EXPERIMENTAL AND NUMERICAL ANALYSIS OF HEAT DISTRIBUTION FOR DIFFERENT JOINING METAL OF TAILOR WELDED PROCESS

MOHD NAQIUDDIN BIN MOHD SALLEH

This thesis is submitted as a partial fulfilment of the requirements for the award of the Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

JUN 2013

EXAMINER'S APPROVAL DOCUMENT

UNIVERSITI MALAYSIA PAHANG
FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled "*Experimental and Numerical Analysis of Heat Distribution for Different Joining Metal of Tailor Welded Process*" is written by *Mohd Naqiuddin Bin Mohd Salleh*. "I have examined the final copy of this report and in my opinion, it is fully adequate in terms of language standard, and report formatting requirement for the award of the degree of Bachelor of Engineering. I here with recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering.

Signature :
Name of Examiner : MR. SAIFUL ANWAR CHE GHANI
Date : 26 JUN 2013

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion this project is satisfactory in terms of scope and quality for the award of Degree in Mechanical Engineering

Signature	
Name of Supervisor	: DR. MOHD ZAIDI BIN SIDEK
Position	: LECTURER
Date	: 26 JUN 2012

STUDENT'S DECLARATION

I hereby declare that the work in this report is my own except for quotations and summaries which have been duly acknowledged. The report has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature

Name : MOHD NAQIUDDIN BIN MOHD SALLEH

ID Number : MA10092

Date : 26 JUN 2012

ACKNOWLEDGEMENTS

I would like to express my gratitude and appreciation to all those who gave me the possibility to complete this report. Special thanks is due to my supervisor Dr. Mohd Zaidi bin Sidek whose help, stimulating suggestions and encouragement helped me in all time of fabrication process and in writing this report.

I would also like to acknowledge with much appreciation the crucial role of the staff in Mechanical Laboratory, who gave me a permission to use the mechanical equipment and also the machine and to design the drawing and giving a permission to use all the necessary tools in the laboratory.

Many thanks go to the all lecturer and supervisors who have given their full effort in guiding the team in achieving the goal as well as their encouragement to maintain our progress in track. My profound thanks go to all classmates, especially to my friends for spending their time in helping and giving support whenever I need it in fabricating my project.

ABSTRACT

Tailor welded blank (TWB) is commonly used in industrial. Tailor welded blanks are defined as two or more separate pieces of flat material, dissimilar thickness, and or mechanical properties. This project aim to do experiment and numerical analysis of heat distribution in TWB process of different material with the same thickness. Heat is major parameter in TWB process. Hence, it must be optimized for the process. Among the considered factors are to minimize heating width and use high intensity heat flux to generate enough heating energy inside the work-piece. This project concentrates on heat transfer characteristic for the common used type of TWB material. Actual heat distribution will be measured in experiment by using DASYLab software and will be used to validate FE model. This project must focusing on fabricate simple heat transfer testing equipment and develop equivalent finite element of heat transfer test. It also focuses on developing finite model for static heat source case of TWB process. Abaqus software has been used to simulate the heat transfer in the case of joining the dissimilar materials. After the result is validated, the parametric study to get the best position of heat source. The result shows the heating source must be far away as possible from the low melting point. For simulation, case 1, the joining aluminium and mild steel, the heating source must be placed at a location where 40% in aluminium and 60% in mild steel. In case 2, the joining is stainless steel and mild steel, the position of heating source must be placed in the middle, 50% in mild steel and 50% in stainless steel. The last case, the joining aluminium and stainless steel, the position of heating source must be placed 40& in stainless steel and 60% in aluminium. The completed joining with dissimilar material that can reduced the final car weight and can improved fuel economy.

ABSTRAK

Tailor welded blank (Twb) selalunya digunakan dalam bidang industri. *Tailor welded blank* ditakrifkan sebagai dua atau lebih jenis *material*, ketebalan berbeza, dan atau sifat-sifat *mechanical* yang dikimpal bersama. Tesis ini bertujuan untuk melakukan experiment dan analisis keatas penyebaran haba didalam proses TWB dengan bahan yang berbeza dan ketebalan yang sama. Haba merupakan satu parameter utama didalam proses TWB. Antara faktor-faktor yang perlu dipertimbangkan adalah untuk meminumkan penyebaran haba dan menggunakan keamatan *heat flux* untuk menghasilkan pemanasan haba yang sesuai didalam *workpiece.* Projek ini menfokuskan kepada ciri-ciri penyebaran haba didalam bahan yang selalu digunakan dalam proses TWB. Penyebaran haba biasanya diukur didalam eksperimen dengan menggunakan perisian DASYLab dan akan disahkan oleh FE model. Projek ini bertujuaan mencipta satu alat *test rig* bagi menjalankan uji kaji dan juga menbuat persamaan *finite element* didalam ujian penyebaran haba. Ia juga fokus dalam mengkaji finite element dengan berdasarkan sumber haba yang statik didalam keadaan TWB proses. Perisian Abaqus digunakan untuk simulasi penyebaran haba setelah dikimpal oleh proses kimpalan laser. Selepas kedua-dua keputusan itu benar, satu ujikaji untuk mengenal pasti keadaan yang sesuai bagi sumber haba yang boleh meleburkan bahan dengan jarak lebur yang sama. Keputusan simulasi menunjukkan haba perlu sejauh yg mungkin daripada bahan yang mempunyai takat lebur yang rendah. Di dalam simulasi, pada kes1, penyambungan diantara aluminum dan mild steel, kedudukan sumber haba mestilah diletakkan 40% di bahan aluminum dan 60% di bahan mild steel. Pada kes 2, penyambungan diantara mild steel dan stainless steel, kedudukan sumber tenaga mestilah ditengah-tengah iaitu 50% di bahagian mild steel dan 50% di bahagian stainless steel. Pada kes terakhir,penyambungan diantara aluminum dan stainless steel, kedudukan sumber tenaga mestilah 40% di bahagian aluminium dan 60% di bahagian stainless steel. Kimpalan yang berjaya dapat mngurangkan berat kereta dan dapat meningkat kesedaran penggunaan minyak kenderaan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

TWB	Tailor Welded Blank
CAE	Computer Aided Engineering
FEA	Finite Element Analysis
CFD	Computational Fluid Dynamics
MES	Mechanical Event Simulation
FEM	Finite Element Method
FE	Finite Element
Nd-YAG	Neodymium-Doped Yttrium Aluminium Garnet
CW	Clock Wise
GTAW	Gas Tungsten Arc Welding
LDH	Limiting Drawing Height
HAZ	Heat Affected Zone
BPP	Beam Product Parameters

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

This chapter explained about the tailor welded blank, computer aided engineering, finite element analysis, case study, project objective, project scope of this research.

1.2 TAILOR WELDED BLANK

1.2.1 Definition

Tailor welded blanks is used in joining two or more separate pieces of flat material with dissimilar thickness, and or mechanical properties, to provide customized and superior qualities in the finished stamping. Traditional practices in automotive industry is to stamp parts with different thickness and different materials individually before welded together to form a complete assembly parts. With the application of tailor welded blank, processing time can be reduced and higher strength component can be produced.

1.2.2 Benefits

By utilizing a tailor welded blank, made up of blanks of different thickness, coatings, and or strength, the final stamped part can exhibit specific desired properties. Tailor welded blanks can yield several benefits such as:

(i) Reduction of final car weight.

- In an automotive application, tailor welded-blanks eliminate the need for reinforcement, resulting in an overall reduction in vehicle body weight. The use of different strength or thickness in a single part can simplify the whole structure of a vehicle. Low car weight means improved fuel economy that is very important to today's energy consumption.

(ii) Reduction of automobile parts number.

- The precision of car body structure can be improved and a lot of press equipment and working procedures can be saved. A door inner panel is taken as an example. It has a relatively deep draw depth to accommodate the design. This requires a soft and thin metal. However, the front of the same door inner, where the hinges will attach the door to the car, must be strong enough to withstand the weight and use of the door. In the traditional methods, reinforcements are required to strengthen the door inner. These extra parts require several processes in the workshop. Now, by using a tailor welded blank with a large, thin, soft piece of material jointed to a smaller, thicker, stronger piece of material, the blank can be formed and used as a one piece door inner, thus completely eliminating the previous reinforcing components.

(iii) Improved raw material utilization and reduction of scrap

- By selective using higher strength, heavier gauge materials to the specific areas where they are required, the reduction in material could be realized. By nesting various blanks during the blanking process, engineered scrap can also be obviously reduced. For example, the complex body side ring is changed from a traditional one piece blank to a tailor welded blank using 5 separated blanks. As a result, the manufacturer could reduce the engineered scrap content.

(iv) Improvement on the functional performance.

- By using tailor welded blanks, the structural rigidity can be improved due to possibility for optimum selection of strength by using appropriate steel strength or gauge.

(v) Potential to produce wide width automobiles.

- Automobile industry shows great concern on the wide width steel sheets while the width of steel sheets is constrained by the roller machine. Tailor welded blanks can solve this problem. Especially at present situation, supply of the steel with wide width cannot meet the large demand of the market. Tailor welded blanks provide this solution.

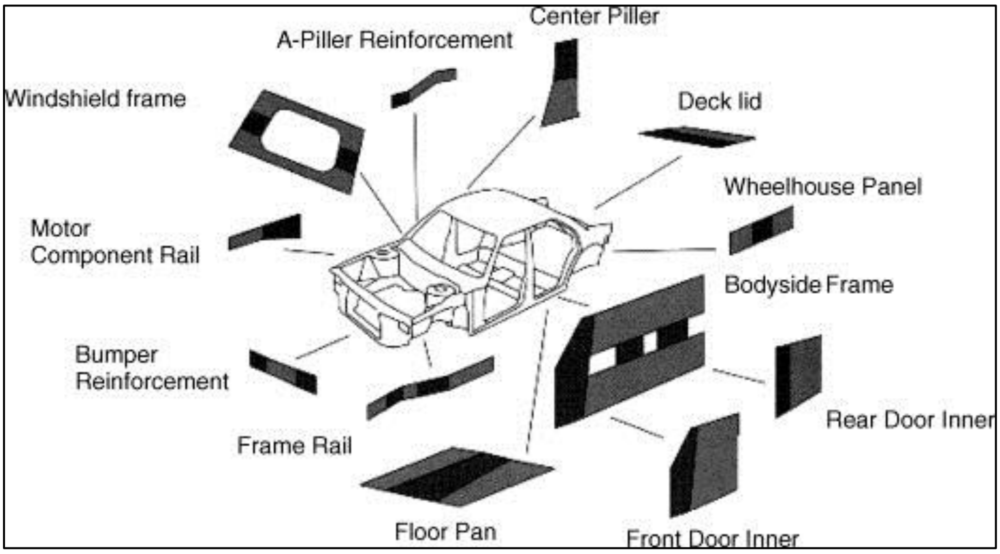


Figure 1.1: Various tailor-welded blank components used in an automotive structure

Source: Millian (1993)

1.3 COMPUTER AIDED ENGINEERING (CAE)

Computer-aided engineering (CAE) is the use of computer software to simulate performance in order to improve product designs or assist in the resolution of engineering problems for a wide range of industries. This includes simulation, validation, and optimization of products, processes, and manufacturing tools.

A typical CAE process comprises of pre-processing, solving, and post-processing steps. In the pre-processing phase, engineers model the geometry and the physical properties of the design, as well as the environment in the form of applied loads or constraints. Next, the model is solved using an appropriate mathematical formulation of the underlying physics. In the post-processing phase, the results are presented to the engineer for review.

CAE applications support a wide range of engineering disciplines or phenomena including:

(i) Stress and dynamics analysis on components and assemblies using finite element analysis (FEA)
(ii) Stress and dynamics analysis on components and assemblies using finite element analysis (FEA)
(iii) Thermal and fluid analysis using computational fluid dynamics (CFD)
(iv) Kinematics and dynamic analysis of mechanisms (multibody dynamics)
(v) Mechanical event simulation (MES)
(vi) Control systems analysis
(vii) Simulation of manufacturing processes like casting, molding and die press forming
(viii) Optimization of the product or process

1.4 FINITE ELEMENT ANALYSIS

Finite element analysis (FEA) is the modeling of products and systems in a virtual environment, for the purpose of finding and solving potential (or existing) structural or performance issues. FEA is the practical application of the finite element method (FEM), which is used by engineers and scientist to mathematically model and numerically solve very complex structural, fluid, and multiphysics problems (Roylance, 2001).

A finite element (FE) model comprises a system of points, called “nodes”, which form the shape of the design. Connected to these nodes are the finite elements themselves which form the finite element mesh and contain the material and structural properties of the model, defining how it will react to certain conditions. The density of the finite element mesh may vary throughout the material, depending on the anticipated change in stress levels of a particular area. Regions that experience high changes in stress usually require a higher mesh density than those that experience little or no stress variation. Points of interest may include fracture points of previously tested material, fillets, corners, complex detail, and high-stress areas.

FE models can be created using one-dimensional (1D beam), two-dimensional (2D shell) or three-dimensional (3D solid) elements. By using beams and shells instead of solid elements, a representative model can be created using fewer nodes without compromising accuracy. Each modeling scheme requires a different range of properties such as section areas, moments of inertia, torsional constant, plate thickness, bending stiffness, transverse shear

To simulate the effects of real-world working environments in FEA, various load types can be applied to the FE model, including:

(i) Nodal: forces, moments, displacements, velocities, accelerations, temperature and heat flux
(ii) Elemental: distributed loading, pressure, temperature and heat flux
(iii) Acceleration body loads (gravity)

1.5 PROBLEM STATEMENT

Heat is major parameters in TWB process. Hence, it must be optimized for the process. Among the considered factors are to minimize heating width and use high intensity heat flux to generate enough heating energy inside the work-piece. This project concentrate heat transfer characteristic of the common type of TWB material. Actual heat distribution will be measured in experiment and will be used to validate FE model. The heat distribution is important to study in welding with different material with the same thickness.

1.6 OBJECTIVES

(i) Fabricate simple heat transfer testing equipment
(ii) Comparison on the result of experimental test with simulation heat transfer modeling
(iii) Parametric study using FE analysis to investigate TWB process

1.7 PROJECT SCOPE

This research is focus on method joining of automotive panels which is to investigate the heat transfer through the joining with different material. This focus area is done based on the following aspect:

(i) Design and machining simple test rig.
(ii) Using specimen test of different material with the same thickness
(iii) Analysis on experimental and numerical method.
(iv) Simulate heat transfer model using finite element method.
(v) Perform heat transfer tests (using localized heating condition on each material thickness).
(vi) Develop finite element (FE) model to simulate heat distribution inside the metal.
(vii) Develop FE model to observe temperature gradient inside the parts of initial stage of welding of TWB.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter explained about the research in focusing of welding, heat affected zone and previous research of different material.

2.2 WELDING

Welding is an assembly process that joints materials, regularly metals or thermoplastics, by producing combination (Kumar, 2012). This happens by melting the workpieces and adding a filler material to form a pool of molten material (the weld pool) that cools to become a strong joint, with pressure sometimes used in conjunction with heat, or by itself, to produce the weld. This is in contrast with soldering and brazing, which involve melting a lower-melting-point material between the workpieces to form a bond between them, without melting the workpieces.

Welding have many different energy sources for example a gas flame, an electric arc, a laser, an electron beam, friction, and ultrasound. Welding also Flexible used in an industrial process, many different environments that welding can be performed including open air, under water and in outer space. Welding is a potentially hazardous undertaking and precautions are required to avoid burns, electric shock, vision damage, inhalation of poisonous gases and fumes, and exposure to intense ultraviolet radiation.

Until the end of the 19th century, the only welding process was forge welding, which blacksmiths had used for centuries to join iron and steel by heating and hammering. Arc welding and oxy fuel welding were among the first processes to develop late in the century, and electric resistance welding followed soon after.

Welding technology advanced quickly during the early 20th century as World War I and World War II drove the demand for reliable and inexpensive joining methods (Kumar, 2012). Following the wars, several modern welding techniques were developed, including manual methods like shielded metal arc welding, now one of the most popular welding methods, as well as semi-automatic and automatic processes such as gas metal arc welding, submerged arc welding, flux-cored arc welding and electro slag welding. Developments continued with the invention of laser beam welding, electron beam welding, electromagnetic pulse welding and friction stir welding in the latter half of the century. Today, the science continues to advance. Robot welding is commonplace in industrial settings, and researchers continue to develop new welding methods and gain greater understanding of weld quality. In TWB, laser welding is commonly use in joining process.

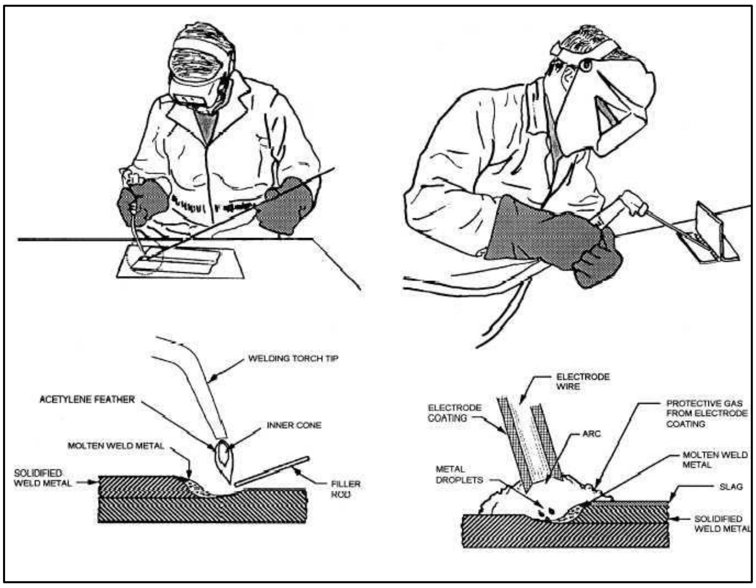


Figure 2.1: Example of welding process

Source: constructionmanuals.tpub.com

2.3 LASER WELDING

2.3.1 CO_2 Laser Welding and Nd:YAG laser welding

Laser welding is a welding technique which is achieved with very high power density obtained by focusing a laser light beam to a very fine spot (Duley, 1999), CO_2 laser dominated the market for industrial applications requiring high laser powers (>3 kW CW). With the rapid development of Nd:YAG laser technology. YAG laser with CW powers up to 4kW become available. In laser welding the advantages of the Nd:YAG laser are shown clearly as follows:

Table 2.1: Advantages of Nd:YAG and CO_2 laser

Advantages of Nd:YAG laser	Advantages of CO_2 laser
1- Enhanced coupling to reflective metal	1- High electrical efficiency
2- Increased processing efficiency	2- low operating cost
3- Fiber – optic delivery	3- easily scaled to high power

Source: Duley, W.W (1999)

Representative welding data for mild steel obtained at the same laser power (3kW) showed that higher penetration could be achieved with YAG welding rather than with CO_2 laser radiation, except for thick material where comparable results were obtained. For thickness near 2mm, YAG welding was 50% faster than co2 laser welding. An increase in welding speed may translate into cost saving in high volume applications such as laser welding of tailors blanks (Duley, 1999). Based on these, an Nd:YAG laser was chosen to weld the tailors made blanks in this study as the thickness of the material used was equal to or below 1mm, making it more efficient and appropriate to use Nd:YAG

2.3.2 Disadvantages of conventional welding

Fusion and resistance welding methods produces buckling or extensive surface oxidation on the production of floor or roof blanks, which requires rework over a large area to obtain an acceptable weld. However, recently the majority of sheets used in the production of body panels were zinc coated, which destroys the galvanic protection conferred by coating and render the substrate liable to rusting, particularly in areas prone to damage by stone chipping (Waddell, 1995). On the other hand, by comparing the application of laser welding with mash seam welding on a material (up to 3mm), mash seam welding of zinc-coated sheets would result in disturbance during weld process and poor mechanical performance. Therefore, mash seam welding can only compete with laser welding restricted numbers of application for pre-welded sheets (Heoven *et al*., 1996)

2.3.3 Advantages of laser welding

Laser welding is more advantageous in welding tailored blanks for car-body panel, as it offers a unique technology to improve structural properties and weld consistency. In addition, it also enhance reduction of weight and cost saving. For instance, reducing the width of pinch weld flanges could eliminate up to 50kg of metal. Furthermore, the high welding speed of lasers, typically 5mm/min with few kilowatt of power, enables substitution of one laser welder to several resistance welders (Baysore *et al*., 1995). At the same time, the high traveling speed and low heat input associated with laser beam welding produces narrow fusion and less heat-affected zones and minimal distortion. The other advantages are listed as follows (Baysore *et al*., 1995):

(i) High degree of automation
(ii) High welding speed
(iii) Non-contact welding
(iv) Welds almost flush with the sheet metal
(v) No filler material required
(vi) Very narrow heat-affected zone

2.3.4 Post-welded heat treatment

Post-welded heat treatment of an entire weldment, or only a localized portion, may be performed to achieve one or more of the following:

(i) Relieve stresses
(ii) Improve toughness
(iii) Increase strength
(iv) Improve corrosion resistance
(v) Remove cold work

A variety of thermal treatments have been developed to accomplish these changes and have been termed stress-relief heat treatment, annealing, normalizing, hardening, quenching and tempering, austempering and martempering. The difference between the heat-treating operations is temperatures employed and methods of cooling. The temperature of stress-relief heat treatment is below the critical range of the steel, whereas temperatures for normalizing, annealing and hardening are always above the critical range (Kim *et al*., 2001)

Normalizing is a heat treatment, which is frequently employed in treating both the plate metal prior to welding and the finished weldment. Normalizing involves heating the steel approximately 100^0c above its critical range to transform the structure to austenite, followed by cooling in still air. Normalizing with its air-cooling treatment creates a finer lamellar pearlite in most steel, slightly harder but quite satisfactory for service. A normalizing treatment may be used to reduce stress from cold working or welding, remove hardened zones adjacent to the weld, create a more uniform and desirable microstructure in both weld metal and base metal, and refine (by recrystallization) any coarse structure developed through hot working or forming operations at a very high temperature above 1900 (Linnert *et al*,. 1965). In TWB, welding process can make effect in the joining material.

2.4 EFFECT OF WELDING TYPES

TWB commonly used welding process were laser welding, mash seam welding, electron-beam welding, GTAW welding, induction welding and fusion and resistance welding. However, only mash seam and laser welding were generally used today as reliable and serial production process for tailor made blanks (Eisenmenger *et al*., 1993). The following section was written on comparison of different types of welding effects and effects of the key welding parameter on the TWB formability.

In order to achieve a higher precision assembly, reduce the production coast and improve driving safety, a new method in sheet metal stamping for car body panels had been developed, in which several blanks of different strength and thickness were integrated by using laser welding technology (Norihiko *et a*., 1993).

Comparing laser welding effects on TWB formability with other type of welding, stretch formability of the TWB was decreased with laser welding by 10 to 18% when compared to the base metal, while resistance mash seam welding decreased it by 29-35% depending on steel grade, thickness and width (Milian, *et al*., 1993). For the fatigue life performance, laser welds was increased by 36 to 126% over resistance welds, while the tensile strength in the range of 34-113% (Baysore, *et al*., 1995). In addition, a narrow bead width and a hard welding part were formed in laser welding, a wide hardening part and a soft welding part were formed in mash seam welding.

Besides that, GTAW welding was associated with poor formability in spite of its low hardness value, when compared to last welding. The weld size of GTAW was 4.5 times wider than laser weld and with a lower limiting drawing height (LDH) value (Adonyi *et at*., 1996).

Furthermore, TWB welded by plasma and induction, was comparable to laser-welded blanks in deep drawing. However, it has lower formability in bending and stretch forming. Indeed, the different in formability for TWB produced with different welding method was partly explainable by variation in width and microstructure change in the heat-affected zone (HAZ) (Sagstrom *et al*., 2000). This further explained that the larger HAZ increased in effective cross-sectional area of the increased hardness that work stiffening in the TWB (Baysore *et al*., 1995). Result show that for any given steel grade, the mechanical properties of base HAZ and weld composite were equally affected (the strength increase and the ductility decrease) throughout uniform deformation by the two welding processes (William *et al*., 1991).

2.5 HEAT AFFECTED ZONE

The heat-affected zone (HAZ) is the part of base material, either a metal or a thermoplastic, which has had its microstructure and properties altered by welding or heat intensive cutting operations. The heat from the welding process and subsequent re-cooling causes this change from the weld interface to the termination of the sensitizing temperature in the base metal. The extent and magnitude of property change depends primarily on the base material, the weld filler metal, and the amount and concentration of heat input by the welding process.

The thermal diffusivity of the base material plays a large role if the diffusivity is high, the material cooling rate is high and the HAZ is relatively small. Alternatively, a low diffusivity leads to slower cooling and a larger HAZ. The amount of heat inputted by the welding process plays an important role as well, as processes like oxy-fuel welding use high heat input and increase the size of the HAZ. Processes like laser beam welding and electron beam welding give a highly concentrated, limited amount of heat, resulting in a small HAZ

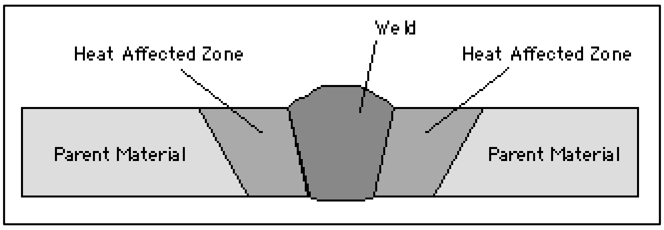


Figure 2.2: HAZ Area

Source: solidmetals.net

2.6 HEAT DISTRIBUTION

The welding heat input has a great influence on the weldments properties. Mechanical properties and toughness of weldment depend of microstructure of weld metal (Cvetković *et al.*, 2005). In Figure 2.3 It shown effect of heat input on the cooling rate, and cooling rate is primary factor that determines the final metallurgical structure of the weld (Funderburk, 1999). The cross sectional area of a weld is generally proportional to the amount of heat input. As more energy is supplied to the arc, more filler material and base metal will be melted per unit length, resulting in a larger weld bead.

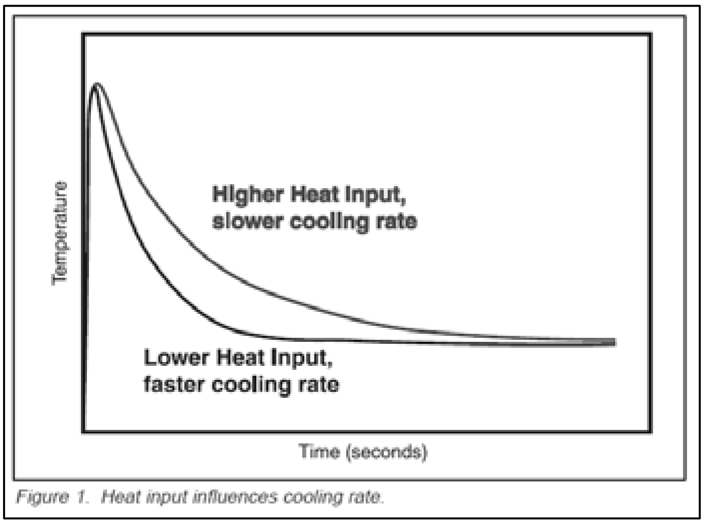


Figure 2.3: Heat input influences cooling rate

Source: Cvetković *et al* (2006)

The most important characteristic of heat input is that it governs the cooling rates in welds and thereby affects the microstructure of the weld metal. A change in microstructure directly affects the mechanical properties of weld. Therefore, the control of heat input is very important in arc welding in terms of quality control.

The change in toughness is not just tied to the heat input, but is also significantly influenced by the weld bead size. As the bead size increases, which corresponds to a higher heat input, the notch toughness tends to decrease. In multiple-pass welds, a portion of the previous weld pass is refined, and the toughness improved, as the heat from each pass tempers the weld metal below it. If the beads are smaller, more grain refinement occurs, resulting in better notch toughness. At surface welding, heat input affects on the mixture degree, as relevant parameter of weld quality.

Mixture degree increase with higher heat inputs, which results in different microstructures of obtained layers, and in different toughness values. The weld toughness of surface welded joint is the result of complex influence of many factors: type of filler material, heat input, mixture degree of base metal and filler material, post heat treatment with next layer, because each subsequent pass alters the structure in regions of the previous pass that are heated. Having on mind interactions of all mentioned parameters, it doesn′t surprise insufficient literature data about obtained results.

2.7 THE EFFECT OF WELD POSITION

The formability of TWBs may change according to weld line position in critical areas. Studies have suggested that the best formability will occur when the weld line is placed away from areas of high strain i.e. place the weld far from the major strain direction (Shi *et al.*,1993). The placing the weld closer to the thinner material in a dissimilar thickness TWB (i.e. decreasing the amount of thinner material in the TWB) increases the formability by allowing the thicker material to deform more (Kridli, 2000). However, weld line location does significantly reduce the forming-limit strains when compared to the unwelded blank (Narayanan, 2008), where increasing the weld line offset increases the forming limit reduction where the decrease in limit strain is in the stretching region.

The weld line movement and formability of dissimilar materials TWB with three different initial weld-line locations for a deep drawing process (Choi, 2000). The weld line was shifted farther from the center of the blank, more weld line movement occurred. The effect of different weld position in a deep drawing process limits the amount of weld line movement (Heo, 2001). Although, with the use of the draw-bead, the weld line movement was reduced, the same effect was observed where the maximum drawing depth and maximum drawing force were reduced as the weld line was placed farther from the center of the blank.

2.8 LASER WELDING OF DISSIMILAR MATERIAL

The majority of applications in a range of industries i.e. automotive, electronics and medical require welding of dissimilar materials. In principle, a laser can weld any material, which can then be joined by conventional processes.

When welding dissimilar metals, good solid solubility is essential for sound weld properties. The trends of welding dissimilar metals present considerable challenges. The weldability of dissimilar metals depends on many factors. The physical properties have a high influence on the amount of energy coupled in and the heat transfer.

When joining dissimilar materials, there may be certain advantages in using laser welding even though brittle intermetallic can form. Since the weld itself is narrow, the volume of intermetallic may be reduced to acceptable limits. Again, it may be possible to offset the beam in one direction or another, thus allowing some control over composition of the resulting alloy.

Although it may be possible to produce sound joints using these methods on a laboratory scale, it is more difficult to achieve similar controls under production conditions

When joining dissimilar materials, there may be certain advantages to using laser welding, even though brittle intermetallics can form. Since the weld itself is narrow, the volume of intermetallics may be reduced to acceptable limits. Again, it may be possible to offset the beam in one direction or the other, thus allowing some control over composition of the resulting alloy.

While it may be possible to produce sound joints by these methods on a laboratory scale, it is more difficult to achieve similar controls under production conditions. Mixing molten metal in a laser weld seldom produces a chemically homogeneous fused zone between two dissimilar materials.

Although the average chemical composition of the weld may be acceptable, local heterogeneity can be responsible for the presence of brittle zones. It will also be apparent that minor variations in the beam position can significantly influence the relative proportions of the two main constituents in the weld zone.

To date, most joining of dissimilar metals has been carried out with pulsed lamp Nd:YAG lasers (Naeem, 2006).2-3 Lamp-pumped lasers are capable of producing long, multi-ms pulses with peak powers many times the rated average power of the laser, provided that the duty cycle is sufficiently low.

This ability stems from the flash-lamp itself, which is often more constrained by the maximum average thermal load than the peak power output. High peak power pulsed lamp pumped Nd:YAG lasers, coupled with pulse shaping, makes these lasers ideal for welding dissimilar materials.

The shaping of pulses is of great importance since the temperature has to be controlled where the two molten phases are mixed. Weld depths that are too deep can lead to defective joints. Insufficient weld depths can be avoided by adjusting the high starting power and the correct decreasing power to the joint geometry as well as the material properties of the pulse shape.

The presence of dissimilar materials highlighted differences in the behavior of laser welding, compared to other fusion welding processes such as arc welding. Thus, mixing in the weld pools was relatively poor and there were usually two distinct regions in each weld cross section, corresponding to where the pool was surrounded by each sheet.

Where there were large differences in melting point between the sheets, e.g. Ti and Al, there was a region, within the lower melting point sheet, which had melted but not mixed with the main weld pool.

Few problems would were anticipated with joints between dissimilar copper alloys, and this generally proved to be the case. Although austenitic stainless steel and copper alloys were characterized by a mixture of copper and iron-rich phases, these welds were mostly sound.

However, the joints with the aluminum alloy sheets contained significant cracking. Both welds to copper and stainless steel-plated copper contained at least some regions where brittle intermetallic phases were present and cracks were observed in these regions. Even the titanium to aluminum weld - which was sound in the aluminum-rich region - contained a few small micro-cracks in the small root area where high dilution with titanium had created brittle intermetallic phases.

CHAPTER 3

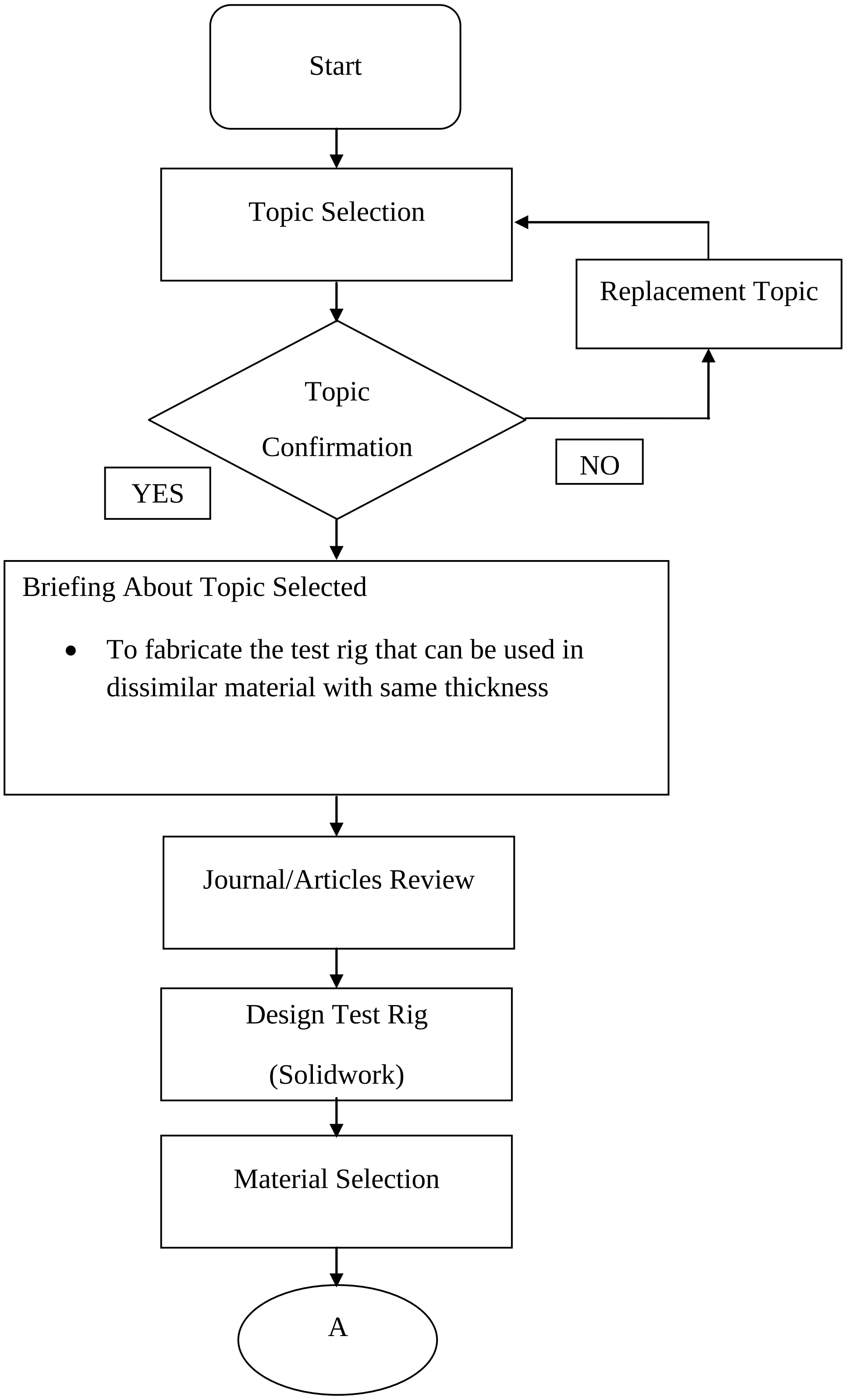
METHODOLOGY

3.1 INTRODUCTION

This chapter focuses on the method to do the experiment. The method that used in this project is analysis and experimental. The analysis method that used Abaqus software and the experimental method used laser welding with contributes test rig.

3.2 PROCESS FLOW

Methodology flow chart is use as guidelines and the sequences to make this project go smoothly. Thus, the process begin with title selection and conformation of the title selected. Then, the process continue with finding the articles relate and identify the objectives, project background and the problem statement related to this project. The process proceeds by starts with design/sketch and identifies the material needed to fabricate the test equipment for this heat transfer experiment. There are brainstorming process in decided the best material for the test equipment fabrication


Start
Topic Selection
Replacement Topic
Topic
Confirmation
NO
YES
Briefing About Topic Selected
• To fabricate the test rig that can be used in dissimilar material with same thickness
Journal/Articles Review
Design Test Rig
(Solidwork)
Material Selection
A

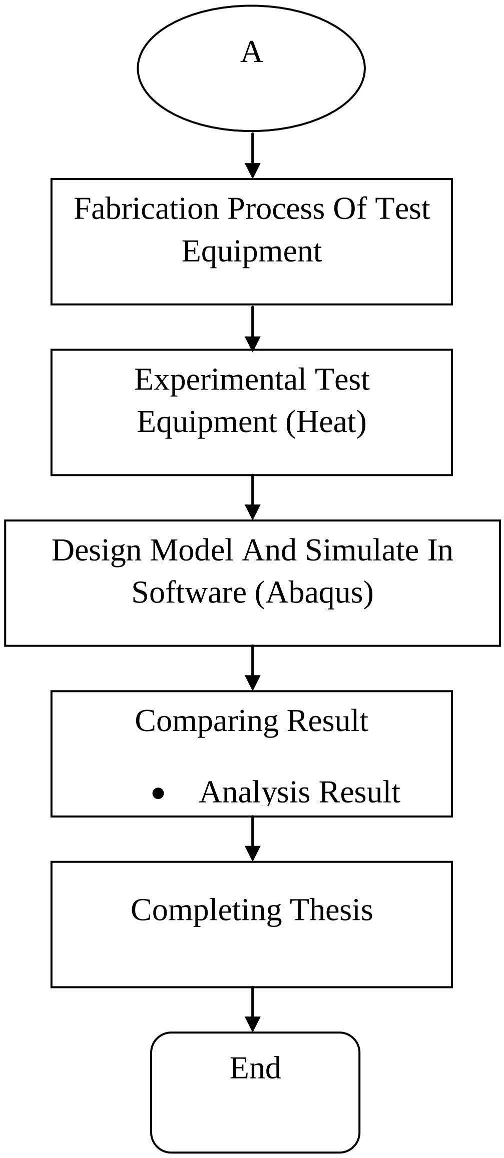


Figure 3.1: Methodology Flow Chart

3.3 TEST RIG FABRICATION

Test rig is the placed that used to clamp the specimen material. It produced by some process such as milling, drilling and slotting. It also can clamp the material with different thickness. It has several parts that must be assembly. Solidwork software used to draw the test rig. (Please refer to Appendix A)

3.3.1 Bill Of Material

Table 3.1: Bill of Material

No	Material	Size (mm)	Quantity
1	Mild Steel	200mm x 190mm x 10mm	1
2	Aluminum	150mm x 15mm x 10mm	2
3	Aluminum	60mm x 40mm x 20mm	2
4	Aluminum	25 Dia. x 100mm	4
5	Stainless steel	100mm x 50mm x 3mm	1
6	Mild steel	100mm x 50mm x 3mm	1

3.3.2 Cutting Process

Band-saw cutting machine was used to cut the raw material. The saw blade is movable, allowing the user to adjust the angle at which the blade comes in contact with the raw material. The blade can be moved up and down, thereby allowing the user to cut raw material at different depths according to their needs. Figure 3.2 show band-saw cutting machine.

Figure 3.2: Band-Saw Cutting Machine

3.3.3 Squaring Process

Conventional milling machine used to clean up the raw material from the carbon layer and also to minimize the size of the material. Milling cutters are cutting tools typically used in milling machines or machining centers and occasionally in other machine tools. They remove material by their movement within the machinery directly from the cutter's shape. Figure 3.3 show the conversional milling machine.

Figure 3.3: Conventional Milling Machine

3.3.4 CNC Machine

Vertical CNC milling machine used to make drilling and slotting. In the vertical mill the spindle axis is vertically oriented. Milling cutters are held in the spindle and rotate on its axis. The spindle can generally be extended (or the table can be raised/lowered, giving the same effect), allowing plunge cuts and drilling. Figure 3.4 show the vertical CNC milling machine

Figure 3.4: CNC Milling Machine

3.3.5 Grinding Process

Grinding process is to produce very fine finishes and very fine accurate dimension. The base of test rig need to do this process and this process can get the smooth surface.

Figure 3.5: Grinding Process

3.3.6 Bench Work

The finishing of the test rig is filing and make the M6 thread. After the drilling and slotting process, the workpiece have burr and need to remove it. To make the thread, it needs used M6 thread. Figure 3.5 show the thread process and figure 3.6 show the filing process

Figure 3.6: Thread Process

Figure 3.7: Filing Process

3.3.7 Complete Test Rig

Table 3.2: Component Part of Test Rig

Component	Material	Dimension (mm)
Base 	Mild Steel	200 x 190 x 10
Stopper 	Aluminum	60 x 40 x 20
Base leg 	Cylinder aluminum	25Dia x 100
Clamper 	Aluminum	150 x 15 x 10

3.4 SPECIMEN PREPARATION

3.4.1 Shearing Process

Cutting processes are those in which a piece of sheet metal is separated by applying a great enough force to cause the material to fail. The most common cutting processes are performed by applying a shearing force, and are therefore sometimes referred to as shearing processes. The specimen that used is aluminum, stainless steel, and galvanized iron with dimension 100mm x 50mm x 2mm.

3.4.2 Drilling Process

The workpiece need to be drilled to insert the thermocouple inside the hole. The machine that was used is electrical discharge machine (EDM). The diameter that used is 0.5mm.

Figure 3.8: Super Drill Machine

3.5 EXPERIMENTAL METHOD

The welding process produces heat and heat transfer in dissimilar material will affect the result of welding. In this study the selection material is done with use mild steel and stainless steel. To collect the data from the laser welding, it will use thermocouple that connect to data logger and it can simulate the data with use DasyLab software

3.5.1 Thermocouple

Thermocouples are a widely used type of temperature sensor for measurement and control and can also be used to convert a temperature gradient into electricity. The Thermocouple is a thermo-electric temperature sensor which consists of two dissimilar metallic wires coupled at the probe tip (measurement junction) and extended to the reference junction. The thermocouple type is used is K due to its ability to withstand at high temperature range -270 to 1350^{o}C

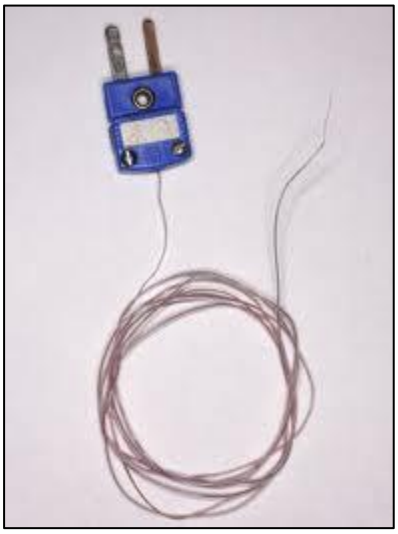


Figure 3.9: Thermocouple wire type K

3.5.2 Data logger

A data logger (also data logger or data recorder) is an electronic device that records data over time or in relation to location either with a built in instrument or sensor or via external instruments and sensors. Data logger a standalone device that can read various types of electrical signals and store the data in internal memory before be downloaded to a computer. The advantage of data loggers is that they can operate independently of a computer, unlike many other types of data acquisition devices. Data loggers are available in various shapes and sizes. The range includes simple economical single channel fixed function loggers to more powerful programmable devices capable of handling hundreds of inputs.

3.5.3 National Instrument, NI 9123

National Instruments has announced the NI 9213, which adds high-density thermocouple measurements to the NI C Series platform. Using the NI 9213, a compact modular data acquisition system can be created to collect data from up to 16 independent thermocouples. The NI 9213 takes up less space than standard instrumentation in a measurement system and provides more channels for measurement with a sampling rate of 75 samples/second per channel, making the device both compact and efficient for high-channel systems.

3.5.4 DASYLab

DASYLab is one of instrument software that can generate the result quickly. Create flexible and powerful monitoring and control applications without programming. DASYLab hardware drivers work with NI-DAQmx devices, as well as NI CAN boards. DASYLab supports Measurement Computing data acquisition hardware. DASYLab provides a comprehensive selection of real-time display capabilities for easily developing custom display. It also includes a wide range of real-time data analysis and control functions for easily developing custom applications

3.6 EXPERIMENT SETUP

The experiment setup is to avoid any mistake when during the data collection. The experiment is like the figure below.

1. Switch on Laptop and open the DasyLab software
2. Clamp the specimen on the test rig, and put the specimen under the laser beam. Make sure the specimen in the middle of laser beam
3. Connect data logger to Laptop and use thermocouple to connect on the surface of specimen workpiece
4. Switch on laser machine
5. Record the data using DasyLab

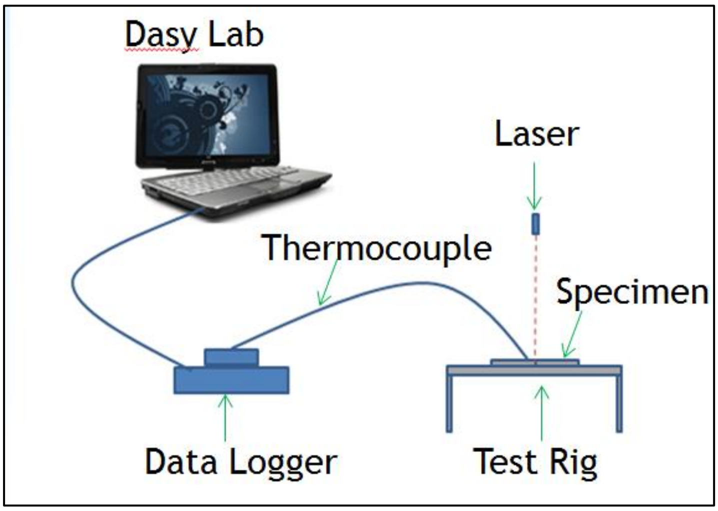


Figure 3.10: Experiment view

3.7 SIMULATION METHOD

3.7.1 Abaqus Software

Abaqus software is a suite of software applications for finite element analysis and computer-aided engineering. Abaqus is used in the automotive, aerospace, and industrial products industries. The product is popular with academic and research institutions due to the wide material modeling capability, and the program's ability to be customized. Abaqus also provides a good collection of multiphysics capabilities. In this study Abaqus it used to simulate the heat transfer after welding.

3.8 EXPERIMENT AND SIMULATION FLOW

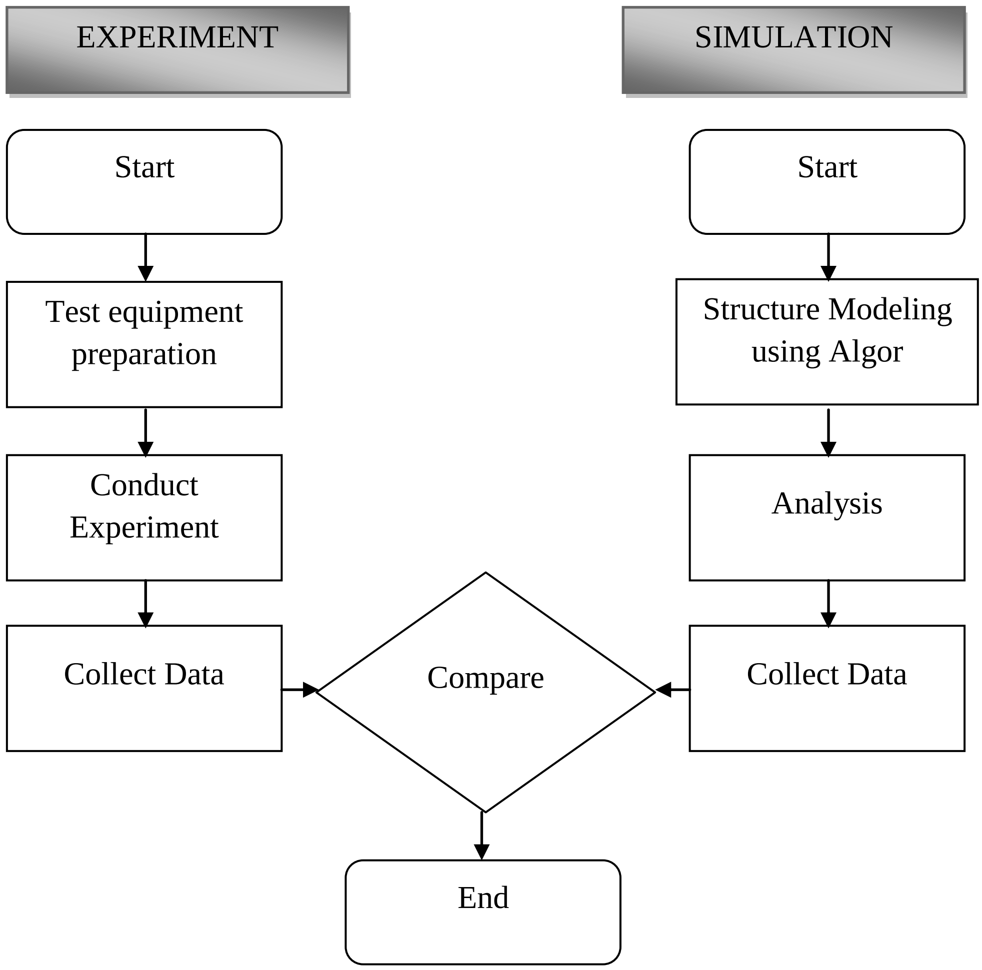


Figure 3.11: Experiment and Analysis Flow Chart

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter shows the result of experimental of joining three different materials with using laser welding. The result of experimental will compare the result of simulation in Abaqus software. The data will validate and another analysis is to study the parametric with high heat flux value and to optimum the position of laser welding to ensure the both material will melt.

4.2 EXPERIMENTAL AND SIMULATION MODELING

The experiment test is dividing by three combination of material. The experiment will run with the low power capacity of laser welding. The pick point is following the figure 4.1. The point 1 is nearest from heat applied, 1mm and second point is 3mm from point 1, and point third point is 3mm from point 2. The width of laser is 1mm and its position in the middle of both specimens. The laser is static position and its take 90 seconds to record the data.

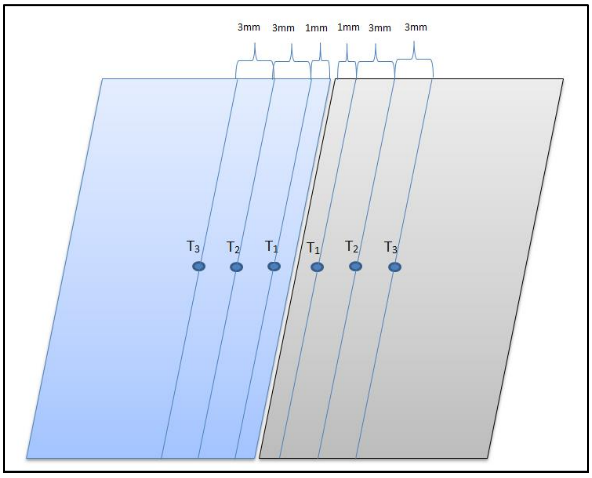


Figure 4.1: Position of Thermocouple

The metric combination of the joining material is follow above. The three selection material that use is mild steel, stainless steel, and aluminum. This material is usually use in industries that perform in tailor welded blank. The experiment will conduct as the figure 4.2.

Table 4.1: Material Combinations

CASE	MATERIAL	THICKNESS
Case 1	Mild Steel/Aluminum	2mm
Case 2	Stainless Steel/Mild Steel	2mm
Case 3	Stainless Steel/Aluminum	2mm

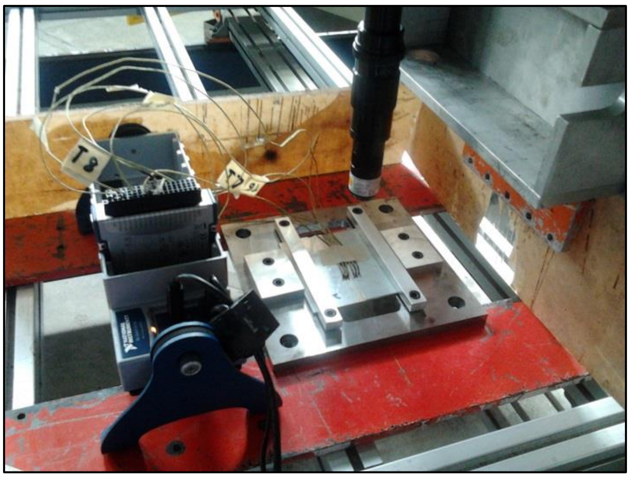


Figure 4.2: Experiment Setup

In the simulation, many boundary conditions of material properties that must be considered. The boundary conditions that use in the simulation analysis will follow the table above.

Table 4.2: Boundary Conditions of material

Boundary Condition	Aluminum 1100	Stainless Steel 416	Mild Steel 1010
Conductivity (W/m.K)	237	14.9	63.9
Density (kg/m^3)	2702	7900	7832
Thermal Expansion Constant (m/m.K)	2.25×10^{-5}	1.73×10^{-5}	1.5×10^{-5}
Specific Heat (J/kg.°C)	903	477	434
Melting Point (°C)	660	1510	1410

4.2.1 Joints of Mild Steel 1010 and Aluminum 1100

4.2.1.1 Experiment

The case 1 is to get the heat distribution in joining of Mild Steel and Aluminum. The material melting properties is wide different, the melting point of aluminum, approximately 660 °C and mild steel approximately 1410 °C. The aluminum melts and flows away well before the mild steel has melted. The result of experiment shows below.

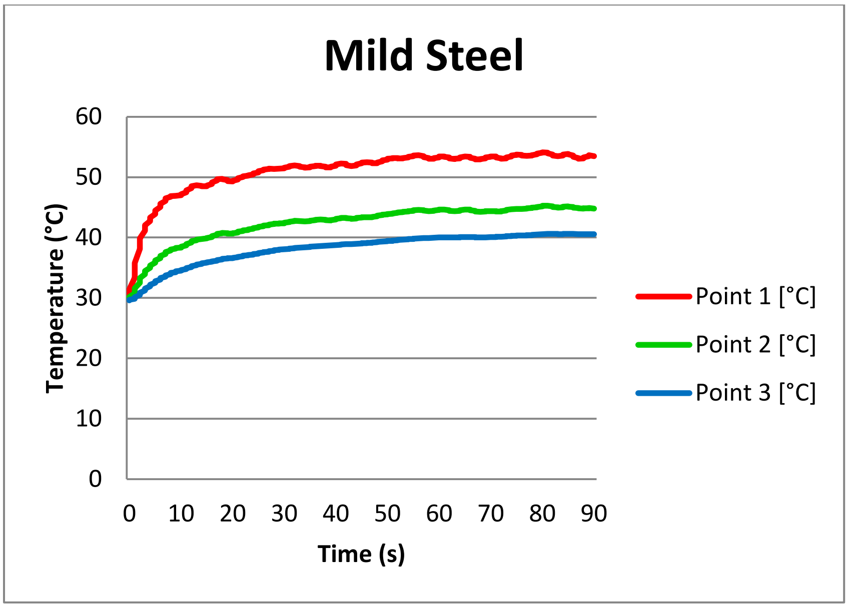


Figure 4.3: Case 1, Mild Steel Experiment Result

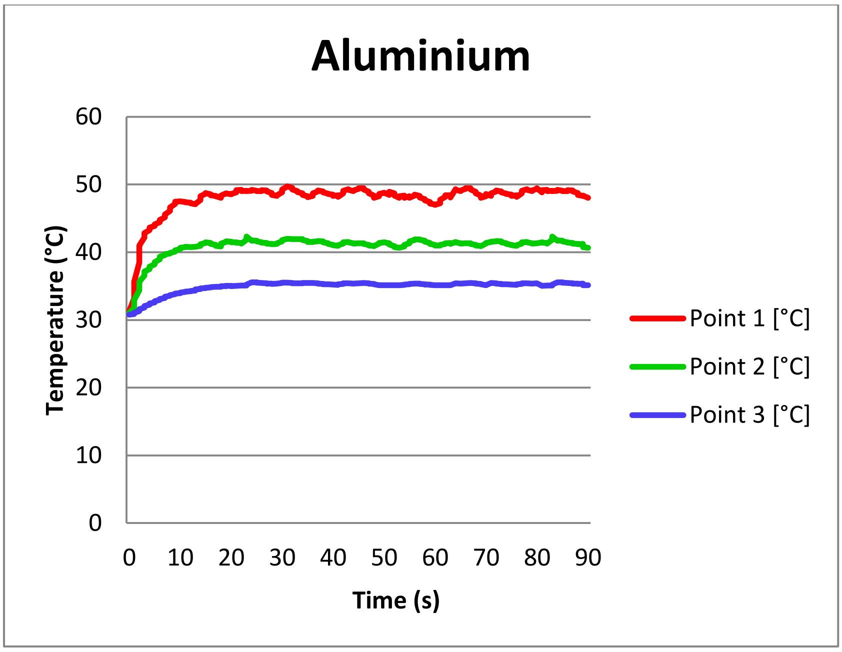


Figure 4.4: Case 1, Aluminum Experiment Result

4.2.1.2 Simulation Modeling

The simulation will generated at the same material properties with using Abaqus software. The heat flux is applied to the modeling and the result of simulation is shown below

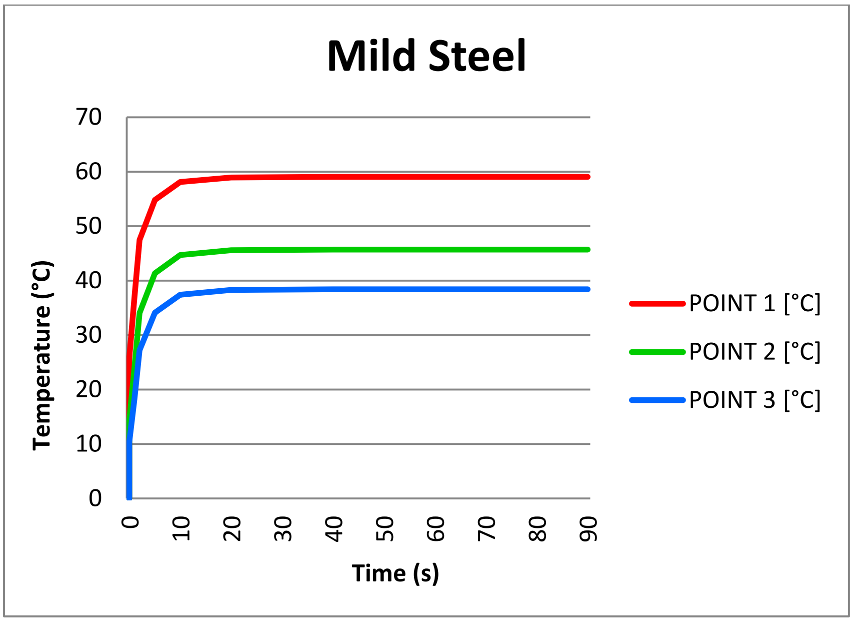


Figure 4.5: Case 1, Mild Steel Simulation Result

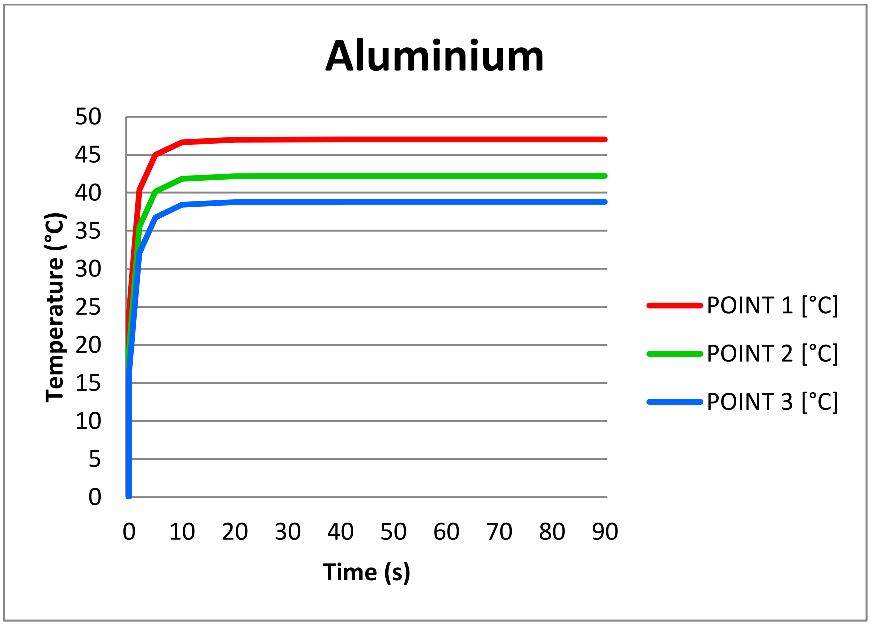


Figure 4.6: Case 1, Aluminum Simulation Result

4.2.1.3 Comparison Data

Table 4.3: Comparison Data Aluminum and Mild Steel

MATERIAL	METHOD	POINT 1	POINT 2	POINT 3
Aluminum	Experiment	49.75	42.33	35.55
	Analysis	47.00	42.20	38.78
Mild Steel	Experiment	54.10	45.27	40.62
	Analysis	59.05	45.68	38.42

From the table that can see the different of the experiment and simulation is not wide different. At point 1, mild steel is high temperature than aluminum because the conductivity of mild steel is lower than aluminum. The aluminum that can conductance the heat is very fast because it high conductivity.

4.2.2 Joints of Stainless Steel 416 and Mild Steel 1010

4.2.2.1 Experiment

The case 2 is to get the heat distribution in joining of Stainless Steel and Mild Steel. The material melting properties is narrow different, the melting point of stainless steel, approximately 1510 ^{o}C and mild steel approximately 1410 ^{o}C. The mild steel melts and flows away well before the stainless steel has melted. The result of experiment shows below.

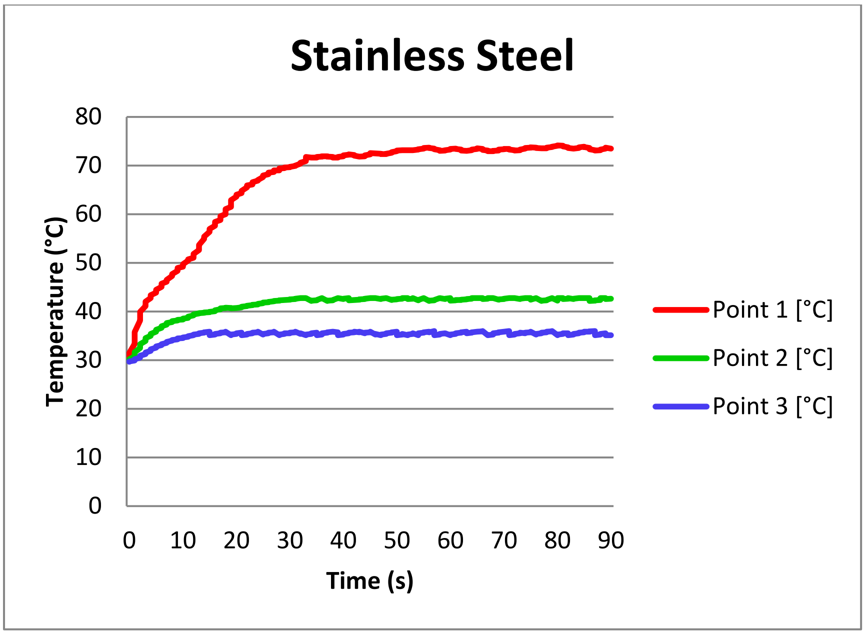


Figure 4.7: Case 2, Stainless Steel Experiment Result

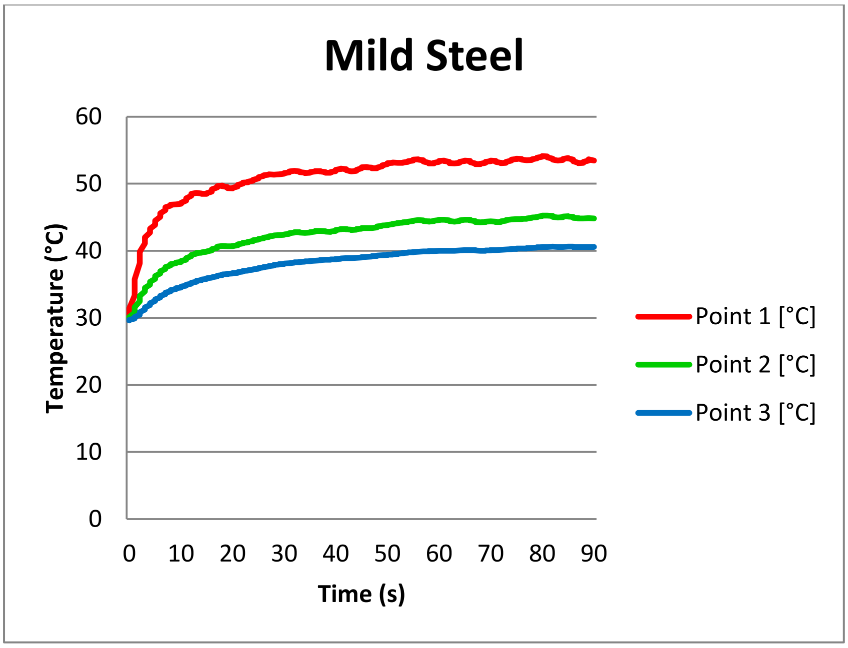


Figure 4.8: Case 2, Mild Steel Experiment Result

4.2.2.2 Simulation Data

The simulation will generated at the same material properties with using Abaqus software. The heat flux is applied to the modeling and the result of simulation is shown below

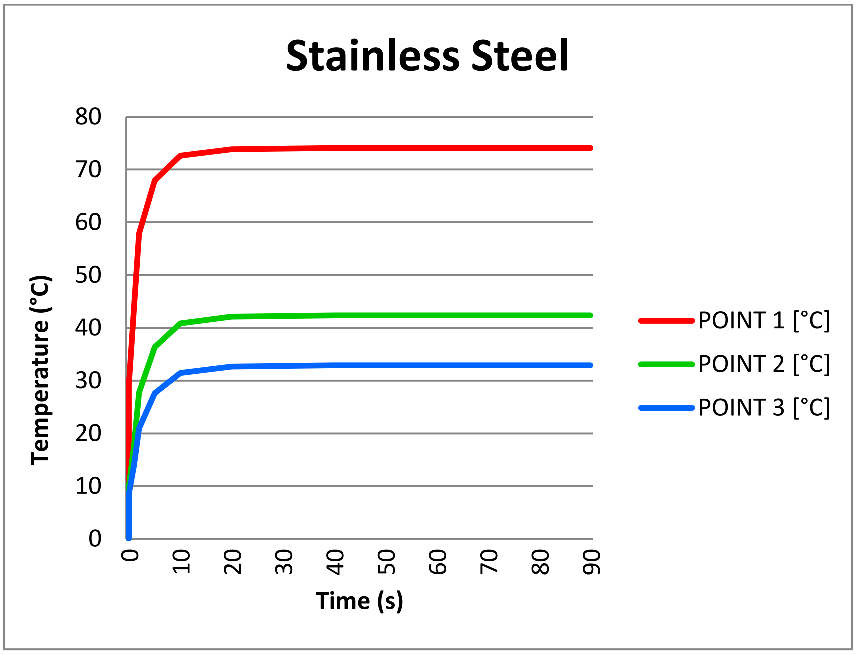


Figure 4.9: Case 2, Stainless Steel Analysis Result

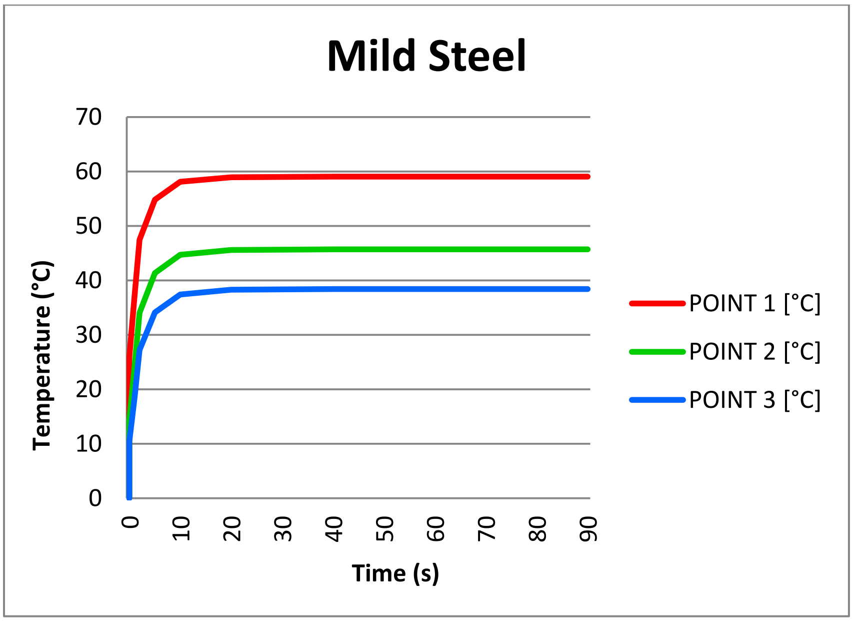


Figure 4.10: Case 2, Mild Steel Analysis Result

4.2.2.3 Comparison Data

Table 4.4: Comparison Data Stainless Steel and Mild Steel

MATERIAL	METHOD	POINT 1	POINT 2	POINT 3
Stainless Steel	Experiment	73.93	42.77	35.98
	Analysis	74.08	42.37	32.89
Mild Steel	Experiment	54.10	45.27	40.62
	Analysis	59.05	45.68	38.42

From the table that can see the different of the experiment and simulation is narrowing different. At point 1 stainless steel is high temperature than mild steel because the conductivity of stainless steel is lower than mild steel. The mild steel that can conductance the heat is very fast because it high conductivity than stainless steel.

4.2.3 Joints of Stainless Steel 416 and Aluminum 1100

4.2.3.1 Experiment

The case 3 is to get the heat distribution in joining of Stainless Steel and Aluminum. The material melting properties is wide different, the melting point of aluminum, approximately 660 ^{o}C and stainless steel approximately 1510 ^{o}C. The aluminum melts and flows away well before the stainless steel has melted. The result of experiment shows below.

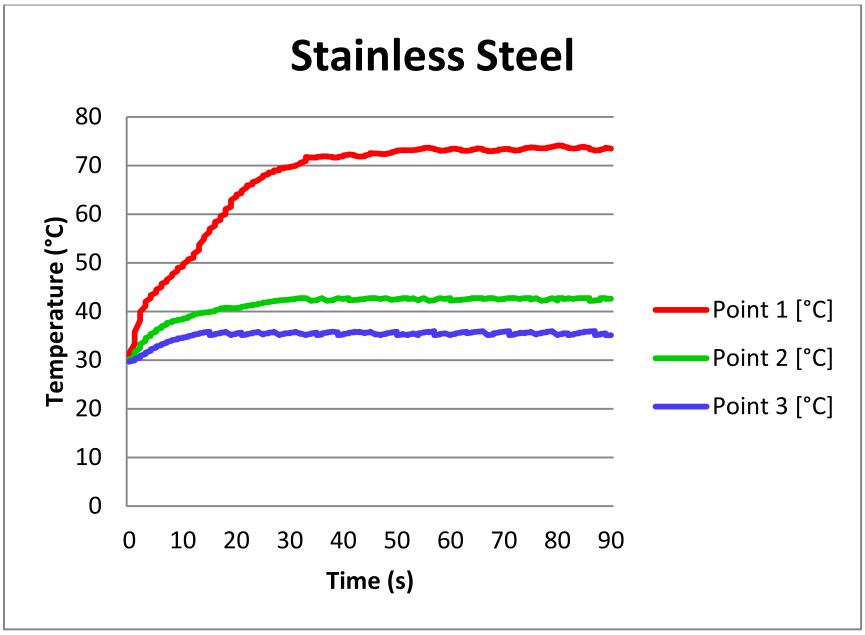


Figure 4.11: Case 3, Stainless Steel Experiment Result

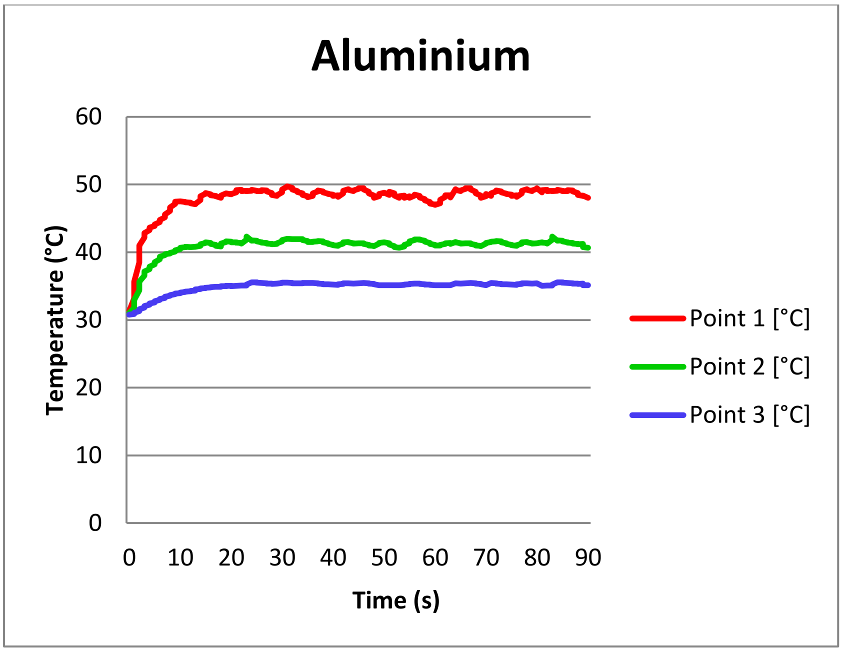


Figure 4.12: Case 3, Aluminum Experiment Result

4.2.3.2 Simulation Data

The simulation will generated at the same material properties with using Abaqus software. The heat flux is applied to the modeling and the result of simulation is shown below

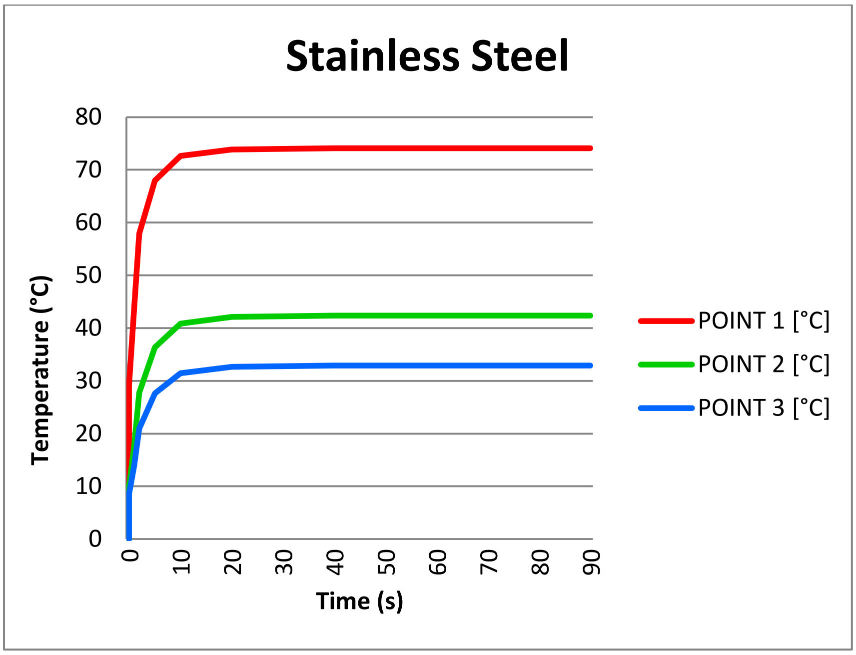


Figure 4.13: Case 3, Stainless Steel Analysis Result

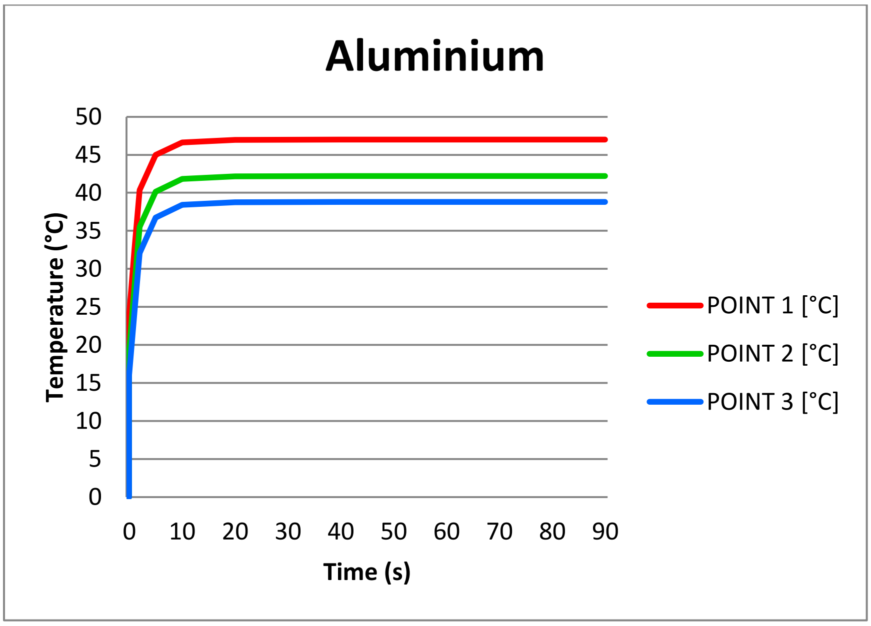


Figure 4.14: Case 3, Aluminum Analysis Result

4.2.3.3 Comparison Data

Table 4.5: Comparison Data Stainless Steel and Aluminum

MATERIAL	METHOD	POINT 1	POINT 2	POINT 3
Stainless Steel	Experiment	73.93	42.77	35.98
	Analysis	74.08	42.37	32.89
Aluminum	Experiment	49.75	42.33	35.55
	Analysis	47.00	42.20	38.78

From the table that can see the different of the experiment and simulation is narrowing different. At point 1 stainless steel is high temperature than aluminum because the conductivity of stainless steel is lower than aluminum. The aluminum that can conductance the heat is very fast because it has high conductivity than stainless steel.

4.3 PARAMETRIC STUDY

The parametric study is to find the best position of laser that can melt the both of the different material properties. The best position is either material that can melt with same or equivalent length of melting area. The combination of position laser is following the table below.

Table 4.6: Position of Laser

CASE	MATERIAL	LASER POSITION (mm)		
Case 1	Mild Steel	0.4	0.5	0.6
	Aluminum	0.6	0.5	0.4
Case 2	Stainless Steel	0.4	0.5	0.6
	Mild Steel	0.6	0.5	0.4
Case 3	Stainless Steel	0.4	0.5	0.6
	Aluminum	0.6	0.5	0.4

4.3.1 Joints of Mild Steel 1010 and Aluminum 1100

In case 1, the material is wide of mechanical properties, the simulation will analyze the get the best position, the pick point is 0.5mm for both material from the center. The heating source will placed at three positions, the first position is heating source in mild steel 0.4mm and aluminum 0.6mm, the second position is 0.5mm in mild steel and 0.5mm in aluminum, the last position is 0.6 in mild steel and 0.4 in aluminum. The figure 4.15 Show the position of laser welding.

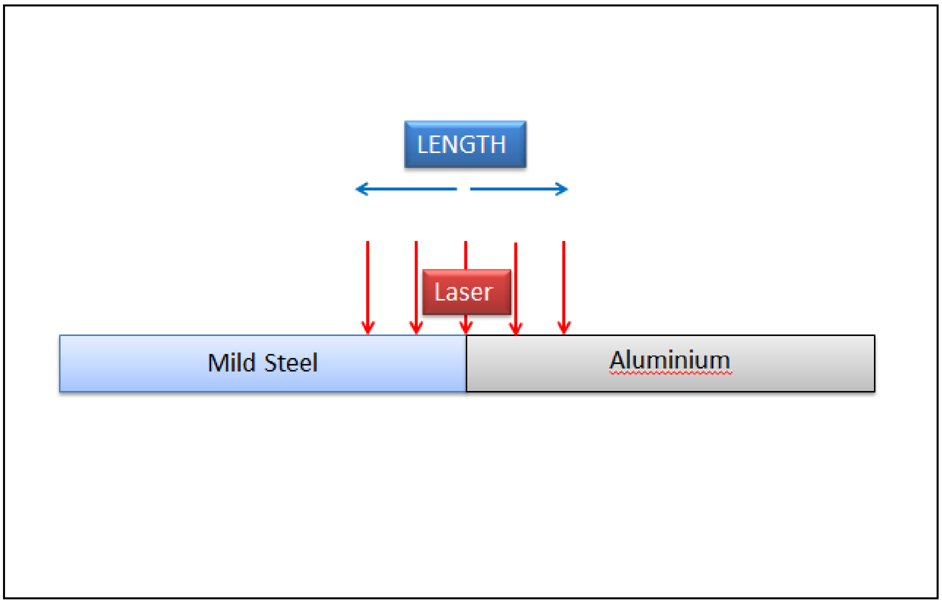


Figure 4.15: Position of Laser Welding Mild Steel and Aluminum

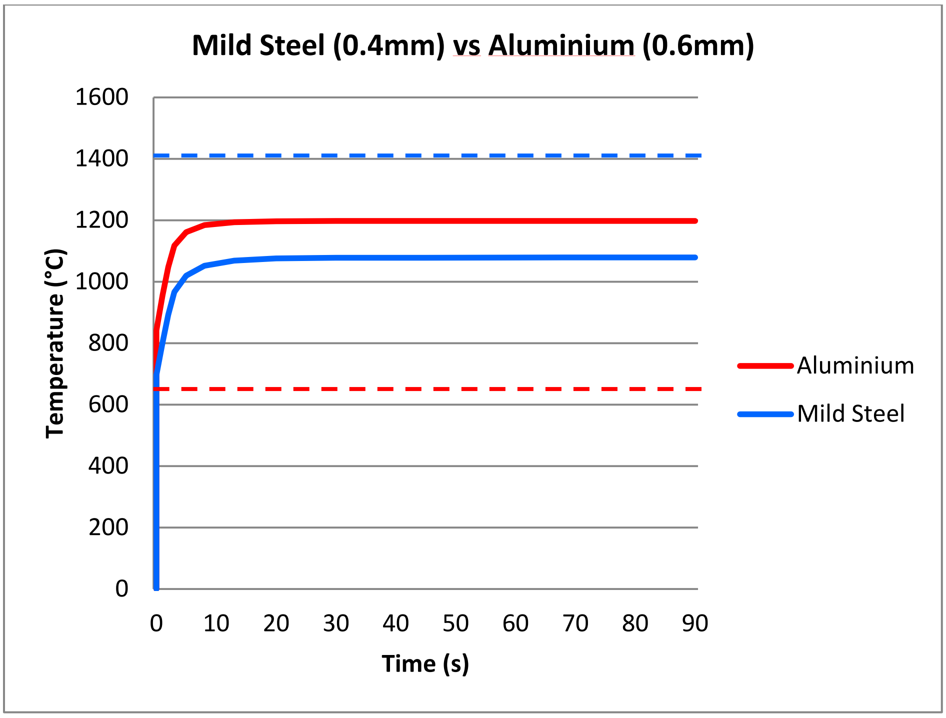


Figure 4.16: Heating Source at Mild Steel 0.4mm and Aluminum 0.6mm

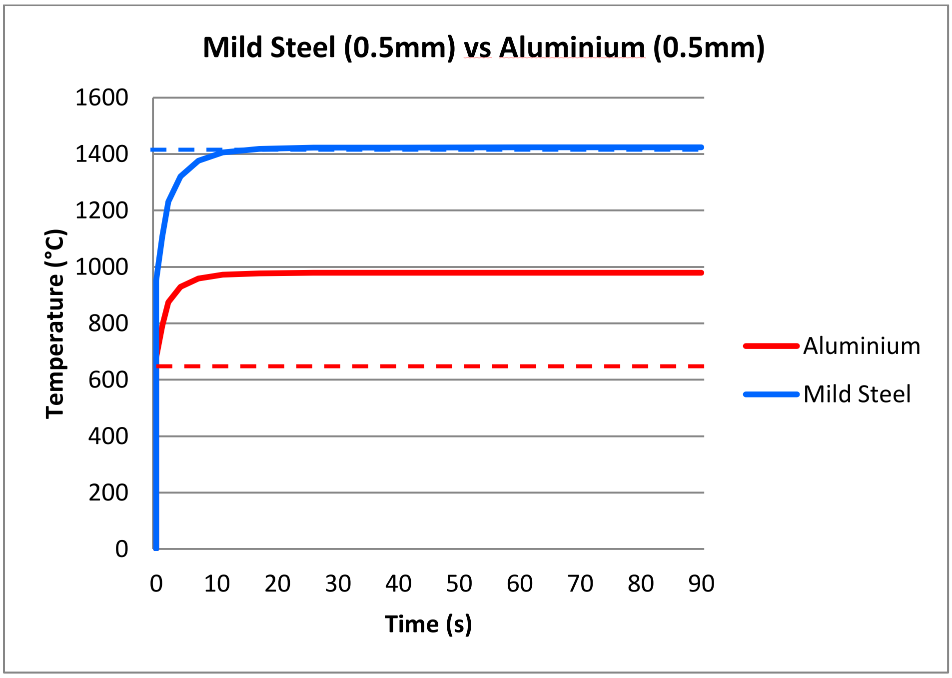


Figure 4.17: Heating Source at Mild Steel 0.5mm and Aluminum 0.5mm

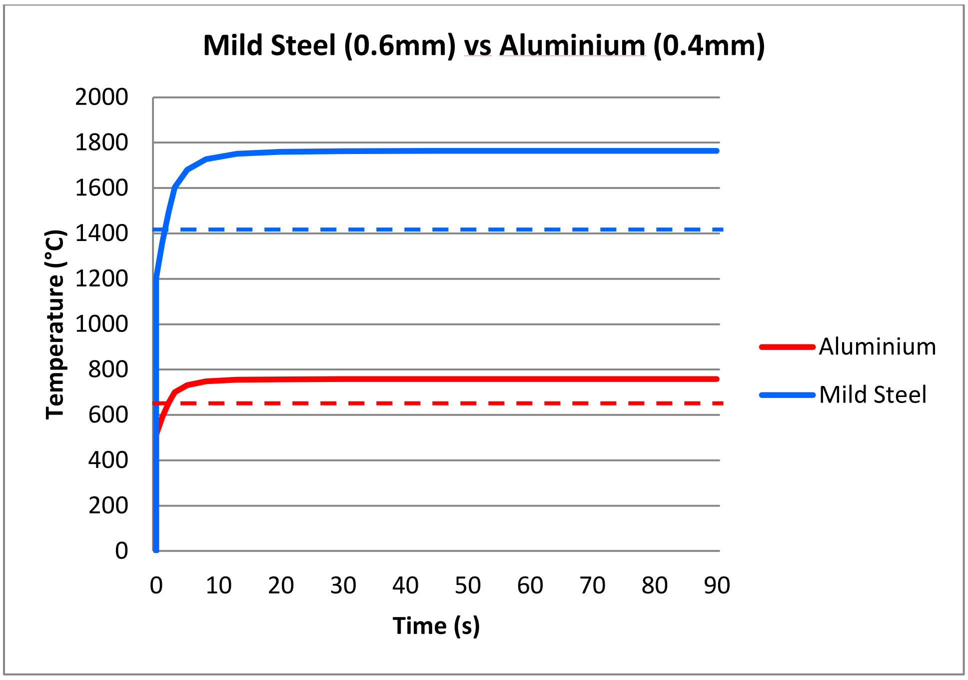


Figure 4.18: Heating Source at Mild Steel 0.6mm and Aluminum 0.4mm

From the figure 4.16 The position heating source of mild steel is 0.4mm and aluminum is 0.6, the aluminum is melt and mild still is still not melt. So the position is cannot suitable because one material only melt. The figure 4.17 show the both of material is melt but aluminum is very far distance of melting area, so this position is also not suitable. The figure 4.18 Show the both material also melt and the distance of melting area is almost the same, the distance of melting area of mild steel is 0.7mm and aluminum 0.8mm, so this melting area almost same. This position is suitable than the others position. The distance of melting area is different for the different position heating source. The data shown is in the appendix B.

4.3.2 Joints of Stainless Steel 416 and Mild Steel 1010

In case 2, the material is narrow of mechanical properties, the simulation will analyze the get the best position, the temperature pick point is 0.5mm for both material from the center. The heating source will placed at three positions, the first position is heating source in mild steel 0.4mm and stainless steel 0.6mm, the second position is 0.5mm in mild steel and 0.5mm in stainless steel, the last position is 0.6 in mild steel and 0.4 in stainless steel. The figure 4.19 Show the position of laser welding.

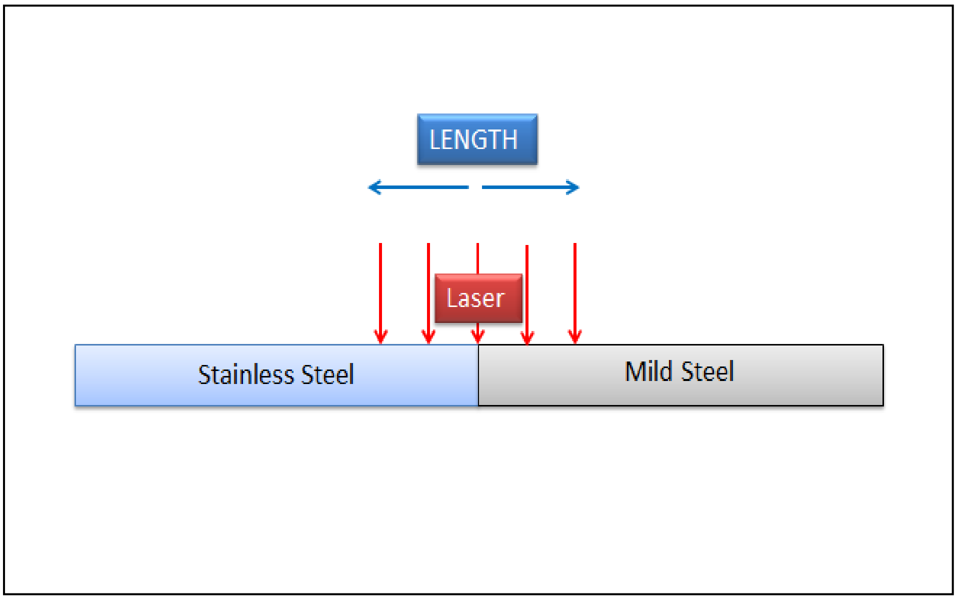


Figure 4.19: Position of Laser Welding Mild Steel and Stainless Steel

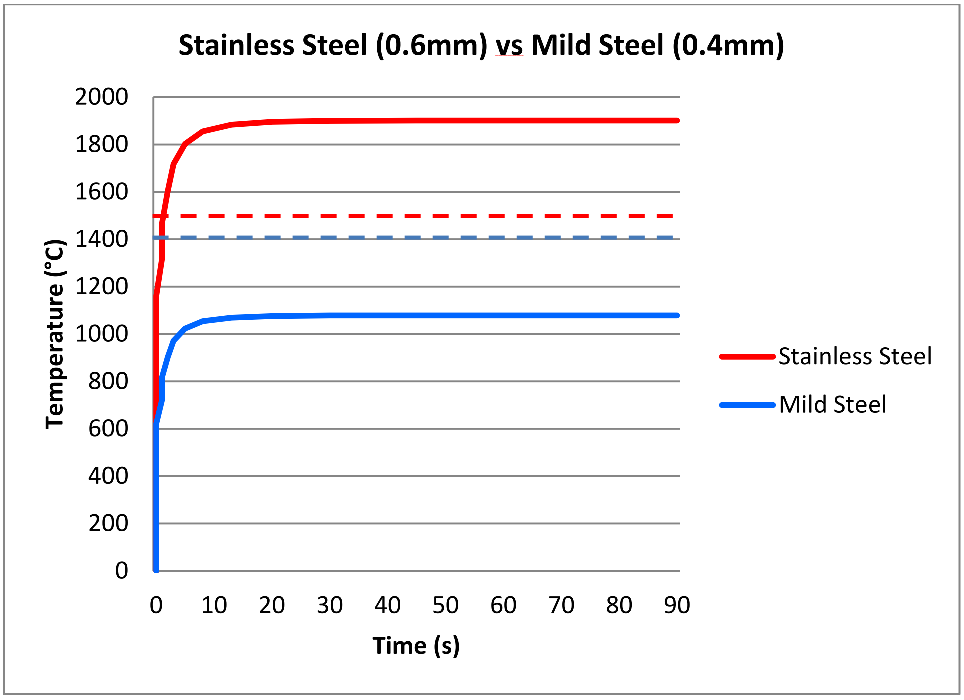


Figure 4.20: Heating Source at Stainless Steel 0.6mm and Mild Steel 0.4mm

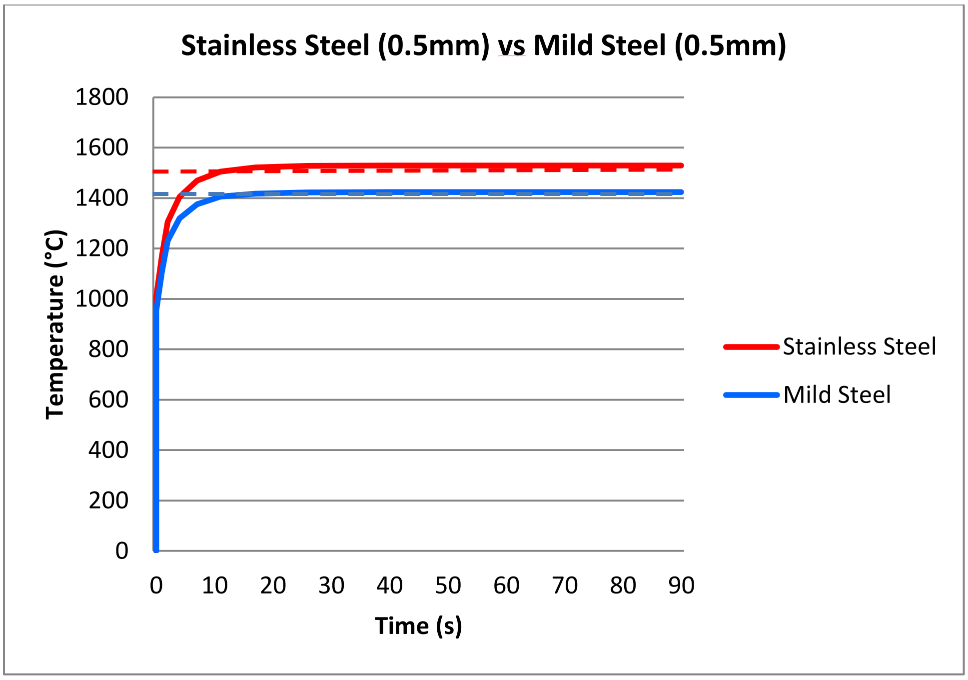


Figure 4.21: Heating Source at Stainless Steel 0.5mm and Mild Steel 0.5mm

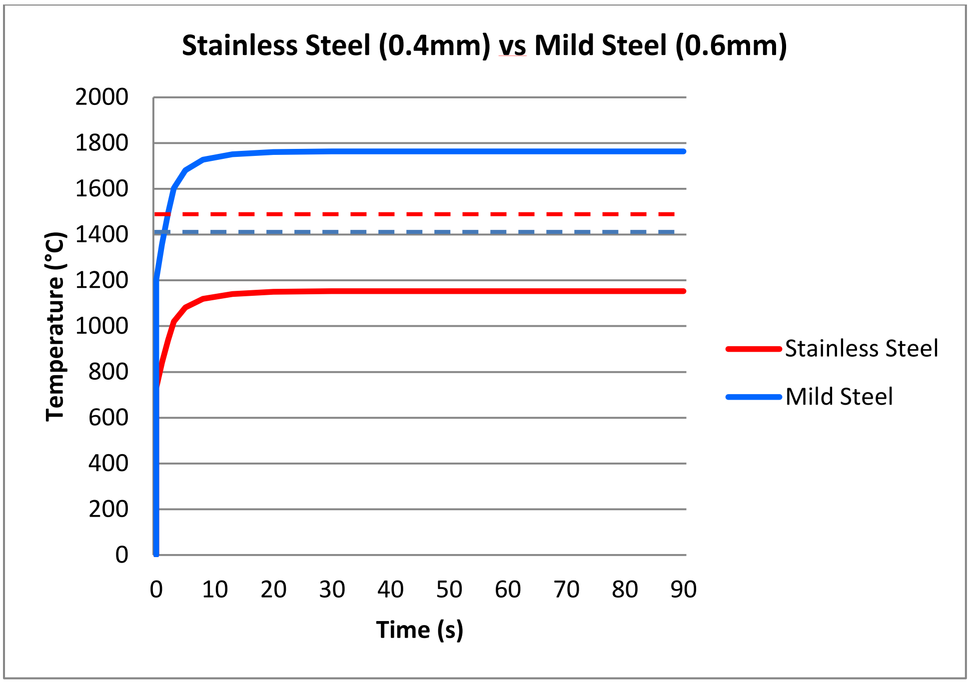


Figure 4.22: Heating Source at Stainless Steel 0.4mm and Mild Steel 0.6mm

From the figure 4.20 The position heating source of mild steel is 0.4mm and stainless steel is 0.6, the stainless steel is melt and mild still is still not melt. So the position is cannot suitable because one material only melt. The figure 4.21 Show the both material also melt and the distance of melting area is equivalent, the distance of melting area of mild steel is 0.5mm and Stainless steel 0.5mm. This position is suitable than the others position. The figure 4.22 Show the stainless steel does not melt and mild steel melt properly. The data can be found in the appendix C.

4.3.3 Joints of Stainless Steel 416 and Aluminum 1100

In case 3, the material is wide of mechanical properties, the simulation will analyze the get the best position, the temperature pick point is 0.5mm for both material from the center. The heating source will placed at three positions, the first position is heating source in aluminum 0.4mm and stainless steel 0.6mm, the second position is 0.5mm in aluminum and 0.5mm in stainless steel, the last position is 0.6 in aluminum and 0.4 in stainless steel. The figure 4.23 Show the position of laser welding.

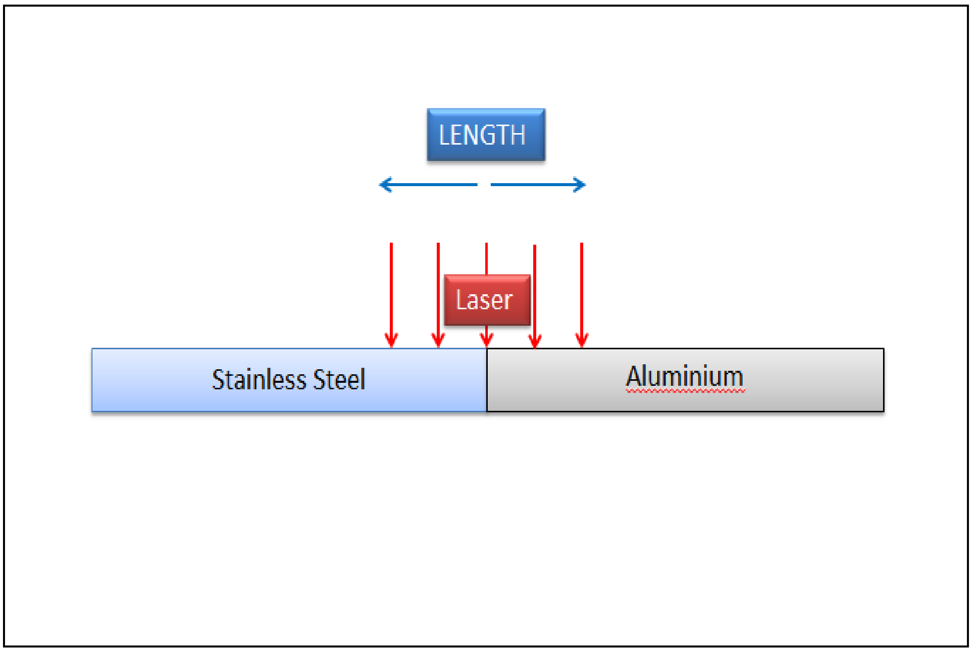


Figure 4.23: Position of Laser Welding Stainless Steel and Aluminum

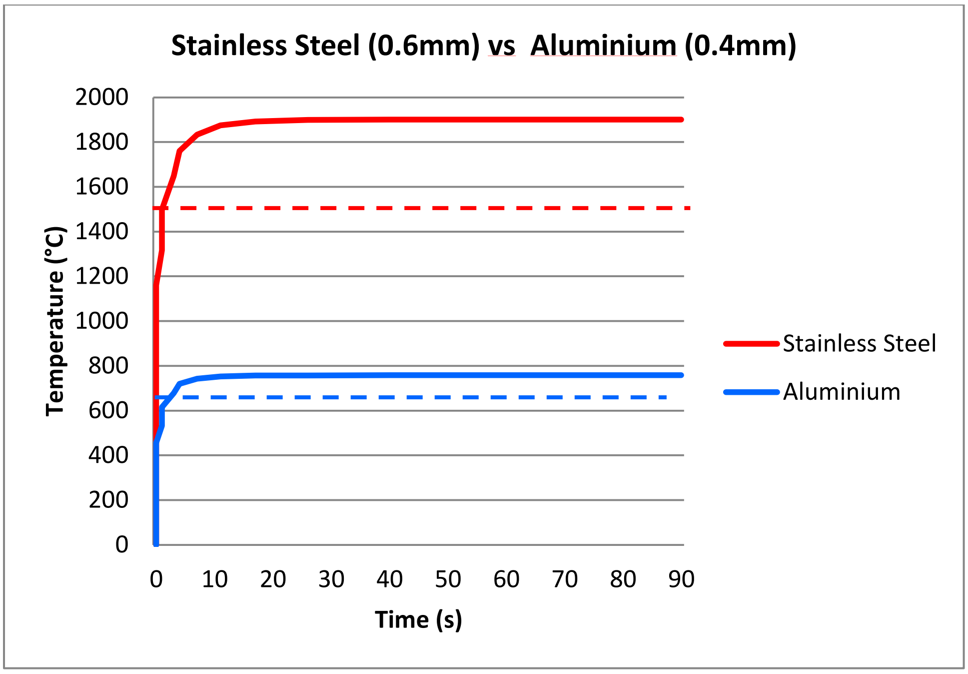


Figure 4.24: Heating Source at Stainless Steel 0.6mm and Aluminum 0.4mm

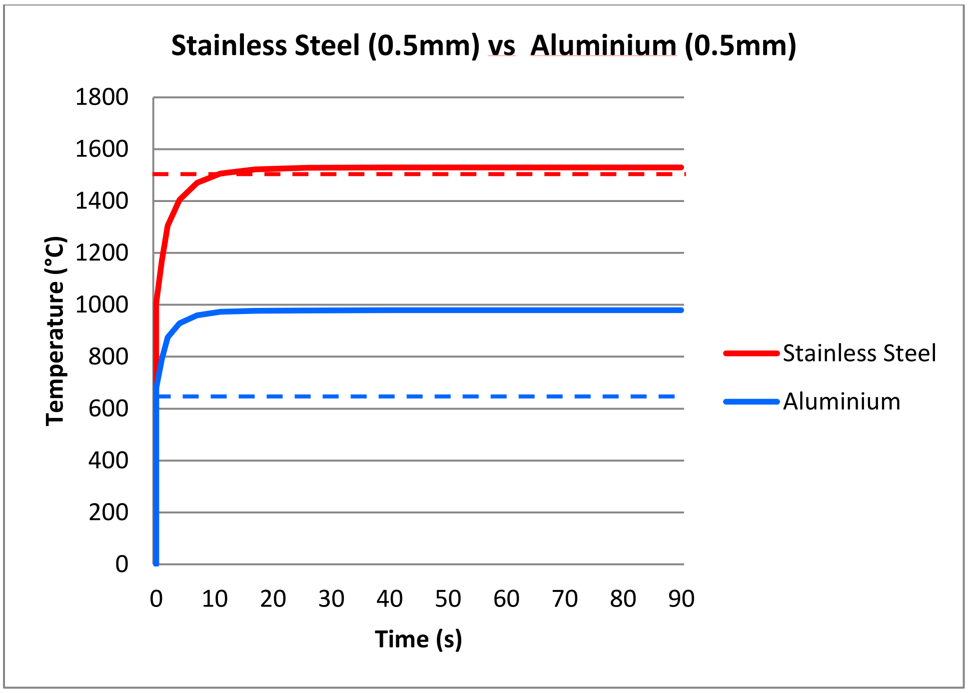


Figure 4.25: Heating Source at Stainless Steel 0.5mm and Aluminum 0.5mm

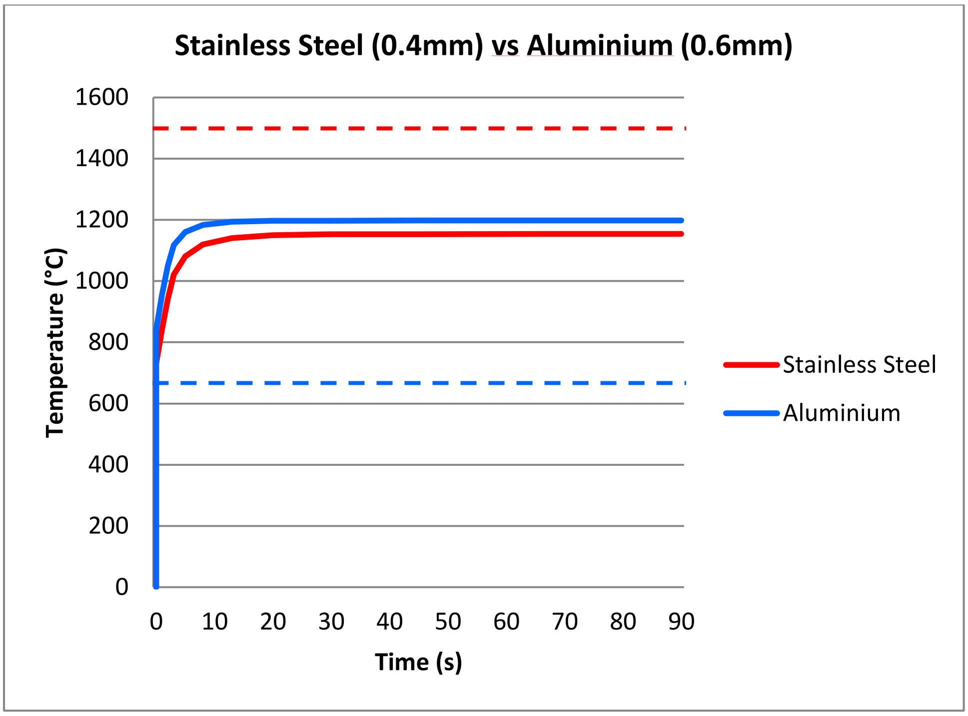
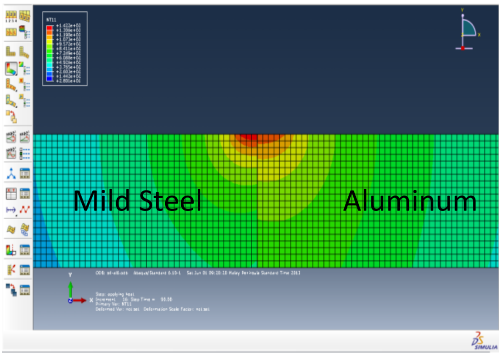
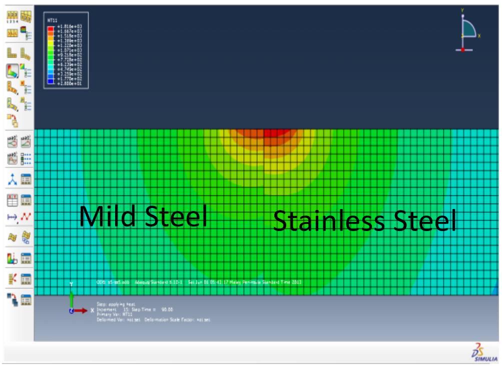
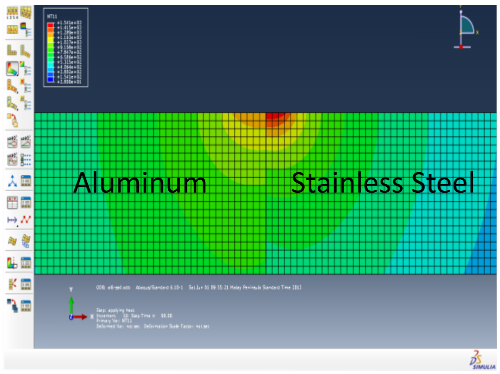


Figure 4.26: Heating Source at Stainless Steel 0.4mm and Aluminum 0.6mm

From the figure 4.24 The position heating source of aluminum is 0.4mm and stainless steel is 0.6, the both of the material are melting. The figure 4.25 Show the both material also melt but the distance of aluminum melting area is very far from the center and it will make the melting area not equivalent. The figure 4.26 Show the stainless steel is not melt and aluminum is melting. The best position of heating source is at aluminum 0.4mm and stainless steel 0.6mm, the distance of melting is aluminum 0.8 and stainless steel 0.7mm, so the result is almost same. The data shown is in the appendix D.

Table 4.7: Suitable Position Heating Source

CASE	SUMMARY	ABAQUS SIMULATION
Mild Steel vs. Aluminum	The heating must 0.6mm in Mild Steel and 0.4mm in Aluminum	
Stainless Steel vs. Mild Steel	The heating must 0.5mm in Mild Steel and 0.5mm in Stainless Steel	
Stainless Steel vs. Aluminum	The heating must 0.6mm in Stainless Steel and 0.4mm in Aluminum	

For this simulation, the table showed the result of the best position to melt the material with different material. The heating source must place as far as possible from the material with have low melting point. If the heating source is large place in material that low melting point, the material will melt very far. So to get the b result, the heating source must place properly large in material that high mel point to get the equivalent distance of melting area.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This chapter concludes this study. Besides that, the objective is also reviewed in this chapter to determine if it achieved or not. The contribution of this study, the limitation are also been discussed in this chapter.

5.2 CONCLUSION

The perfect welding with different material can be accessed by analyze the heat distribution. TWB usually comprise of more than two materials with similar or different strength or thickness joining together to form a single part before the forming operation. TWBs provide numerous advantages including in vehicle weight, lower manufacturing cost and improved structural integrity.

In this study, this experiment and simulation analysis was successfully performed and heat distribution has been identified. The different material properties can affect the weld area. The melting point is different and need to find out the best position of the heating source. The comparison of heat distribution from experiment and simulation will to validate the data and the result nearly to same. The percentage of error is less than 10%.

The high melting point is needs more energy to melt that low melting points, the heating source must more in the material that have high melting point. The best position will get the equivalent of distance of welding area.

Based on the analysis result, for joining aluminum and mild steel, the heating source must be placed 40% in aluminum and 60% in mild steel. The second case, the joining stainless steel and mild steel, the heating source must be placed in the middle, 50% in stainless steel and 50% in mild steel. The third case is joining stainless steel and aluminum, the heating source must be placed 60% in stainless steel and 40% in aluminum.

5.3 RECOMMENDATION

For the improvement of the study, there are several matter can be done

i) The experiment must running in the closed room to avoid the heat loss
ii) Using the laser with high capacity to conducted the welding
iii) Using the variety of material with different thickness in experiment and simulation
iv) Using the movement of the heating source method in experiment and simulation
v) Study the microstructure of the material when finish the laser welding

REFERENCES

Shi, M.F., Pickett, K.M. and Bhatt, K.K. 1993. Formability Issues in the Application of Tailor Welded Blank Sheets. SAE Technical Paper. pp. 27-35

Kridli, G.T., Friedman, P.A. and Sherman, A.M. 2000. Formability of Aluminum Tailor-Welded Blanks. SAE 2000-01-0772. pp. 1-9

Narayanan, R.G. and Narasimhan, K. 2008. Influence of the Weld Conditions on the Forming-Limit Strains of Tailor-Welded Blanks. 43: 217-227.

Choi, Y., Heo, Y., Kim, H.Y. and Seo, D. 2000. Investigations of Weld-Line Movements for the Deep Drawing Process of Tailor Welded Blanks. Journal of Materials Processing Technology. 108: 1-7.

Heo, Y., Choi, Y., Kim, H., and Seo, D. 2001. Characteristics of Weld Line Movements for the Deep Drawing with Drawbeads of Tailor-Welded Blanks. Process. Technol 111: 164-169.

Cvetković, R.P., Milosavljević, A. and Popović, O. 2005. The effect of heat input on the ferrit modification in weld metal of low-carbon steels, Welding and welded structures. 73-77. Belgrade.

Cvetković, R.P., Milosavljević, A. and Popović, O. 2006. The influence of heat input on the microstructure and toughness of microalloyed steel weldments. Timisoara, Romania.

Funderburk, R.S. 1999. A look at heat input, Welding Innovation, Vol.XVI, No.1.

Naeem, M. 2006. Microjoining of Dissimilar Metals with Pulsed Nd: YAG Laser, Conference Proceeding. Melbourne, Australia

Kumar, S. 2012. To Analyze the Permissible Strength, Stress And the Safety Factor of Steel. Assistant Professor, Mechanical Department, Vaish College of Engineering, Rohtak (India)

Duley, W.W. 1999. Laser Welding. John Wiley and Son. Inc

Waddell, W. and Davies, G.M. 1995. Laser Welded Tailored Blanks in the Automotive Industry. Welding and Metal Fabrication. Pp105-108

Heoven, V.D., Rubben, K., Lambert, F. and Rycke,I. 1996. Tailored Blanks: A key Technology For Light Weight Steel Auto Body structures. International Symposium on Automotive Technology And Automation, Florence, Italy. 29: 177-184

Baysore, J.K., Williamson, M.S., Adonyiadn, Y. and Milian, J.L. 1995. Laser Beam Welding And Formability of Tailored Blanks. Welding Reaserch Supplement. 345-351.

Kim, S., Young, I.M. and Lee, S. 2001. Effects of Alloying Elements on Mechanical and Fracture Properties of Base Metals and Simulated Heat-Affected Zones of SA 508 Steels. Metallurgical and Material Transaction. 32A:903-911.

Linnert, G.E. 1965. Welding Metallurgy. American Welding Society, New York. 2:158-159

Eisenmenger, M. and Bhatt, K.K. 1995. Influence of Laser Parameters on Formability and Robustness of Blank Manufacturing: An Application to a Body Side Frame. 27:171-182

Sagstrom, E., Larsson, H., Nilsson, B. and Wadman, B. 2000. The Formability of Tailor-Welded Blanks Depending on Welding Methods and Material Combinations. Biennial Congress, Michigan USA. Pp9-16

Norihiko, Nakagawa, Shin, and Natsumi. 1993. Finite Element Simulation Of Stamping of Laser-Welded Blank. Pp 189-197

Milian, J.L. and Adonyi, Y. 1993. Formability of Tailored Blanks for Automative Applications. Pp83-91

Adonyi, Y. and Chen, C.C. 1996. Laser-Welded Steel Performance in Tailored Blank Applications. International Symposium on Automotive technology and Automation, Florence, Italy. 29: 157-165

William, M. 1991. Laser Material Processing.

Roylance, D. 2001. Finite Element Analysis. Department of Materials Science and Engineering Massachusetts Institute of Technology Cambridge.

APPENDICES

APPENDIX A1

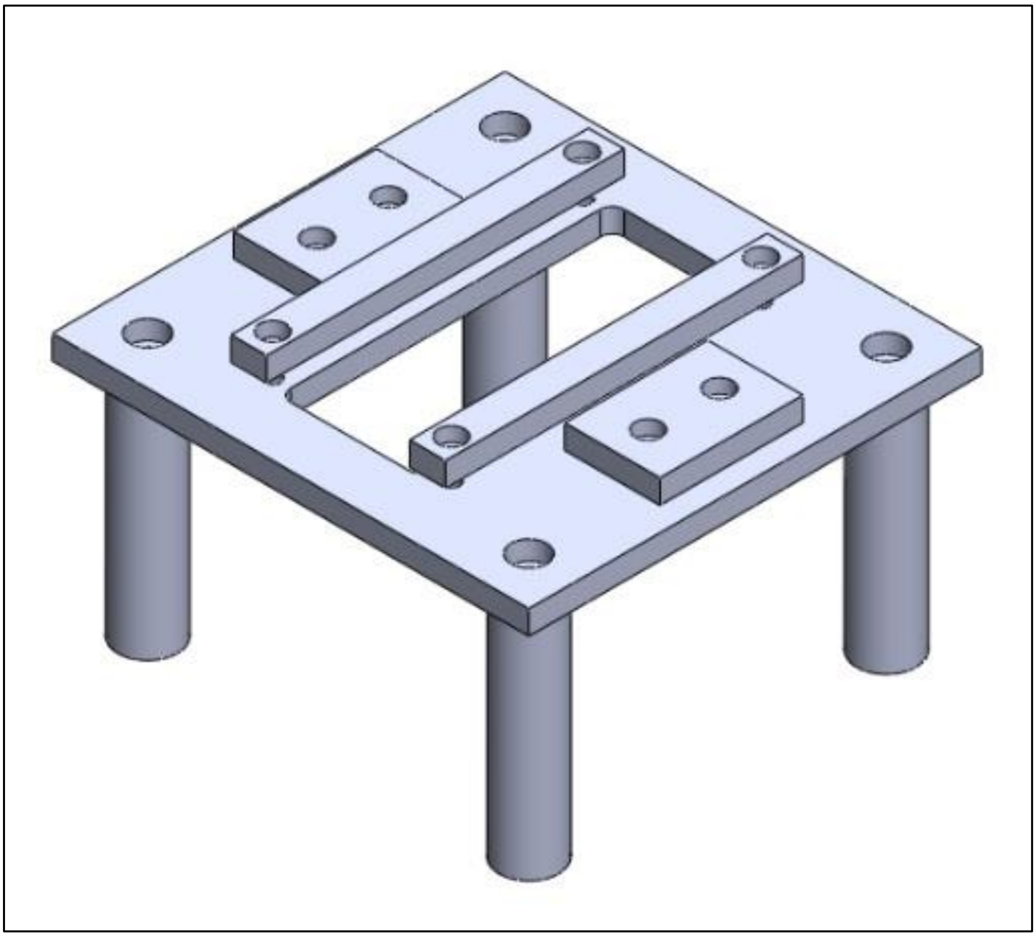


Figure A1: 3D Drawing of Test Rig

APPENDIX A2

	MILD STEEL (MELTING POINT 1410 °C)															ALUMINIUM (MELTING POINT 660 °C)															
(mm)	1.5	1.4	1.3	1.2	1.1	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	(mm)
0.4	694.81	716.32	739.51	763.73	792.43	823.31	857.91	897.81	944.91	1002.87	1078.34	1213.91	1342.86	1410.23	1421.82	1281.53	1276.01	1261.48	1236.37	1197.5	1124.15	1048.54	1002.88	966.34	935.58	908.74	884.77	863.01	843	824.41	0.6
0.5	866.38	893.86	923.61	956.09	991.95	1032.1	1077.85	1131.28	1196.14	1279.24	1423.32	1561.9	1628.39	1665.13	1678.15	1111.58	1102.78	1082.67	1048.26	978.93	907.01	864.76	831.4	803.63	779.6	758.31	739.09	721.53	705.28	690.13	0.5
0.6	1039.98	1073.87	1110.7	1151.15	1195.15	1247.07	1306.03	1376.85	1466.4	1617.54	1763.93	1839.15	1885.83	1910.4	1915.95	931.96	918.41	889.62	825.22	757.7	719.44	689.74	665.34	644.46	626.13	609.71	594.78	581.08	556.36	556.45	0.4

Load position

Melting position

Suitable position

Figure A2: Melting Area of Mild Steel and Aluminum

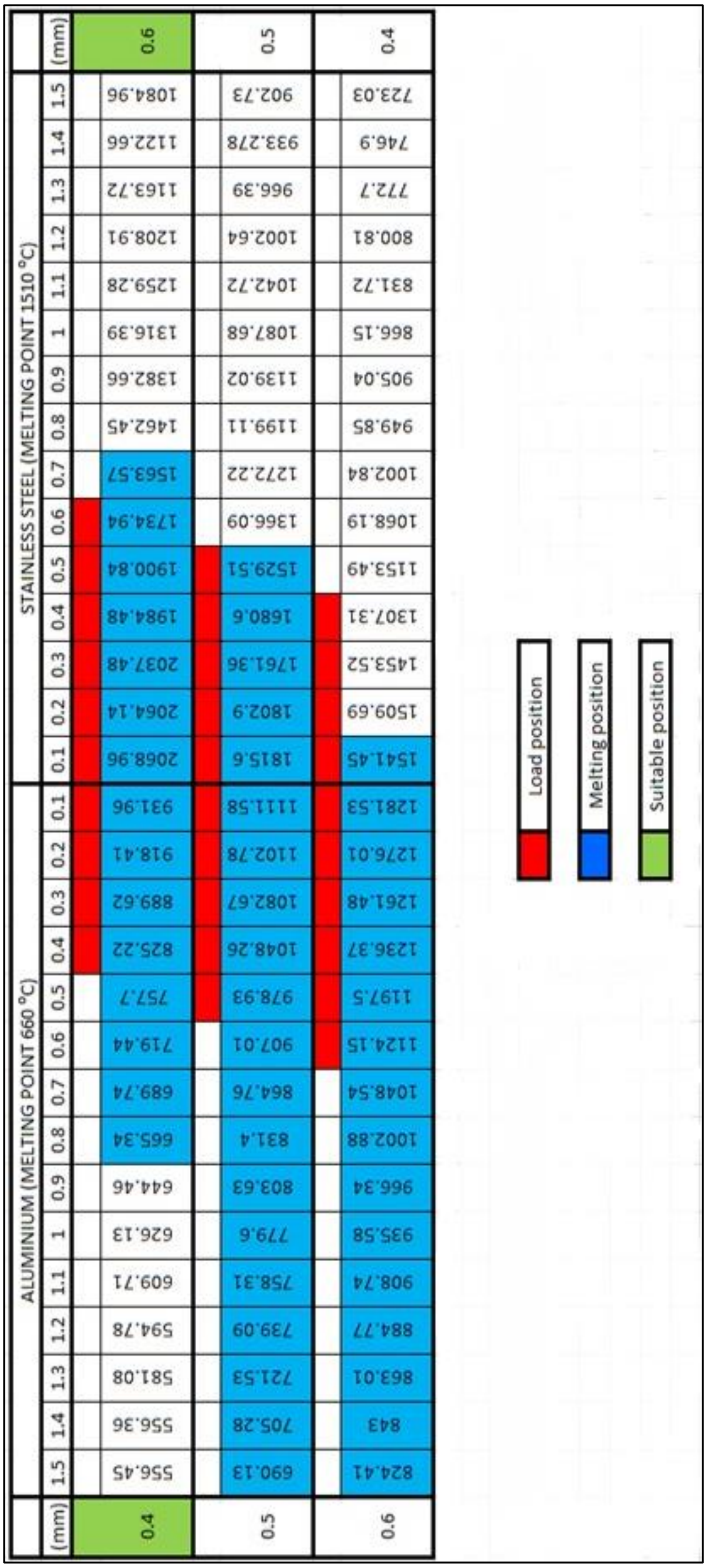
APPENDIX A3

(mm)	MILD STEEL (MELTING POINT 1410 °C)															STAINLESS STEEL (MELTING POINT 1510 °C)															(mm)
	1.5	1.4	1.3	1.2	1.1	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	
0.4	694.81	716.32	739.51	763.73	792.43	823.31	857.91	897.81	944.91	1002.87	1078.34	1213.91	1342.86	1410.23	1421.82	2068.96	2064.14	2037.48	1984.48	1900.84	1734.94	1563.57	1462.45	1382.66	1316.39	1259.28	1208.91	1163.72	1122.66	1084.96	0.6
0.5	866.38	899.86	923.61	956.09	991.95	1032.1	1077.85	1131.28	1196.14	1279.24	1423.32	1561.9	1628.39	1665.13	1678.15	1815.6	1802.9	1761.36	1680.6	1529.51	1366.09	1272.22	1199.11	1139.02	1087.68	1042.72	1002.64	966.39	933.278	902.73	0.5
0.6	1039.98	1073.87	1110.7	1151.15	1195.15	1247.07	1306.03	1376.85	1466.4	1617.54	1763.93	1839.15	1885.83	1910.4	1915.95	1541.45	1509.69	1453.52	1307.31	1153.49	1068.19	1002.84	949.85	905.04	866.15	831.72	800.81	772.7	746.9	723.03	0.4

- Load position
- Melting position
- Suitable position

Figure A3: Melting Area of Mild Steel and Stainless Steel

APPENDIX A4



(mm)	ALUMINIUM (MELTING POINT 660 °C)															STAINLESS STEEL (MELTING POINT 1510 °C)															(mm)
(mm)	1.5	1.4	1.3	1.2	1.1	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	(mm)
0.4	556.45	556.36	581.08	594.78	609.71	626.13	644.46	665.34	689.74	719.44	757.7	825.22	889.62	918.41	931.96	2068.96	2064.14	2037.48	1984.48	1900.84	1734.94	1563.57	1462.45	1382.66	1316.39	1259.28	1208.91	1163.72	1122.66	1084.96	0.6
0.5	690.13	705.28	721.53	739.09	758.31	779.6	803.63	831.4	864.76	907.01	978.93	1048.26	1082.67	1102.78	1111.58	1815.6	1802.9	1761.36	1680.6	1529.51	1366.09	1272.22	1199.11	1139.02	1087.68	1042.72	1002.64	966.39	933.278	902.73	0.5
0.6	824.41	843	863.01	884.77	908.74	935.58	966.34	1002.88	1048.54	1124.15	1197.5	1236.37	1261.48	1276.01	1281.53	1541.45	1509.69	1453.52	1307.31	1153.49	1068.19	1002.84	949.85	905.04	866.15	831.72	800.81	772.7	746.9	723.03	0.4

Load position

Melting position

Suitable position

Figure A4: Melting Area of Aluminum and Stainless Steel