Chapter 1

Introduction

Chapter 1 gives a brief introduction to the various types of welding processes, their classifications, materials and their applications. It also describes the GMAW Process and its components in detail. The material chosen for this investigation and the problems encountered in the welding of aluminium alloys are briefly discussed. The motivation of the research work and outline of the thesis are also presented in this chapter.

1.1 Introduction

Welding and Joining processes are essential for the development of virtually every manufactured product. However, these processes often appear to consume greater fractions of the product cost and create more of the production difficulties that might rightfully be expected. There are a number of reasons that explain this situation. Welding and joining are multifaceted, both in terms of process variations (such as fastening, adhesive bonding, soldering, brazing, arc welding etc.) and in the disciplines which must be brought to bear to solve a problem. Non-Ferrous Metals and alloys are the most widely used material in engineering application. Most of steel welding to this date is done by fusion welding which lead to several problems like residual stresses/distortion, formation of unfavorable microstructure and defects like porosity, hot cracking, hydrogen embrittlement etc. Most of these defects are present because of inherent melting of base metal and thermal cycles involved in fusion welding process.

Welding as one of the most important fabrication and maintenance process, has been playing an important role in the industrial and infrastructural development of any nation in the world since the industrial revolution that took place around 1850. Welding is having an illustrious history and glorious past. People knew how to join two pieces of metals since longer-at least about five thousand years from the present time. The remains of Mohenjo-Daro and Harappa and the Buddhist sculptures spread all over India bear testimony of this fact. Welding is a permanent joining process used to join different materials like metals, alloys or plastics, together at their contacting surfaces by application of heat and or pressure. During welding, the work-pieces to be joined are melted at the interface and after solidification a permanent joint can be achieved. Sometimes a filler material is added to form a weld pool of molten material which after solidification gives a strong bond between the materials. Weldability of a material depends on different factors like the metallurgical changes that occur during welding, changes in hardness in weld zone due to rapid solidification, extent of oxidation due to reaction of materials with atmospheric oxygen and tendency of crack formation in the joint position. The assembled parts that are joined by welding are called a weldment. Welding is primarily used in metal parts and their alloys.

1.2 Background of the Research Study

In fabrication, many types of joining processes are available out of them welding is recognized all over the world, today, as a remarkable versatile means of metal joining. The main welding processes are fusion welding, Electric Resistance welding, Solid Phase, Soldering and Braze welding. Among these Fusion welding covers major parts of application. Metal arc welding, a sub group of electric arc welding is used to the largest extent in industries today. Different types of metal arc welding processes are shielded metal arc welding (SMAW), gas metal arc welding (GMAW), submerged arc welding (SAW), flux cored arc welding (FCAW), and gravity welding etc. These processes are being used in industries as per requirements. The wide range and variety of these processes enable the fabricator to join almost all commercial metals and alloys in many different shapes, sizes and thickness ranging from a fraction of millimeter to over 500 millimeters. Electric arc welding is the process, where heat is generated by the arc, produced between electrode tip and work material. In modern times, it is a wide spread technique due to its low cost and effectiveness. Gas metal arc welding (GMAW), sometimes referred to by its subtypes metal inert gas (MIG) welding or metal active gas (MAG) welding process in which an electric arc forms between a consumable wire electrode and the work piece metal(s), which heats the work piece metal(s), causing them to melt, and join. The amount of heat which is generated during welding is depended on welding parameter such as welding current, voltage, welding speed, temperature of base metal and electrode wire, gas flow rate and welding polarity. Out of above parameter welding current, voltage and welding speed are most significant. Along with the wire electrode, a shielding gas feeds through the welding gun, which shields the process from contaminants in the air. The process can be semi-automatic or automatic. Originally developed for welding aluminium and other non-ferrous materials in the 1940s, GMAW was soon applied to steels because it provided faster welding time compared to other welding processes. The cost of inert gas limited its use in steels until several years later, when the use of semi-inert gases such as carbon dioxide became common. Further developments during the 1950s and 1960s gave the process more versatility and as a result, it became a highly used industrial process.

Joining is literally where all the parts of the manufacturing process come together. As such these processes are essential to virtually every manufactured product. A very large percentage of product failures occur at joints. Joints are often the weakest part of the assembly and usually are located at the most highly stressed points. Careful attention to the joining processes can produce great rewards in manufacturing economy and product reliability. Welding is one of the most important technological process that is used extensively in many branches of engineering such as industrial engineering, shipbuilding, pipeline fabrication, bridges and others. Many different energy sources can be used for welding, including a gas flame, an electric arc, a laser, an electron beam, friction, and ultrasound. While often an industrial process, welding can be done in many different environments, including open air, underwater and in space. Regardless of location, however, welding remains dangerous, and precautions must be taken to avoid burns, electric shock, poisonous fumes, and overexposure to ultraviolet light.

1.3 Weldability of Aluminium and Its alloys:

Aluminium and its alloys can readily be arc welded except specific types of Aluminium alloys, however, their inherent physical and metallurgical characteristics should sufficiently be understood in order to implement successful arc welding.

1.3.1 Characteristics of Aluminium and Its alloys:

a. Higher specific heat, latent heat of fusion and thermal conductivity

b. Stronger oxide film formation

c. Larger distortion

d. Softening of heat-affected zone

e. Sensitivity to hot cracking

f. More likely to cause porosity

a. Higher specific heat, latent heat of fusion and thermal conductivity:

Aluminium and its alloys feature lower melting point but higher specific heat, latent heat of fusion.

b. Stronger oxide film:

Aluminium and its alloys produce strong oxide films on their surfaces when heated to high temperatures and fused, unless the surface is shielded.

c. Larger distortion:

Welding aluminium and its alloys causes much more distortion compared to welding steel because the expansion coefficient of aluminium and its alloys is larger than that of steel.

d. Softening of heat-affected zone:

The heat-affected zone (HAZ) with respect to base metal features lower hardness, thus lower strength.

e. Sensitivity to hot cracking:

Hot cracking is the most noticeable type of cracking in welding aluminium alloys, which may occur in the welds at temperatures close to the solidus of the base metal.

f. More likely to cause porosity:

The arc welding is more likely to cause porosity in weld metals, relative to welding other metals. It is reported that the main cause of porosity is hydrogen in the weld metal.

1.4 Use of Aluminum Alloy:

Household utensils, autos, railroad cars, buildings, bridges Aircrafts, Spacecrafts, ships, chemical equipments and storage tanks, Electrical goods, architectural works and process industry etc.

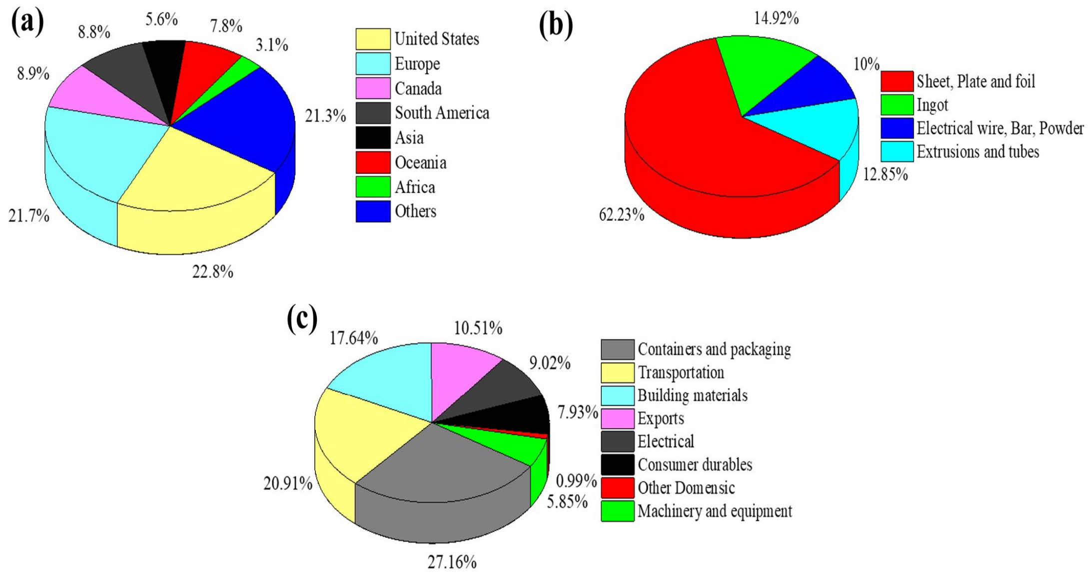


Figure 1.1: Pie chart of utilization of aluminium (a) across the world (b) in different shapes (c) in various engineering sectors [Ahmad, R& Bakar, MA 2011]

1.5 Application of A6061& A6063 Aluminium alloys

a. A6061

Is a common alloy for general use and, in aerospace applications is used for wing and fuselage structures. It is especially common in home built aircraft.

b. A6063

Often referred as the “architectural alloy” is known for providing exemplary finish characteristics and is often the most useful alloy for anodizing applications.

1.6 Weldability of Aluminium Alloys

Table 1.1: Weldability of Aluminium Alloys [Ahmad, R& Bakar, MA 2011]

Aluminium Alloys	**Weldability**	**Welding processes**	**Remarks**
Series 1000, pure Al	Readily weldable	MIG, TIG, gas resistance, laser	Sheets and pressings
Series 2000, Al-Cu	Poor	Resistance	Not normally fusion welded
Series 3000, Al-Mn	Readily weldable	MIG, TIG, gas resistance, laser	Building and transport applications
Series 4000, Al-Si			Not normally welded
Series 5000, Al-Mg	Readily weldable	MIG, TIG, resistance, gas, laser	High-strength welded applications
Series 6000, Al-Mg-Si	Weldable	Resistance, MIG, TIG	Low strength and care must be taken to avoid cracks
Series 7000, Al-Zn-Mg	Can be welded	Resistance, MIG,TIG	High mechanical strength through age hardening
Series 8000, Al-Li	Can be welded	MIG, TIG, laser, electron beam	Careful choice of filler wire to avoid cracking

1.7 Different type of Processes used for Welding Aluminium

Aluminium and its alloys are readily weldable but needs some special attention for sound welds. Oxyacetylene welding, Resistance welding, MIG/GMAW welding, TIG welding, Solid state welding.

1.8 Based on the heat source used welding processes can be categorized as follows:

a. Arc Welding

In arc welding process an electric power supply is used to produce an arc between electrode and the work-piece material to joint, so that work-piece metals melt at the interface and welding could be done. Power supply for arc welding process could be AC or DC type. The electrode used for arc welding could be consumable or non-consumable. For non-consumable electrode an external filler material could be used. This method is probably the most popular type of welding process since it includes many of the most popular kinds of welding, such as MIG, TIG, submerged arc welding and shielded metal arc welding.

b. Gas Welding

In gas welding process a focused high temperature flame produced by combustion of gas or gas mixture is used to melt the work pieces to be joined. An external filler material is used for proper welding. Most common type gas welding process is Oxyacetylene gas welding where acetylene and oxygen react and producing some heat.

c. Resistance Welding

Resistance welding works on the principle of heat generation due to electric resistance. In resistance welding heat is generated due to passing of high amount current (1000–100,000 A) through the resistance caused by the contact between two metal surfaces. The amount of heat produced depends on the resistance of the material, surface conditions, the current supplied and the time duration of the current supplied. This heat generation takes place due to the conversion of electric energy into thermal energy. Most common types resistance welding is Spot-welding, seam welding,, flash welding, butt welding etc.

d. High Energy Beam Welding

In this type of welding a focused energy beam with high intensity such as Laser beam welding (LBW) or electron beam welding (EBW) is used to melt the work pieces and join them together. These types of welding mainly used for precision welding or welding of advanced material or sometimes welding of dissimilar materials, which is not possible by conventional welding process. In EBW, the energy of the high-velocity electron beam is converted into heat energy which is used for welding purpose and this process is done under vacuum. In LBW, a concentrated coherent light beam impinges at the desired spot to weld the metal.

e. Solid State Welding

Solid-state welding processes do not involve melting of the work piece materials to be joined. This process relies on the parameters such as time, temperature, and pressure, individually or in tandem to join the metals without significantly melting them. Common types of solid-state welding are ultrasonic welding, explosion welding, electromagnetic pulse welding, friction welding, friction-stir-welding etc.

f. Shielded Metal Arc Welding (SMAW)

This is most common type arc welding process, where a flux coated consumable electrode is used. As the electrode melts, the flux disintegrates and produces shielding gas that protect the weld area from atmospheric oxygen and other gases and produces slag which covers the molten filler metal as it transfer from the electrode to the weld pool. The slag floats to the surface of weld pool and protects the weld from atmosphere as it solidifies.

g. Gas Metal Arc Welding (GMAW)

In this type of welding process a continuous and consumable wire electrode is used. A shielding gas generally argon or sometimes mixture of argon and carbon dioxide are supplied through a welding gun to the weld zone which acts as protective cover for the weldment from oxidation. The application of GMAW generally requires DC positive electrode, which is known as direct current reverse polarity (DCRP). In DCRP, 2/3rd heat is generated at the electrode and 1/3rd heat is generated at the work-piece, so melting of the electrode is more than direct current straight polarity.

GMAW process involves a consumable electrode of 0.8mm to 2.4 mm diameter, wounded in spool form which is feed at a preset speed through a welding torch which provides the electrical connection and the shielding gas.

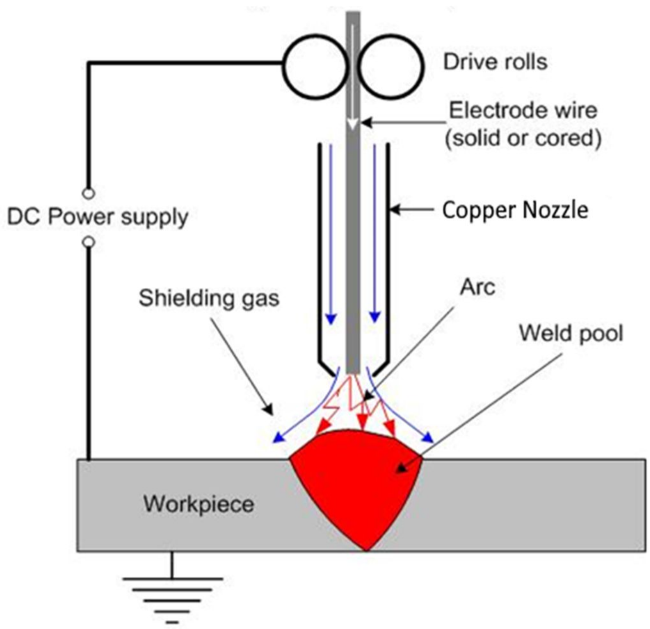


Figure 1.2: Schematic diagram of MIG welding process [Akio Hirose et al.,1999]

1.9 Advantages of MIG Welding

Metal inert gas welding is one of the widely used techniques for joining Ferrous and non-ferrous metals.MIG welding process offers several advantages like joining of unlike metals, low heat-affected zone, absence of slag, Superior Mechanical

Characteristics, Virtually Defect free welding and Long welds, Welding Dissimilar alloys, Provides opportunities for new solutions to old joining problems, Versatile applications for welding all Joint Geometries etc.

1.10 Shielding Gas Functions

- Provides a plasma for commutation of current
- Protects the weld pool from reaction with air environment
- Provides cleaning action, which partially removes the aluminum oxide from the base material (DCEP)

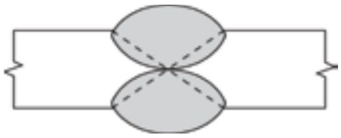
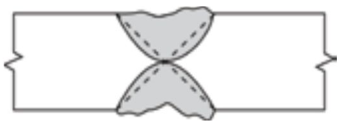
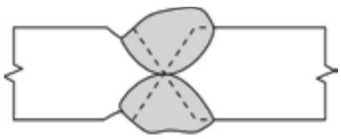
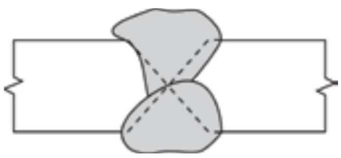
1.10.1 Properties of Shielding Gases

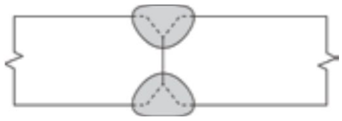
Table 1.2: Properties of shielding gas

Argon	**Helium**
Advantages	
Good arc initiation and stability	Higher arc voltage
More effective shielding	Broad weld root width
Lower cost	Reduced porosity
Good cleaning	
Disadvantages	
Narrow weld root width	Poor cleaning
	Poor arc initiation and stability
	Higher cost

1.10.2 Weld Profile Troubleshooting

Table 1.3: Weld Profile Troubleshooting

Welding Defect	Example Groove Weld	Solution
Excessive Convexity/ Reinforcement Reduced fatigue strength		Increase arc length Increase torch angle Increase travel speed
Insufficient Leg Length Reduced mechanical properties	N/A	Change torch angle Change torch position
Insufficient Throat/Under-fill Reduced mechanical properties		Reduce cooling rate Increase electrode feed rate Decrease travel speed Decrease arc length
Undercut Reduced mechanical properties		Change torch position to compensate for: Dissimilar section sizes Dissimilar thermal conductivity Out-of-position welds
Overlap Severe reduction in fatigue strength		Increase voltage Decrease wire speed Increase travel speed

Incomplete Penetration/ Lack of Fusion Reduced weld strength and increased sensitivity to crack propagation		Increase amperage Decrease arc length Decrease torch forehand angle Increase travel speed

1.11 Welding process parameters

During a manual welding operation, the welder has to have control over the welding parameters, which affect the weld yield strength, ultimate tensile strength, percentage elongation, penetration, bead geometry, and the overall weld quality. A proper selection of welding parameters will increase the chances of producing welds of a satisfactory quality. However, these parameters are not completely independent and changing one variable generally requires the changing of some of the others to achieve the desired result. When all these parameters are in proper balance, the welder can deposit higher quality weld metal and produce sound welds. The selection of the welding variables should be made after the base metal, filler metal and joint design have been determined.

The welding process parameters mainly affect the yield strength, ultimate tensile strength, percentage elongation and the deposition rate. Deposition rate is the weight of the metal deposited per unit of time. These parameters are as follows:

1.11.1 Welding current

Welding current used in GMAW has the most significant effect on the yield strength, ultimate tensile strength, percentage elongation, deposition rate, the weld bead shape and size. In GMAW, metals are generally welded with direct current electrode positive (DCEP) because it provides the maximum heat input to the electrode and therefore a relatively more metal deposition rate can be obtained. The oxide removal effect of the DCEP, which is very important in the welding of aluminum and magnesium alloys, contributes to clean the weld deposit. When all the other welding parameters are held constant, increasing the current will increase the weld depth and the weld width of the weld penetration and also the size of the weld bead. In a constant voltage system, the wire feed speed and the welding current is operated by the same knob. As the wire feed speed is increased the welding current also increases, resulting in increases in the wire melt- off rate and the rate of deposition. Each electrode wire size has a minimum and maximum current range which give the best results. An excessively low welding current for a given electrode size produces a poor penetration and the pileup of the weld metal on the surface of the base metal transfer by the arc is sluggish, the bead is rough and reinforcement is high. If the current is very high, the size of the weld bead is large and the excessive deep penetration that wastes the filler metal causes burn-through and undercut. Very high or very low welding current also affects the mechanical properties of the weld metal. Porosity, excessive oxides and impurities can be seen in the weld metal.

1.11.2 Welding voltage

The arc voltage is one of the most important parameters in GMAW that must be done under control. When all the variables such as the electrode composition and sizes, the type of shielding gas and the welding technique are held constant, the arc length directly depends on the arc voltage. For example, the normal arc voltage in carbon dioxide and helium is much higher than those obtained in argon. A long arc length disturbs the gas shield.

The arc tends to wander and thus affects the bead surface of the bead and the penetration. In GMAW the arc voltage decides effect upon the penetration, the bead reinforcement, and the bead width. By increasing the arc voltage, the weld bead becomes flatter and wider. The penetration increases until an optimum value of the welding voltage is reached, at that time it begins to decrease. High and low voltages cause an unstable arc. The high welding voltage causes the formation of excessive spatter and porosity, in fillet welds it increases undercut and produces concave fillet welds subject to cracking. Low voltage produces narrower beads with greater convexity (high crown), but an excessively low voltage may cause porosity and overlap at the edges of the weld bead.

1.11.3 Travel speed

Movement along the work-piece of the torch is known as travel speed. In semiautomatic welding, it is controlled by the welder and in automatic welding, it is controlled by the machine. The effects of the travel speed are just about similar to the effects of the arc voltage. The penetration is maximum at a certain value and decreases as the arc speed is varied. For a constant given current, slower travel speeds proportionally provide larger beads and higher heat input to the base metal because of the longer heating time. The high heat input increases the weld penetration and the weld metal deposit per unit length and consequently results in a wider bead contour. If the travel speed is too slow, unusual weld build-up occurs, which causes poor fusion, lower shows opposite effects, less weld metal gets deposited with lower heat input that produces a narrower bead with less penetration. Excessively high speeds cause high spatter and undercutting, and the beads show an irregular form because of very little weld metal deposit per unit length of weld. The travel speed, which is an important parameter in GMAW, just like the wire speed (current) and the arc voltage, is selected by the operator according to the thickness of the metal being welded, the joint design, joint fit-up, and welding position.

1.11.4 Electrode size

The influences of electrode diameter on weld bead configuration (such as the size), the depth of penetration, bead reinforcement, bead width and has a consequent effect on the travel speed of the welding. As per general rule, for the same welding current (wire feed speed setting) the arc becomes more penetrating when the electrode diameter decreases. The same characteristics require a higher minimum current for a larger electrode.

At a given current to maximize deposition rate one should have the smallest wire possible that provides the necessary penetration of the weld. The larger electrode diameters create welds with less penetration.

The thickness of the work-piece to be welded, the required weld penetration, the desired weld profile, deposition rate, the position of welding and the cost of electrode wire decide the choice of the wire electrode diameter. For many purposes, small diameter wires are suitable for thin sections and welding in vertical and overhead positions. Large diameter wires are desirable for heavy sections and hard surfacing and built-up works with low current applications because of less weld penetration.

Taking into account all the factors mentioned above, especially the fact that small diameter electrode wires cost more on the weight basis, one can find a wire size that will produce minimum welding costs for any welding application.

1.11.5 Inert gas

The choice of shielding gas is depends on the working metals and effects on the welding cost, weld temperature, arc stability, weld speed, spatter, electrode life etc. It also affects the finished weld penetration depth and surface profile, porosity, corrosion resistance, strength, hardness and brittleness of the weld material. Argon generally provides an arc which operates more smoothly and quietly. Penetration of arc is less when Argon is used than the arc obtained by the use of Helium. For these reasons argon is preferred for most of the applications, except where higher heat and penetration is required for welding metals of high heat conductivity in larger thicknesses. Aluminium and copper are metals of high heat conductivity and are examples of the type of material for which helium is advantageous in welding relatively thick sections. Pure argon can be used for welding of structural steels, low alloyed steels, stainless steels, aluminium, copper, titanium and magnesium. Argon hydrogen mixture is used for welding of some grades of stainless steels and nickel alloys. Pure helium may be used for aluminium and copper. Helium argon mixtures may be used for low alloy steels, aluminium and copper.

1.12 Motivation of the research work

GMA Welding are the most commonly selected fusion welding process for joining various types of aluminium alloys due to their easier applicability, low cost process and better weld quality when compared to other welding processes. In this welding process, the weld quality mainly depends on the selection of suitable heat input and proper filler material. The heat input mainly depends on the current, voltage and speed of the process. Therefore, in order to obtain better weld quality of thin aluminium plates, optimum weld process parameter is required. High solubility of hydrogen and other atmospheric gases in the molten state and formation of oxide layer are the major problem associated with this kind of joining process. Problems like low welding speed, partial penetration and lack of the deposited metal occurred during these process. AA6061 and AA6063 alloys found wide applications in automobile, aerospace, marine and structural industries due to its light weight and higher strength to weight ratio. It is also understood that welding of these alloys using GMAW process at higher welding speed is very much challenging which may lead to various weld defects. Hence, in this work AA6061 and AA6063 are chosen as base materials and GMAW process are selected as joining process for this investigation.

1.13 Summary

This chapter describes the introduction to various types of welding processes, their classifications, materials and their applications. It also describes the GMAW process and its components in detail. The material chosen for this investigation and the problems encountered in the welding of AA6061 and AA6063 aluminium alloys are briefly discussed. The motivation of the research work and outline of the thesis are also presented in this chapter. The next chapter enumerates and discusses the various literatures available related to welding of AA6061and AA6063 aluminium alloys using GMA welding process with Argon shielding gas.