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ABSTRACT

NUMERICAL STUDY ON FATIGUE LIFE OF SPOT WELDED FOR AUTOMOTIVE COMPONENTS

(Keywords: Automotive components, fatigue life, spot weld, simulation)

The automotive industries are always carrying out the optimizations on vehicle's performance and cost. One of the ways is by using different materials at different vehicle locations to utilize the materials' functionalities to the fullest extent. Engineers are becoming more and more open minded about choosing the best material for certain applications. Today aluminium and steel are the most important construction materials for the mass production of automotive structures. The combined use of these materials offers automotive designers the best compromise between weight reduction and strength of the body. With the trend to multiple materials in vehicle designs, a reliable joining method must be developed and evaluated. Continuing pressure to improve quality, minimize cost and meet fuel economy, high environmental stand and safety requirements, has led a demand for automotive industries to use lighter and stronger materials. High strength steels are used resulting in significant weight reductions in high volume vehicles. However, the use of new materials raises challenges for the manufacturing processes. Spot welding is the predominant joining techniques in the assembly process. Assessing the spot welding quality is a very important issue in ensuring vehicle structure integrity. A scientific and systematic study of quality of resistance spot welding will benefit the automotive industry by producing high quality and low cost automobiles through consistent and quality welding.

ABSTRAK

KAJIAN NUMERIKAL PENETUAN HAYAT KIMPALAN TITIK UNTUK KOMPONEN OTOMOTIF

(Kata kunci: Komponen otomotif, hayat lesu, kimpalan titik, simulasi)

Pihak pengeluar kenderaaan sentiasa berusaha untuk menghasilkan kenderaan yang baik dan menjimatkan kos, bahan yang digunakan adalah memainkan peranan yang penting bersama lokasi pengeluaran untuk menggunakan bahan tersebut dengan fungsi bahan yang digunakan mencapai tahap yang terbaik. Aluminium dan besi adalah bahan yang terpenting untuk membuat kenderaan yang menjimatkan dan baik. Kombinasi bahan bahan ini menjanjikan pereka kenderaan keputusan yang terbaik untuk mengurangkan berat kenderaan dan kekuatan serta ketahanan badan kereta. Teknik baru ketahanan sambungan/kimpalan mestilah di bangunkan dan di nilai. Permintaan untuk meningkatkan kualiti, mengurangkan kos dan menjimatkan bahanapi, mencapai tahap dibenarkan untuk alam sekitar dan tahap keselamatan yang tinggi telah menjadikan menjadikan pihak pengeluar kenderaan mengeluarkan kenderaan yang lebih ringan dengan bahan yang lebih tahan. Steel ketahanan tinggi telah menghasilkan pengurangan berat yang amat ketara dalam pengeluaran kenderaan yang berkuantiti tinggi. Walaubagaimanapon penggunaan kombinasi bahan ini meningkatkan cabaran untuk proses-proses pengeluaran. Kepentingan untuk menguji dan menilai kualiti "spot welding" atau kimpalan titik adalah untuk memastikan ketahanan struktur kenderaan. Kajian simulasi yang mendalam perlu untuk pengujian "spot welding" akan memberikan kelebihan kepada industri otomotif untuk mengeluarkan kenderaan yang berkualiti tinggi dengan kos yang rendah melalui mutu kimpalan yang tinggi dan stabil.

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CHAPTER 1

INTRODUCTION

Automotive manufactures are in the demanding by consumer to produce safer and more durable vehicles while improving fuel economy and emission standards. The automotive industry envisions that the optimized vehicle, in terms of performance and cost, can only be achieved by using different materials at different vehicle locations to utilize the materials' functionalities to the fullest extent. Engineers are becoming more and more open minded about choosing the best material for certain applications. Today aluminium and steel are the most important construction materials for the mass production of automotive structures. The combined use of these materials offers automotive designers the best compromise between weight reduction and strength of the body. With the trend to multiple materials in vehicle designs, a reliable joining method must be developed and evaluated.

Resistance spot welding is one of the primary methods to join sheet metals for automotive components. A typical car or truck may have more than 2000 spot welds. Since spot welds in automotive components are subjected to complex service loading conditions, various specimens have been used to analysis fatigue lives of spot welds (Sheppard and Pan 2001; Zhang 2001). The static strengths of spot welds has also been investigated. Ewing et al. (1982) investigated the strength of spot welds in terms of the specimen geometry, welding parameter, welding schedule, base metal strength, testing speed and testing configuration. Zuniga and Sheppard (1997) examined the failure modes of spot welds in coach-peel and lap-shear specimens. Lee et al. (1998) adopted a fracture mechanics approach using the stress intensity factor to model their experimental results on the strength of spot welds in U-tension specimens under combined tension and shear loading conditions. Wung (2001) and Wung et al. (2001) obtained and analyzed test results from lap-shear, in-plane rotation, coach-peel, normal separation, and in-plane shear tests and proposed a failure criterion based on the experimental data of spot welds in various specimens.

In this proposed research, we will be investigated the maximum load carrying capacity of spot welds under cyclic loading conditions and develop failure criteria for spot welds under variable amplitude loading conditions based on experimental and numerical results. The failure criterion for spot welds under variable amplitude conditions can be used as the reference for a failure criterion for the spot welds under cyclic random loading. In this investigation, experiments of spot weld specimens of mild steel with two different thicknesses will be conduct under various amplitude of cyclic loading conditions. Micrographs of spot welds before and after failure will be acquired to understand the physical failure processes under different loading conditions. The effects of the sheet thickness, weld nugget radius, and combination of loading on failure will be investigated by experimentally and numerically. Finally, an engineering formula will be proposed to characterize the load carrying capacity of spot welds with consideration of nugget size and sheet thickness under cyclic loading conditions for automotive components.

RESEARCH OBJECTIVES

To study he fatigue life behaviour and characteristics of spot welded high strength steel joints for automotive components

To develop a new fatigue life prediction model under variable amplitude loading.

Collect the variable amplitude loading data

The appropriate data sets need to be identified for the application in computational and experimental analysis. The loadings will be experimentally measures on spot welded structures.

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CHAPTER 2

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EFFECTS OF SPOT DIAMETER AND SHEETS THICKNESS ON FATIGUE LIFE OF SPOT WELDED STRUCTURE BASED ON FEA

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Abstract
This paper presents the effect of the spot weld and sheets thickness on the fatigue life of the of the spot-weld joints to predict the lifetime and location of the weakest spot-welds due to the variable amplitude loading conditions. A simple model was used to illustrate the technique of spot-weld fatigue analysis. Finite element model and analysis were carried out utilizing the finite element analysis commercial codes. Linear elastic finite element analysis was carried out to predict the stress state along the weld direction. It can be seen from the results that the predicted life greatly influence the sheet thickness, nugget diameter and loading conditions of the model. Acquired results were shown the predicted life for the nugget and the two sheets around the circumference of the spot-weld at which angle the worst damage occurs. The spot-welding fatigue analysis techniques are awfully essential for automotive structure design.

Keywords: Spot-weld structure, finite element analysis, fatigue-life, sheet thickness, variable amplitude loading.

1. Introduction

Spot welding is a widely employed technique to join sheet metals for body and cap structure in the automotive industry. The strength of the spot welds in the unibody vehicle structure determines the integrity of the structural performance during the vehicle operations. Most spot welds generally carry only shear forces but spot welds can also experience a significant amount of peel force or the force normal to the spot weld in certain loading conditions. The combination of the stress states and geometric shapes of the spot welds lead to stress concentration that can result in fatigue crack initiation around the spot weld. The presence of fatigue cracks can degrade structural performance and increase noise and vibration of the vehicle structure. Therefore, understanding of the fatigue strength for the spot welds is very important in automotive component design.

The static strengths of spot welds have also been investigated. Ewing et al. [1] investigated the strength of spot welds in terms of the specimen geometry, welding parameter, welding schedule, base metal strength, testing speed and testing configuration. Zhang and Taylor [2] reported the thickness effect of spot welded structure on fatigue life. Pan and Sheppard [3] calculated stress intensity factors for crack propagation through the thickness of plate by numerically utilizing finite element analysis. Lee et al. [4] adopted a fracture mechanics approach using the stress intensity factor to model their experimental results on the strength of spot welds in U-tension specimens under combined tension and shear loading conditions. Wung [5] and Wung et al. [6] obtained and analyzed test results from lap-shear, in-plane rotation, coach-peel, normal separation, and in-plane shear tests and proposed a failure criterion based on the experimental data of spot welds in various specimens.

Some researchers [7-9] have studied on the effects of base metal properties on the fatigue life of spot welds. They have also studied on the effects of loading conditions with different specimen types such as tensile shear, coach peel and cross tension specimens. These studied showed in general that fatigue life of spot welds depended on the loading conditions and base metal properties.

On the other hand, numerous researchers [1,10-14] proposed analytical and/or empirical models to predict the fatigue strength of spot welds in the early vehicle design stage. Most of these models were developed based on the relationship between a fatigue damage parameter and number of cycles to failure of spot welds. The objective of this paper is to investigate the effect of the sheet thickness and diameter of the spot weld nugget on the fatigue.

2. Structural Stress Parameter

Welded joints experience highly localized heating and cooling from welding processes. As a result, the material properties around the welding joints can be significant variations after welding. The local geometry of the welded joints may have variations due to the amount of heat inputs and welding skills. These variations present significant difficulties for reliable fatigue prediction of welded joints.

Dong [15-16] proposed a structural stress parameter for welded joins based on local stresses at weld toe. A typical through-thickness stress distribution at a fatigue critical location and the corresponding structural stress definition for through-thickness fatigue crack at the edge of a spot weld are shown in Fig. 1 and Fig. 2. Stress distribution at the edge of the spot weld nugget is assumed as shown in Fig. 1. In Fig. 1, t represents the thickness of the sheet steel, σ_x and τ are the normal and transverse shear stress under axial force P respectively. The corresponding structural stress distribution is shown in Fig. 2. The structural stress (σ) is expressed in Eq. 1.

$$\sigma = \sigma_m + \sigma_b \qquad (1)$$

where σ_m is the membrane stress component and σ_b is the bending stress component due to the axial force P in the x direction. The transverse shear stress can be calculated based on local structural shear stress distribution, however, the effect of transverse shear stress neglected since the spot weld does not experience significant transverse shear loads in general [15].

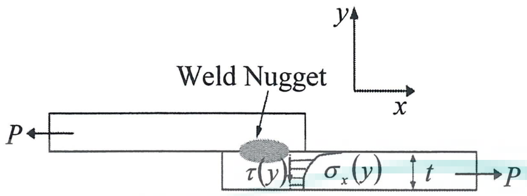

Fig. 1 Local normal and shear stress in thickness direction at the edge of a spot weld.

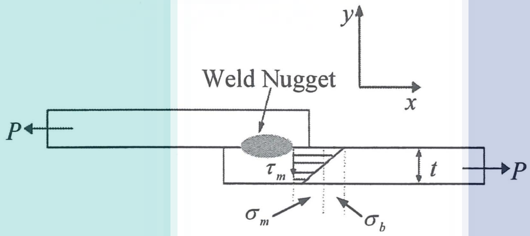

Fig. 2 Structural stress definition at the edge of spot weld nugget.

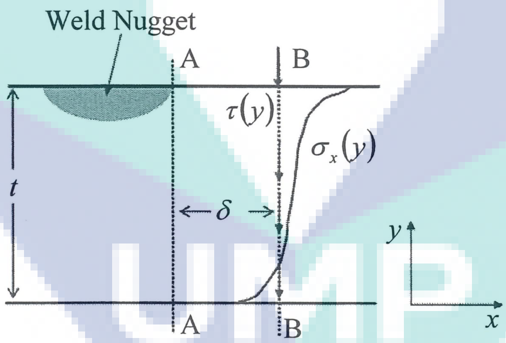

Fig. 3 Structural stress calculation procedure for fatigue crack in thickness direction at the edge of the weld nugget.

The structural stress is defined at a location of interest such as plane A-A in Fig. 3 and the second reference plane can be defined along plane B-B. Both local normal and shear stress along plane B-B can be obtained from the finite element analysis. The distance in local x-direction between plane A-A and B-B is defined as δ. The structural membrane stress and bending stress must satisfy Eq. (2) and Eq. (3) for equilibrium conditions between plane A-A and B-B. Eq. (2) represents the force balances in x-direction, evaluated along the plane B-B. On the other hand, Eq. (3) represents moment balances with respect to plane A-A at y = 0. When δ between plane A-A and B-B becomes smaller then transverse stress τ in Eq. (3) is negligible. Therefore, Eq. (2) and Eq. (3) can be evaluated at Plane A-A in Fig. 3.

$$\sigma_m = \frac{1}{t}\int_0^1 \sigma_x(y)dy \qquad (2)$$

$$\sigma_m\left(\frac{t^2}{2}\right) + \sigma_b\left(\frac{t^2}{2}\right) = \int_0^t y\sigma_x(y)dy + \delta\int_0^t \tau(y)dy \qquad (3)$$

3. Development of FEM

Traditionally, a very detailed finite element model of a spot welded joint is required to calculate the stress states near the joint [17-19]. This model produces reasonable results but it requires a good amount of effort for modeling and computational time. Therefore, the very detailed finite element modeling of spot welds is not feasible for 3000- 5000 spot welds in a typical automotive body structure [12]. Instead of the detailed modeling of the spot welds, a simple beam element represents a spot weld for fatigue calculation of the spot welds in a vehicle structure [12, 14, 20].

For the mesh insensitive structural stress calculation, the specimen for a spot welded joint is modeled with shell/plate, beam and rigid elements. The circular weld mark in each plate is modeled by triangular shell elements and rigid beams forming a spoke pattern as shown in Fig. 4. The rigid beam elements are connected from the center node to the peripheral nodal points of the circular weld marks in the both plates. Then the center nodes of the circular weld marks in both plates are connected with a beam element. Fig. 4 shows a finite element mesh around a circular weld mark. The geometry of the circular weld mark is required in the finite element model since the structural stress is calculated along the periphery of the weld. The normal direction of the shell elements (weldline elements) along the outside of the weldline is important for the calculation of the structural stress. Here, the weldline is defined as the periphery of the weld mark as shown in Fig. 4. A beam element represents the weld nugget to connect the top and bottom sheet steels. The length of the beam element is determined to be equal to one half of the total thickness for two sheets.

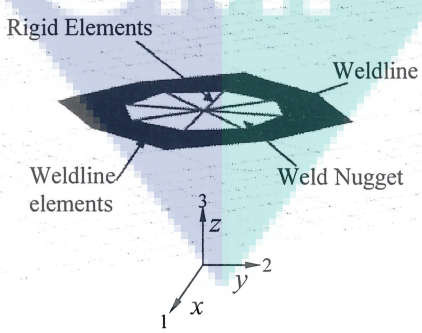

Fig. 4 FEM around spot weld nugget

4. Finite Element Analysis

The nodal forces and moments in a global coordinate system at each mesh corner along the weld line (nugget periphery) with respect to the shaded elements in Fig. 4 are directly obtained from a linear elastic finite element analysis. The forces and moments in the global coordinate system are then transferred into the local coordinate systems since the structural stresses are defined as those components normal to the weld line of the spot weld. Fig. 5 shows a local coordinate system at a node used to convert the global forces and moments to local forces and moments on the weldline.

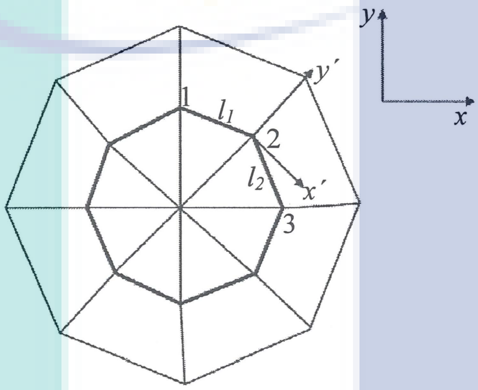

Fig. 5 Local coordinate system at a grid point

The nodal forces and moments in the local coordinate system are then converted to the distributed forces in terms of line forces and moments using the assumption that the work done by the nodal forces is equal to the work done by the distributed forces. The transfer equations for the line forces and moments are derived along the welding between to nodes on the weld periphery. The simultaneous equations for converting local forces to line forces are shown in Eq. (4).

$$\begin{Bmatrix} F_1 \\ F_2 \\ F_3 \\ \bullet \\ \bullet \\ F_{n-1} \end{Bmatrix} = \begin{bmatrix} \frac{l_1+l_{n-1}}{3} & \frac{l_1}{6} & 0 & 0 & \bullet\bullet & \frac{l_{n-1}}{6} \\ \frac{l_1}{6} & \frac{l_1+l_2}{3} & \frac{l_2}{6} & 0 & \bullet\bullet & \bullet\bullet \\ 0 & \frac{l_2}{6} & \frac{l_2+l_3}{3} & \frac{l_3}{6} & \bullet\bullet & \bullet\bullet \\ \bullet\bullet & \bullet\bullet & \bullet\bullet & \bullet\bullet & \bullet\bullet & \bullet\bullet \\ \bullet\bullet & \bullet\bullet & \bullet\bullet & \bullet\bullet & \bullet\bullet & \bullet\bullet \\ \frac{l_{n-1}}{6} & 0 & 0 & 0 & \frac{l_{n-2}}{6} & \frac{l_{n-2}+l_{n-1}}{3} \end{bmatrix} \times \begin{Bmatrix} f_1 \\ f_3 \\ f_3 \\ \bullet \\ \bullet \\ f_{n-1} \end{Bmatrix} \qquad (4)$$

where $f_1, f_2, f_3, \ldots f_{n-1}$ are the line forces at nodal point 1,2, 3, …, n-1 and $F_1, F_2, F_3, \ldots, F_{n-1}$ are the nodal forces in local coordinate systems at the nodal point 1, 2, 3, …, n-1. The line forces at nodal point n is the same as the line force at nodal point 1 since the weld line along the nugget periphery is closed. The line forces and nodal forces are presented for a single element case in Fig. 6. The line moments at the nodal points can be obtained from the nodal moments in the local coordinate systems suing simultaneous equations similar to Eq. (4).

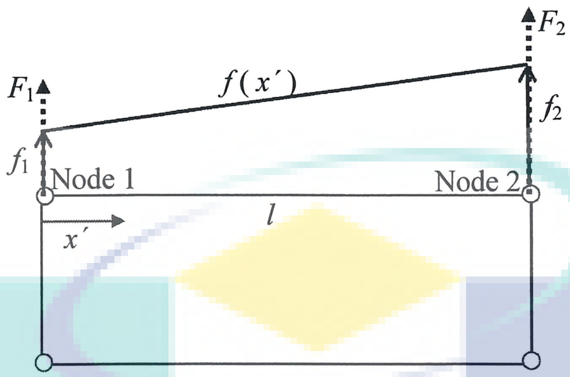

Fig. 6 Definition of the line forces at the nodal element

Linear static stress is calculated suing the line forces and moments at each nodal point on the periphery of the nugget. The structural stress consists of a membrane stress component (σ_m) and a bending stress component (σ_b) at each nodal points as expressed in Eq. (5) [15-16].

$$\sigma = \sigma_m + \sigma_b = \frac{f_{y'}}{t} + \frac{6m_{x'}}{t^2} \quad (5)$$

where t represents sheet thickness, $f_{y'}$ is the line force in the direction of y' and $m_{x'}$ is the line moment about x' axis in a local coordinate system as shown in Fig. 5. The structural stress (σ) was shown to be constant even though the size of the finite element mesh was changed [15-16, 21].

The specimen geometry and dimensions with the finite element meshes are shown in Fig. 7. Eight nodal points are located along the weldline of the spot weld in the finite element models for tensile shear and coach peel specimens. The sheet thickness of the specimens was 1.5 mm and the diameter of the spot weld was considered 7.0 mm in the finite element models. One side of the specimen was constrained in all directions and the other side of the specimen was constrained in all directions except the direction of the loading that was applied at the center of the grip with RBE3 elements [22]. The RBE3 stands for rigid body element type 3. This element distributes the loads on the reference node to a set of nodes connected to the RBE3 element without adding extra stiffness in the model [23]. The sheet-2 is loaded with 25 N loads in the X, Y and Z directions while the legs of the sheet-1 are clamped at the edges. The load-time histories are shown in Fig. 8.

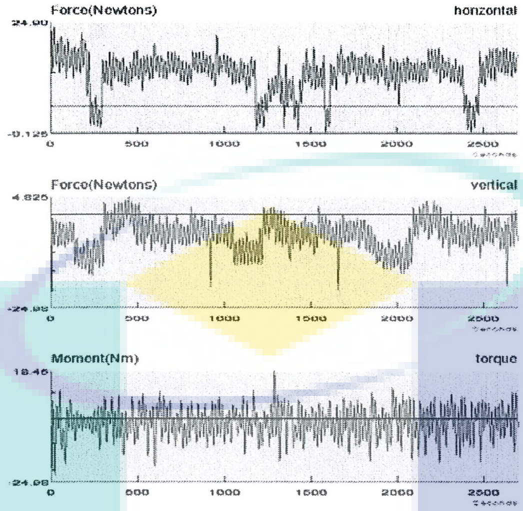

Fig. 8 Load-time histories

5. Materials properties

The data on material properties required for the numerical calculations were collected after extensive search through information of literatures and handbooks. Table 1 shows the mechanical and fatigue properties of the sheets and nugget in which the young's modulus, poison's ratio and density and so on.

Table 1 Mechanical and fatigue properties of the sheets and nugget

Name of Properties	Sheet-1	Sheet-2	Nugget	Unit
Modulus of elasticity	205900	205900	205900	MPa
Ultimate tensile strength	500	500	500	MPa
Poison's ratio	0.3	0.3	0.3	
Density	7850	7850	7850	Kg/m^3
Stress range intercept (SRI1)	2100	2100	2900	MPa
First fatigue strength exponent (b_1)	-0.1667	-0.1667	-0.1667	
Fatigue transition point	1×10^{-6}	1×10^{-6}	1×10^{-6}	Cycles
Second fatigue strength exponent (b_2)	-0.0909	-0.0909	-0.0909	
Mean stress sensitivity	0.1	0.1	0.1	
Standard error of Log (N)	0.334	0.334	0.330	

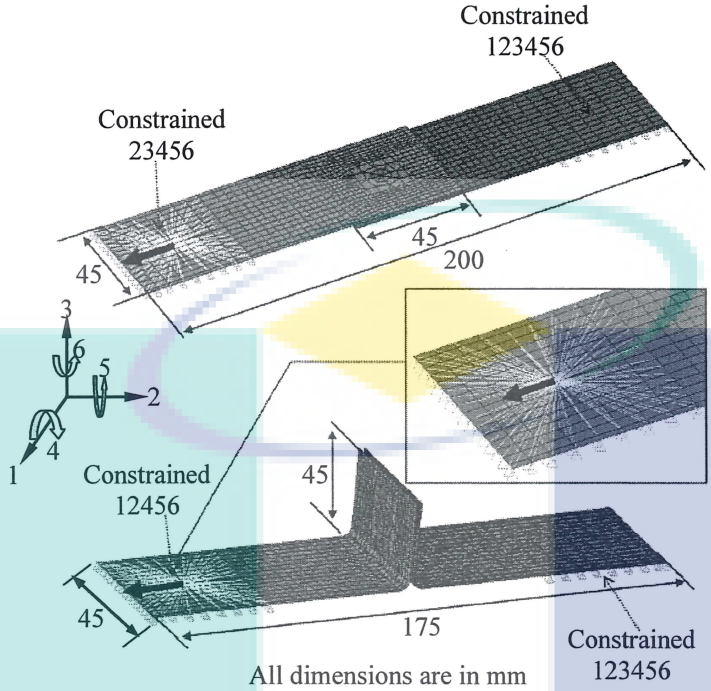

Fig.7 Dimensions and FEM for tensile shear and coach peel specimens

6. Results and Discussion

The aim of this paper was to illuminate the effect of sheet thickness on the fatigue behavior of spot welds and in particular to investigate the use of fatigue life prediction approach. In this respect, the problem was a special one due to the geometry of the spot weld contains a stress singularity. The model clearly needs to be tested against more experimental data in a variety of situations, an exercise which is beyond the scope of this paper.

Figures 9 and 10 show the effect of the sheet thickness and spot diameter on the fatigue life of the spot weld structure. Spot weld diameter of 2.5 mm to 8.5 mm and sheet thickness for 1 and 2 of 0.2 mm to 1.2 mm are considered in this study. It can be seen that from Figures 9 and 10, the spot weld diameter and the thickness of the sheet metals are influences the fatigue life of the structure. It is observed that the fatigue life of the structure increases with the increases of the spot weld diameter and thickness of the sheet.

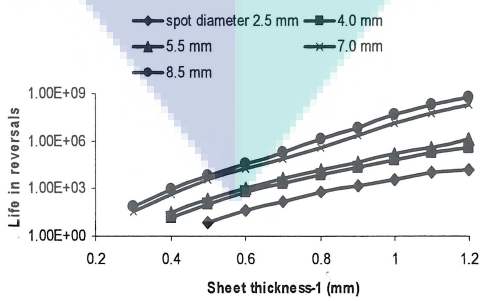

Fig. 9 Effect of spot diameter and sheet-1 thickness on the fatigue life

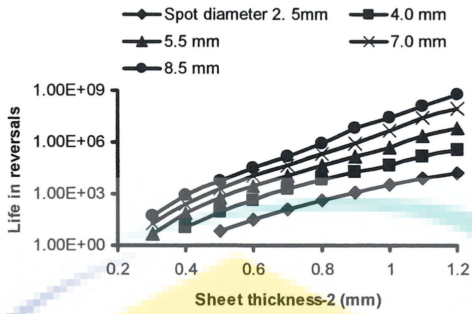

Fig. 10 Effect of spot diameter and sheet-2 thickness on the fatigue life

Figures 11 and 12 show the effects of the loads and confidence of survival on the fatigue life on the spot weld structure. From the obtained results, it can be seen from Fig. 11 that the fatigue life decreases linearly with the increases of loads, however, the increases of fatigue life with increases of spot weld diameter. The obtained results from Fig. 12, it is clearly seen that the fatigue life influences on the confidence of survival parameter which is based on the standard error of the *S-N* curves. The prediction of the fatigue life distribution with the range of probabilities of 50 to 97.5 % is shown in Fig. 12.

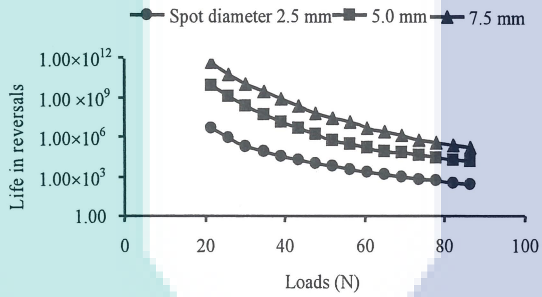

Fig. 11 Effects of the loads on the spot fatigue life

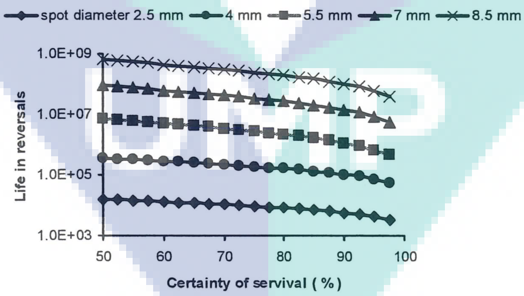

Fig. 12 Effect of the confidence of survival on the fatigue life

7. Conclusion

A computational technique developed and has been applied to predict the fatigue life of spot welded structures in tensile loading. In this paper, the effect of sheet and nugget diameter was investigated under variable amplitude loading. The behavior of diameter of spot weld and sheet thicknesses are very important parameters in stress distribution near spot welds. The acquired results seen that the spot diameter and thickness of the sheets are greatly influence the fatigue life of the spot welded structures. This application and related experiments will be the subject of further investigations. The effects of the loading and geometric configuration on the fatigue life of spot welded joints can be directly incorporated in the structural stress method.

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CHAPTER 3

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INVESTIGATION INTO THE EFFECT OF MATERIALS ON JOINING FOR AUTOMOTIVE PANEL

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ABSTRACT

A laser welded blank for use in applications calling for tailor welded blank (TWB) in vehicle panel assemblies. A promising approach to reduce manufacturing costs, decrease vehicle weight, and improve the quality of automotive body components is through the use of tailor-welded blanks. This term refers to blanks where multiple sheets of material are welded together to create a single blank prior to the forming process. The welding process creates formability concerns in a traditional forming process due to material property changes in the weld and in the heat-affected zone adjacent to the weld. Malaysian automotive manufacturers are still lack of this advancement. Hence, this project endeavours to build a platform for the industries by pioneering researches in this area. This paper presents to investigate the weld properties of high strength steel laser weld for joining the automotive panel. Laser weld and different types of steel are considered in this study. Experiment was carried out to determine the properties of materials after welding, forming and drawing process of TWB. It is observed from the acquired results that the potential TWB gives the best material combination. It can be seen that cross sectional area and steel grade are the most significant subjected to the tensile loading.

Keywords: TWB, automotive panel, laser welding, high strength steel.

INTRODUCTION

During the past two decades, government fuel conservation and safety mandates along with environmental concerns have prompted the automotive industry to design lighter cars for reduced fuel consumption, while improving the overall structure of their vehicles for occupant safety. Corrosion protection was also much improved during this period. These changes added to escalating manufacturing costs at a time when the industry was struggling with a serious threat from global competition. To reduce weight and costs, alternative materials such as aluminium and composite materials have been proposed and used for body panels, but none has shown the versatility of steel. High strength steels, coated steels, laminated steels and various drawing quality grades give steel the ability to meet most automotive requirements. Tailor welded blank where multiple sheets of material prior to the forming process are welded together. The differences in the material within the TWB can be in the thickness, grade, or coating of the material (1, 2).

TWB are those in which sheets of different thickness and/or properties are joined by laser, seam or plasma welding before press forming (2,3).Tailor-welded blanks (TWB) are comprised of two or more sheets of metal which has dissimilar strength or thickness that are welded into a single blank. Tailor Welded Blanks are stamped into automotive body panels and offer reduced part weight and improved material use (2, 4).To produce a fusion weld; Laser-beam Welding utilizes a high-power laser beam as the source of heat. It has high energy density and, therefore, deep- penetrating capability because the beam can be focused onto a very small area. The beam can be directed, shaped, and focused precisely on the work pieces.

Laser-beam Welding creates good quality welds with minimum shrinkage and distortion. This type of welds have good strength and generally ductile and free of porosity. The process can be automated and can be used on a variety of materials thickness of up to 25mm (1in.). It is particularly effective in thin workspaces'. Laser welding techniques nowadays are highly developed resulting very strong weld joints. Significant flexibility in product design, structural stiffness, crash behaviour, and formability can be achieved by the growing trend toward welding and forming sheet-metal pieces. Therefore, making it possible to use different materials in one component, weight savings, and cost reduction in materials, scrap, equipment, assembly, and labour (5).

The most commonly used welding technique in tailor-welded blanks is laser-beam welding. Because of the small thickness involved, the proper alignment of the sheets prior to welding is important (3). The laser beam tailor welded blank has a butt-welded joint with a slight concavity at the joint with a narrower (about 1.0 mm/0.04 inch) heat-affected zone (6). Minimizing concavity of the weld joint is critical to good formability and mechanical properties. Minimum concavity in the weld joint is usually achieved by precision shearing the blank edges to be welded. A good fit up prior to welding and a laser beam alignment with respect to the joint are important for a good laser weld (7).

EXPERIMENTAL SET-UP

After a series of preliminary study, 5 automotive steel panels/ sheets with different grades each was chosen as potential specimen. These panels are divided into two thicknesses that will be joined according to combinations. Table 1 shows grades, thicknesses and combination of creating a specimen

Table 1: List of specimen needed for the project

No.	Combinations (0.7t - 1.2t)	Specimen No.
1	SPCC - SPHC	3
2	SPCC - SAPH 370	3
3	SPCC - SGACC	3
4	SPCEN - SPHC	3
5	SPCEN - SAPH 370	3
6	SPCEN - SGACC	3
	Total	18

For specimens' preparation, first the base panels are sheared into thin strips according to dimension that is 60mm x 10mm as shown on Figure 1 a. The panels are sheared by using a shearing machine .The sheared specimens are then checked for accepted tolerance. Strips that do not comply with the tolerance range will be voided. Figure 1 b show a sheared base metal of each grade.

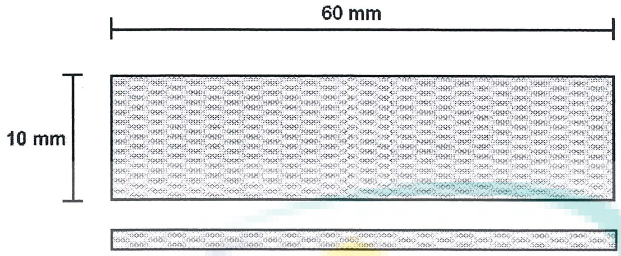

Figure 1: (a) Dimension for shearing

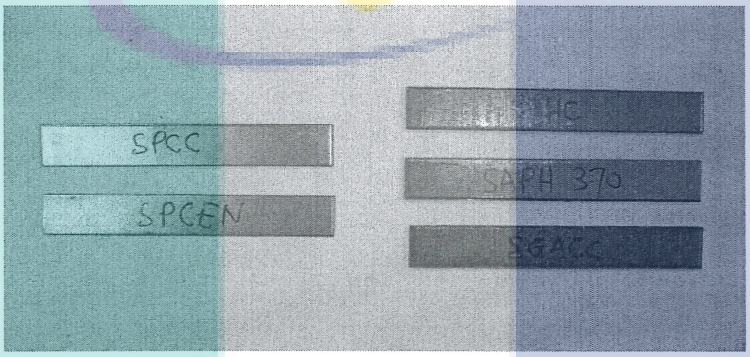

Figure (b) NC shearing machine model 6131

The specimen's combinations with two base specimens of different thickness are combined according to Table 1.Then, the specimen's joint with laser welding. A set of constant parameter of laser welding were selected for the combination specimens to gives better results. The laser weld was set for high penetration from top to bottom in one encounter for the finest quality. Tables 2 show the welding parameter for this testing, Figure 2 a shows the laser welding machine used for the project, Figure 2 b shows the combination being laser welded and Figure 3 show the specimens that have been welded. After the specimens were prepared, then the testing began.

Table 2: Laser Welding Parameters

Laser Welding Parameter	Value
Laser Type	Nd:YAG
Power	3.5 kW
Pulse Width	7.5 ms
Frequency Rate	7.5 ms
Speed	Manual
Focal	60mm -70mm
Filler Metal	Hi Nickel wire 0.3mm
Shield Gas	Argon

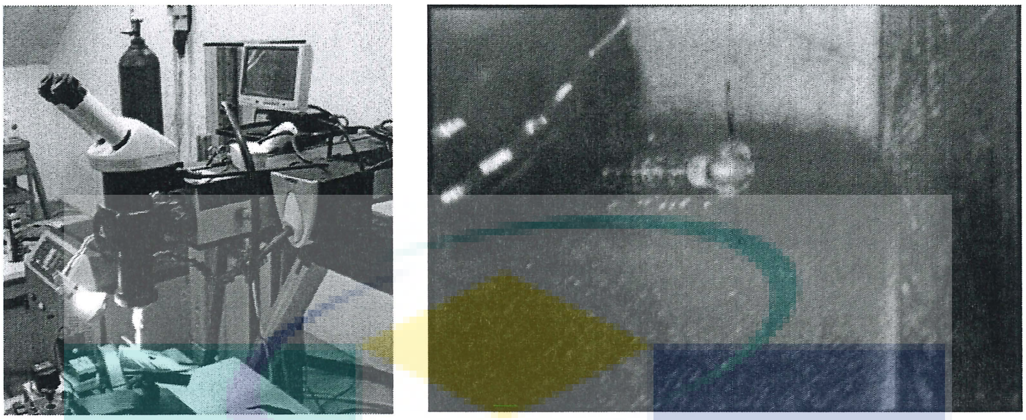

Figure 2: (a) An ORLaser laser beam welding machine model HTS 160 (b) Laser welding process

Figure 3: Laser welded TWBs

Tensile test will be use for testing each mechanical properties of the specimen such strength, ductility, toughness, elastic modulus, and strain of the weldment area. The specimen with dimension of 60 x 10 mm for base metal (refer Figure 1) and 120mm x 10mm for TWBs (refer Figure 4) will be snugly fit the grip teeth. Instron Universal Testing Model 3369 tensile test machine from mechanical faculty lab will be used in executing the test. For every specimen, repetition will be done three times.

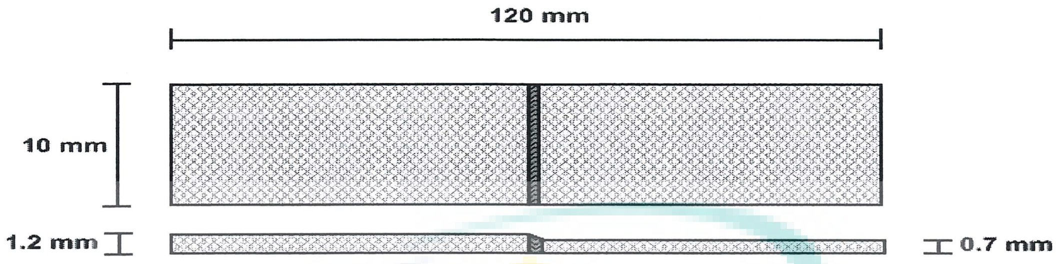

Figure 4: TWBs tensile specimen dimension

RESULTS AND DISCUSSION

The purpose of taking tensile test for the base metal is to create a reference data of same sheet metal that were used to the TWB specimens. The obtained data then can be use to compare the data obtained from the TWBs. So, the data collections for the base metals are not extensive taken as the data from the TWBs. Only certain valuable values are taken from the data. Table 3 below shows the tensile values of the same base materials mentioned.

Table 3: Materials properties of different combination of TWBs

Exp. No.	TWBs Combinations (0.7t - 1.2t)	Readings	Yield Strength (MPa)	UTS (MPa)	% Strain	E. Modulus (GPa)
1	SPCC - SPHC	1	181.71	310.97	17.55	95.19
		2	210.69	284.91	16.86	93.34
		Ave.	196.20	297.94	17.21	94.27
2	SPCC - SAPH 370	1	181.71	283.03	16.66	97.63
		2	178.80	281.83	17.64	93.62
		Ave.	180.26	282.43	17.15	95.63
3	SPCC - SGACC	1	185.66	288.51	17.29	95.19
		2	182.57	288.51	17.71	93.34
		Ave.	184.12	288.51	17.50	94.27
4	SPCEN - SPHC	1	141.03	265.03	18.76	95.66
		2	134.42	258.17	19.08	101.18
		Ave.	137.73	261.60	18.92	98.42
5	SPCEN - SAPH 370	1	133.49	262.63	17.96	96.39
		2	138.55	262.63	19.28	91.46
		Ave.	136.02	262.63	18.62	93.93
6	SPCEN - SGACC	1	171.52	236.06	7.19	92.01
		2	131.38	260.74	19.10	97.65
		Ave.	151.45	248.40	13.14	94.83

Tensile testing was conducted using Instron Universal Testing Model 3369 machine. Consequently, almost all the specimens subjected to this testing have the same characteristic. The TWBs tend to fracture at the thinner strip of 0.7mm where the area is smallest except one of the SPCEN- SGACC TWB which fractures across the weld line. This proves that the welding fuse the two perfectly creating strong joints as stated in the literature review.

Based on the Figure 5, there could be seen two distinct patterns that are divided into SPCCs and SPCENs. The yield strength (YS) of the TWBs of the thinner (0.7mm) combination sheet of SPCCs gives higher yield strength than of that SPCENs. The SPCCs have higher yield strength than SPCENs counterpart. But overall YS show every TWBs have a lower value either 0.7mm or 1.2mm base metals.

If the thicker (1.2mm) materials were compared, for SPCC combinations, the value of those SPHC, SAPH 370 and SGACC are quite the same. The same goes with SPCEN combinations, the value of those SPHC, SAPH 370 and SGACC are almost the same. This means that 0.7mm strip gives much influence in determining the yield value. SPCENs exhibit lower strength value than the SPCCs.

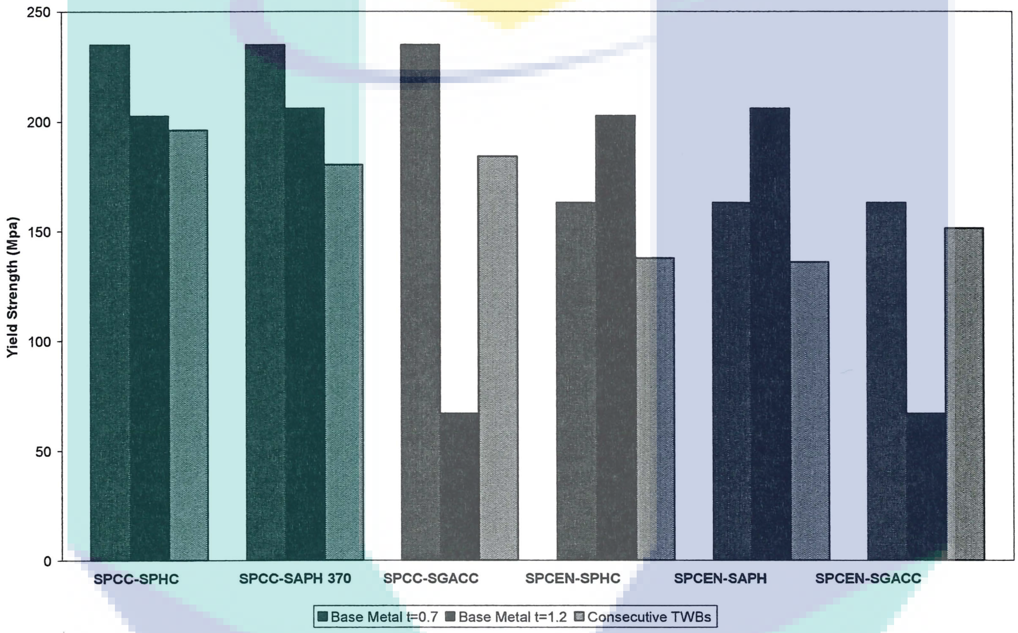

Figure 5: Comparison of TWBs yield strength to their base metals

The discussions will base on the results obtained from the investigation. From the Table 3 and Figure 5 it shows that, the mechanical properties of the TWBs are much lower than the rest of its bases either the 0.7mm or 1.2 thicknesses. It is found out that the thinner strip 0.7mm of the TWBs plays a major role in determining the overall mechanical properties mainly for the YS, UTS and strain value than the 1.2mm thick partner. This means that the smallest cross sectional area of the TWBs will be the most affected when subjected to testing such as tensile. When a high load is given base on the formula below the smallest cross sectional area generate the highest levels of stress. The SPCEN based TWBs emit lower YS and UTS than the SPCC based.

The grade of the materials also plays an important role in influencing the obtained data. Different grade of steels are produced by altering the chemical composition. The level of strain of the specimen are much affected by the chemical composition itself than the cross sectional area. It is also found out that 0.7mm strip play a major role in determining the overall strain value. This is happen not because of the small cross section, but more to the steel grade. SPCCs are manufactured for Drawing Quality while SPENs are manufactured for Extra Deep Drawing Quality. Obviously, SPCENs will outwit SPCCs in strain value comparison. A more ductile steel grade elongate better than the vice versa grade.

The smaller of the specimen's area and the ductile the grade, bring the base metal prone to overwhelm the TWBs. If the crucial base (SPCCs & SPCENs) of the TWBs were compared, the SPCENs produce superior quality than the SPCCs if those were adapted in automotive manufacturing application; car door panel. The SPCEN have a higher in formability because of its lower YS and higher in draw ability because of its higher strain. The candidate to be paired with SPCEN is either SPHC or SAPH 370 because of their high strength use for structural stability.

CONCLUSION

From the investigation conducted the most significant parameter of TWBs are the cross sectional area and steel grade when subjected to tensile testing. Located at the thinner base (0.7mm) of the TWBs with smallest cross sectional area and type of high ductility steel, SPCC and SPCEN base hold major influence of overall TWBs properties. Comparing the 0.7mm SPCC with SPCEN, SPCEN have the desirable superior property formability and drawability to be made as the intermediate panel. While SAPH 370 and SPHC base are choosen than SGACC because of higher strength value can be made as the hinge panel. Hence, the proposed TWB combinations would be SPCEN-SPHC and SPCEN- SAPH 370.

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CHAPTER 4

International Conference on Mechanical and Manufacturing Engineering
(ICME 2008), 21- 23 May, Johor Baharu, Malaysia, 1-8, 2008.

FINITE ELEMENT ANALYSIS ON THE EFFECTS OF SPOT DIAMETER AND SHEETS THICKNESS ON FATIGUE LIFE OF SPOT WELDED STRUCTURE

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Abstract

This paper presents the finite element analysis of the effect of the spot weld and sheets thickness on the fatigue life of the spot-weld. A simple model was used to illustrate the technique of spot-weld fatigue analysis. Finite element model and analysis were carried out utilizing the finite element analysis software. Linear elastic finite element analysis was carried out to predict the stress state along the weld direction. It can be seen from the results that the predicted life greatly influence the sheet thickness, nugget diameter and loading conditions of the model. Acquired results were shown the predicted life for the nugget and the two sheets around the circumference of the spot-weld at which angle the worst damage occurs. The spot-welding fatigue analysis techniques are very useful for automotive structure design.

Keywords: Spot-weld structure, finite element analysis, fatigue-life, sheet thickness

CHAPTER 5

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Investigation on the Different Types Method of Joining for Automotive Panel

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Abstract

In this paper, the objective is to study Quality comparison between different type methods of joining in tailor welded blank and selection the type of welding process used to make a tailor blank. Tailor-welded blanks (TWBs) of the different material and with different thickness combinations were welded together to form a single part before the formability process . Thus, SPCC steel sheets of thickness of 0.7 mm and SPHC steel sheet of thickness 1.2 mm were studied and combined to form TWBs .Different types of welding such as ,shield metal arc welding(SMAW), metal inert gas welding(MIG), tungsten inert gas welding(TIG) and laser beam welding were used to weld the tailor-made blanks before the formability tests of the uniaxial tensile test. The laser welding and the TIG welding were the most suitable process of welding for tailor welded blank. The uniaxial tensile tests show that there are no significant differences between the tensile strengths of TWBs and their relative base metals.

Keywords: Tailor-welded blanks (TWBs), Laser beam, Tungsten inert gas, Metal inert gas

1. Introduction

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 [1]. Tailor welded blank is a new technology that allow the designer or 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 1 shows the potential automotive tailor welded blank applications.

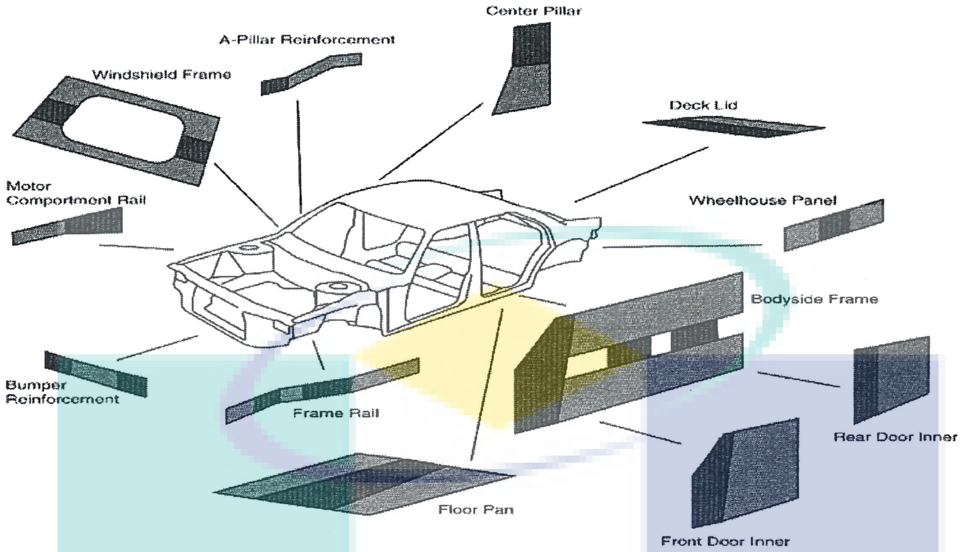


Figure 1: Exploded view of current and potential automotive tailor welded blank applications [1]

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 [2].

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 [3].The choice of the welding technique depends on the production of a sound, heterogeneous, mixture of aluminum and steel at the interface [4].

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. The attention 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[5].The advantages 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[6].

Gas tungsten arc welding used in many manufacturing operation primarily on thinner material. This process was originally developed for the hard to weld metal. It can be used to weld more different kinds of metals than any other arc welding process. This process can be weld thin metals normally by the automatic method and without the addition of filler metal. A joint preparation usually required. However this depends on the base metal type and welding position [7].

The diameters of the electrode employed by gas metal arc welding are smaller than those employed by shield metal arc welding. Because it can reduces the groove angles.

Reducing groove angle, will still allow the electrode to be directed to the root of the weld joint so that complete penetration will occur [7].

Shield metal arc welding is the simplest, versatile joining and one of the oldest joining processes. A weld form after the molten metal, a mixture of the base metal, and substance of the coating on the electrode, solidified in the weld area. The electrode coating deoxidizes the weld area and provides a shielding gas to protect it from oxygen in the environment [7].The advantages of this process due to simple and versatile of requiring smaller variety of electrode.

To produce a fusion weld, laser beam welding utilize high power laser as a source of heat. The beam can focus the small area because it has energy density. The beam can be directed shaped and focused precisely on the workpiece. The process is suitable for welding deep and narrow joint. Laser beam maybe pulsed (in milliseconds) for application such as spot welding of thin material with power level up to 100 kw Oxides, residual gas levels or impurities associated with the sintering process can promote blowholes or weld porosity because these constituents tend to absorb greater amounts of laser radiation which results in overheating. Additionally, P/M (Full name) ability could not be successfully welded without filler metals [8].

2. Experimental set-up

Tailor welded blank process must have the best method of joining to ensure the strength and the quality of the weld. This investigation will using four types of welding process. Each of the welding process will be use to weld part of the specimen provided. Figure 2 shows the Tailor Welded Blanks Door Inner Panel.

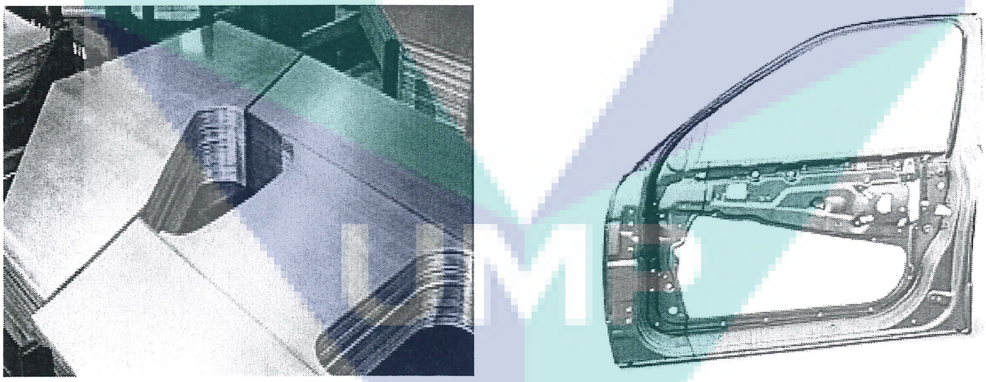
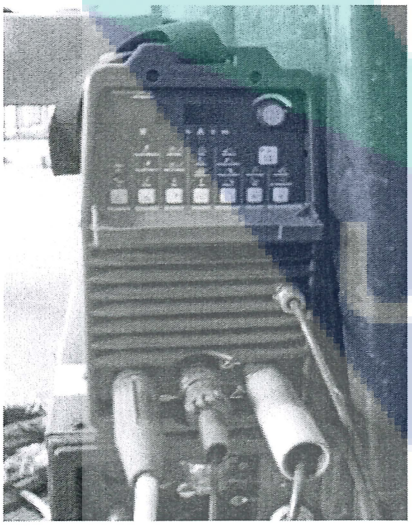


Figure 2: Tailor Welded Blanks Door Inner Panel.

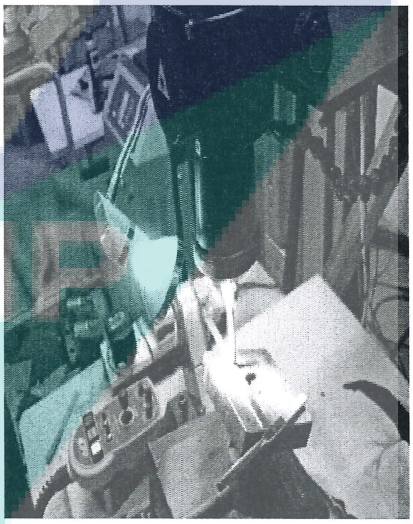
After specimen had been welded, the specimen will undergoes tensile test, impact test and also will be scan the weld part using scanning electron microscope. All of the testing process is very important in order to determine the result of the investigation. By using the tensile test, the mechanical properties of the specimen such as ductility toughness and elastic modulus will be determine especially at the weld area. Impact test also use to determine the failure and fracture of the specimen. Because failure is the one of the most important aspect of material behaviors because it direct influence the selection of the material or specimen for a certain application especially weld area of welding in tailor welded blank. Another machine that will use in this investigation is SEM (scanning electron microscope) machine. This machine is use to view the microstructure of the weld part. The SEM has a large depth of field, which allows a large amount of the sample to be in focus at one time. So, the structure of the specimen will analyzed and the data will recorded. Figure 3 shows the type of welding that used in these studies.

(a) SMAW welding machine

(b) MIG welding machine



(c) TIG welding machine



(d) Laser beam welding

Figure 3: Type of welding

3. Results and discussion

3.1.1 Result of tensile test shield metal arc welding (SMAW)

The specimens of the welding type of shield metal arc welding were tested to study the strength at the weld zone. Figure 4 shows the specimen after welded. Figure 4 shows that the surface not very smooth and from the surface can observe that lot of small particle. The tensile properties are shown in the Figure 5.

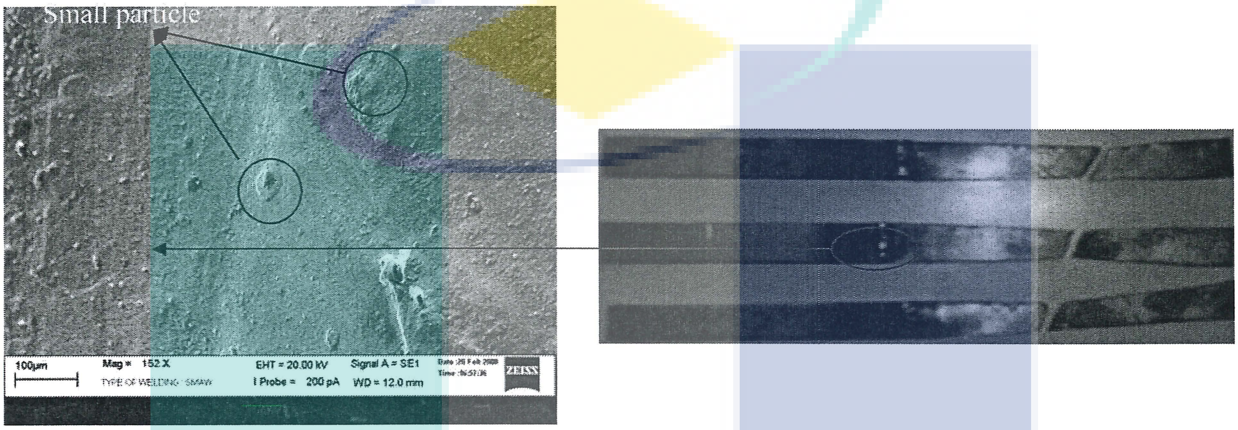


Figure 4: Tailor-welded SMAW specimens with SEM picture.

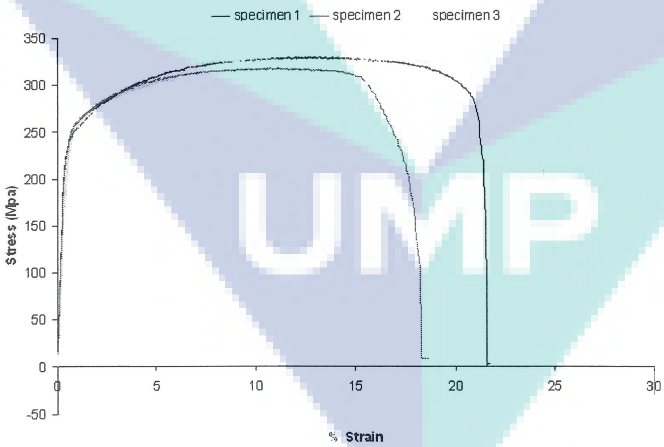


Figure 5: Tensile Stress (Mpa) vs % Strain curve for SMAW specimens

Table 1 shows the average data of tensile properties during the tensile test. Three specimen of shield metal arc welding was tested in tensile testing machine. From the table, we can see the average load that the each of the specimen can withstand is 2.275 KN. The maximum tensile stress and the % strain are come from the specimen 1 with 239.32 Mpa and 21.54. The average stress and % strain that are getting from the 3 specimen is 325.03Mpa and 21.65 .The Figure 5 show the specimen elongates uniformly at along the entire length. The diameter of the specimen gradually decreases particularly for SPCC which thickness 0.7mm.There is no necking occurred at the welding area while of the 3 specimen is tested. The necking just occurred at the thinner primary material which is SPCC. It forms necking which is the specimen of SPCC gradually narrowing and contract.

Table 1: The average data of tensile properties during the tensile test

Specimen	Yield Strength(Mpa)	Max Stress(Mpa)	% Strain	Max Load (KN)	Max Displacement (mm)
1	236.57	239.32	21.54	2.305	7.743
2	234.52	317.66	18.25	2.224	6.778
3	247.37	328.12	25.15	2.297	6.469
Average	239.48	325.03	21.65	2.275	6.996

3.1.2 Result of tensile test Metal Inert Gas welding (MIG)

The specimen welded Metal inert gas welding was tested to study the strength of shield metal arc welding weld area. Figure 6 shows the specimen after welded. The SEM picture shows that the welding areas that use MIG are full of small particle and not as smooth as SMAW. The tensile properties are shown in the Figure 7.

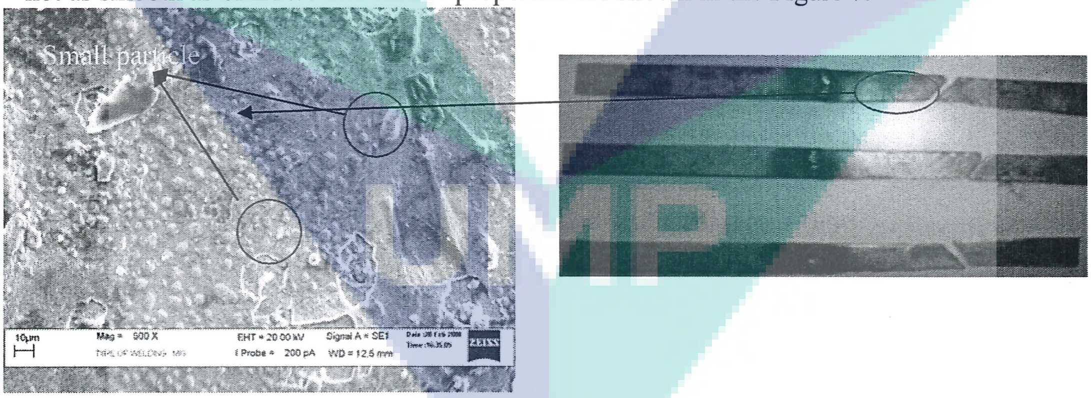


Figure 6: Tailor-welded MIG specimens with SEM picture

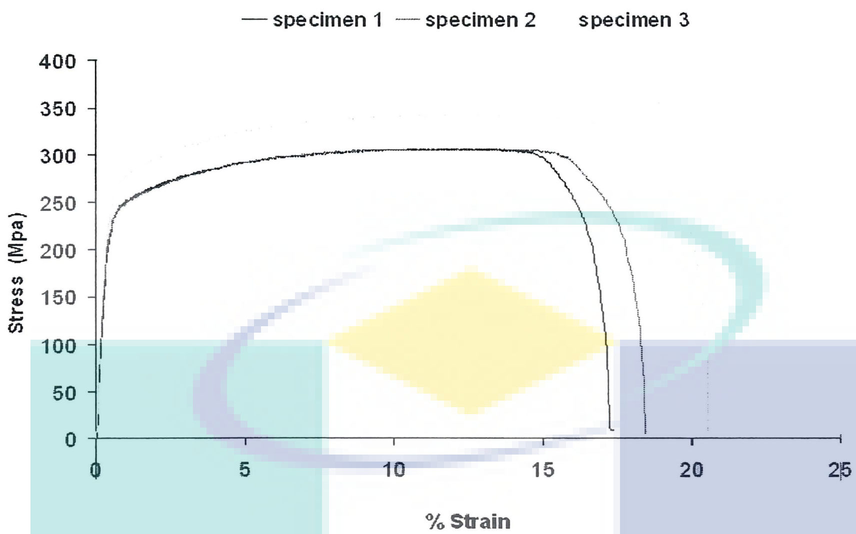


Figure 7: Tensile Stress (Mpa) vs %Strain curve for MIG welding

Figure 7 above shows the stress vs % strain graph of specimen 1, specimen 2 and specimen 3. Table 2 shows the average data of tensile properties during the tensile test for MIG specimen .There are three specimens which are joining by metal inert gas welding. The average maximum load for the tensile test is 2.228 KN. The average maximum stress that can withstand by all of the three specimens is 318.27 Mpa. Meanwhile the average % strain is 18.720. While the specimen was being tested, it shows the primary material gradually elongates and the necking occurred at this primary material and this material finally fractured. At the welded area, there were no changes or deformation occurred at this part. It shows the welded part capable to withstand the load was given. The surface finish welded parts for MIG welding are not quite good enough because if see from the naked eyes the welded zone area is not continuous. It also shows the reproducibility of the welding is low. By using the MIG welding in tailor welded blank it is difficult to control the filler wire and welding speed. Because of this, it's very difficult to get the nice surface and good weld part.

Table 2: Tensile properties of the MIG specimen

Specimen	Yield Strength(Mpa)	Max Stress(Mpa)	% Strain	Max Load(KN)	Max Displacement (mm)
1	225.77	306.17	17.21	2.142	7.317
2	222.17	306.85	18.4	2.148	6.93
3	248.74	342.28	20.54	2.393	7.176
Average	232.12	318.27	18.72	2.228	7.141

3.1.3 Result of tensile test Tungsten Inert Gas welding (TIG)

The specimen welded Tungsten Inert Gas welding was tested to study the strength of shield metal arc welding weld area. Figure 8 shows the specimen after welded. The

TIG produces a smoother area if compare with MIG and SMAW. The tensile properties are shown in the Figure 9.

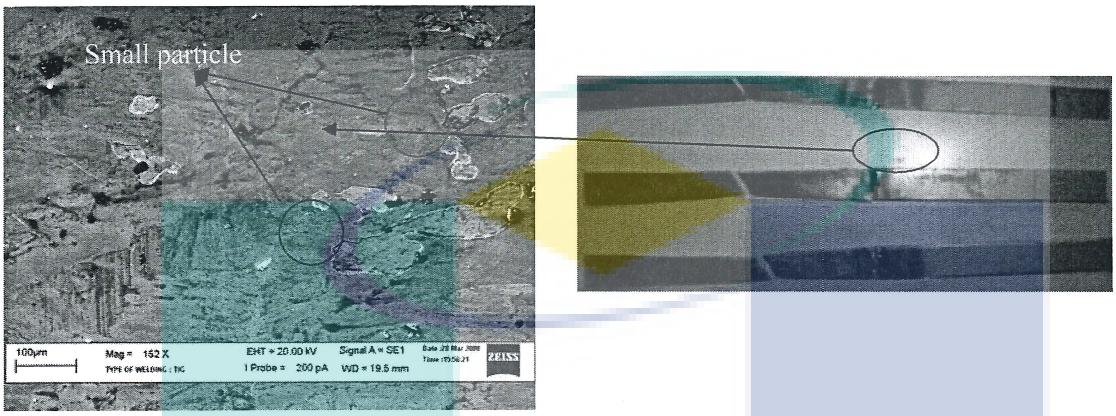


Figure 8: Tailor-welded TIG specimens after the tensile test with SEM picture

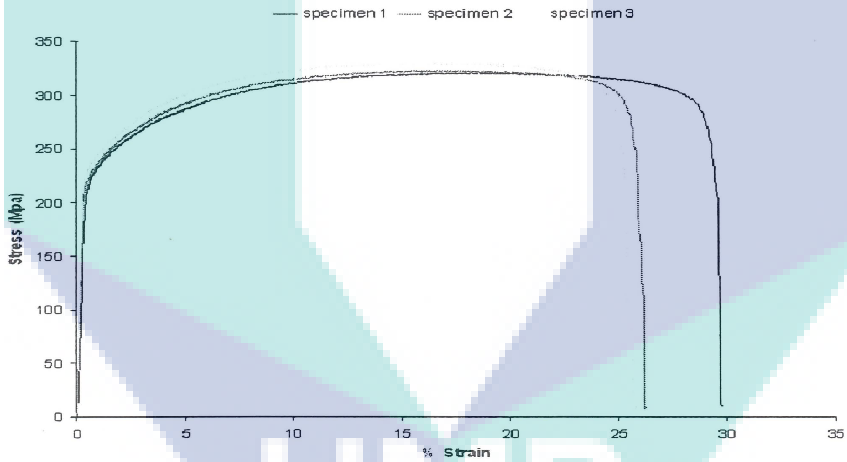


Figure 9: Tensile Stress (Mpa) vs % Strain curve for TIG welding

Table 3 shows the tensile properties of the TIG specimen. From the table the average data of maximum load, maximum displacement, maximum stress and the maximum strain was recorded. The average maximum load is 2.269 KN. The average max stress and % strain for the TIG weld specimen is 324.17Mpa and 27.17%.From the observation of the specimen while the specimen was tested; it observed that necking occurred at the thinner parent metal. This clearly shows that the weld zone is not the portion where the crack would initiate when it is deformed in tension. It has also shows that the weld was sound without porosity and free from any crack because when the small porosity or any crack occurred at any part of the specimen, it will initiate necking and specimen failure or fracture will occur. TIG welding is suitable for welding thin metal. TIG welding will produce good quality of weld for any metals and alloys. TIG welding has good surface weld area and continuously. The hardness of welded parts in welding material was higher than the primary material, there came out the crack and decreased the elongation rate in primary material. It was suggests that the mechanical character of the welded part is of good condition. A defect at the welded part can cause rupture, so that the formability can decrease. Thus, it is possible to increase the formability of the sample to the level of the primary material only if defects in the welding part are sufficiently restricted and the hardness of it is reduced.

Table 3: Tensile properties of the TIG specimen

Specimen	Yield Strength(Mpa)	Max Stress(Mpa)	% Strain	Max Load(KN)	Max Displacement(m)
1	219.08	320.57	29.71	2.244	10.74
2	220.80	322.28	26.17	2.256	10.76
3	228.68	329.65	25.63	2.307	9.733
Average	222.85	324.17	27.17	2.269	10.411

3.1.4 Result of tensile test Laser beam welding

The specimen welded Laser beam was tested to study the strength of shield metal arc welding weld area. Figure 10 shows the specimen after welded. The laser welding produces a very good surface among other welding method. There is no small particle at the welded surface. The tensile properties are shown in the Figure 11.

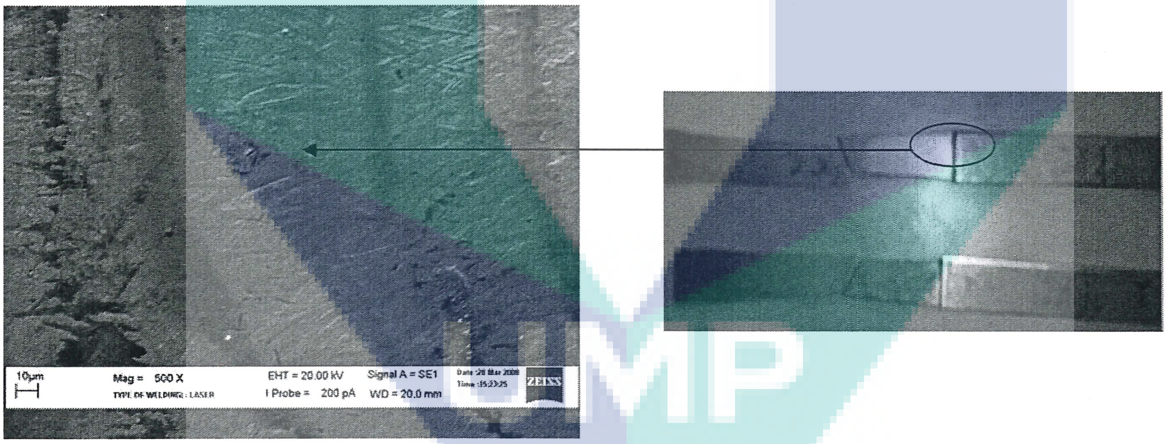


Figure 10: Tailor-welded Laser beam specimens after the tensile test with SEM picture

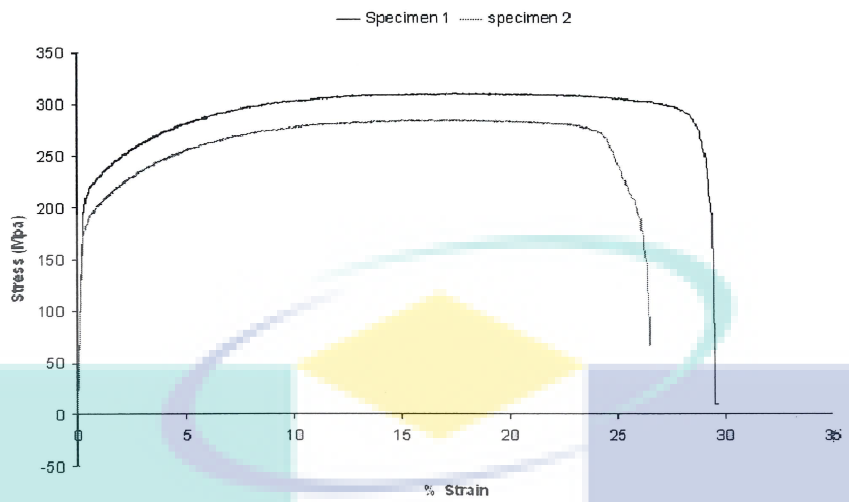


Figure 11: Tensile Stress (Mpa) vs %Strain curve for Laser beam welding

Table 4 shows the tensile properties of the laser beam specimen. There was two of specimen that had been use in tensile testing. The average maximum load is 2.086KN. Meanwhile the average maximum stress and % strain are 297.94 Mpa and 28 %. While the tensile test was operated for the specimen of laser beam welding, the same case occurred which is the parent material of SPCC will elongate, contracted and necking occurred before it fractured. Laser beam welding has finest welding area and also produces welds good of quality. It also frees of porosity and also has good strength. Because of that, the possibility failure occurred at the weld part is too small.

Table 4: Tensile properties of the laser beam welding specimen

Specimen	Yield Strength(Mpa)	Max Stress(Mpa)	% Strain	Max Load(KN)	Max Displacement (mm)
1	210.68	310.97	29.52	2.177	10.53
2	181.72	284.91	26.48	1.994	10.11
Average	196.28	297.94	28.00	2.086	10.32

Figure 12 shows the % strain comparison between types of welding with the parent material SPCC and SPHC. The highest average of % strain between four types of welding is laser welding which is the value is 28 %.The second is TIG welding with 27.17%.The lowest value of percent strain is MIG welding with 18.72% and the value of SMAW is 21.65 %.The value of percent strain for parent material SPCC is 36.73% and the value for SPHC is 30.62%. Figure 12 also show the % strain and the elongation of the specimen decrease if compare to the parent material, SPCC. Meanwhile, if we can see at the laser welded area and TIG welded area, the effect of heat affected zone was small if compare to the SMAW and the TIG weld area. % Strain of TIG and Laser welding almost close to the % strain of parent material. Because the HAZ for TIG and Laser welding just for small effect especially for laser welding.

Figure 13 shows the graph comparison between 4 types of welding. The highest of maximum stress 325.05 Mpa which is SMAW types. Meanwhile the value for TIG and MIG welding is 324.17Mpa and 318.27Mpa.And the max stress for laser beam welding is 297.94 Mpa The different values are case by the heat affective zone (HAZ).The heat affected zone is within the base metal itself. It has the microstructures different from the base metal prior to welding, because it has been subjected to the elevated temperature during the welding process. Therefore it can reduce the formability of the parent material especially for SPCC. From the observation at the each of the specimen, the biggest effect from the heat affected zone is shield metal arc welding weld area. And the second rank was TIG welding weld area.

Figure 12: Types of welding percent strain comparison with parent material

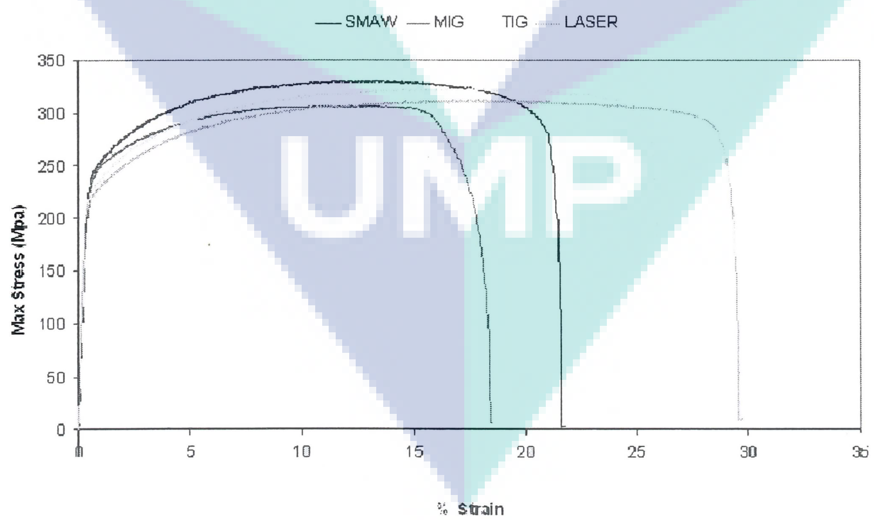


Figure 13: Stress (Mpa) vs % Strain curve for four types of welding

4. Conclusion

The main objective of this study is to determine the strength of the joining process by using tensile test and also to find tensile properties of the welded part for four types of welding. From the result it showed that all of the welding types can withstand the load was given and there was no necking and fracture occurred at the welding area.

The laser welding and the TIG welding was the most suitable process of welding for tailor welded blank because of the effect HAZ was too small and also the formability of the parent material was not great affected. For the SMAW and MIG welding, it was not suitable welding process in tailor welded blank, because of these two types of welding cause great effected to the formability of parent material beside gave problem in stamping process of tailor welded blank parts.

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CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

These researches are established few papers and journals in the spot welding simulation and numerical study. It is concluding that the researches are meeting the early target or outcome setting and all the milestones.

5.2 Recommendation

Future researches are recommended to enhance the analysis for the spot welding by simulation and experimental with aluminium and steel weld.

ATTACHEMENT

(FKM Spot Welding Machine)