# EFFECT OF CORROSION ON ALUMINIUM TAILOR WELDED BLANKS (SIMILAR MATERIAL WELDING)

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# ABSTRACT

In this study, the effect of corrosion on aluminium tailor welded blank with similar metal of aluminium type AA 1100 with different thickness joint by using filler ER 4043 and filler ER 4047 was investigated. Tungsten Inert gas (TIG) was used for butt welding of the process. Corrosion test was tested in 3.5 % Sodium Chloride (NaCl) solution by immersed the specimen for 30 days. Microstructure of base metal (BM), fusion zone (FZ), and heat affected zone (HAZ) was study with image analyzer. Tensile properties of welded joint were investigated by tensile test and hardness of the FZ, HAZ and BM was obtained by Vickers hardness test. From the corrosion test result, it shows that specimen weld by filler ER 4047 has good corrosion resistance than specimen weld by filler ER 4043. The data observed also show that the hardness and tensile properties of welded joint did decrease after the corrosion test. Microstructure at the FZ, HAZ and BM also change with the existence of pitting corrosion.

# ABSTRAK

Kesan kakisan pada aluminium plat yang di sambung melalui teknik penyambungan kekal iaitu kimpalan di kaji di dalam tesis ini. Kaedah kimpalan pada plat aluminium yang berlainan tebal atau dipangil *Tailor Welded Blanks* diaplikasikan untuk kajian ini. Dua jenis pengisi digunakan untuk proses kimpalan iaitu ER 4043 dan ER 4047 dalam kajian ini. Proses kakisan di jalankan untuk komponen yang di sambung di uji melalui rendaman dalam larutan 3.5 % Sodium Chloride (NaCl). *Tungsten Inner Gas* (TIG) adalah teknik kimpalan yang di gunakan. Mikrostruktur sambungan pada zon *Fusion* (FZ), zon *Heat Affected* (HAZ) dan zon asas aluminium (BM) di kaji pada sebelum dan selepas proses kakisan. Sifat tegangan pada sambungan juga di kaji melalui ujian tegangan. Tahap kekerasan pada tiga zon iaitu FZ, HAZ dan BM juga di kaji. Hasil dari keputusan ujian kakisan menunjukan sambungan yang mengunakan pengisi ER 4047 mempunyai keputusan yang lebih baik dari sambungan yang mengunakan pengisi ER 4043 dari segi kadar pengaratan. Keputusan kajian juga menunjukan sifat tegangan dan kekerasan sambungan berkurangan selepas proses kakisan. Mikrostruktur pada FZ, HAZ, dan BM juga berubah dengan kehadiran bopeng.

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| | |
|---|---|
| *HV* | Hardness |
| *P* | Load |
| *d* | the average length of the diagonals |
| *Θ* | angle between opposite faces of the diamond (usually measured as $136^{o}$) |
| σ | Stress |
| Ao | Initial cross-sectional area |
| lo | Initial gage length |
| e | Strain |
| W | Mass loss |
| A | Area |
| D | Density |
| K | Constant |
| T | time of exposure in hours |

# LIST OF ABBREVIATIONS

| | |
|---|---|
| ASTM | American Society for Testing and Materials |
| BM | Base Metal |
| FZ | Fusion Zone |
| HAZ | Heat Affected Zone |
| MIG | Metal Inert Gas |
| SCC | Stress Corrosion Cracking |
| TIG | Tungsten Inert Gas |
| TWB | Tailor Welded Blank |

# CHAPTER 1

# INTRODUCTION

## 1.1 BACKGROUND

Nowadays, the transportation industries such as automotive and aerospace are growing quick. In these industries, the weight and strength of the material are considered an important need. Along with those two elements, costs also are the main factor need to be considered. For transportation industries the need of lightweight and cost effectiveness product with exceptional performance is essential.

The uses of alternative material, composite material and combination of different thickness at certain area have been introduced in order to reduce the weight and cost which is very important elements need to be considered in transportation industries. As example, Aluminium is a material that widely use to as the lightweight metal to replace other metal. In order to full fill those elements, Tailor Welded Blanks (TWB) provides a perfect solution. TWB is a method of joining more than two materials with similar or different strengths or thicknesses to form a single part. TWB did reduce manufacturing costs, decrease vehicle weight, and improve the quality of sheet metal stampings. To join the material into a single part, a permanent joint technique has been use which is welding. The types of welding has been use are Tungsten Inert Gas (TIG), Metal Inert Gas (MIG), Friction Welding, Shield metal ARC welding and laser beam welding.

However, the part that has to been joint together still under threat of corrosion. Corrosion is one of the main problems available in manufacturing process the transportation industries where the TWB are most applied. Corrosion is a degradation of materials properties due to interactions with their surrounding environments.

Corrosion makes the strength of the joint decrease gradually and affects the strength of part. Microstructure features of welded joint need to recognize in order to predict and understand the acceptable corrosion for the welded joint. There are several welding techniques can be applied to minimize the effect of corrosion. One of the methods utilized to minimize the corrosion on welded joint is surface preparation. The proper cleaning process before the welding process is important in reducing defects that are often offered a site for corrosive attack in aggressive environments. The other method are joining design, welding practice and surface finish.

## 1.2 PROBLEM STATEMENT

To join a material with a different thickness is not a simple task. In purpose to joint that kind of joining, TWB method is applied for joining two different thicknesses quite challenging when the thinner part will melting first than the thicker part. That will affect the welded joint. Corrosion did affect the microstructure and strength of the weld joint. The hardness of the joint is decreasing since the corrosion occurs. The different types of filer used while joining the part give the different result of corrosion rate. The types of corrosion occur at the welded joint are important to analyze to predict the acceptable corrosion service life of welded structures

## 1.3 OBJECTIVE OF PROJECT

The objectives of the project are:

(i) To characterize the microstructure of the welded material
(ii) To determine the effect of corrosion on welded joint

## 1.4 SCOPE OF STUDY

This research is focus on different method of joining and investigates the best method to join the material in TWB. Focus area is done based on the following aspect:

(i) The material uses in the project which is aluminium type 1100 series. Three different type of thickness used which is 1mm, 2mm, and 3mm

(ii) The equipment used in this project which is (TIG) welding machine to weld the joint.

(iii) The filler types used which is ER4043 and ER4047

(iv) Material characterization of the welded joint area

(v) The Corrosion medium is 3.5 % NaCl solution

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION OF TAILOR WELDED BLANK (TWB)

In several industries such as automotive and aerospace industries, the lightweight and cost effective product with exceptional performance is crucially needed in order to be competitive. To fulfil that needed, TWB is some kind of method that meets all those important element of lightweight and cost effective product with exceptional performance. Generally, the TWB concept is to customize the sheet metal thickness and grade at different location within the same sheet (Kinsey, 2010). Some critical parts of the sheet metal blank need thicker or stronger material (Chan, 2003).

Beside to reduce the weight, the TWB also give advantage for increasing the local stiffness. It is some kind like new process and new concept of manufacturing. Normally the process of creating the structural and skin component for vehicle, sheet metal is used due to superior strength to weight ratio compared with bulk material products. To assemble the sheet metal with various component traditionally, individual sheet metal parts are form and then subsequently welded. In TWB, multiple sheet metals are seam welded or bond together prior to deformation process, thus requiring only one forming operation. The multiple sheets could be the material within difference in the thickness, grade, or coating of the material for example galvanized versus none galvanized. For example, the manufacturing of the door inner panel of a car (Figure 2.1) has satisfy the stiffness requirement only at the hinge area, so the TWB technique can be applied here to use the thicker portion in hinge area and the rest of the sheet can be made from a thinner gauge to reduce the overall weight of the panel. When creating a tailor welded blank, designers are able to tailor, hence the name, the location in the blank where specific material properties are desired. Forming of TWB is challenging due to a significant reduction of formability associated with this type of blank. First, material property changes in the heat-affected zone of the weld decrease the potential strain in the material prior to tearing failure. The thinner part of TWB maybe undergoes deformation than the thicker part which is stronger material in the forming area. The main advantage of this method is the opportunity to place the optimum steel thickness and strength where they are really needed. Not only that, this method also give advantage in weight saving and with no reinforcement. TWB is a new technology that allows the designer or engineer to create the 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 (Khairi, 2007). For automotive industry, the Tailor welded method give the advantage in:

(i) Fewer parts
(ii) Reduce design and development time
(iii) Reduce material use
(iv) Weight reduction
(v) Improve dimensional accuracy

**Figure 2.1:** View of current and potential automotive tailor welded blank applications

Source: www.twi.co.uk, 2013

This joining of various sheets into a single blank that makes the 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.

### 2.1.1 Similar material of TWB

Nowadays, TWB application is quite widely used, especially in the fields of use of metal materials such as transportation industries.TWB with blanks of similar materials and dissimilar thicknesses have been introduced in order to reduce cost. It is widely use in application that require different strength at different section and proper weight distribution. Some critical parts of the sheet metal blank need thicker material and that why the different thickness joining are needed (Chan, 2003). Resulting from that, it is not only reducing the weight but also did increasing the local stiffness of the blanks. This change in thickness creates a discontinuity in the TWB that alters the stress state and consequently the strain that occur during forming (Kinsey, 2010). By decreasing the thickness of mismatch the weld line movement has reduces since the stress concentration is the one responsible for failures in the transition zone.

The thickness ratio in forming the TWB is quite important. Every different thickness ratio has its own effect to the formability of TWB. According to K.Narasimhan cited in his journal, the thinner blank did give the contribution to the plastic deformation increases as the thickness ratio increase. The thinner blank will dominate the overall deformation behaviour for higher thickness ratios.

## 2.2 Welding Process

To joining the part in TWB welding is the best method. Welding is a permanent type of joining. Welding is a fabrication technique which done by melting the work piece until it form the melting pool and adding the filler onto it and let it joint together with the melting pool and cools to become strong joint. Today there a lot of welding process available such as TIG, MIG, Fusion welding, laser beam welding and many more.

### 2.2.1 Tungsten Inert Gas Welding (TIG)

There are several types of welding to joint dissimilar material or thickness. TIG is one of those. TIGs use a non-consumable electrode made of tungsten. Principally, TIG welding is an electric arc welding process using an electric arc as fusion energy burning between the work piece and the tungsten electrode. During the welding process, the electrode, the arc and the weld pool are protected against the damaging effects of the atmospheric air by an inert shielding gas. 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. Inert gas is the types of gas which is does not combine with others element as same as inactive gas. Commonly Argon and helium or mixtures of both has been use as gasses for shielding (Larry, 2012). Argon gas is more preferred because of its excellent in providing arc stability and having a cleaning action in certain materials. Mostly, the TIGs welding have been use to weld thin section of stainless steel, and non-ferrous metal such as aluminium. It can also weld many dissimilar metals together. This kind of welding has a large area of application due to its advantages which is;

- (i) Provides a concentrated heating of the work piece
- (ii) Provides an effective protection of the weld pool by an inert shielding gas
- (iii) Can be independent of filler material
- (iv) The filler materials do not need to be finely prepared if only the alloying is all right
- (v) There is no need for after treatment of the weld as no slag or spatter are produced
- (vi) Places of difficult access can be welded

### 2.2.2 Metal Inert Gas Welding (MIG)

Other type of welding to join the material in TWB is MIG welding. This kind of welding is applied commonly due to its effectiveness to weld variety of materials, ferrous and non ferrous (Larry, 2012). MIG welding use a small diameter of electrode wire also known as filler which has been fed continuously into the arc from a coil. As a result, it can produce a quick and neat weld at the joint. Generally, MIG welding is an arc welding process, in which the weld is shielded by an external gas such as Argon, helium, $CO_2$, argon + Oxygen or other gas mixtures. The electrode wire or filler is consumable and made from chemical composition similar to that parent material supply from a spool to the arc zone. The melting process will occurred as the arc heat did melt the filler and the edges of the work pieces. The fused electrode material is supplied to the surfaces of the work pieces, fills the weld pool and forms joint. The selection of the filler crucially and proper selection is required to produce a weld deposit with these basic objectives:

(i) A deposit closely matching the mechanical properties and physical characteristic of the base metal.
(ii) A sound weld deposit, free of discontinuities

The selection of the welding electrode should be based principally upon matching the mechanical properties and the physical characteristics of the base metal. MIG welding is a technique that has a lot of advantage such as following:

(i) Continuous weld may be produced
(ii) High level of operator's skill is not required
(iii) Slag removal is not required (no slag)

### 2.2.3 Filler Types

Filler is a component used during welding process by adding it onto the weld pool throughout welding duration. There are four types identified as covered electrodes, bare electrode wire or rod, tubular electrode wire, and welding fluxes. Filler ER 4043 and ER 4047 was widely use during aluminium alloy weld. The major different between these two types of filler is the amount of silicon where the ER4043 filler contain 4.5 – 6.0 % while for filler ER4047 contain 11.0 – 13.0 % silicon. Different filler types will give different corrosion rate on the fusion zone of the welded joint

### 2.2.4 Joining Design

There are several types of design during joining process. The most common used are butt join (Figure 2.2) and lap joint (Figure 2.3).

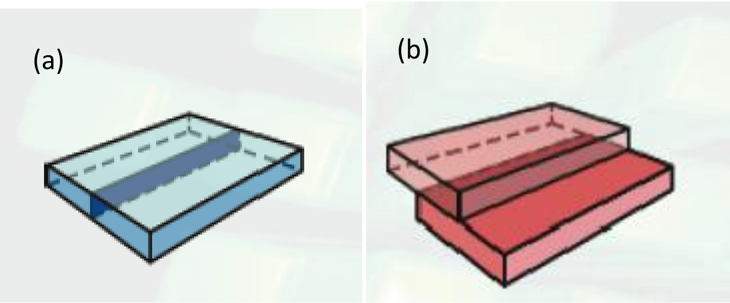


**Figure 2.2:** Butt joint (a), Lap joint (b)

Source: Junglan, 2012

Butt joint is a joint type which two separated members are joined at the same plane at the edge of the material. It is the simplest joint. For thicker material, a gap between the materials is needed. This design of joint is more application in manufacturing pressure vessels, piping, tanks and other applications that require a smooth weld face. Lap joint applied by overlapping items that do not lie directly on top of one another and a fillet weld is deposited along the joint. Lap joint normally used to weld thin section.

In order to join the various sheets into single blank in TWB, the permanent joint is the type of the join that has been determined to apply. Permanent joint is the join type that is to stay put and there are two types of it, which is welding and riveting. To perform the permanent joint in TWBs the method to use is welding.

Generally, welding means a process of joining two or more metallic material by using a fused metal also known as welding rod upon the joining by raising the temperature of their surfaces or edges to the fusion temperature. But nowadays the function of the welding are wide and various, based on American Welding Society's

(AWS), welding can be describe as a localized coalescence of metal or non-metals produced either by heating the materials to required welding temperature, with or without the application of pressure, or by the application of pressure alone, and with or without the use of filler materials (Larry, 2012). Coalescence means the fusion or growing together of the grain structure of the materials being welded. Nowadays, there are a lot of welding types that have been used for industry. These four types are the most commonly used in the industry which is MIG welding, Arc welding, Gas welding and TIG welding. For TWB, several types of welding have been used as it meets the requirement. The types of welding that commonly use nowadays are such as TIG, MIG, Shield metal arc welding, and laser beam welding.

## 2.3 MATERIALS

In TWB, there are several materials that have been used to meet the demands for lightweight for manufacturing. The lightweight metal alloys materials are chosen in these industries because of their low density and high specific strength alongside the special features such as corrosion resistance, dimensional stability and many more. Metal alloys also preferred due to environment concerns, government regulations and consumer demands (Kinsey, 2010).

### 2.3.1 Aluminium

Aluminium is known as lightweight material. Aluminium is available in abundance on the earth’s crust, largely in form of cryolite or bauxite. Aluminium has a unique combination of attractive properties such as low weight, high strength, superior malleability, easy machining, excellent corrosion resistance and good thermal and electrical conductivity (Jacobs, 2007). The melting point for aluminium is 660.32 °C. The strength of the Aluminium alloy can be increase by alloying it with manganese, silicon, cooper, magnesium, zinc, and many more (Kinsey, 2010). By applied different alloying element and heat treatment, aluminium can be dividing into several groups. That group using four digit number starting from 1XXX to 8XXX. The 1XXX series of aluminium has low yield strength, while the 5XXX and 6XXX series have yield strength equivalent to mild steel (Figure. 2.4) and 7XXX series have yield strength equivalent to high strength steels (AluMatter, 2010). The different strength of aluminium between grades can be described as show in Figure 2.5.

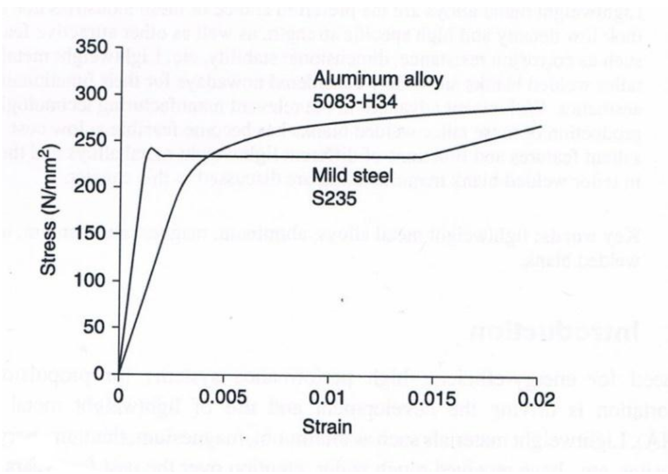


**Figure 2.4:** Comparison of Al 5083 and mild steel

Source: AluMatter, 2010

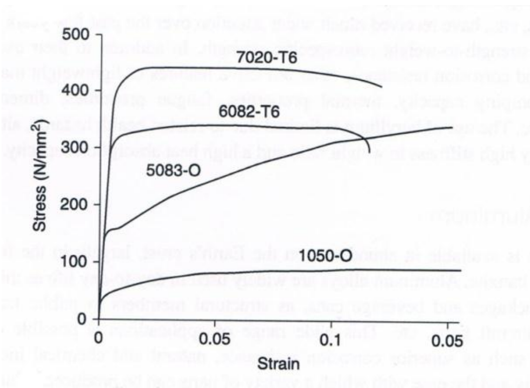


**Figure 2.5:** Aluminium alloy strength according to different grades

Source: AluMatter, 2012

### 2.3.2 Aluminium Alloy AA1100

Aluminium alloy AA1100 are in the group of type 1XXX which is has the Principal characteristics and applications as shown below;

(i) Strain harden ability

(ii) High formability, corrosion resistance, and electrical conductivity
(iii) Electrical and chemical applications
(iv) Typical ultimate tensile strength range: 10 to 27 ksi (70 to 185 MPa)

These type of aluminium consist almost 99 % aluminium properties. It is also non heat treatable and also known as commercially pure aluminium. The main important of the aluminium alloy AA1100 type is high corrosion resistance. AA100 also display excellent forming, welding and finishing characteristic. It has been widely used in for packaging chemical equipment, tank car or truck bodies and aircraft industries. Table 2.1 and 2.2 summarized the properties of an aluminium alloy AA1100.

**Table 2.1:** Composition of aluminium AA1100

| **Al** | **Mg** | **Si** | **Fe** | **Cu** | **Zn** | **Ti** | **Mn** | **Cr** |
|---|---|---|---|---|---|---|---|---|
| 99 | - | 0.7 | 0.25 | 0.20 | 0.10 | - | 0.05 | - |

Source: (Ali, 2012)

**Table 2.2:** Strength and elastic properties of the AA1100

| **Properties** | **AA1100** |
|---|---|
| Ultimate Tensile strength, $\sigma_{UTS}$ (MPa) | 147 |
| Yield strength, $\sigma_{0.2\%}$ (MPa) | 69.8 |
| Elongation, $\varepsilon_r$ (%) | 24.5 |
| Microhardness (0.2 kg) | 50.5 |

Source: (Ali, 2012)