STRESS BEHAVIOUR OF TAILOR WELDED BLANKS FOR DISSIMILAR METALS USING FINITE ELEMENT METHOD

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ABSTRACT

This project presents the stress analysis on tailor welded blanks for dissimilar metals using finite element method. The application of the tailor welded blanks in automotive industries has a large potential and the critical location on the tailor welded blanks based on the stress analysis is important. The structural modeling of the tailor welded blanks is developed using computer aided design software. The method used for tailor welded blanks are later welding. The effect of different materials combination and different configuration on tailor welded blanks on welding behavior is another importance of this study. Finite element method is used to investigate the stress on the tailor welded blanks. Goldak's double ellipsoid source model is used as the heat source model of the investigation. The changes of power in current and voltages, dissimilar metals of aluminium and steel; and the plate-configuration, L-configuration and T-configuration are investigated in this study. The increase of power increases the hot affected zone and distortion of the plate. The heat is dissipated faster at the aluminium plate compared to steel plate makes the stress concentrated at the steel plate. The stress is distributed outside the welding line for the T-configuration due to the fusion process is not complete.

ABSTRAK

Projek ini menerangkan tentang analisis tekanan pada *tailor welded blanks* untuk logam yang berbeza menggunakan *finite element method*. Penggunaan *tailor welded blanks* dalam industri automotif mempunyai potensi yang besar dan lokasi kritikal pada *tailor welded blanks* berdasarkan analisis tekanan adalah penting. Pemodelan struktur untuk *tailor welded blanks* dihasilkan menggunakan perisian *computer aided design*. Kesan daripada kombinasi logam yang berbeza dan konfigurasi yang berbeza pada kombinasi atas kimpalan adalah salah satu daripada kajian. Kaedah *finite element method* digunakan untuk mengkaji tekanan pada *tailor welded blanks*. *Goldak's double ellipsoid source model* digunakan sebagai model sumber haba. Perubahan kuasa arus dan voltan, logam berbeza daripada aluminium dan keluli dan plat-konfigurasi, L-konfigurasi dan T-konfigurasi disiasat dalam kajian ini. Peningkatan kuasa meningkatkan *Hot Affected Zone* dan penyelewengan plat. Haba yang hilang lebih cepat pada plat aluminium berbanding dengan plat keluli membuat tekanan tertumpu pada plat keluli. Tekanan ini diedarkan di luar garisan kimpalan untuk T-konfigurasi kerana proses gabungan tidak lengkap.

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LIST OF SYMBOLS

Δt	Time steps
n_1	Refinement level
n_2	Time steps per element
l	Element size along weld path
v	Velocity
c_f	Length of front ellipsoidal
c_r	Length of rear ellipsoidal
b	Depth of heat source
a	Width of heat source
Q	Input power of the welding heat source
q_f	Front heat fraction
q_r	Rear heat fraction
A	Ampere
V	Voltage

LIST OF ABBREVIATIONS

TWB	Tailor Welded Blanks
IF	Interstitial-free
DP	Dual Phase
HSLA	High Strength Low Alloy
FEM	Finite Element Method
LWB	Laser Weld Bonding
HAZ	Hot Affected Zone
AISI	American Iron and Steel Institute
SS	Stainless Steel
Al	Aluminium
MPS	Maximum Principal Stress
EPS	Effective Plastic Strain
ES	Effective Stress

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Tailor-welded blanks (TWB) are very popular in industry nowadays especially in automotive application due to the competitiveness among the industries. These industries compete in term of technological innovation to gain the trust and confidence of the customers. Although the automotive products have their own feature, but the customer demands more in fuel efficiency, performance, safety, and comfort at the lowest price. (Kinsey et al., 2000) A tailor-welded blank consists of two or more sheets that are welded together in a single plane prior to forming. The sheets can be identical, or having different thicknesses, mechanical properties or surface coating which can be join by various welding processes (Zhao et al., 2001). The weight of the part could be reduced while the strength of the part is maintained. Anand et al. (2006) mentioned that the tailor-welded concept allow the engineer to join the best material at the best place according to the material properties within the part where needed. TWB are popular among the automotive application because the weight of the part in a vehicle is very crucial in fuel efficiency and TWBs is a very viable solution in reducing the weight of the part. The higher strength material is used on the critical region while the lower strength material is used on the less critical region could highly reduce the weight of the part and this concept is very useful in automotive application.

Anand et al. (2006) have investigated that no other material has shown the versatility of steels in the automotive applications. Various new grades of steels – interstitial-free (IF), dual phase (DP) and high strength low alloy (HSLA) – have been developed which show excellent formability and are able to meet the most automotive requirements. These grades of steels have penetrated their use in the TWBs alongside raising challenges which include the prediction and evaluation of the performance of these TWBs in forming and other structural properties. This shows that the steel is a very good choice in automotive application which implicated the TWBs concept. Therefore, an investigation should be taken to determine the deformation pattern and weld line displacement due to the effect of TWBs in the parts. There are many method could be taken to analyse the results and one of it is numerical method. Finite element modeling and analysis is the method that well known predictor on the deformation pattern and weld line displacement when the forces and material properties are known accurately. Raymond et al. (2004) carried out an analysis using the finite element method to investigate the weld modeling techniques based on simulation results. According to Luo (2009), the finite element method is used to solve many complicated engineering problems which is more to the strain energy density. With this method, the analysis of the part with the mesh is more accurate and can be used to predict the complicated part. Other than fatigue, many other analyses are available to predict the reaction in the part when there is outer reaction acting on the part.

1.2 PROBLEM STATEMENT

Tailor welded blanks is comprised of two or more sheets that have been welded together in single plane previous to forming. This type of forming is getting popular among the automotive application due to the fuel efficient, cost and safety factor (Zhao et al., 2001). TWB is popular due to the combination of two or more sheets which allows variants of material properties in a piece of blank. By using this method, the weight of the blanks can be reduced dramatically while can maintain the strength of certain portion of the part which high strength is needed and the reduced the other portions. (Davies et al., 2001) The TWB could comprised of steel for the portion which the higher strength of material properties and other lower weight and strength for the other portion of the parts. But the problem is the procedure and the method used to weld the steel-steel blanks and the different materials blanks can be used for both of these combinations? Are the power used to weld the TWB play a role in the weld line? This issue is very critical when fabricating the tailor welded blanks. (Raymond et al., 2004) Therefore, this project will be performed to study about the critical point of the tailor welded blanks. By comprising of dissimilar metals with different configuration of welding, the critical points where the force is concentrated and the maximum forces that exerted at that particular point can be estimated. It is very costly and time consuming to investigates using the experimental method without knowing the expected results. To overcome these issues, the simulation using the finite element method is used to estimate the critical point of the TWB. The proposed method is to simulate the TWB welding composed of the dissimilar metals, dissimilar power and dissimilar configuration to estimate the critical point from the result obtained from the simulation. The suggested materials used are the steel and aluminium with various configurations.

1.3 OBJECTIVE OF THE PROJECT

The objectives of this project are as follows:

(i) To determine the stress on tailor welded blanks and identify the critical location of the welded blanks.
(ii) To investigate the effect of power on welding characteristics for the tailor welded blanks
(iii) To investigate the dissimilar metals and configuration on welding behavior.

1.4 SCOPE OF THE STUDY

The chosen method to analysis the tailor welded blanks is the finite element method. This method is widely used nowadays to estimate the critical point on the tailor welded blanks. In this study, there are two different metals are considered including the steels and aluminium. The welding parameter of current, voltage and welding velocity is modified to analysis the effect on the welding part. The different configuration of TWB is the L-Shape and T-Shape and the plate.

1.5 OVERVIEW OF THE PROJECT

There are five chapters in this project including Chapter 1. Chapter 2 presents literature review related to the information of tailor welded blanks, finite element method, welding method, welding parameters and materials. The previous study of these topics is discussed in this chapter. Chapter 3 presents methodology including the welding power, materials, welding configuration, finite element analysis, time steps and heat source. The power chosen, type of materials, type of configuration, information of finite element analysis, information of time steps and heat source is discussed in this chapter. Chapter 4 presents the result and discussion of the simulation results. The effect of power, different materials and different configuration is discussed in this chapter. Chapter 5 is summarized results and recommendation for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter provides the review from previous research efforts related to tailor welded blanks, finite element methods, welding methods, welding parameters and type of materials of the components. This review has been well elaborate to cover different dimensions about the current content of the literature, the scope and the direction of current research. This study has been made in order to help identify proper parameters involved for this experiment. The review is fairly detailed so that the present research effort can be properly tailored to add to the current body of the literature as well as to justify the scope and direction of present.

2.2 TAILOR WELDED BLANKS

Tailor welded blanks is a very important study for the automotive application nowadays. A tailor welded blanks consists of two or more sheets that have been welded together in a single plane prior to forming. (Zhao et al., 2001) Tailor welded blanks is widely used due to the advantages of tailor welded blanks is important in the automotive application. This is due to the TWB can increase the possibility of economizing in use of material for reducing the manufacturing cost. (Seto et al., 2009) Tailor welded blanks technology gives automotive designers the ability to selectively use of materials. By select the particular materials in the correct places of a part, it can reduce the unnecessary waste of materials and reduce the weight of the part but maintain the durability of the part. The development of TWB began with steel applications and proved to be an effective technique in achieving weight reduction is been proved by the previous product. (Davies et al., 2001)

The uses of TWB although is important, but the testing of the capability of the TWB is also important. (Martinson et al., 2009; Alberg and Berglund, 2003) The stress analysis is one of the method is using the simulation. Simulation is used to test the TWB and normal specimen. The non-welding specimen to compare the results of the TWB simulation is studied (Raymond et al., 2004). The study compares TWB and normal specimen to study the differences of the TWB and normal specimen. The uses of TWB for upset welding that can be adapted to the automotive industries (Min et al., 2000). This study stated that the application of TWB is important in the automotive industries. Thus, the automobile and airplane manufacturing industries are making many diversified efforts to promote productivity by the introduction of tailor-welded blank, whereby upset forming with upset welding material with the aim of satisfying each proper purpose.

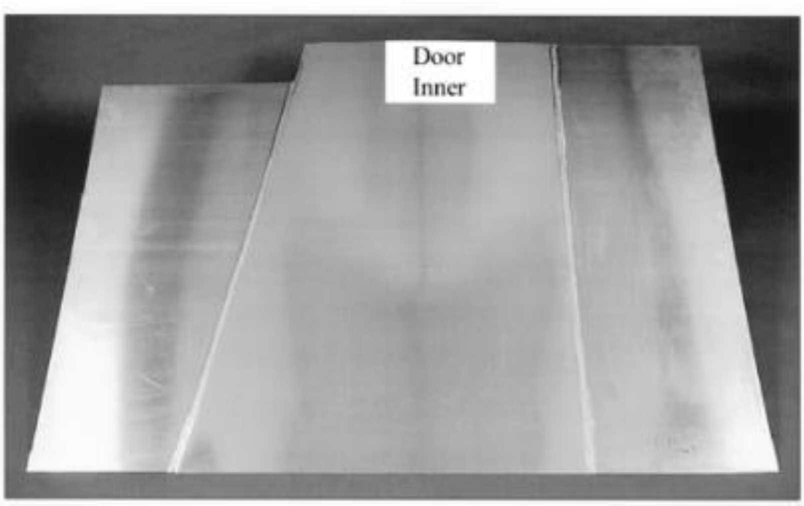


Figure 2.1: TWB before manufacturing process

Source: Davies et al. (2001)

Since the automotive industries is important in innovative of the transport issues, it is important to study the TWB because it could increase the fuel efficiency due to light weight, economizing of material cost by reducing the material at the unnecessary location of the part (Cheng et al., 2007). As shown in Figure 2.1 and Figure 2.2, the TWB is used in producing the door inner panel (Davies et al., 2001). This is reduced the material used to produce the door panel by maintaining the strength of the material at the critical point by using thicker sheets and reduce the thickness of the sheets at the neutral point. By this method, the material used to produce the product is reduced meanwhile the strength could maintain at the critical point and the weight of the part could be reduce. This may greatly help in the economizing the manufacturing cost and increase the fuel efficiency. (Anand et al., 2006)

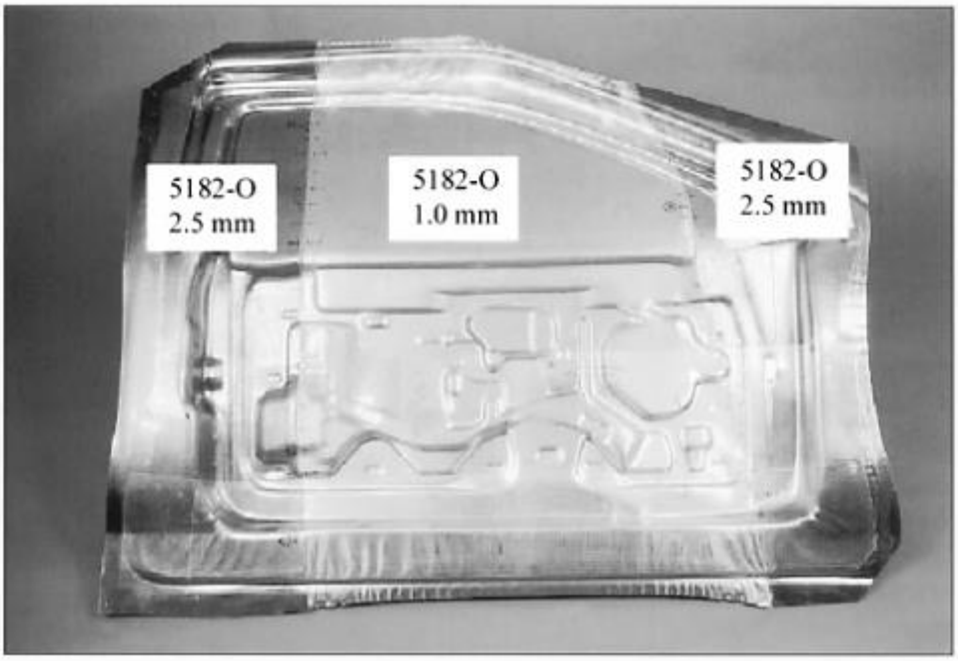


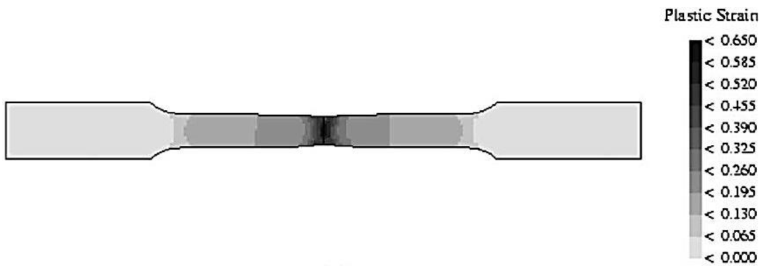
Figure 2.2: TWB after manufacturing process

Source: Davies et al. (2001)

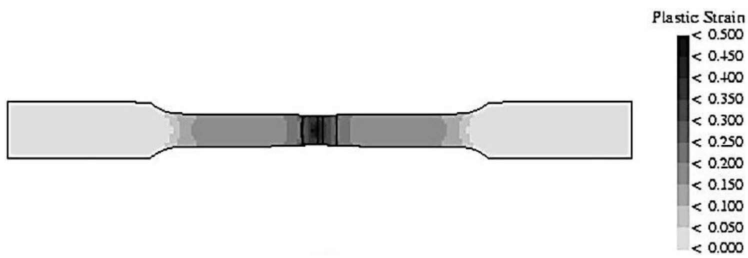
2.3 FINITE ELEMENT METHOD

Testing is important before manufacturing a part in mass production. Raymond et al. (2004) stated that the method used in investigates the part or specimen behavior is also important. A correct method used to investigate can ensure the results obtain is correct and accurate. One of the methods is using the simulation method to predict the behavior of the part after welding. (Martinson et al., 2009) By this method, the prediction results could be obtained before the experiment is conducted to test the part behavior. Finite element method (FEM) is of the method to predict the behavior of the part. Zhao et al. (2001) investigate the uses of finite element analysis of tailor-welded blanks. Proposed FEM model correctly predicts the failure pattern, buckling, and springback of tailor-welded blanks. This study shows that the finite element method is used to analysis the stress behavior of the tailor welded blanks. The finite element analysis is one of the methods to predict the behavior of the part after the boundary condition and force is applied. The simulation result is compared with the experimental result and the comparison is showing a good similarity.

(a) Weld Properties Included



(b) Weld properties excluded



(c) Weld Properties Included (Same as Materials Properties)

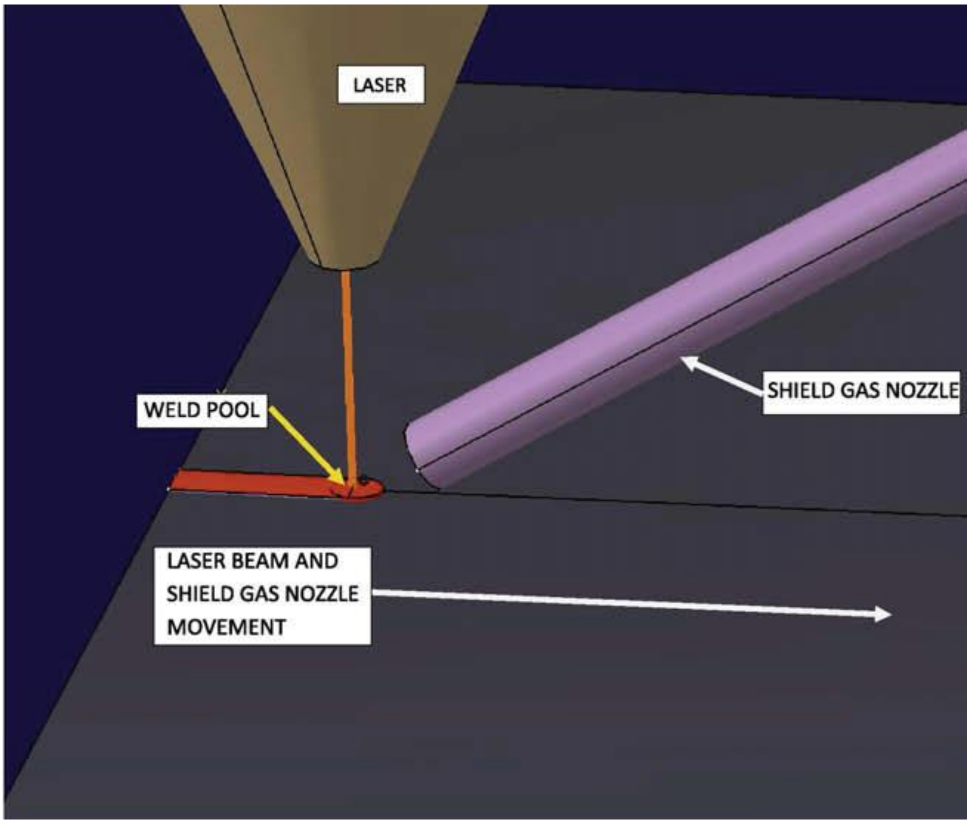
Figure 2.3: Strain distribution for tailor-welded blanks of forming operations

Source: Raymond et al. (2004)

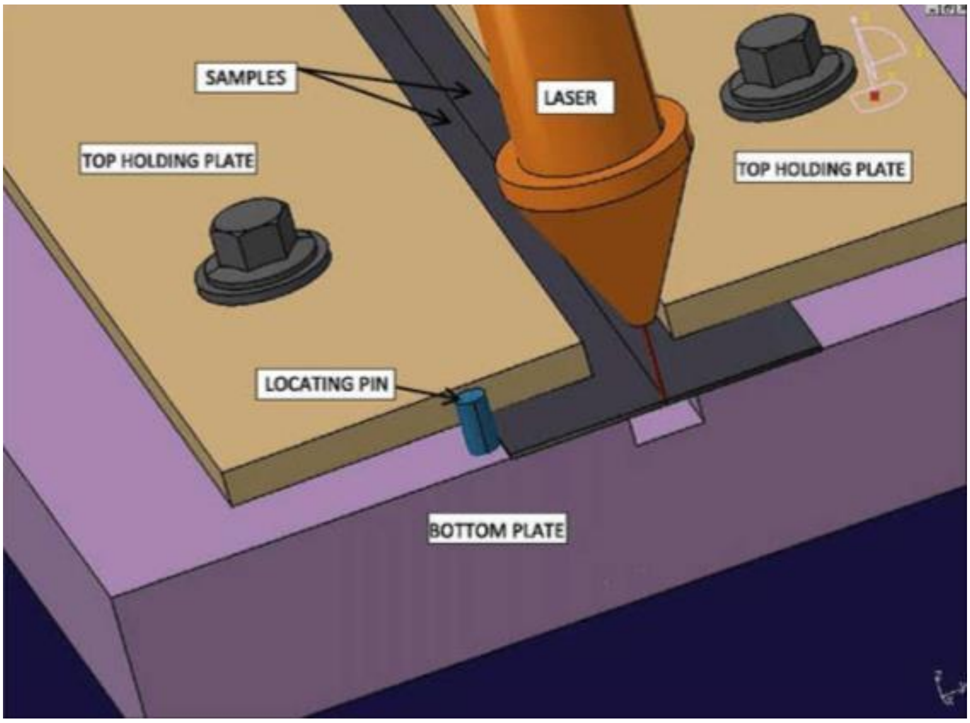
Figure 2.3 shows the strain distribution for inclusion or exclusion of welding characteristic specimen of forming operation. The weld modeling techniques are affecting the finite element simulation of tailor-welded blanks forming operations (Raymond et al., 2004). This study included the non-welding specimen to compare the results of the TWB and normal simulation. The result shows that the specimen with the welding is displaced less than the non-welding specimen. This giving support that the finite element method could be used to investigates not only the TWB specimen but also to compare the results with the normal specimen. This shown the reliability of finite element method in investigating the behavior of a specimen is capable. The failure likely to occur on the parent materials in Figure 2.3(a) and the failure is likely to occur in the center of the specimen (Raymond et al., 2004). The numerical method shows good agreement with the experimental temperature distributions, and able to qualitatively predict the residual stress distribution of each of the weld geometries (Martinson et al., 2009). This study shows the simulation is giving an accurate prediction of the specimen behavior after force is applied into the specimen. This could let the designer to aim for the critical point of the specimen and design the part which more strength is required or less strength of material is needed.

2.4 WELDING METHODS

There are various welding method used to weld the metals. A common method used in the automotive industries is the laser weld. A CO_2 laser was used to butt-weld the TWBs. (Anand et al., 2006). The comparison of fatigue strength of laser weld and resistance spot weld is carried out. The result shows that the laser weld reported higher fatigue strength than the resistance spot weld. The lasers offer significant advantages such as high strength, excellent finish, simplicity, flexibility and reliability in manufacturing compared to other processes such as resistance spot welding, gas metal arc welding and electron beam welding (Sharma and Molian, 2009). This is the reason why the laser weld is more common use in the automotive industries. Figure 2.4 shows the illustration on how the laser weld is performed.



(a)



(b)

Figure 2.4: (a) Illustration on laser set-up; (b) weld fixture arrangement

Source: Sharma and Molian (2009)

There are various of research carried out on the laser welding and the results shows that the effect of the welding speed is on the porosity rather than microhardness values, weld tensile strength is depends upon steel grade, weld penetration, and weld width, weld fatigue strength is depends on material thickness, and the weld fatigue performance is affected by the weld concavity and presence of zinc (Sharma and Molian, 2009). The precaution shield gas should be used to shielding the molten weld pool because the reactivity of the metal with the atmospheric element is increased at high temperature (Akman et al., 2009). Other than laser welds, the fusion temperature is high, there is another method of weld used when the joining temperature need to be lower. The Friction stir welding (FSW) is a suitable method when the joining temperature cannot be too high or else the cracking will occur at the join when welding process is done (Aonuma and Nakata, 2012). This method is rotating the tools at the join area and the heat caused by the friction when the tool is rotating used to join the 2 metals. The Figure 2.5 shows the illustration on how the joining process is done.

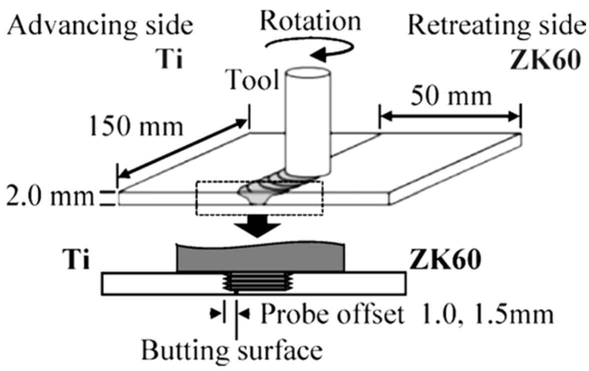
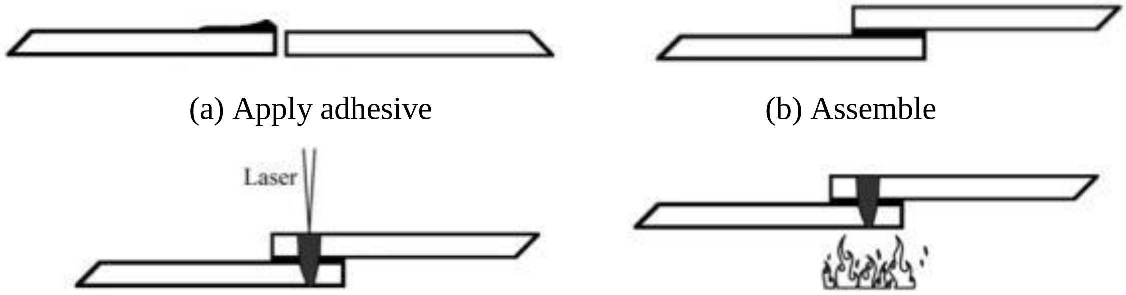


Figure 2.5: Illustration of the friction stir welding

Source: Aonuma and Nakata (2012)

There are a few welding method which is been used like the laser weld bonding (LWB). The laser weld bonding is applying the adhesive into the faying surface of metal part to be joined. Figure 2.6 shows the process of the welding process of the LWB. The LWB can offer including excellent strength in shear, uniform distribution of loads, softening of stress concentrations, excellent fatigue resistance and good energy absorption. But LWB are suitable for the overlapped sheet of welding.



(a) Apply adhesive (b) Assemble

(c) Laser welding (d) Heat

Figure 2.6: Laser weld bonding process

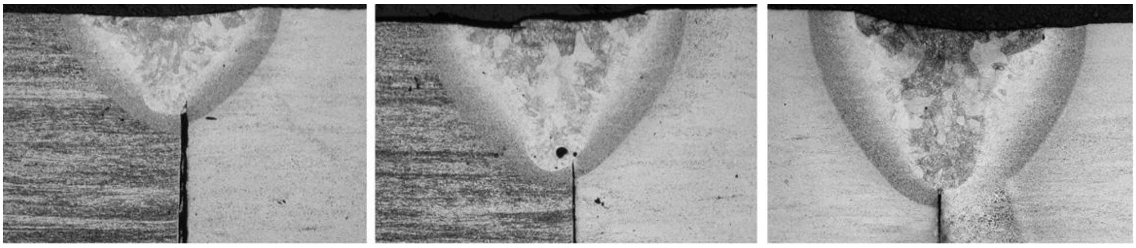
2.5 WELDING PARAMETERS

There are parameters need to be determined before proceeding the welding. The shielding gas is a crucial importance to prevent embitterment of the weld region and the ensuing losses in weld ductility. (Akman et al., 2009) The helium gas shows an advantage compared to argon because helium has higher ionization energy than argon then energy transfer to the materials is higher. Other than shielding gas, the other parameters are as shown in the Table 2.1 is listed the parameters used in laser welding.

Table 2.1: Parameters used from previous literature

Sources	**Parameters**						
	Pulse Energy	**Pulse Duration**	**Power**	**Speed**	**Focal location**	**Gas Pressure**	**Gas Flowrate**
Anand et al. (2006)			✓	✓			✓
Sharma and Molian (2009)			✓	✓	✓		✓
Akman et al. (2009)	✓	✓		✓	✓	✓	

The penetration depth of the weld is important for the welding process. (Gao et al., 2007; Liu and Ren, 2010) The force of joining is depends on the area of fusion for the two metals for the fusion welding process. The research shows that the effect penetration depth is affected by the peak power used for the laser weld (Akman et al., 2009). Figure 2.7 shows the effect of peak power on penetration depth with the constant pulse duration. The penetration depth is increased proportional to the peak power. Peak power of 2 kW is used for full penetration depth (Sharma and Molian, 2009). The effects of peak power on hot affected zone (HAZ) width (h_1), penetration ability (h_2), crater formation (h_3) and weld pool (h_4) is determined.



Peak Power	= 1.12 kW	Peak Power	= 1.3 kW	Peak Power	= 1.7 kW
Pulse duration	= 5 ms	Pulse duration	= 5 ms	Pulse duration	= 5 ms
h_1	= 1.654 mm	h_1	= 1.945 mm	h_1	= 2.353 mm
h_2	= 0.740 mm	h_2	= 1.047 mm	h_2	= 1.401 mm
h_3	= 0 mm	h_3	= 0 mm	h_3	= 0 mm
h_4	= 1.384 mm	h_4	= 1.489 mm	h_4	= 1.598 mm

Figure 2.7: Effect of peak power on penetration depth (< 2 kW)

Source: Akman et al. (2009)

After the peak power goes over 2 kW, the HAZ and weld pool is growing more proportional to the peak power than the penetration ability (Akman et al., 2009). Figure 2.8 shows the effect of penetration depth for the peak power above 2 kW. For higher peak power, the power is transmitted is melted the materials without vaporization and this create the crater formation. (Akman et al., 2009) This mean the material loss makes the crater formation and this directly decrease the fusion area. To overcome the crater formation, the pulse duration is increased to depth of craters. Figure 2.9 shows the effects of pulse duration to the craters formation. When the pulse duration is increased, the crater depth is decreased but the HAZ and weld pool width also increase. Therefore, the balance of the peak power and pulse duration should be determined so that the penetration depth can be deepest with the lowest HAZ, weld pool, and craters depth. Figure 2.10 shows the best condition is 3 kW of peak power with 10 ms pulse duration.