INVESTIGATION OF MECHANICAL PROPERTIES OF ALUMINIUM-STEEL WELDING USING DIFFERENT WELDING TECHNIQUE AND PROCESSES

MOHD SANI BIN IDRIS

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Faculty of Mechanical Engineering
UNIVERSITY MALAYSIA PAHANG

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ABSTRACT

This report is presents about the investigation towards mechanical properties property of dissimilar welding by using different welding technique and processes. The objective of this research is investigate the weld joint quality of aluminium AA6061 and galvanized iron with different types of joining those are butt and lap joint and with different of welding processes, namely Metal Inert Gas (MIG) and Tungsten Inert Gas (TIG). The experiments carried out along this research such as non-destructive test (NDT), Vickers hardness test, tensile test and microstructure optical analysis. Based on the result of experiment, there are a few defects on weld appearances such as porosity, crack, and incomplete penetration. Butt joint of TIG welding (TBAG) shows a better weld appearance compared to other groups. Microstructure analysis showed that joint of TBAG has thinner brittle intermetallic compound layer (IMC) than the other group which shows thicker IMC, indicating a weaker joint. Based on the Vickers hardness analysis, the TIG welding shows higher hardness value than the MIG welding with average hardness value of 114 HV and 82 HV respectively , while tensile strength analysis showed that the butt joint samples has greater strength than the lap joint counterpart. TBAG has the highest tensile strength compared to the others group with value of 107 MPa while MLAG has the lowest strength with the value of 42 MPa. It can be concluded that TBAG is the best joint since TIG and butt joint showed the best value based on the analysis that had been carried out.

ABSTRAK

Laporan ini membentangkan mengenai penyiasatan ke arah sifat-sifat kebendaan mekanikal kimpalan berbeza dengan menggunakan teknik dan proses kimpalan yang berbeza. Objektif kajian ini adalah menyiasat kualiti sendi kimpalan aluminium AA6061 dan besi digalvani dengan sambungan yang berbeza iaitu sambungan sisi dan sambungan berlapik dan dengan proses kimpalan yang berbeza, iaitu Logam Gas Lengai (MIG) dan Tungsten Gas Lengai (TIG). Eksperimen yang dilaksanakan sepanjang kajian ini seperti ujian bukan pemusnah (NDT), ujian kekerasan Vickers, ujian tegangan dan analisis mikrostruktur optik. Berdasarkan keputusan eksperimen, terdapat beberapa kecacatan pada penampilan kimpal seperti keliangan, retak, dan penembusan lengkap. Sambungan sisi bersama kimpalan TIG (TBAG) menunjukkan penampilan kimpal yang lebih baik berbanding dengan kumpulan lain. Analisis mikrostruktur menunjukkan bahawa bersama TBAG mempunyai lapisan rapuh sebatian intermetallic nipis (IMC) yang lebih nipis daripada kumpulan lain yang menunjukkan sendi lemah pada lapisan IMC yang semakin. Berdasarkan analisis kekerasan Vickers, kimpalan TIG menunjukkan nilai kekerasan yang lebih tinggi daripada kimpalan MIG dengan purata nilai kekerasan 114 HV dan 82 HV masing-masing, manakala analisis tegangan kekuatan menunjukkan sampel sambungan sisi kekuatan lebih tinggi daripada sambungan berlapik. TBAG mempunyai kekuatan tegangan yang tinggi berbanding dengan kumpulan yang lain dengan nilai 107 MPa manakala MLAG mempunyai kekuatan yang paling rendah dengan nilai 42 MPa. Ia boleh membuat disimpulkan bahawa TBAG adalah sambungan terbaik kerana TIG dan sambungan sisi menunjukkan nilai terbaik berdasarkan analisis yang telah dijalankan.

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LIST OF SYMBOLS

P	Pressure
A	Area of material surface
D	mean diagonal of a indentation (mm)
e	Strain
Ө	Angle between opposite faces of the diamond
g	Gravitational weight
σ	True stress, local stress
σ_{all}	Allowable stress
σ_{uts}	Ultimate tensile Strength
σ_m	Local mean stress

LIST OF ABBREVIATIONS

A	Ampere
AA	Aluminium Alloy
ASTM	American Society for Testing and Materials
FYP	Final Year Project
GI	Galvanized Iron
GMAW	Gas Metal Arc Welding
HAZ	Heat Affected Zone
IMC	Inter Metallic Compound
MBAG	Butt Joint of Aluminium and Galvanized By MIG Process
MIG	Metal Inert Gas
MLAG	Lap Joint of Aluminium and Galvanized By MIG Process
NDT	Non Destructive Testing
SEM	Scanning Electron Microscope
TBAG	Butt Joint of Aluminium and Galvanized By TIG Process
TIG	Tungsten Inert Arc Welding
TLAG	Lap Joint of Aluminium and Galvanized By TIG Process
TWB	Tailor Welded Blank
UMP	University Malaysia Pahang
V	Volts

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Aluminum alloys are becoming to be widely used in the automotive industry. Material substitution from steels to aluminum alloys is the one of the approaches to reduce vehicle weight and the fuel consumption. Recently, vehicles made of hybrid body structures which combine steel and aluminum parts have been produced in the automotive companies. Therefore, the efficient joining method and Tailor Welded Blank (TWB) is needed to join different components made of aluminum and steel sheets.

TWB is composed of more than two materials with similar or different strength or thicknesses joined together to form a single part before the forming operation. This joining of various sheets into a single blank enables automobile designers to tailor the location in the blank where material properties are located leading to reduced weight, improved part stiffness and lower manufacturing costs due to elimination of process dies and reduced scrap (Kinsey, 2003).

The terms welding is defining the joining of two or more surface (usually metals, but not always) under the influence of heat, so the product shall be nearly homogeneous union as possible. In TWB, it is important to select the proper welding process for joining the part of tailored blank. The method of welding that usually in TWB process are tungsten inert gas (TIG) welding and metal inert gas (MIG) welding.

TIG welding is the process of blending together reactive metals such as magnesium and aluminum.TIG has greatly propelled the use of aluminum for welding and structural processes. During the process of TIG welding, an arc is formed between a pointed tungsten electrode and the area to be welded. As a result of the gas shield, a clean weld is formed. This prevents oxidization from occurring (Kalpakjian, S., 2001). While MIG welding is an automatic or semi-automatic process in which a wire connected to a source of direct current acts as an electrode to join two pieces of metal as it is continuously passed through a welding gun. A flow of an inert gas, originally argon, is also passed through the welding gun at the same time as the wire electrode. This inert gas acts as a shield, keeping airborne contaminants away from the weld zone. The primary advantage of MIG welding is that it allows metal to be welded much more quickly than traditional "stick welding" techniques. This makes it ideal for welding softer metals such as aluminum. When this method was first developed, the cost of the inert gas made the process too expensive for welding steel (Kalpakjian, S., 2001).

1.2 PROBLEM STATEMENT

The increasing demand for improved fuel efficiency and weight reduction results in the automotive industry seeking new methods to reduce the weight of existing vehicle structures. Tailor welded blank is one of the best method to fulfill the demand especially in automotive field. However, the investigation have shown that tailored blanks of different material such as combination of aluminum and steel would produce a brittle, intermetallic compound (IMC) layer of the joint that greatly affects the mechanical properties of the product. Selection of the type of welding process used to make a tailor welded blank such as TIG and MIG also can greatly affect mechanical properties of the joint. Therefore, it is crucial to investigate the different output of both welding processes in order to determine the best welding method for TWB applications.

1.3 OBJECTIVE OF THE PROJECT

The objective of the project is as follows:

i. Fabrication of weld specimens by using different welding process.
ii. Investigate the mechanical properties on the welded specimens by using different material and types of joining.
iii. Analyze the macrostructure and microstructure of the joint.

1.4 SCOPE OF THE PROJECT

The scope of the project is as follows:

i. Fabricate weld joints by using TIG and MIG.
ii. Investigate the specimen's mechanical properties (fracture behavior) of the joints by using tensile tests and Vickers hardness test.
iii. The defect will be tested by using NDT method. Analyze the microstructure and phase composition of the joints by using optical microscope.

CHAPTER 2

LITERITURE REVIEW

2.1 DEFINITION OF TAILOR WELDED BLANK

Tailor welded blank, is multiple sheets of material are welded together prior to the forming process. The differences in the material within a TWB can be in the thickness, grade, or coating of the material for example galvanized versus none galvanized. Forming of tailor welded blank forming tailor welded blank is challenging due to a significant reduction of formability associated with this type of blank. First, material property changes in the heat-affected zone (HAZ) of the weld decrease the potential strain in the material prior to tearing failure. The thinner part of tailor welded blank maybe undergoes deformation than the thicker part which is stronger material in the forming area, (Kinsey, 2003)**.**

Forming of tailor welded blank is a very challenging due to a significant reduction of formability associated with this type of blank. Material property changes in the heat-affected zone of the welded part in terms of decrease the strain in the material prior to tearing failure. The thinner part of tailor welded blank maybe undergoes deformation than the thicker part which is stronger material in the forming area (Garmo, 1974). Tailor welded blank is a new technology that allow the engineer to create something new in automotive technology in order to reduce component weight and the number of component in a structure without compromising the final strength, stiffness and durability of the component. Figure 2.1 shows the potential automotive tailor welded blank applications.

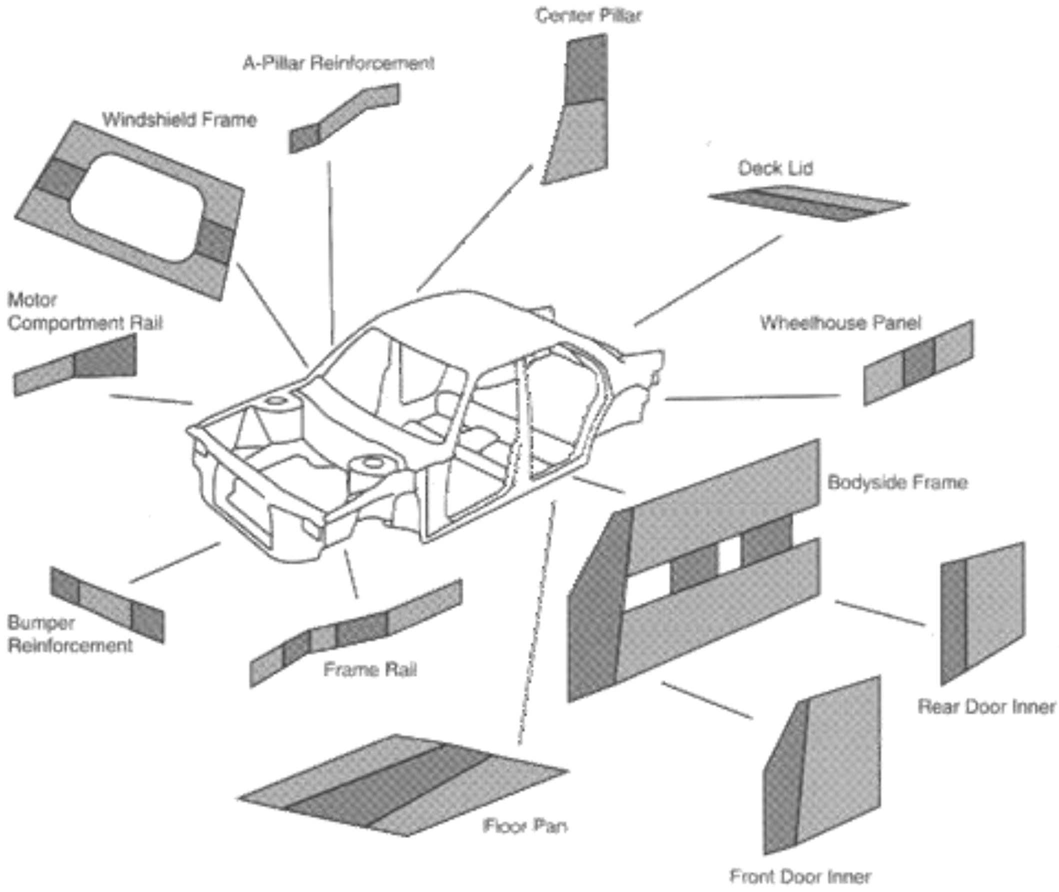

Figure 2.1: Exploded View of Current and Potential Automotive Tailor Welded Blank Applications (Kinsey, 2003)

2.1.1 Benefit of TWB

There are many benefits of tailor welded blank in automotive vehicles included:

i. Fewer parts and dies
ii. Reduce design and development time
iii. Reduce material use
iv. Weight reductions
v. Improve dimensional accuracy

As for the material for automobile industry, this technology was one of the development trends for automobile industry because of its weight reduction, safety improvement and economical use of materials (Yan, 2005).

This joining of various sheets into a single blank enables automobile designers to tailor the location in the blank where material properties are located leading to reduced weight, improved part stiffness, and lower manufacturing costs due to elimination of process dies and reduced scrap (Jiang, et al., 2004).The choice of the welding technique depends on the production of a sound, heterogeneous, mixture of aluminum and steel at the interface (Padmanabhan, et al., 2006).

2.2 WELDING PROCESS

Joining of two dissimilar materials has been given more attention in recent years because of their superior capabilities. The example of the combination two dissimilar materials is the combination between aluminum and steel due to their potential in automotive applications. Suitable welding process and the welding technique is a significant consideration in tailor welded blank process. For example joining of aluminums and steel should be made through some advance welding technique and welding process due to the melting temperature between these two materials are quite different. The choice of the welding technique depends on the production of a sound, heterogeneous, mixture of aluminum and steel at the interface. (Padmanabhan, et al., 2006).

Welding is the permanent joining of two materials usually metal through localizes, resulting from a suitable combination of temperature, pressure and metallurgical conditions. The various welding process differ considerably in terms of temperature and pressure are combined and achieved. They also vary as to the attention that must be given to the cleanliness of the metal surfaces prior to welding and to possible oxidation or contamination of the metal during welding. If high temperature is used, most metal are affected more adversely by surrounding environment. (Garmo, 1974). Nowadays, there are a few welding process which widely used for dissimilar welding in automotive industries such as TIG and MIG welding.

2.2.1 TIG Welding

Gas tungsten arc welding or also called TIG welding as shown on Figure 2.2 is a process that uses a no consumable tungsten electrode and an inert gas for art shielding. Filler metal is added to the weld pool from a separate rod or wire. The filler metal will be melted by the heat of the arc. Because of the tungsten has high melting point, (3410 ^{0}c) is a good electrode material. Gas tungsten arc welding applicable to all metal in a wide range stock of thickness and also can be use for joining various combinations of dissimilar material. The most common application for these applications is stainless steel and aluminum. TIG welding is generally slower and more cost than consumable electrode in steel welding application except when thin section are involved and high quality weld required. The benefits of TIG in the applications, it is suit include high quality welds and also no weld spatter because no filler metal is transferred across the arc and no post welding cleaning because no flux is use (Groover, 2004).

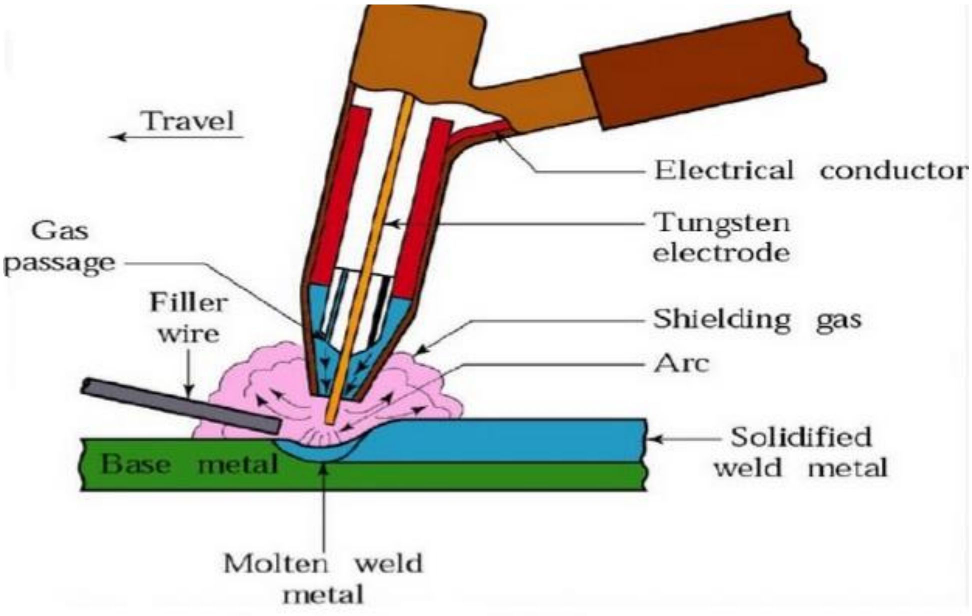

Figure 2.2: The Gas Tungsten Arc Welding Process (KaIpakjian, S., 2001)

The power supply that is used either DC at 200 A or AC at 500 A and its depending on the metals to be welded. AC current is preferred for aluminum and magnesium because cleaning action of AC removes oxides and removes weld quality. Thorium and zirconium maybe use in tungsten electrodes to improve the electrode emission characteristics. The power requirement range from 8 kw to 20 kw, (KaIpakjian, S., 2001). A schematic diagram showing the weld bead geometric parameters shown on Figure 2.3.

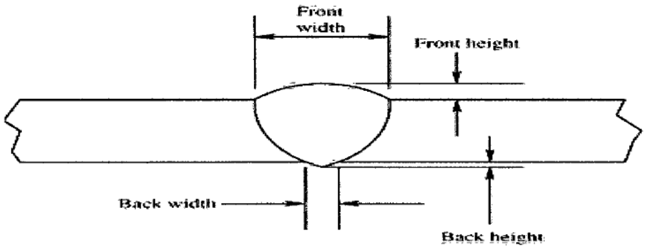

Figure 2.3: Schematic Diagram Showing the Weld Bead Geometric Parameters (KaIpakjian, S., 2001)

2.2.2 Advantages of TIG Welding

There are three advantages of TIG welding such as the following (KaIpakjian, S., 2001):-

i. Cleaner - Using Tungsten to provide its electrical current, TIG welding decreases the amount of sparks, smoke and fumes produced.
ii. Precision - TIG welding has less contamination in its weld, providing more precise and higher quality welds.
iii. Autogenous Welds - These welds do not require a filler material to be used. TIG welding can create a weld by melting one part to the other. Autogenous welds are most commonly used when welding thinner materials.

2.2.3 Disadvantages of TIG Welding

There are two disadvantages of TIG welding such as the following (KaIpakjian, S., 2001):-

i. Setup - TIG welding requires more setup time and is not as user-friendly.
ii. Complexity - TIG welding is more complex and requires more skill than the MIG welding process.

2.2.4 MIG Welding

Gas metal arc welding (GMAW or MIG welding) is an electric arc welding process that uses a spool of continuously fed wire. It can be used to join long stretches of metal without stopping. The weldor, or apparatus, holds the wire feeder and a wire electrode is fed into a weld at a controlled rate of speed, while a blanket of inert argon gas shields the weld zone from atmospheric contamination. Shielding the arc and molten weld pool is done by "externally" supplying gas or a gas mixture. MIG welding can be used on all thicknesses of steels, on aluminum, nickel, and even on stainless steel, etc. However, it is most typically utilized in manufacturing and in commercial fabrication settings (Serope KaIpakjian 2001).

MIG equipment consists of a welding gun, a power supply, a shielding gas supply, and a wire-drive system which pulls the wire electrode from a spool and pushes it through a welding gun. A source of cooling water may be required for the water cooled welding gun. The majority of MIG welding applications require direct current, reverse polarity. This type of electrical connection yields a stable arc, helps to smooth the metal transfer, has relatively low spatter loss, and gives good weld bead characteristics. Direct current straight polarity (electrode negative) is seldom used, since the arc can become unstable and erratic even though the electrode-melting rate is higher. Gas metal arc welding (GMAW or MIG welding) as shown on Figure 2.4

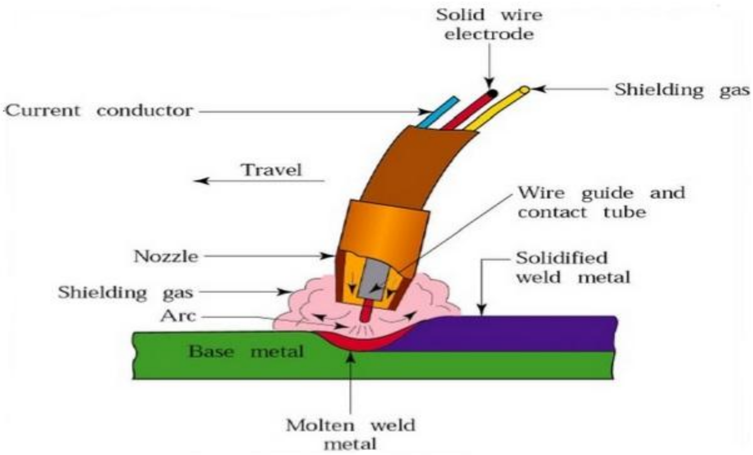

Figure 2.4: Schematic Illustration of the Gas Metal Arc Welding Process (Kalpakjian, S.,2001)

Alternating current has found no commercial acceptance with MIG welding because the arc is extinguished during each half cycle as the current reduces to zero and it may not re-ignite if the cathode cools sufficiently.

MIG guns are available for manual manipulation, semiautomatic welding, and for machine or automatic welding. Because the electrode is fed continuously, a welding gun must have a sliding electrical contact to transmit the welding current to the electrode. The gun must also have a gas passage and a nozzle to direct the shielding gas around the arc and the molten weld pool. An electrical switch is used to start and stop the welding current, electrode feed, and the shielding gas flow.

Semiautomatic and or hand-held guns are usually used. They are shaped like a pistol but can be shaped like an oxyacetylene torch, with the electrode wire fed running through the barrel. Selecting air or water-cooled guns is based on the type of shielding gas, welding current range, materials, weld joint design, and existing shop practice and conditions. Air-cooled guns are usually limited to work using 200 amperes or less. Water-cooled guns are usually used for applications requiring 200 to 750 amperes. However, air-cooled guns are easier to manipulate in confined areas. The water line in a water cooled gun adds weight and reduces maneuverability of the gun for welding.

2.2.5 Advantages of MIG Welding

There are five advantages of MIG welding such as the following (KaIpakjian, S., 2001):-

i. High quality welds can be produced much faster
ii. Since a flux is not used, there is no chance for the entrapment of slag in the weld metal resulting in high quality welds
iii. The gas shield protects the arc so that there is very little loss of alloying elements. Only minor weld spatter is produced
iv. MIG welding is versatile and can be used with a wide variety of metals and alloys
v. The MIG process can be operated several ways, including semi and fully automatic

2.2.6 Disadvantages of MIG Welding

There are two disadvantages of MIG welding such as the following (KaIpakjian, S., 2001):-

i. The MIG welding cannot be used in the vertical or overhead welding positions because of the high heat input and the fluidity of the weld puddle
ii. The equipment is complex.

2.2.7 Difference between TIG Welding & MIG Welding

There are five differences between TIG and MIG welding such as the following (KaIpakjian, S., 2001):-

i. Electrode

TIG welding uses a tungsten electrode that is not consumed during the welding process. MIG welding uses a metal electrode that doubles as filler material for the weld and is consumed during welding.

ii. Shielding Gas

TIG welding primarily uses argon as a shielding gas, with helium occasionally used. Argon is also the primary shielding gas used in MIG welding, but argon mixtures and carbon dioxide are often used for different applications.

iii. Filler Material

TIG welding requires a separate filler material in rod or wire format because the electrode is not consumed. MIG welding delivers the filler material via the electrode.

iv. Work Piece Materials

TIG welding can be applied to just about any metal, from steel to aluminum and exotic alloys. MIG welding was developed for nonferrous metals, but can be applied to steel.

2.3 TYPES OF JOINT

There are five types of joint those identified in welding processes such as the following (KaIpakjian, S., 2001):-

i. Butt Joints

A butt joint is the simplest type of welded joint. It is used to join two objects that rest on the same plane. The joint between the two objects may consist of two square edges, a V-shape or a U-shape. This profile is dependent upon the materials being welded, and may also be impacted by the intended application of these materials. All butt joints can consist of a single or double weld, with single welds being the most cost-effective.

ii. Corner Joint Welds

A corner joint weld is used to join two objects at a 90 degree angle. The objects are arranged so that they only touch along one edge. This leaves a V-shaped groove that must be filled with a welding filler material. Using this V-groove allows for a much stronger bond, and also allows the welder to join the objects with a single action. If the objects were arranged without the V-groove, it would require two separate welds (along the top and bottom) and would not be as strong.

iii. Edge Joints

An edge joint is similar to a butt joint, but is used along the edges of two vertical objects. For example, this joint is commonly used to create a double-layered steel plate. The plates are stacked directly on top of one another, and at least one edge is welded using an edge weld.

iv. Lap Joints

Lap joints are used on two overlapping items that do not lie directly on top of one another. Because only a small portion of the objects may overlap, an edge lap will not be sufficient. Instead, the joints where the edge of one object meets the face of another is welded. A lap joint would be placed at the intersection where each vertical riser meets the adjacent stair tread.

v. T-Welds

T-welds are used to join two objects at a right angle to one another to form a T-shape. The weld would be placed at one of both sides of the rafter at the joint where it meets the steel roof deck. If a metal object were placed at the top of the roof deck to form a cross-shaped formation, the resulting welds would be known as a cruciform joint.The figures type of joint is shown on below Figure 2.5.

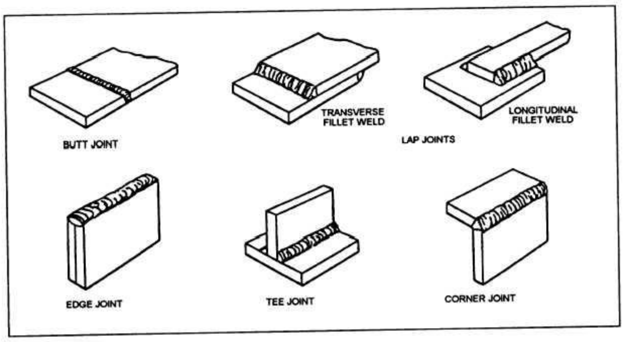

Figure 2.5: Types of Joints (Kalpakjian, S., 2001)

2.4 MATERIALS

2.4.1 Galvanized Iron

Hot-dip galvanizing is a form of galvanization. It is the process of coating iron, steel or aluminum with a thin zinc layer, by passing the metal through a molten bath of zinc at a temperature of around (460 °C). When exposed to the atmosphere, the pure zinc (Zn) reacts with oxygen (O_2) to form zinc oxide (ZnO), which further