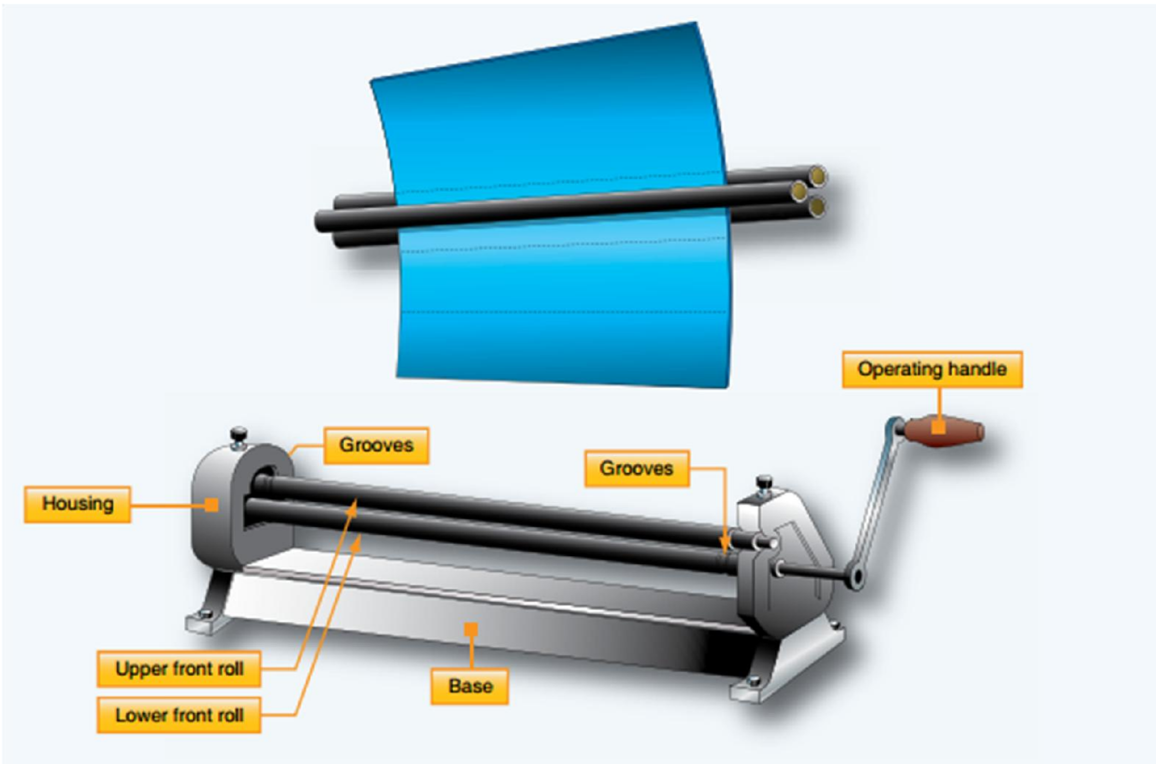


APPENDIX (C): STRETCHING & FORMING METAL



APPENDIX (D): STRETCHING SHRINKING MACHINE

APPENDIX (E): SLIP ROLL FORMER



APPENDIX (F): AVIATION SNIPS

APPENDIX (G): CLECO & CLECO PLIERS

APPENDIX (H): FILES

APPENDIX (I): MATERIAL PROPERTIES OF ALLUMINUM ALLOY 2024 - T3

Table. 1: Material properties of Aluminium 2024-T3

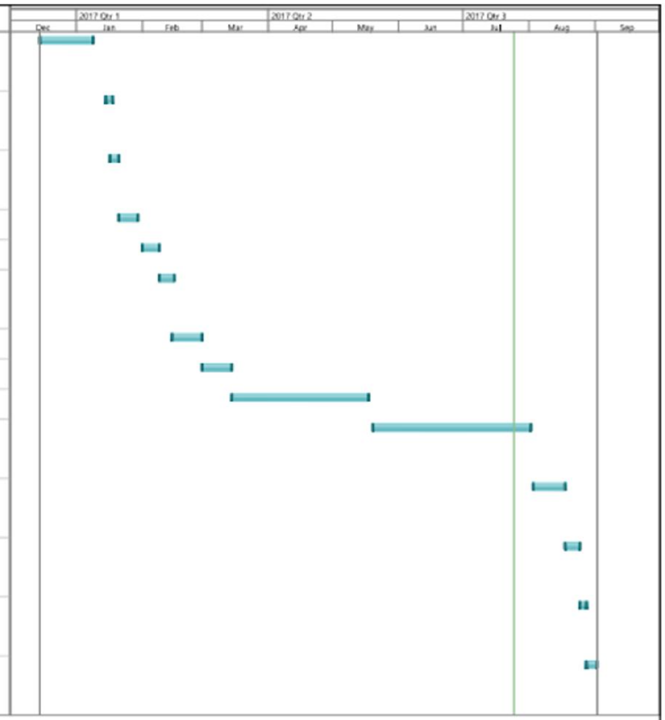
Property	Aluminium 2024-T3
Density	2.77 g/cm3
Ultimate Tensile Strength	483Mpa
Tensile Yield Strength	362Mpa
Young's Modulus	72Gpa
Poisson's Ratio	0.33
Material Constant, C	5×10^{-11}
Material Constant, n	3

APPENDIX (J): RIVETED PASSENGERS' COMPRATMENT

APPENDIX (K): PLASMA WELDING MACHINE

APPENDIX (L): PROJECT PLANE

ID	Task Mode	Task Name	Duration	Start	Finish	Predecessors
1		Data collection	18 days	Thu 16-12-15	Sun 17-01-08	
2		Chapter one	3 days	Sun 17-01-15	Tue 17-01-17	
3		Bckground(Types of a/c welding)+Bonding +Fueslage bonding	4 days	Tue 17-01-17	Fri 17-01-20	
4		Rivets + Disadvantages	7 days	Sat 17-01-21	Sun 17-01-29	
5		Plasma in general+ applications	6 days	Wed 17-02-01	Wed 17-02-08	
6		How to get plasma	5 days	Thu 17-02-09	Wed 17-02-15	
7		Plasma welding in a/c	10 days	Wed 17-02-15	Tue 17-02-28	
8		Advantages of plasma welding	10 days	Wed 17-03-01	Tue 17-03-14	
9		Computerized model	46 days	Wed 17-03-15	Wed 17-05-17	
10		Practical section	53 days	Sat 17-05-20	Tue 17-08-01	
11		analysis	11 days	Thu 17-08-03	Thu 17-08-17	
12		calculation	5 days	Fri 17-08-18	Thu 17-08-24	
13		results & discussion	2 days	Fri 17-08-25	Sun 17-08-27	
14		conclusion	5 days	Mon 17-08-28	Fri 17-09-01	



Project: Project1
Date: Tue 17-07-25

Task | Split | Milestone | Summary | Project Summary | Inactive Task | Inactive Milestone | Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only | External Tasks | External Milestone | Deadline | Progress | Manual Progress

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