UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS

JUDUL: MODAL ANALYSIS ON DISSIMILAR METAL USING DIFFERENT THICKNESS (STEEL AND ALUMINIUM)

SESI PENGAJIAN: 2011/2012

Saya, **MOHD RIDWAN BIN SULAIMAN (870323-11-5179)**
(HURUF BESAR)

mengaku membenarkan tesis (Sarjana Muda / ~~Sarjana / Doktor Falsafah~~)* ini disimpan di perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Tesis ini adalah hakmilik Universiti Malaysia Pahang (UMP).
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (√)

☐ **SULIT** (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)

☐ **TERHAD** (Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi / badan di mana penyelidikan dijalankan)

☑ **TIDAK TERHAD**

Disahkan oleh:

(TANDATANGAN PENULIS)

(TANDATANGAN PENYELIA)

Alamat Tetap:
2048- A Kampung Batu Enam
21200 Kuala Terengganu
Terengganu

MUHAMMAD HATIFI BIN MANSOR
(Nama Penyelia)

Tarikh: **21 JUNE 2012**

Tarikh: **21 JUNE 2012**

CATATAN: * Potong yang tidak berkenaan.

** Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali tempoh tesis ini perlu dikelaskan sebagai SULIT atau TERHAD.

◆ Tesis dimaksudkan sebagai tesis bagi Ijazah Doktor Falsafah dan Sarjana secara Penyelidikan, atau disertasi bagi pengajian secara kerja kursus dan penyelidikan, atau Laporan Projek Sarjana Muda (PSM).

MODAL ANALYSIS ON DISSIMILAR METAL USING DIFFERENT THICKNESS (STEEL AND ALUMINIUM)

MOHD RIDWAN BIN SULAIMAN

Report submitted in partial fulfilment of the requirements
for the award of Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

JUNE 2012

UNIVERSITI MALAYSIA PAHANG
FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled "*Modal Analysis on Dissimilar Metal Using Different Thickness (Steel and Aluminium)*" is written by *Mohd Ridwan Bin Sulaiman*. I have examined the final copy of this project and in our opinion, it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering.

MR. NASRUL AZUAN ALANG
Examiner Signature

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project report and in my opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with "specialization".

Signature :
Name of Supervisor : MUHAMMAD HATIFI BIN HAJI MANSOR
Position : FACULTY OF MECHANICAL ENGINEERING LECTURER
Date : 21 JUNE 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 concurently submitted for award of other degree.

Signature :
Name : MOHD RIDWAN BIN SULAIMAN
ID Number : MA09003
Date : 21 JUNE 2012

Dedicated to my father, Mr. Sulaiman bin Mamat, my beloved mother, Mrs. Asmalaini binti Ali, and last but not least to all my fellow friends

ACKNOWLEDGEMENTS

Praise is to Allah S.W.T, the Most Gracious, the Most Merciful for all the blessings and guidance upon me through my study. Thank you so much dear Allah forgiving me strength and answering my prayers.

This thesis would not have been possible without the guidance and the help of Several individuals who in one way or another contributed and extended their valuable assistance in the preparation and completion of this research.

First and foremost, I would like to record my sincere gratitude to my supervisor, Mr. Muhammad Hatifi bin Hj. Mansor for his supervision, advice and guidance from the very early stage of this research as well as giving me extraordinary experiences throughout the work. Above all and the most needed, he provides me unflinching encouragement and support in various ways. I am indebted to him more than she knows. One simply could not wish for a better or friendlier supervisor.

Many thanks go to all FKM laboratory instructor and technicians who are willingly landing their hands in laboratory and experimental work and all these staff of the Mechanical Engineering Department, UMP, who helped me in many ways and made my stay in UMP pleasant and unforgettable. Special thanks from me also go to my friends who are under same supervisor. I would like to acknowledge their comments and suggestions which were crucial for the successful completion of this study.

Where would I be without my family, my parents deserve special mention for their inseparable support and prayers. My father, Sulaiman bin Mamat, in the first place is the person who put the fundament by learning character, showing me the joy of intellectual pursuit ever since I was a child. My mother, Asmalaini binti Ali, is my special one who sincerely raised me with her caring and gentle love. Brothers and sisters, thanks for being supportive and caring siblings.

Finally, I would like to thank everybody who was important to the successful realization of this thesis, as well as expressing my apology that I couldn’t mention personally one by on

ABSTRACT

This project report deals with dynamic behaviour of joining between stainless steel and aluminium alloy by MIG welding using theoretical and experimental analysis method. This project report is to study the dynamic properties and behaviour of joining between stainless steel and aluminium alloy by MIG welding by using modal analysis and compare with the finite element analysis. The structural three-dimensional solid modelling of joining between stainless steel and aluminium alloy by welding was developed using the SOLIDWORK drawing software. The finite element analysis was then performed using ALGOR 23.1 (FEA). The finite element model of the components was analyzed using the linear modal analysis approach. Finally, the experimental modal analysis was performed using Impact Hammer Testing method. The natural frequency of the mode shape is determined and comparative study was done from both method results. The comparison between natural frequencies of finite element modelling and model testing shows the closeness of the results. From the results, the percentage error had been determined and the limitation in the natural frequency of the joining between stainless steel and aluminium alloy by welding is observed. The results of this project shown the mode shape of the joining plate by MIG welding for simulation are generally is not in agreement with the experimental value and the frequencies of the experimental modal analysis are a bit different with the frequencies of the simulation. The percentage error is bit high because there are some errors occur during the experimental modal analysis. The experimental modal analysis is conducted with fix condition of the joining plate between aluminium alloy and stainless steel by welding and the effect of damping which effect test rig by using polystyrene as a base of the plate is a factors as the higher percentage error. It is conclude that the in experimental method uses the polystyrene as a base affected the result.

ABSTRAK

Laporan projek ini berkaitan dengan perilaku dinamik sambungan plate antara aluminium aloi dan keluli tahan karat oleh kimpalan menggunakan kaedah analisis teori dan eksperimen. Laporan ini adalah untuk mempelajari sifat dinamik dan perilaku sambungan plate antara aluminium aloi dan keluli tahan karat oleh kimpalan dengan menggunakan analisis modal secara eksperimen dan membandingkannya dengan analisis elemen secara teori. Pemodelan struktur tiga-dimensi spiral wound gasket dilukis menggunakan perisian melukis SOLIDWORK. Analisis elemen modal kemudian dijalankan dengan menggunakan perisian ALGOR 23.1. Analisis di dalam perisian ini menggunakan pendekatan analisis linier modal. Kemudian, analisis modal secara eksperimen dilakukan dengan menggunakan kaedah kesan ketukan. Frekuensi dan bentuk mod ditentukan dan kajian perbandingan dilakukan dari kedua-dua keputusan kaedah. Perbandingan antara frekuensi dari pemodelan elemen secara teori dan ujian model secara eksperimen menunjukkan keputusan yang hampir sama. Dari hasil tersebut, peratus perbezaan antara kedua kaedah telah direkod dan had frekuensi asas sambungan plate antara aluminium aloi dan keluli tahan karat oleh kimpalan telah diamati. Keputusan projek ini telah menunjukkan bahawa bentuk mod sambungan plate oleh kimpalan MIG bagi simulasi secara umumnya adalah tidak sama dengan nilai eksperimen dan frekuensi analisis ragaman eksperimen adalah agak berbeza dengan frekuensi simulasi. Peratus ralat agak tinggi kerana terdapat beberapa kesilapan berlaku semasa eksperimen. eksperimen dijalankan dengan keadaan tetap bagi sambungan plate antara aluminium aloi dan keluli tahan karat oleh kimpalan dengan menggunakan polistirena sebagai pelapit plate dan memberi kesan redaman berlaku. Ia menyimpulkan bahawa dalam kaedah eksperimen, penggunaan polistirena sebagai pelapit memberi kesan terhadap result.

TABLE OF CONTENTS

CHAPTER 3 METHODOLOGY

CHAPTER 4 RESULT AND DISCUSSION

CHAPTER 5 CONCLUSIONS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

ºC	Degree Celsius
w	Watt
A	Ampere
Iw	Welding current
vw	Welding rate
vf	Wire feed rate
nr	welding speed
mm	Milimeter
min	Minute
N	Newton
%	Percent
volt	Voltan
Hz	Hertz
Al	Aluminium
Zn	Zink
Si	Silicone
Cu	Cuprum
Mg	Magnesium
Cr	Chromium
Ni	Nickel
Mn	Mangan
C	Carbon

LIST OF ABBREVIATIONS

MIG	Metal Inert Gas
TIG	Tungsten Inert Gas
IMC	Intermetallic Compounds
GTA	Gas Tungsten Arc
NVH	Noide,Vibration And Hardness
FEA	Finite Element Analysis
FEM	Finite Element Method
DOF	Degree Of Freedom
SDOF	Single Degree Of Freedom
MDOF	Multi Degree Of Freedom
FRF	Frequency Response Function
DAS	Data Acquisition System
CAD	Computer Aided Diagram
IGES	Initial Graphics Exchange Specification
FFT	Fast Fourier Transform
ESAB	Elektriska Svetsnings-Aktiebolaget (English: Electric Welding Limited company)
2D	Two Dimensional
3D	Three Dimensional
ASCII	American Standard Code for Information Interchange
SI	International System of Units

CHAPTER 1

INTRODUCTION

1.1 GENERAL INTRODUCTION

Metal inert gas welding is an effective technology use throughout the industry. It used widely in advanced construction and equipment, especially in the automotive industry to join the parts. The combination of building materials which commonly using aluminium and steel has high demand for welding technology. Joining between aluminium alloys and stainless steel proved to be significant for the construction industry. Joining between aluminium alloy and steel are also prominent in the transportation industry, particularly the need to design a lightweight vehicle body.

In this project, we will investigate the stability and detect the vibration that occurred in the dissimilar metal joint by MIG welding using different thickness. The vibration occurred is obtained by performing dynamic analysis using ALGOR Finite Element Analysis (FEA).

1.2 PROJECT OBJECTIVE

The purpose of this research is to study the dynamic properties and behavior of a dissimilar metal joint by MIG welding using different thickness by using modal analysis and comparison with the finite-element analysis.

1.3 PROJECT SCOPE

This project focuses on the following points:

i. Dissimilar metal with different thickness will weld.
ii. Experimental analysis using modal testing on weld metal
iii. The theoretical data for dynamic analysis using ALGOR will be taken.
iv. Comparative study between numerical and experimental analysis

1.4 PROBLEM STATEMENT

Hybrid component between aluminium alloys and stainless steel have a higher technical and economic potential. Vibration is a frequent problem that affecting the result of joining dissimilar material between aluminium alloys and stainless steel by welding. The vibration problem occurs and affects the surface finish of joining plate.

Modal analysis is done to obtain the actual dynamic properties. The dynamic properties which consist of natural frequency, mode shape and damping are unknown on the design. The frequency of vibration of the dissimilar metal joint by MIG welding using different thickness is directly related to the stiffness and the mass of it while the mode shapes are related to the defect location. Therefore, vibration testing needs to be carried out to obtain the data of those dynamic properties. The parameters that describe each mode are natural frequency or resonance frequency (modal) damping mode shape; these are called the modal parameters. By using the modal parameters to model the structure, vibration problems caused by these resonances (modes) can be examined and understood. The purpose of this project is to determine the natural frequencies of the dissimilar metal joint by MIG welding using different thickness for structural health monitoring and evaluation.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter is based on the initial study on vibration in the joint MIG welding on dissimilar metals by using different thickness of aluminium alloy and stainless steel, the dynamic properties and behaviour with the MIG welding using different thicknesses and vibration analysis was done using two distinctive methods, one by experimental of modal analysis and another one is simulated using ALGOR finite element analysis.

2.2 BASIC VIBRATION THEORY

Method and the type of metal joint is an important role for the Structural durability, structural integrity and NVH (noise, vibration and Harshness). These effects can cause an adverse effect on the joint. The structural durability, structural integrity, and NVH automotive structural performance often depended on the change in compliance with the various joints in automobile bodies. Lots of vehicle body structure contains welding points, changes in compliance areas welded joints due to fatigue damage can have a major impact on the nature of the above mentioned structure. (De-Guang Shang et al, 2002)

2.3 WELDING SYSTEM

Aluminium and steel joined by fusion welding is difficult because the compound is a mixture of two substances form a brittle intermetallic compound (IMCs) in the joints. To control the formation of the IMC layer, the shape and size of the joints are very important. The joint has two characteristics: on the base, metal is aluminium alloy with a low melting point of the weld joint, mixed with molten filler metal to form a weld joint, while the steel is the surface of a high melting point metal with brazing, which acts like response with the filler metal melts to form a solder layer interface formed braze joints. (Lin et al, 2009)

The joining of aluminium alloy and stainless steel can be difficult for aluminium and non-metallic iron fusion welding as far as appropriate. The reason for this is due to the large difference between the melting point (660 ºC for Al and 1538 ºC to Fe), close to zero solid solubility of aluminium metal, and the formation of brittle intermetallic compounds. The difference in thermal properties of both materials, such as expansion coefficient, conductivity, and specific heat leads to internal stresses after welding fusion. (Song et al, 2009)

Song et al said tungsten arc inert gas (TIG) welding, brazing of new techniques and become a hot research field to participate in an aluminium alloy to stainless steel. In the dynamic arc heating process, the liquid filler metal (aluminium alloy) is not wet and spread on the surface of steel. Although Al-Zn coated steel surface can promote the wetting and spreading to fill the metal. For this project, using metal inert gas welding (MIG), brazing may produce the same result.

Tungsten Inert Gas (TIG) or Gas Tungsten Arc (GTA) welding is the arc welding process in which arc is generated between non consumable tungsten electrode and workpiece. The tungsten electrode and the weld pool are shielded by an inert gas normally argon and helium. Figures 2.1 show the principle of tungsten inert gas welding process.

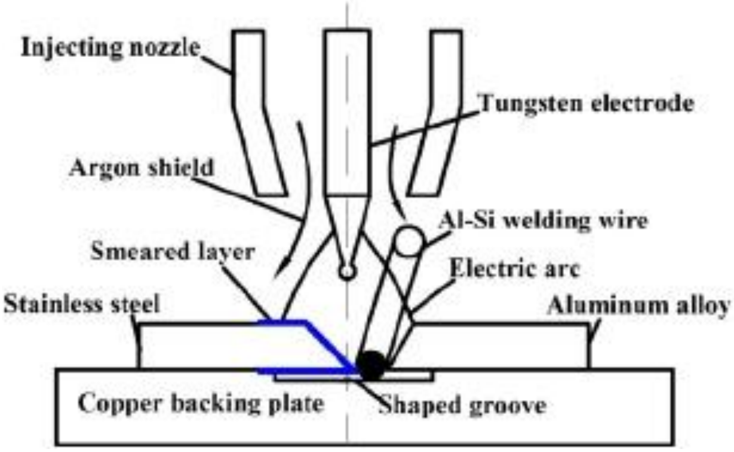


Figure 2.1: Schematic illustration of butt TIG welding–brazing.

Source: Song et al (2009)

Figure 2.2 show effects of different welding currents on the joint characteristics. Welding current changes (w) and welding speed (nr) is important because dissimilar materials joined by tungsten inert gas (TIG) give various effects. This project uses metal inert gas (MIG) and maybe has the same effect. Welding current at 170 A, the molten steel flow and fracture occurred at the root interface seams / welded steel after welding for high heat input. At 140 A and 120 A, a reduction in welding time causes no cracks in the seam at the interface of steel. At 90 A, incomplete join steel and aluminium parts are presented for low heat input. (Song et al, 2009)

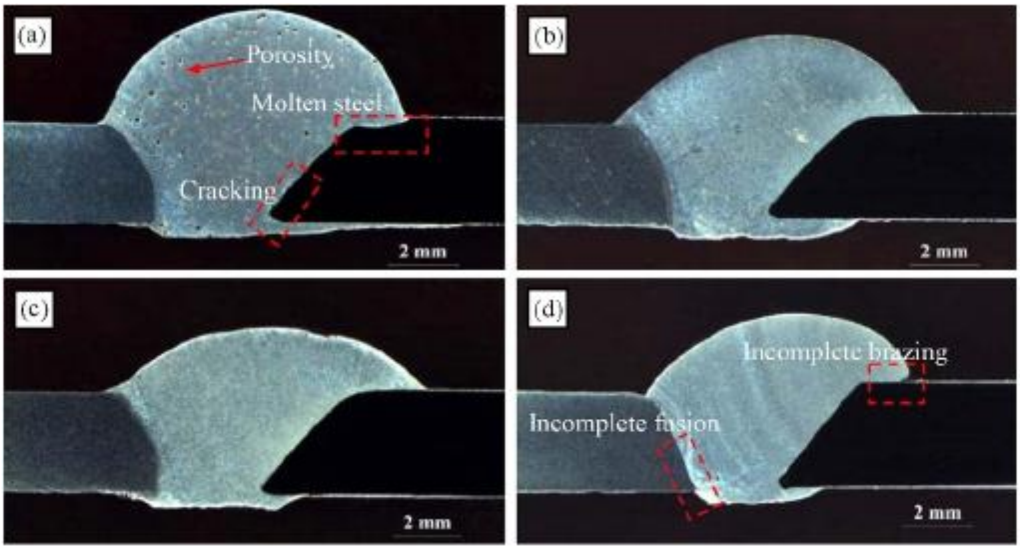


Figure 2.2: Effect of different welding currents (Iw) on the joint characteristics: (a) 170 A, (b) 140 A, (c) 120 A and (d) 90 A.

Source: J.L. Song et al (2009)

Figure 2.3 show effect of different welding rate (*v*w) on the joint characteristics. Welding rate (nr) also affects the normal characteristics. At low vw 100 mm / min, the part of the melted steel flow, while the fracture was not found in interface seam / steel and seams with a good formation. At the 140 mm / min, sewing has an excellent formation and no filler metal spreads over the surface of molten steel. For 180 mm / min, liquid filler metal diffusion incomplete take on the steel surface and the angle of contact between metal and welded steel increases rapidly. At high vw 220 mm / min, severe combined incomplete set forth in the aluminium side due to the low heat input. (Song et al, 2009)

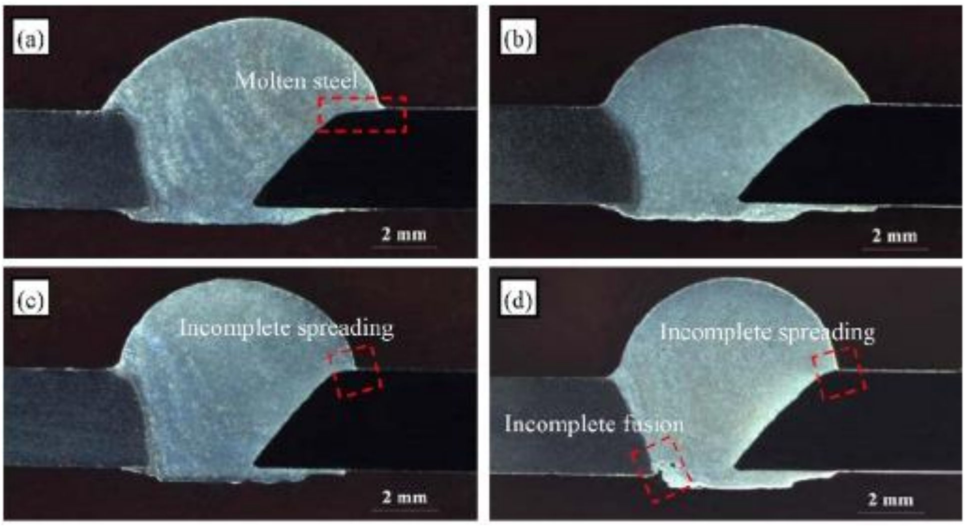


Figure 2.3: Effect of different welding rate (*v*w) on the joint characteristics: (a) 100 mm/min, (b) 140 mm/min, (c) 180 mm/min and (d) 220 mm/min.

Source: J.L. Song et al (2009)

Formation of the pleated welded seam influenced behaviour outbreak filler metals that are liquid at the surface of the groove in the wetting film of liquid flux. And levels of wetting liquid flux film influenced the differing levels of bribery wiring (vf). Figure 2.4 show effect of different wire feed rate of TIG welding. The levels of bribery wiring filler 200 mm/min, the liquid filler metal firstly spread on the root of the groove to realize the back formation. Levels of wiring bribery charges for 300 mm/min and 400 mm/min, the spread of the molten filler metal is difficult on the front face of the groove. At levels of 500 mm/min, the liquid filler metal realized the front formation of the seam. (Song et al, 2009)

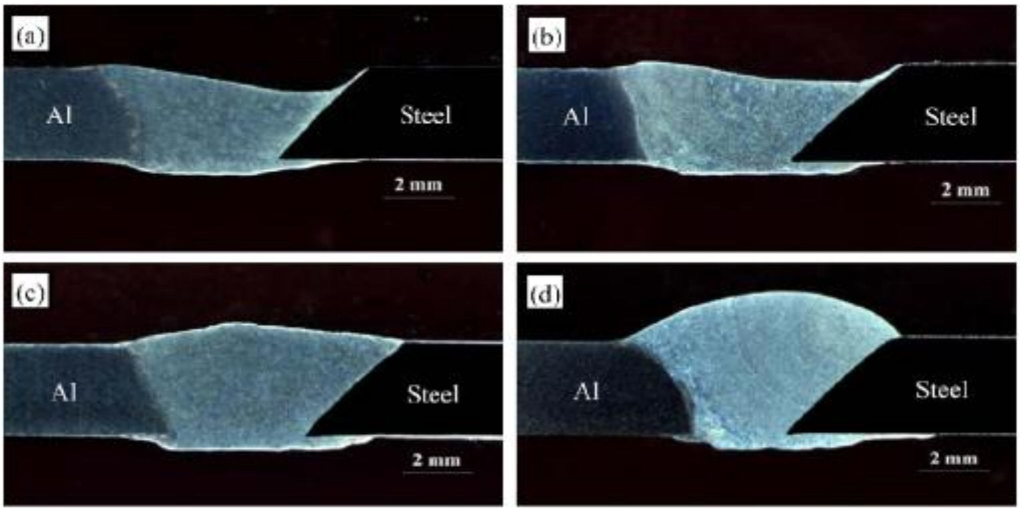


Figure 2.4: Effect of different wire feed rate (*v*f): (a) *v*f = 200 mm/min, (b) *v*f = 300 mm/min, (c) *v*f = 400 mm/min and (d) *v*f = 500 mm/min.

Source: J.L. Song et al (2009)

Figure 2.5 show the Physical model of spreading behaviour of liquid filler metal. Under the TIG arc heat flux, this is near the front face of the beam in both the liquid material to form a thin film of liquid flux on the steel surface. Then, aluminium-based filler feed and touch the source of the beam-shaped grooves. When the filler metal melts, it starts to get wet and spread on the surface of the steel and cause the liquid flux film. And molten slag from flux floated up to the surface of the molten pool due to the low specific gravity, while the high specific gravity metal, such as Sn and Zn, which is deposited onto the surface of steels and alloys with the filler metal, which will strengthen the joint. Spreading behaviour of the filler metal can be divided into two parts, with the spread on the face of the steel behind to pack and form a seam of the back with the help of noise-shaped grooves. Together, gravity itself has been overcome and the liquid filler metal can be spread on the hill in front of the beam. . Finally, with the sound of solder has been established in the sight of steel and aluminium in the presence of liquid filler is mixed with liquid and form the basis of weld joints. (Song et al, 2009)

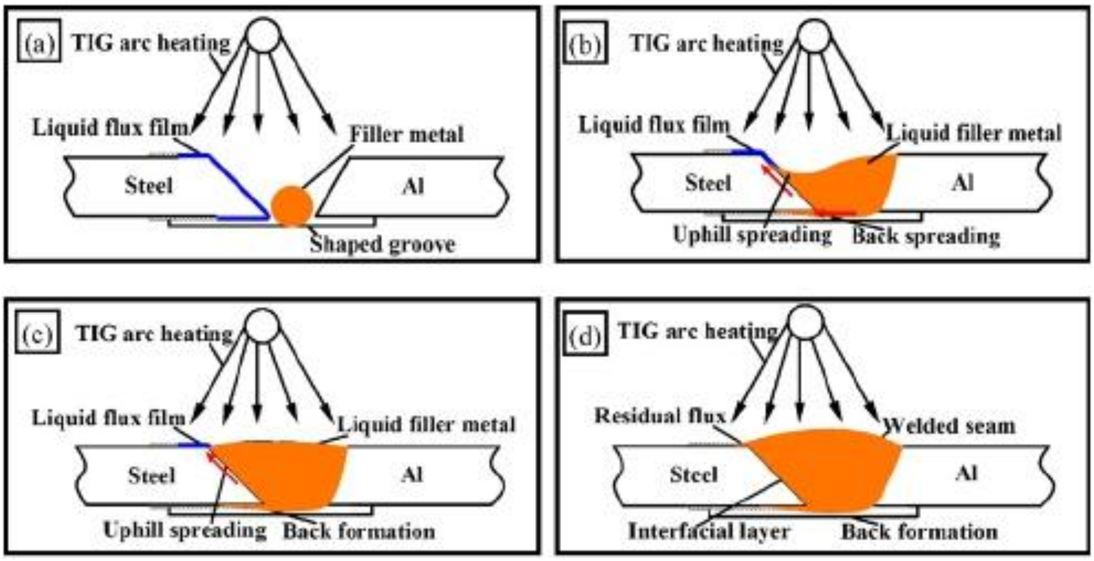


Figure 2.5: Physical model of spreading behaviour of liquid filler metal: (a) liquid flux film on the groove surface, (b) back spreading, (c) uphill spreading and (d) formation of the seam.

Source: J.L. Song et al (2009)

In the welding process that is dynamic, various temperatures led to different IMC layer thickness. Figure 2.6 show the cross-section of typical butt joint on the surface of the interface, zone A and rush the liquid filler metal. In the middle and upper layers of the interface at zone B, the IMC layer thickness is less than 5 m due to the short-term heating and rapid spread of the filler metal. At zone C, a heated vertical surface is heated until it’s the highest temperature is reached. Groove root in zone D with a thin IMC layer about 5 m thick due to low heat input. In the area of fusion of aluminium alloy, at the zone is part of the aluminium alloy is melted and mixed with the filler metal. (Song et al, 2009)

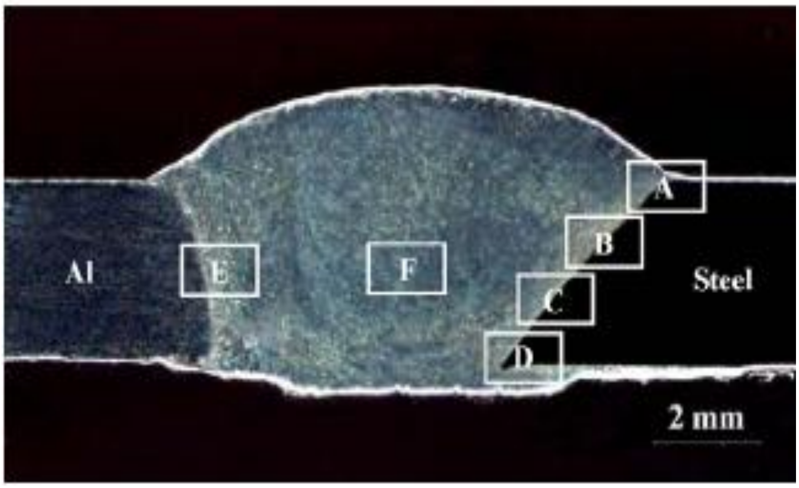


Figure 2.6: Cross-section of typical butt joint.

Source: J.L. Song et al (2009)

2.4 METAL INERT GAS (MIG) WELDING

MIG welding has been proposed as a process that can be implemented to join aluminium and steel for the two structures. Aluminium and steel are arranged close to allow some gaps. Emissions from MIG nozzle is placed on the aluminium. When joined, the edge of the molten aluminium sheet meets with the wire melts causing the gap between the aluminium and steel reduced wet by melted aluminium.

Figure 2.7 show principle of the laser MIG hybrid joining process. In MIG welding process, a large pool of molten melts pool created and filler materials for welding supply, which operates in the keyhole mode to provide uniform heat in a deep way to increase the speed to stabilize the MIG arc welding to reduce the heat input. (C Thomy and F Vollertsen)

Among the process, parameters have a different MIG arc, wire feed rate, welding speed and arc position abutting against the edge. (C Thomy and F Vollertsen). Table 2.1 shows basic parameter setting

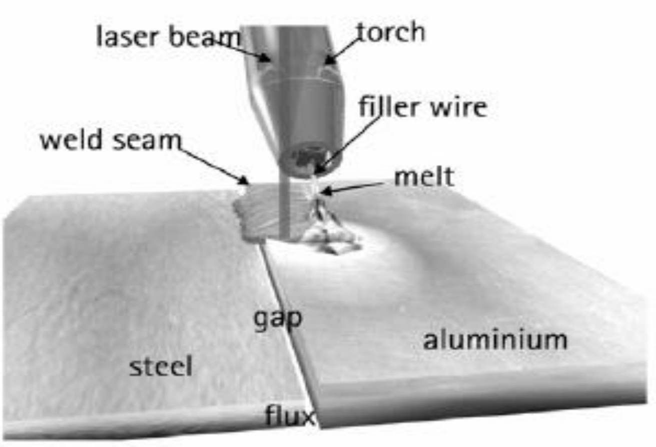


Figure 2.7: Principle of the laser MIG hybrid joining process

Source: C Thomy and F Vollertsen

MIG's position is measured as the distance projection of the filler wire (about point arc feet) to the side of an aluminium sheet, with negative values indicating the position of the steel sheet. To improve performance based on process parameters optimized parameter settings, parameter proportional change was implemented, increasing the while keeping constant welding speed:

i. The heat input per unit length
ii. The ratio of heat input by the arc MIG
iii. The ratio of the wire feed rate and welding speed.

Table 2.1 Basic parameter setting

MIG Power	**W**	**224**
Welding Speed	m/min	6
Wire Feed Rate	m/min	6
MIG Position	mm	+1

Welding speed on the contrary does not change the parameters (especially wire feed rate) has some influence on the wetting behaviour. Wire feed rate does not affect the phase in the wetting layer thickness. MIG arc position with the edge of the sheet thickness influences the phase and the tensile strength. Figure 2.8 show Influence of welding speed during proportional variation of process parameters. To evaluate the root joint and side welding speed of 7 m/min the speed that usually being used. At a speed of 8 m/min, this is less stable, resulting in the formation of large holes and watering splash. At a speed of 9 m/min, this process is more stable, and there is a smooth root formation, but the weld is still weak. (C Thomy and F Vollertsen)

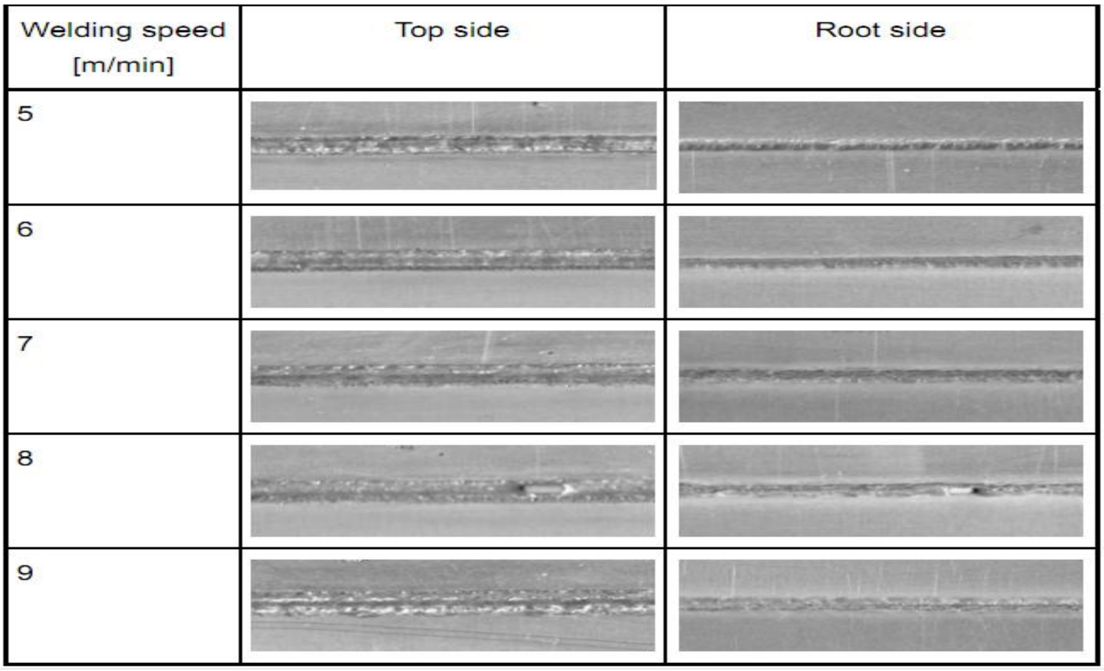


Figure 2.8: Influence of welding speed during proportional variation of process parameters

Source: C Thomy and F Vollertsen

2.5 WELDING AND BRAZING

Welding is to create a metal joint using concentrated heat at the joint to melt and filler metals with brazing while also using a much lower melting temperature that does not involve the base metal. In welding and brazing, the joint strength is often in excess of the basic materials. However the heat used in the solder is low, this process does not change the physical properties and reduce distortion, warping and stress on the joints. For addition, a lower temperature solders which translates to fewer energy requirements. (Katrina C. Arabe, 2005)

2.5.1 Factors of Welding and Brazing Process

i. The size of the assembly: To join the large assemblies, welding is a more appropriate method. Larger assembly requires high heat while heating the brazing requires less heat, making it difficult to achieve the required temperature of the filler metal flow.
ii. Thickness: To join thin sheets, brazing has the advantage of the high heat as welding can wrap or burn through that section. Instead, brazing can help to avoid distortion.
iii. Shape of joint: more economical welding time and cost. In addition, brazing can just as easily draw the filler metal into straight, curved or irregular weld configurations.
iv. Types of materials: brazing welding soundly beats when joining dissimilar metals. As long as the filler material is compatible with both base metals and melts at a lower temperature, brazing joints can make a sound. In contrast, thin base material during welding to join two dissimilar metals using this method can involve complex and expensive techniques.

2.6 MATERIAL

2.6.1 Aluminium Alloy 1100

Aluminium alloy 1100 contains at least 99% aluminium. It has superior electrical conductivity, good formability and high corrosion resistance, and is used where high strength is required. It has a low density and excellent thermal conductivity common to all aluminium alloys. Pieces of aluminium alloys have moderate strength and lightweight.

Alloy Welding 1100 can be welded by the TIG and MIG processes. Commonly used filler alloy 4043 and 1050. Aluminium alloy 1100 can also be gas welded or resistance welded, but the resulting joints are not strong or as corrosion resistant as the inert gas welded joints. (Austral Bronze Crane Copper Limited, 2005)

2.6.2 Stainless Steel SUS304

Stainless steel SUS304 with chemical composition: 18.52Cr- 8.34Ni- 0.42Si 0.89Mn- 0.046C- 0.002P- 0.002S in percent weight and approximately Fe. (Xiaohong Chen, 2004)

Stainless steel SUS304 is the foundation of the evolution of austenitic stainless steel. Has good corrosion resistance, heat resistance, low temperature strength and mechanical properties, thermal processing, such as stamps, good bending and non-hardening heat treatment. For welding of thin-walled, stainless steel SUS304 are widely used. For welding stainless steel SUS304 is good without the heat treatment after the welding process, the welding method can determine the thickness and only 2mm should be applied in the welding material, medium plate submerged arc welding can be used.

2.6.3 Filler Aluminium Alloy 4043

Selection of filler alloy for aluminium is usually based on the strength of the voltage. Filler alloy selection is important for its use effects such as ease of welding, the welded joint strength, ductility, corrosion resistance, sustained service temperature, colour match and post-weld heat treatment.

As a basic description, aluminium alloy 4043 is filler with 5% added silicone. 4043 is suitable for service temperatures above 150 °C. Aluminium alloy 4043 has low ductility and strength to form and was also lower after the welding has been carried out. Aluminium alloy 4043 is a softer alloy in the form of spooled wire. Gas Metal Arc Usually when Welding (GMAW), 4043 can produce welds with a better cosmetic appearance, smooth surface, the splash of less and less soot. (ESAB, 2011)

2.7 FINITE ELEMENT ANALYSIS SYSTEM

Finite element analysis is a computerized procedure for the analysis of structures. Rapid engineering analyses can be performed because the structure is represented (modelled) using the known properties of standard geometric and the finite element method.

Finite element analysis used in this manner provides the dynamic properties of structures, including mode shapes and corresponding natural frequencies. (Neville F. Rieger). The finite element method (FEM) has been used extensively to predict residual stress in welding repairs. (Jiang et al, 2010)

2.7.1 Advantages of Finite Element Analysis

Finite Element Analysis of the digital computer enables effective problem solving and complex problems in structural dynamics. Structural dynamics can be solved in the frequency domain using the transformation of the modal. Finite element computer code efficiently performs structural dynamic response calculations involving harmonic response, transient response and random structure of the complex. Therefore, the finite element method offers a highly efficient procedure for the calculation of complex linear structures under dynamic excitation conditions variables. (Neville F. Rieger).

2.8 FEMPRO ALGOR

ALGOR is a leading provider of design, analysis and simulation software. Another advantage in this ALGOR application is allowed engineers to use the result of an ALGOR stress analysis to carry out the easy to use pressure and strain life fatigue calculations based design products. Fatigue analysis is important for the product as steel rails, beams and girders, to avoid mechanical failure under repeated. (Julie Halapchuk, 2005). Fatigue ALGOR guide users step by step through the process set up a fatigue analysis including:

i. Choose between stress and strain-based fatigue analysis.
ii. Presenting material using information extensive database edited.
iii. Enter data simulated real-world conditions such as local stress concentrations and the effect of surface finish.
iv. Define the burden of historical data.
v. Specify the number of repetitions for loading cycle.
vi. Calculate the fatigue life model.
vii. View the results as the life or safety-factor contour directly in FEMPRO.
viii. Generating customizable reports with minimal time and effort.

2.9 MODAL ANALYSIS

As used in the general literature of vibration analysis, modal analysis can refer to either:

a) Formal testing procedures to identify the dynamic structural properties.
b)Mathematical procedures to improve the efficiency computation of structural dynamics.
c) A technique for balancing the rotor.

Modal testing is a formal method to identify natural frequencies and mode shapes of structures. It is used with modal testing equipment in accordance with certain procedures. For example, analyzed the structure in motion and recording the resulting distribution of movement throughout the structure. The final result of testing provides a variety of natural modal frequencies, mode shapes and structural impedance data. This identified data from the input signal is digitized using the efficiency curve-fitting routine. The decision is then displayed as an impedance plot and mode shapes (possibly animated). (Neville F. Rieger)

Mathematical analysis of diversity is an analytical procedure used to release the structure equations of motions by users of the recognized the transformation. Structural diversity reception later found through inverse transformation, followed by a summing of the respective modal responses, in accordance with their degree of participation in the structural motion. (Neville F. Rieger)

Modal balancing is a rotor balancing procedure in which the respective modes of a rotor system are first isolated and then corrected for residual unbalance in sequence. The balance corrections used for one mode are carefully arranged in accordance with modal principles so as not to re-introduce the other modes of the rotor system. (Neville F. Rieger).

2.9.1 Parameters of Modal Analysis

Dynamic behaviour of structures in the range of frequencies that can be modelled as a single individual set of mod vibration. Vibration problems caused by these resonances (modes) may be examined by using the parameter. Diversity parameters may be extracted rather than a set of Frequency Response Functions (FRF) measurements between one or more reference positions and a number of measurement positions required in the model. Degree of Freedom (DOF) is also the point position and direction on the structure. Resonance frequency and attenuation values may be found everywhere from FRF measurements on the structure. (H. Herlufsen, Brüel & Kjær, Denmark)

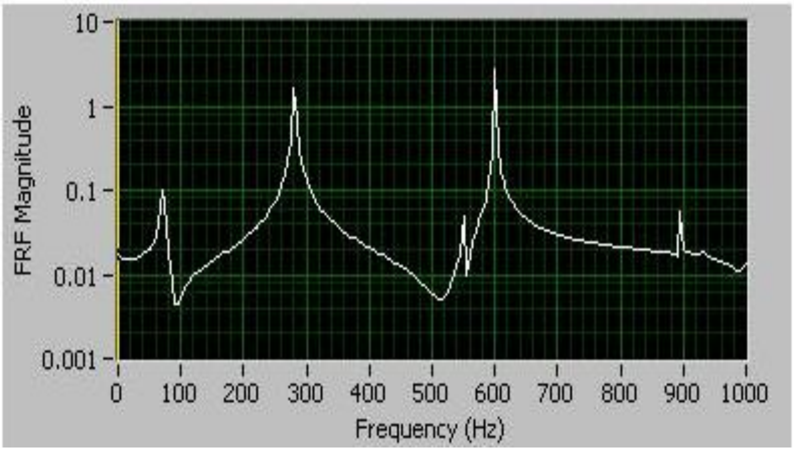


Figure 2.9: FRF results for a test scenario

Source: National Instruments, 2011

Modal Analysis is performed to assess the dynamic characteristics of structures under vibration excitation. Using modal analysis, the modal parameters (dynamic properties) structure can be extracted. For the modal parameters, it’s covered the natural frequency, damping ratio, and mode shape, the principle elements that describe the movement and follow-back structure for excitation ambient and forced excitation. (National Instruments, 2011).

2.9.2 Advantage of Modal Analysis

Basic dynamic characteristics of the modal analysis are the mode shapes and natural frequencies of structures. Modal testing is used to quickly identify their natural modes and frequencies, and has matrix structure, which govern the natural modes and frequencies. Advantage of modal analysis, first, that the procedure most quickly and effectively provided for acquisition of data on the dynamic characteristics of structures to test the use of public transport. Second, modal analysis effective analytical procedure for solving a large set of dynamic structure as it reduces the matrix equation and equation (which in turn must be solved by some iterative procedure) to a set of linear independent equations, each with well-known closed-form solution given above. These solutions are then combined to form a complete solution to the problem of the structural response. (Neville F. Rieger).

2.9.3 Disadvantages of Modal Analysis

Output of modal testing of the natural frequencies, mode shapes modal stiffness, modal damping and mass matrix of the modal. In practice this structure is not always perfect system sometimes non-linear structure to a certain extent, the reasons for system non-linear structure is: -

i. The nature of the material may not be linear, for example, composite structures, viscoelastic materials, the material elastic-plastic materials, where non-linear displacements are related to force.

ii. If the amplitude is large, the geometry can result in a shift, a non-linearly related to the load.

iii. The structure of the boundary conditions can introduce non-linear, for example, the structure where the numbers of points support the change.

Non-linear effects tend to complicate the analysis and error into the data reduction and curve fitting estimates of natural frequencies. Modal analysis decisions cannot always be accurate because of the characteristics vary with the magnitude of the applied load. Modal testing is limited which it does not directly address the response to problems or the transient response of a random response. (Neville F. Rieger).

2.10 DYNAMIC PROPERTIES

Before this study the dynamic characteristics of a welded joint have been performed by Wang and Lim by using three sets of place-welded specimens to simulate the frequency response function of the place-welded structure and analyze a lot of natural frequencies. Pal and Cronin in the analysis, he states that the distance of the weld affects the dynamic response of the parent structure and analyzes the natural frequency and damage effects in the frequency response of the welded joints. (De-Guang Shang et al, 2002).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In general, methodology means a set or system of methods. This chapter is about the about how the research is carried out. The research is to study about the dynamic properties and behaviour of dissimilar metal joint by MIG welding using different thickness between stainless steel and aluminium alloy by doing the experimental modal analysis and performing ALGOR (FEA) method. All the result and data from the ALGOR will be compared with the data collected from the experimental modal analysis. The flow chart of the methodology is as shown in figure 3.1.

This study begins with the problem statement; determine the project objectives and scopes, literature review on previous work and theoretical study on joining by MIG welding and modal analysis. After gathering the information, the model of sheet metal joining by MIG welding is a sketch using SOLIDWORK software. Then a simulation is conducted to observe the dynamic properties of sheet metal joining by MIG welding such as natural frequency and mode shape. In this project, the simulation is performed using ALGOR Finite Element Analysis software. After that, joining between stainless steel and aluminium alloy by MIG welding and an experimental modal analysis is performed. Lastly, after gathering information from both results, a comparative study will be done and discussed on performance and stability of sheet metal joining by MIG welding.

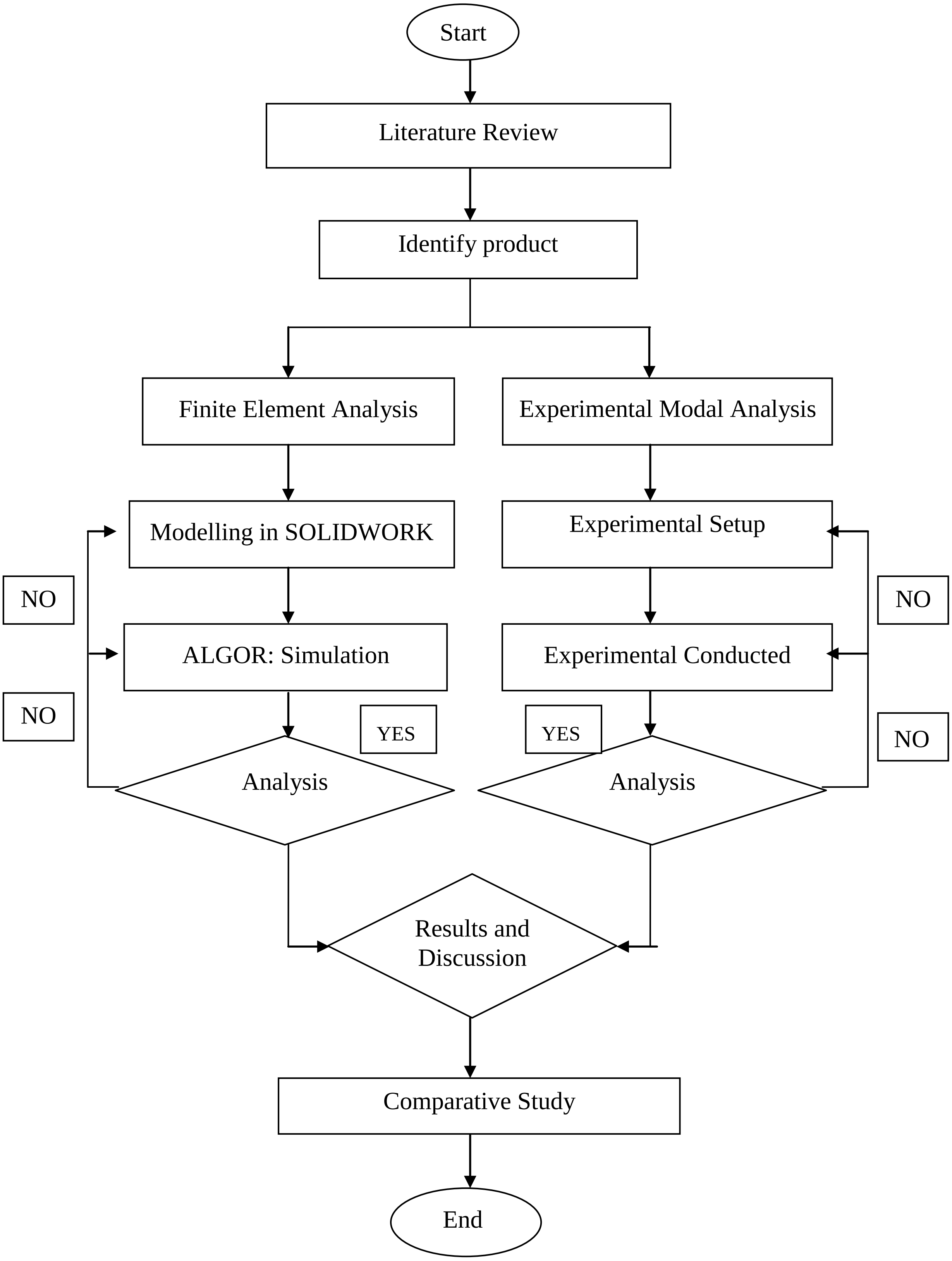


Figure 3.1: Flowchart methodology

3.2 MATERIAL

The material, size and thickness, filler metal and bevel angle of sheet metal joining by welding must be determined before running the experiment like figure 3.2. These considerations are important to make sure the experiment and the simulation run smoothly. Materials used are aluminium alloy 1100 in 3.0 mm thickness and stainless steel Sus304 plates in 2.0 mm thickness. The filler metal used is aluminium alloy 4043 welding wire, with a diameter of 1.0 mm. The two types of plates that have been cut to Size 150 mm x 100mm, and the surface was cleaned by abrasive paper and acetone before the experiment. A single-V groove has been opened on the plate, with a bevel angle of 40° in steel side and 30° in the aluminium alloy side

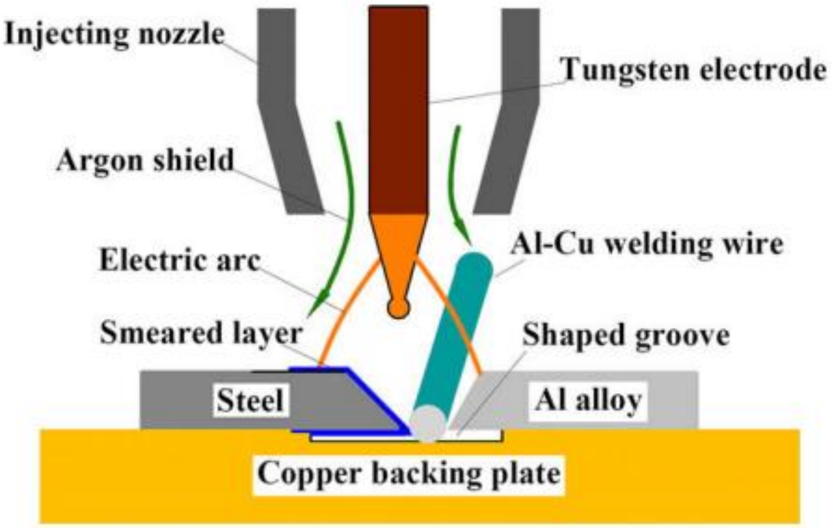


Figure 3.2: Schematic of aluminium-steel butt TIG welding

Source: S.B. Lin et al, 2009

3.2.1 Aluminium Alloy 1100

Aluminium alloy 1100 contains at least 99% aluminium. Aluminium alloy 1100 filler metal easily welded with commercial techniques such as electrical resistance, arc inert gas, inert gas arc welding-protected option. If welding of aluminium alloy Al 1100 alloy is higher, such 6063 or 5052, then the filler rod should be aluminium alloy 4043.

Table 3.1: Aluminium alloy 1100 chemical composition

Fe	**C**	**Mn**	**Cu**	**Si**	**Mg**	**Zn**	**Al**
0.581	-	-	0.073	1.110	0.001	0.008	00.220

3.2.2 Stainless Steel SUS304

For welding stainless steel Sus304 is good without heat treatment after welding, the welding method can determine the thickness, the thickness of 2mm should be applied in the welding material, medium plate submerged arc welding can be used.

Table 3.2: SUS 304 chemical compositions

C	**Cr**	**Ni**	**Si**	**Mn**	**Mo**	**Al**	**Co**
0.08	18.03	8.74	0.426	1.153	0.36	0.003	0.17
Cu	**Nb**	**Ti**	**V**	**W**	**Fe**	**P**	**S**
0.39	0.02	0.004	0.05	0.03	70.48	0.019	0.002

3.2.3 Filler Aluminium Alloy 4043

As a basic description, aluminium alloy 4043 is a silicone filler with 5% added. 4043 is suitable for service temperatures above 150 °C. The alloy has very good welding characteristics and may be welded by all of the common welding techniques. Gas tungsten arc welding is generally used in thin sections and gas metal arc welding is used for heavier sections. 4043 alloy filler wire is used for best results.

Table 3.3: Filler Aluminium Alloy 4043 chemical composition

Si	**Fe**	**Cu**	**Al**	**Mn**	**Mg**	**Be**	**Co**
0.08	18.03	8.74	0.426	0.39	0.02	0.004	0.05

3.3 WELDING / BRAZING

For arc welding those different two materials, these are a few aspects which require to be proposed. Firstly, from a practical viewpoint, it may not be possible to make a fusion weld if the melting point of the two materials is too different, as it is essential to have controlled melting on both sides of the joint simultaneously. Secondly, even if this criterion is met, it may not be possible to produce an adequate joint if the two materials are metallurgical incompatible. Metallurgical incompatibility may lead to uncontrollable weld metal/HAZ cracking or a weld metal microstructure that cannot provide adequate mechanical or corrosion performance. In the case of aluminium alloy welding on stainless steel, the fusion boundary may consist of hard martensite.

Zone which covered district a parent material mixture with, that partial blend with weld metal bulk, for example. Due to difference in melting point, could be established next to with fusion border. When arc welding metals that dissimilar, 'arc blow' or deflection uncontrolled arc may have happened because electric current flow thermo-electric between other sides.

3.3.1 Method of Welding

In this project, will joining stainless steel 2-millimeters thickness and aluminium alloy 3-millimeter thickness by using aluminium filler wire 1-millimeter in diameter by tungsten inert gas (TIG) or metal inert gas (MIG). Aluminium alloy 4043 is filler metals used are alloys of aluminium alloy standards and a basic aluminium alloy that was specially adapted for this application and was mainly intended to improve corrosion resistance.

The sheets were cut in the size of 100 mm × 150 mm, the surface of which was cleaned by abrasive paper and acetone before arc brazing. The groove of the joint was in the pattern of ‘V’, and the bevel angle was 45◦ in steel side and 30◦ in aluminium side like figure 3.3. The length of butt gap was 1 mm. The butt TIG welding–brazing was carried out using COOLS AC-TIG welding source. The welding parameters were that welding current (Iw) of 90–170 A, arc length of 3–4 mm, welding rate (vw) of 100–220 mm/min, wire feed rate (vf) of 200–500 mm/min, argon flow rate of 8–15 L/min.

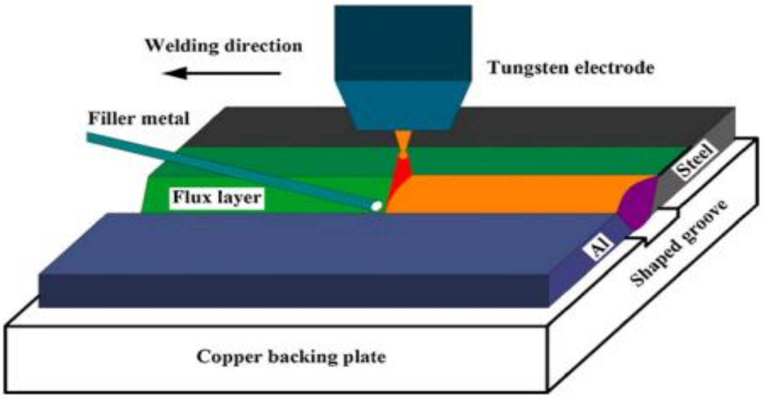


Figure 3.3: Schematic of aluminium–steel butt TIG welding

Source: Song et al, 2009

3.4 MODELLING

3.4.1 Modelling Method

From the data measured, the assembler part is drawn using SOLIDWORK. The design of the model is shown in figure 3.4 to 3.6. The assemble part consist of 2 part that is an aluminium alloy plate which have thickness 3mm and stainless steel plate have thickness 2mm. These two parts are assembled to the weld bead.

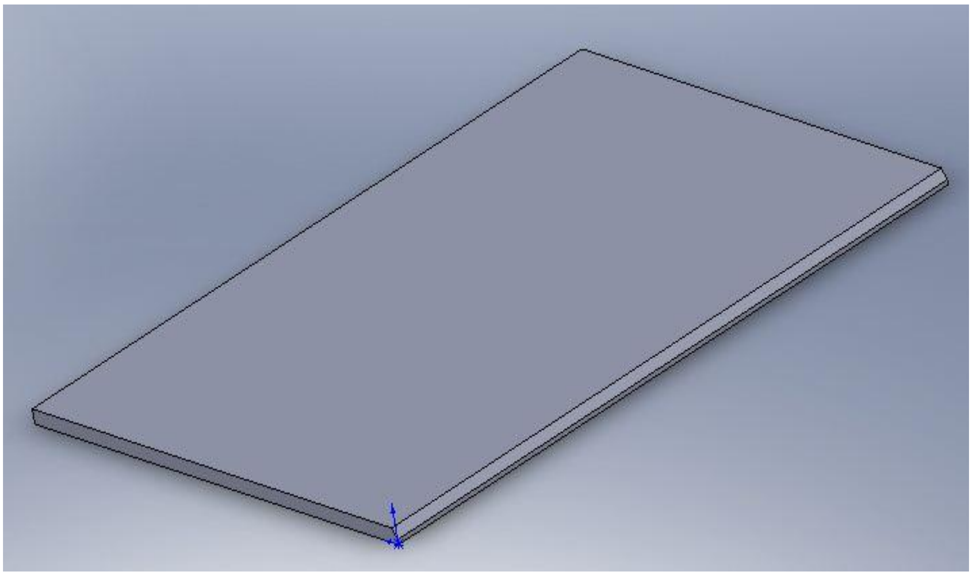


Figure 3.4: Isometric view of aluminium alloy plate

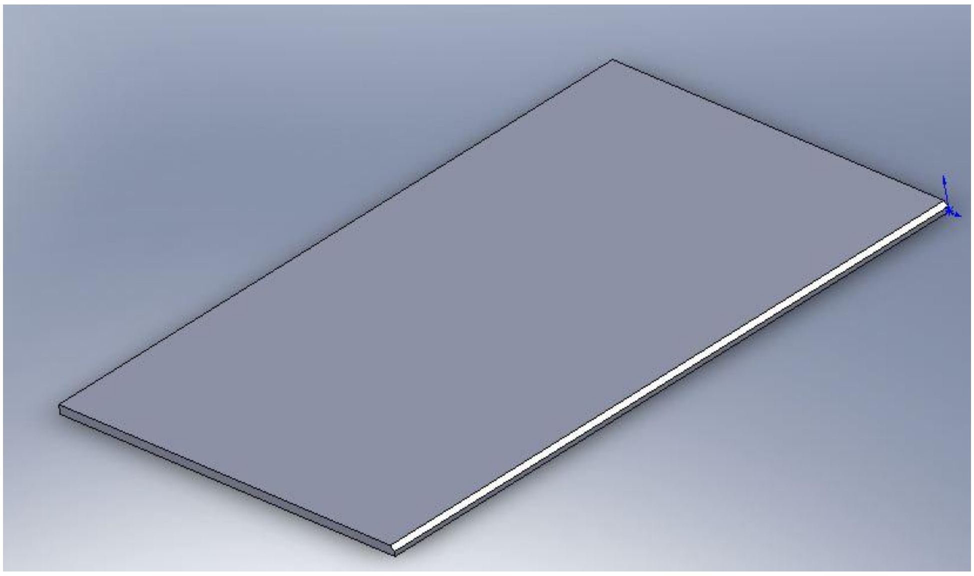


Figure 3.5: Isometric view of stainless steel plate

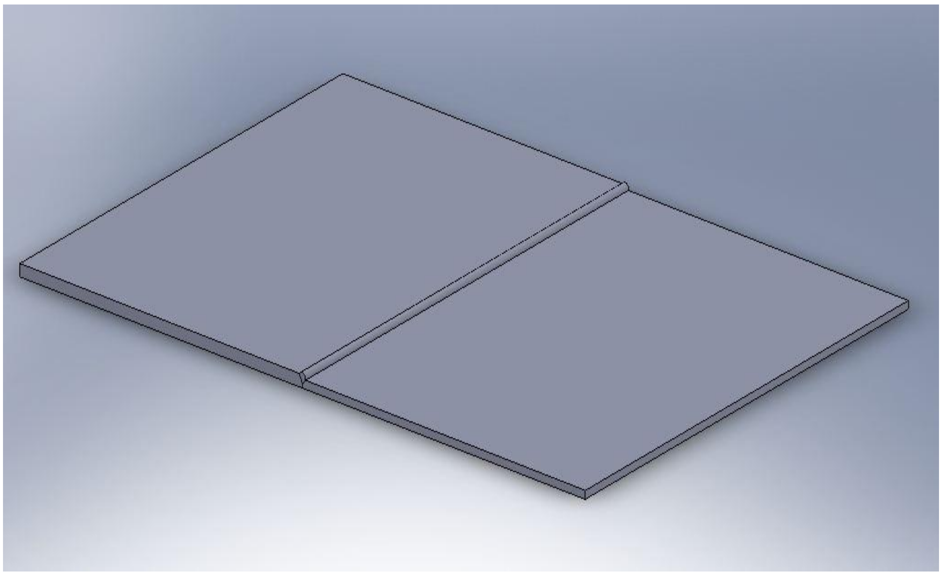


Figure 3.6: Isometric view of assembling parts with weld bead

3.5 SIMULATION

3.5.1 Simulation Method

The finite element analysis is carried out is using ALGOR FEMPRO 23.1. ALGOR is capable of generating meshes automatically because its support for multi-CAD environment and also an extensive finite element modelling tool that help manufacturers study initial design intent and accurately predict product performance. It also allows user to validate and optimize designs before manufacturing which can increase efficiency, minimizing reliance on physical prototypes, reducing costs, and decreasing errors. It also allows complex geometries to be generated easily and support mesh types of 2D and 3D simulation.

ALGOR FEMPRO 23.1 software is used to conduct the analyzing of joining aluminium alloy and stainless steel with weld bead. ALGOR Finite Element Analysis (FEA) uses a complex system of point called nodes which make grid called mesh. Natural frequency (modal analysis) in ALGOR determined a part’s natural frequencies and mode shape to avoid frequencies that are disruptive or harmful in the design. The software use studies of oscillating modes to determine if a part resonates at the frequency of an attached power- driven device, it makes design changes to reduce the amplitude of oscillations and account for stiffening effects from applied loads.

3.5.2 Transferring Model

The 3D model of joining aluminium alloy and stainless steel with weld bead by SOLIDWORK is transferred into the ALGOR software in type of IGS file. IGS file is a 2D/3D vector graphics format based on the Initial Graphics Exchange Specification (IGES) used by many CAD programs as a standard ASCII text- based format for saving and exporting vector data which can store wireframe models, surface or solid object representation, circuit diagram and other object. The IGES format was introduced in 1979 and has since become a standard for transferring three dimensional models between CAD programs.

3.5.3 Grid Generation

The mesh was constructed using three parts that represent the aluminium alloy plate, stainless steel plate and weld bead. The element type for the aluminium alloy plate inset of aluminium alloy 1100 H14, stainless steel plate insert to stainless steel SUS304 and weld bead in set to aluminium alloy 4043 specification as in figure 3.7. The experiment is carried out by setting the analysis type to Natural Frequency (modal), change the units from metrics mks (SI) to custom unit and change the length to millimeter (mm) and force to Newton (N). The element definition is set to tetrahedron and defines the mesh size to 70%. The result will be better if a higher percentage of mesh size is set up it need a supercomputer to perform the analysis. For this experiment, 30-50 mode shapes were analyzed and there are no loading and boundary condition were imposed on the test specimen. The free boundary condition is simulated by supporting the structure with soft material such as sponge. The mesh structure for joining aluminium alloy and stainless steel with weld bead is shown in figure 3.7. The simulation is done part by part so then it can be compared to the experimental analysis later.

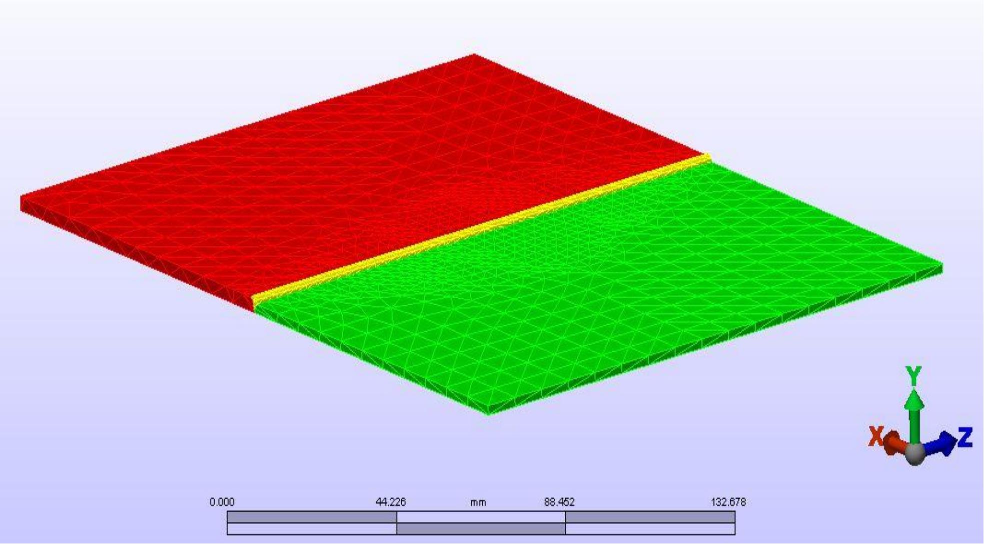


Figure 3.7: Mesh diagram of assembling parts with weld bead

3.6 MODAL TESTING

3.6.1 Impact Hammer Testing

In the experiment, impact hammer is used to run modal testing. The component is interfaced with a host computer allowing for coordination of the operation of the overall system and enhancing the data processing capabilities. An impact hammer test is the most common method of measuring FRFs (Frequency Response Functions). The hammer impacts a transient impulsive force excitation to the device. The impact is intended to excite a wide range of frequencies so that the DAS (Data Acquisition System) can measure the vibration of the device across this range of frequencies. In the experiment, Accelerometer is used as the sensor to connect with the DAS. The accelerometer is a device for measuring vibration of a structure, producing an output signal proportional to acceleration. They work by having some kind of force measuring sensor, with a mass attached to it so that when the device is forced to vibrate a force is produced by Newton’s law, proportional to acceleration. The frequency content of the excitation input depends on the size and type of impact hammer and Accelerometer that is used. The dynamic force signal is recorded by the DAS. After the impact, the device vibration is measured with Accelerometer recorded by the DAS. The DAS then computer the FRF by comparing the force excitation and the response acceleration signals.

There are important when performing impact testing. The selection of the hammer tip can have a significant effect on the measurements obtained. The Input frequency of the excitation controlled mainly by the hardness of the tip selected. The harder the tip, the wider the frequency range that is excited by the excitation force. The tip needs to be selected such that all the modes of interest are excited by the impact force over the frequency range to be considered. Figure 3.8 shows a typical set-up for a measurement system.

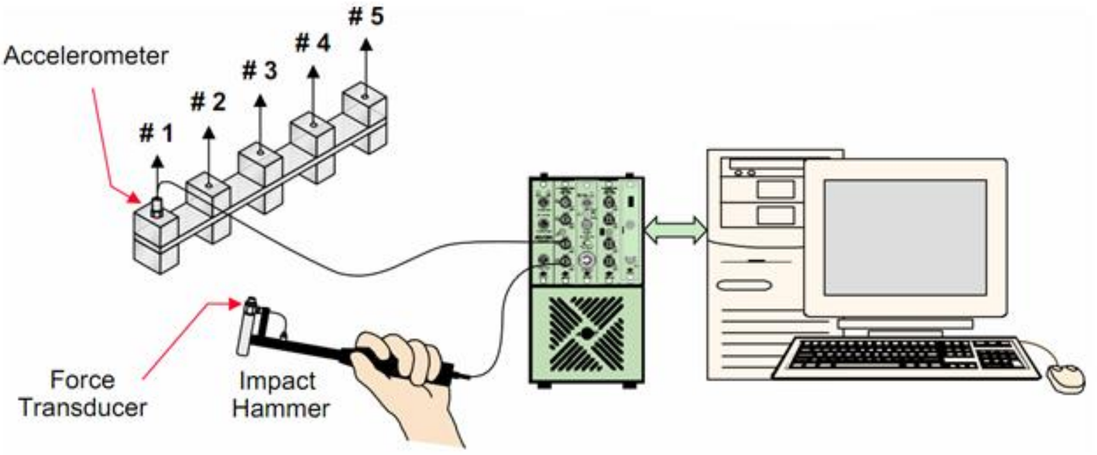


Figure 3.8: Modal testing systems

Source:Brüel & Kjær, Denmark

Table 3.4: List of apparatus

No	Apparatus	Function
1	Modal Hammer Model: Endevco Type: 2302-10	i. Excites the system. Impact all the DOF's point on the SWG.
2	8 Channel FFT Analyzer	i. Collect time data and convert it to FRF measurement. ii. Response will displayed in PC
3	Computer with PULSE-Lite software version 10.2, ME'scope version 4.0	i. PULSE-Lite – display the collected data ii. ME'scope – simulate or analyzer the data converted from the analyzer.
4	Tri-Axial Accelerometer Model: Bruel & Kjaer Type: 4507B	i. Measure signal respone in each DOF from impact hammer test. Measurement includes 3 axis (X,Y,Z)

3.6.2 Modal Analysis Procedures

Practical modal analysis, or modal testing, involves the following operations:

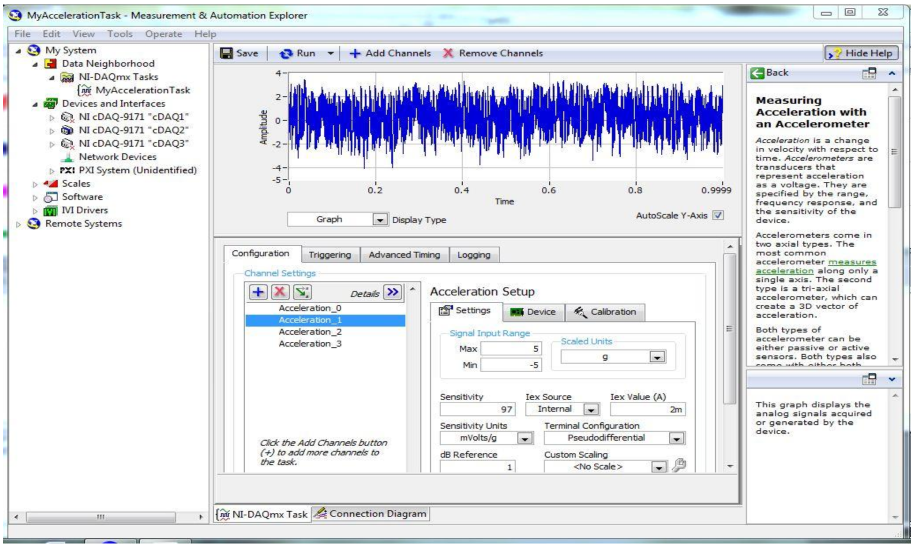
i. The structural response amplitude is acquired in digital format throughout a prescribed frequency domain.
ii. The modal minicomputer automatically develops and stores this digitized frequency response data in a designated memory for subsequent processing.
iii. Curve-fit routines are applied to the frequency response data to identify the natural frequencies within the given frequency range. The corresponding mode shapes are extracted from the digitized amplitude data at the natural frequencies.
iv. The mode shapes may be animated in terms of the simplified structural model, corresponding to those locations at which the response has been determined.
v. The modal damping is estimated from the magnitude of the response at each natural frequency. This is often the most approximate structural parameter obtained by modal testing.

vi. Modal matrix data are identified in the structure. Output is developed for mass, stiffness, and damping matrices suitable for further computations, based on the structural modal properties. These data are printed out for subsequent use.

vii. Some software packages permit modifications to be made to the matrix data, to evaluate the influence of possible changes on the natural frequencies and mode shapes. These packages can be run on certain commercially available modal analyzers.

3.6.3 Step of Experimental Modal Analysis

From the Measurement & Automation software, the sensitivity of the accelerometer and hammer set up. Sensitivity is the sensitivity of the sensor. This value is in the units you specify with the sensitivity unit's input. Refer to the sensor documentation to determine this value. The sensitivity of the hammer is 2.24 mvolts/g and sensitivity of the accelerometer is 5 mvolts/g. The setting of the sensitivity is shown in figure 3.9. This graph displays the analog signals acquired or generated by the device.



Display Type: Graph

AutoScale Y-Axis ☑

Max: 5

Min: -5

Scaled Units: g

Sensitivity: 97

Iex Source: Internal

Iex Value (A): 2m

Sensitivity Units: mVolts/g

Terminal Configuration: Pseudodifferential

dB Reference: 1

Custom Scaling: <No Scale>

Click the Add Channels button (+) to add more channels to the task.

Measuring Acceleration with an Accelerometer

Acceleration is a change in velocity with respect to time. *Accelerometers* are transducers that represent acceleration as a voltage. They are specified by the range, frequency response, and the sensitivity of the device.

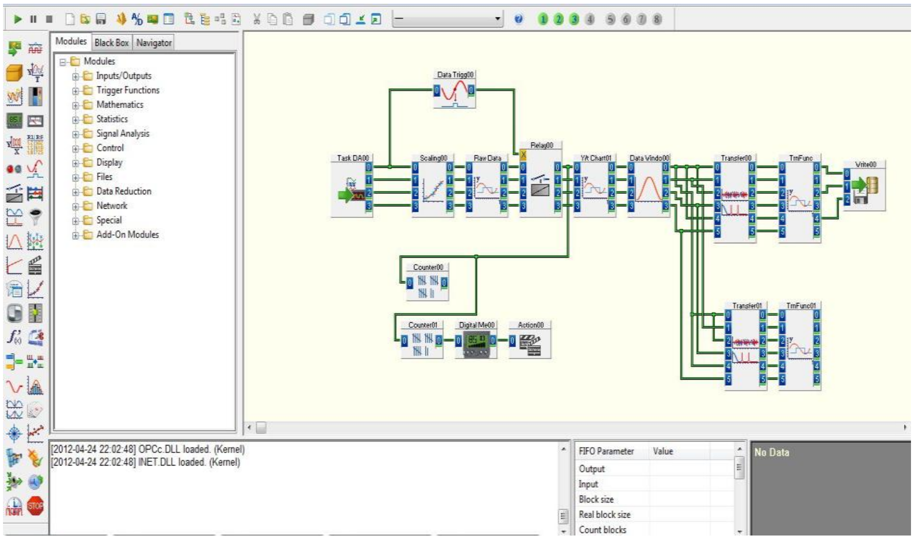
Accelerometers come in two axial types. The most common accelerometer measures acceleration along only a single axis. The second type is a tri-axial accelerometer, which can create a 3D vector of acceleration.

Both types of accelerometer can be either passive or active sensors. Both types also

This graph displays the analog signals acquired or generated by the device.

Figure 3.9: Setting of sensitivity

The experimental modal analysis is carried out is using DASYlab 10.0 software. The figure 3.10 is show draw schematic diagram.

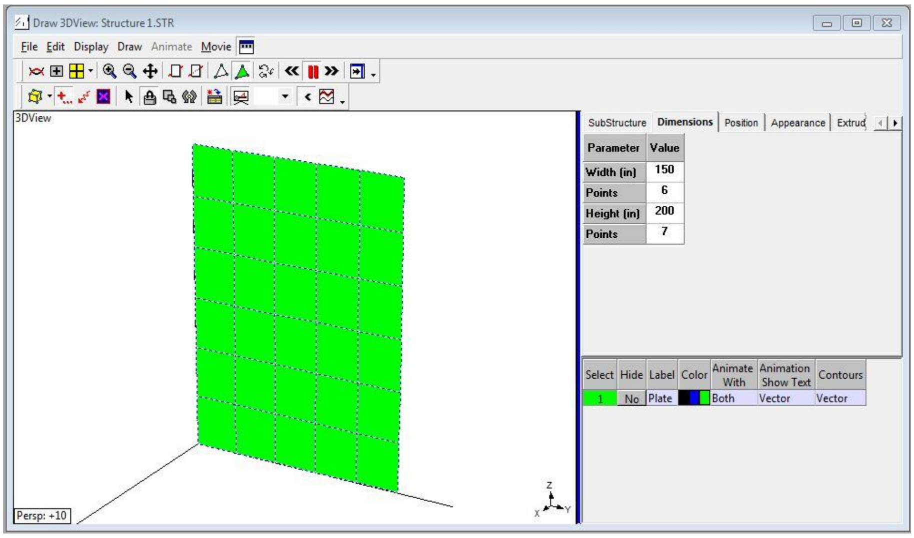


```
[2012-04-24 22:02:48] OPCc.DLL loaded. (Kernel)
[2012-04-24 22:02:48] INET.DLL loaded. (Kernel)
```

FIFO Parameter	Value
Output	
Input	
Block size	
Real block size	
Count blocks	

Figure 3.10: Schematic diagram at DASYlab 10.0

The data experimental modal analysis from DASYlab 10.0 is carried out is using ME'scope software. 3D models with simple are easily built in ME'scopeVES by using the Drawing Assistant. More complex models can be built by repeatedly using the Drawing Assistant to model the structure using several simpler Substructures. A grid of Points spaced 150 mm with 6 points in the Global X direction and 200 mm with 7 points in the Global Y direction will be added to the plate. The setting of the dimension is shown in figure 3.11.

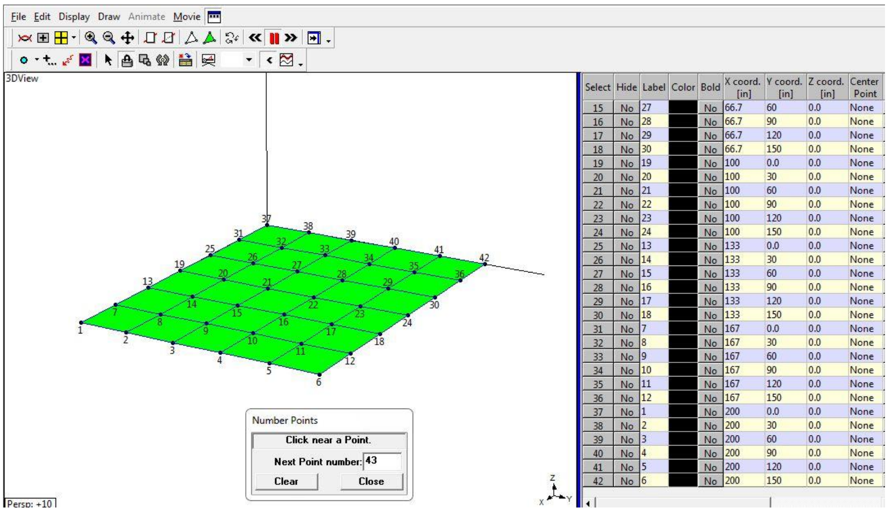


Parameter	Value
Width (in)	150
Points	6
Height (in)	200
Points	7

Select	Hide	Label	Color	Animate With	Animation Show Text	Contours
1	No	Plate	■🟦🟩	Both	Vector	Vector

Figure 3.11: Dimension of plate

In ME'scopeVES, each Point on a 3D model is animated using Animation Equations. Each Point has its own Animation Equations. Measured Points (Points were measurements were made) are animated using Measured Animation Equations. Before that, the Points on the 3D model must be numbered to match the Point numbers in the Roving DOFs of the FRF Traces. Structure Points are numbered by editing their Point Labels. Figure 3.12 shows 3D views during point numbering.

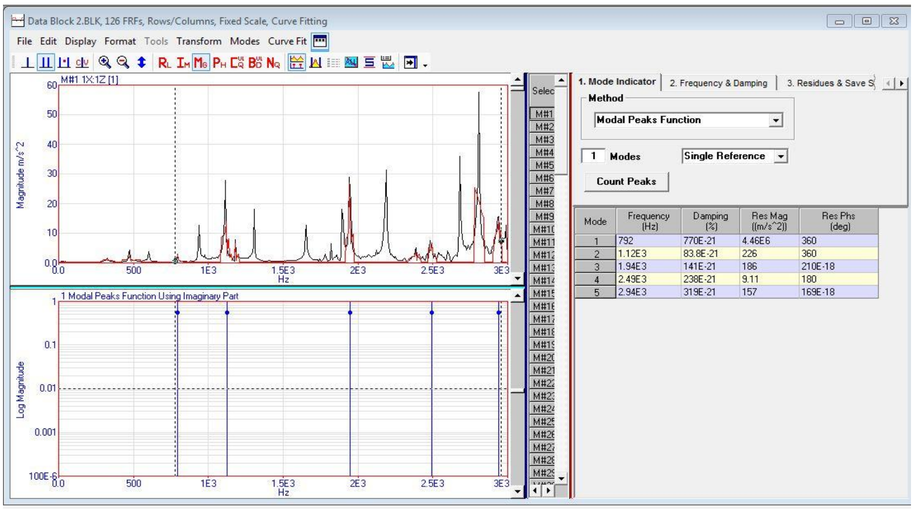


Number Points
Click near a Point.
Next Point number: 43

Select	Hide	Label	Color	Bold	X coord. [in]	Y coord. [in]	Z coord. [in]	Center Point
15	No	27	■	No	66.7	60	0.0	None
16	No	28	■	No	66.7	90	0.0	None
17	No	29	■	No	66.7	120	0.0	None
18	No	30	■	No	66.7	150	0.0	None
19	No	19	■	No	100	0.0	0.0	None
20	No	20	■	No	100	30	0.0	None
21	No	21	■	No	100	60	0.0	None
22	No	22	■	No	100	90	0.0	None
23	No	23	■	No	100	120	0.0	None
24	No	24	■	No	100	150	0.0	None
25	No	13	■	No	133	0.0	0.0	None
26	No	14	■	No	133	30	0.0	None
27	No	15	■	No	133	60	0.0	None
28	No	16	■	No	133	90	0.0	None
29	No	17	■	No	133	120	0.0	None
30	No	18	■	No	133	150	0.0	None
31	No	7	■	No	167	0.0	0.0	None
32	No	8	■	No	167	30	0.0	None
33	No	9	■	No	167	60	0.0	None
34	No	10	■	No	167	90	0.0	None
35	No	11	■	No	167	120	0.0	None
36	No	12	■	No	167	150	0.0	None
37	No	1	■	No	200	0.0	0.0	None
38	No	2	■	No	200	30	0.0	None
39	No	3	■	No	200	60	0.0	None
40	No	4	■	No	200	90	0.0	None
41	No	5	■	No	200	120	0.0	None
42	No	6	■	No	200	150	0.0	None

Figure 3.12: 3D View during point numbering.

ME'scopeVES contains SDOF (single mode), MDOF (multiple modes) and Multiple Reference curve fitting methods for estimating modal parameters from experimental data. Since ME'scopeVES displays both ODS's & mode shapes, can see the differences and correlate the two. The figure 3.13 shows curves fitting of number frequency for choose number of modes. With the UMM result can be animated a plate model for getting modes shape.



Method: Modal Peaks Function

1 Modes — Single Reference

Mode	Frequency (Hz)	Damping (%)	Res Mag ((m/s^2))	Res Phs (deg)
1	792	770E-21	4.46E6	360
2	1.12E3	83.8E-21	226	360
3	1.94E3	141E-21	186	210E-18
4	2.49E3	238E-21	9.11	180
5	2.94E3	319E-21	157	169E-18

Figure 3.13: Curve fitting of number frequency

CHAPTER 4

RESULT AND DISCUSSIONS

4.1 INTRODUCTION

In this chapter, the result from the simulation and experiment will be discussed. The study was carried out using the finite element analysis (FEA) using ALGOR software and experimental analysis using impact hammer testing. There will be discussion about dynamic properties and behaviour and comparative study between experimental and numerical analysis.

4.2 RESULT OF JOINING BETWEEN ALUMINIUM ALLOY AND STAINLESS STEEL (MIG WELDING)

Joining between aluminium alloy and stainless steel is done by using metal inert gas (MIG) welding before doing the experimental modal analysis. The effect of different welding on the joint characteristics of aluminium alloy and stainless steel with MIG welding is shown in the figure 4.1 and 4.2 below. From this figure left side is stainless steel and right side is aluminium alloy. This project use metal inert gas (MIG) with welding current at 252 W and speed is 18 m/min

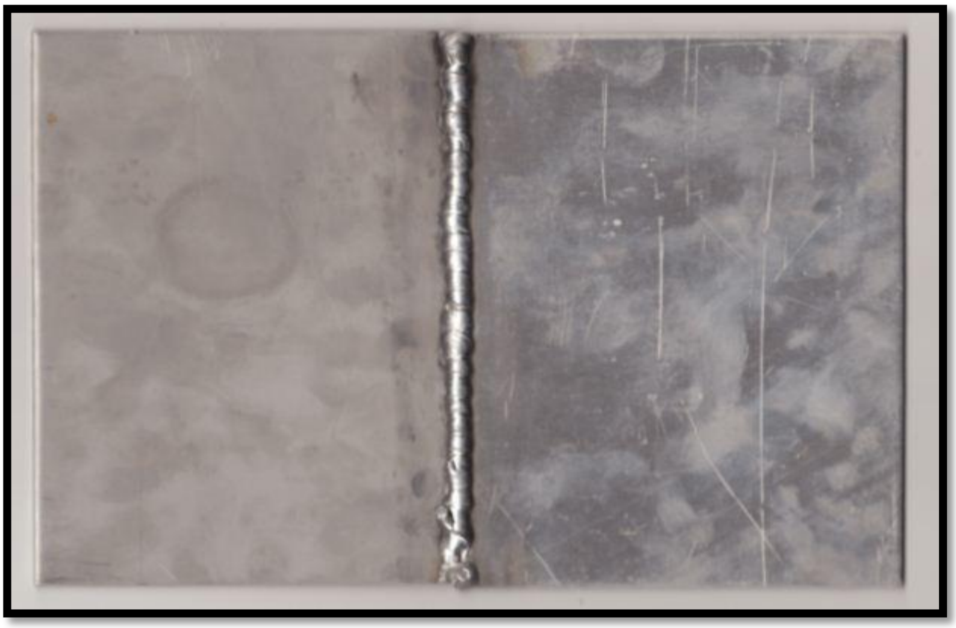


Figure 4.1: Front view of joining plate by MIG welding

Figure 4.2: Back view of joining plate by MIG welding

The figure shows the appearance of aluminium–steel butt joint made by MIG welding–brazing. The joint has a good front and back and no crack appears on the welded seam/steel interface. The flux slag carpets on the half surface of welded seam in steel side due to its low gravity and the residual flux deposits on the steel surface near the welded seam.

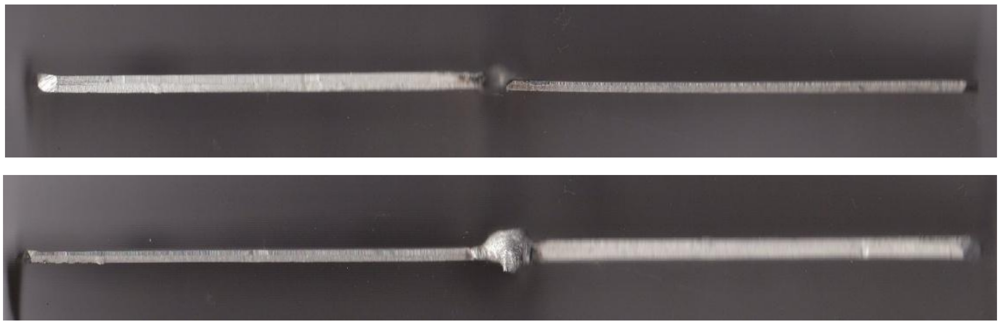


Figure 4.3: Side view of joining plate by MIG welding

Figure 4.3 show the molten steel flow and fracture occurred at the root interface seams / welded steel after welding for high heat input. The side view shows the typical cross-section of aluminium–steel butt joint. Stainless steel plate is 2mm thickness while aluminium plate is 3mm thickness. The Al–Cu filler metal spread fully on steel surface to form a sound joint. The joint has typical welding–brazing dual characteristics: in aluminium alloy side, the base metal with a low melting point is a welding joint, which mixes with the molten filler metal to form fusion area, while in a stainless steel side, the steel surface with a high melting point is a brazing joint, which reacts with the molten filler metal to form the brazing interface layer.

4.3 RESULT OF NATURAL FREQUENCY

Natural frequency was an excitation frequency that produces one exaggerated response. This is important because resonant frequency a structure will often produce adverse effects which involve excessive vibration leading to potential fatigue failures, damage to the most delicate parts of the structure or, in extreme cases, complete structural failure.

4.3.1 Natural Frequency of Finite Element Analysis (FEA)

Modal analysis is done by using ALGOR finite element analysis (FEA) to determine the natural frequency of joining aluminium alloy and stainless steel with weld bead. From the natural frequencies, resonance in the system can be neglected. Hence, it will save a lot of cost from shutting down. The table 4.1 shows the frequency, max displacement and min displacement of each mode. Range of frequency between 700Hz to 3000Hz

Table 4.1: Frequency and displacement of joining plate between stainless steel and aluminium alloy (Finite Element Analysis)

Mode	**Frequency (Hz)**	**Max. Displacement (Mm)**	**Min. Displacement (Mm)**
1	839.676	124.328	1.65487
2	1043.95	160.18	0.0475328
3	1848.8	120.59	1.17595
4	2605.52	154.576	0.715272
5	2935.05	136.549	0.474612

4.3.2 Natural Frequency Of Experimental Modal Analysis

Experimental modal analysis is done by using impact hammer testing to determine mode shape of joining aluminium alloy and stainless steel with weld by MIG welding. From the experimental analysis, a set data is collected during the impact hammer testing. The testing is made within 42 points selected at the joining plate between aluminium alloy and stainless steel which consist of 18 points of the aluminium alloy area, 18 points of the stainless steel area and 6 points at welded area. Number of points from 1 to 24 represent by the aluminium plate and point 19 to 42 represent by stainless steel plate. The table 4.2 shows Frequency and displacement of joining plate between stainless steel and aluminium alloy of each mode. Range of frequency between 700Hz to 3000Hz

Table 4.2: Frequency and displacement of joining plate between stainless steel and aluminium alloy (Experimental Modal Analysis)

Mode	Frequency (Hz)	Max. Displacement (Mm)	Min. Displacement (Mm)
1	792	216	-216
2	1120	1.3	-1.3
3	1940	1.33	-1.33
4	2490	0.0516	-0.0516
5	2940	0.666	-0.666

4.3.3 Comparison of Natural Frequency Between FEA and Experimental Modal Analysis

Table 4.3 shows natural frequencies obtained from the finite-element models and experimental modal testing by joining aluminium alloy and stainless steel with weld and the amount percent of their errors in the different cases. Mode shape 5 had the lowest percentage error while mode 2 had the highest percentage error in the result.

Table 4.3: Comparison of natural frequency analysis Between FEA and Experimental Modal Analysis

Mode Shape	Theoretical	Experimental	Error (%)
1	839.676	792	5.678
2	1043.93	1120	7.287
3	1848.8	1940	4.933
4	2605.52	2490	4.434
5	2935.05	2940	0.169

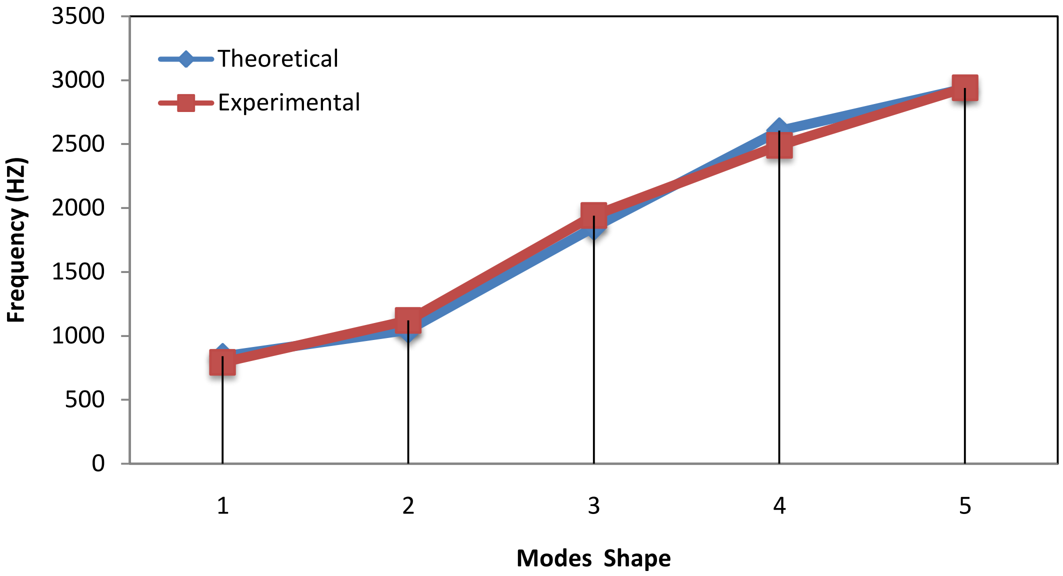


Figure 4.4: Graft of Comparison of natural frequency analysis

The graph in the figure 4.4 shows the frequency of finite element models and the experimental modal testing of the joining plate between aluminium alloy and stainless steel. Every each of the points that were tanked by the hammer show resembles the other point. This show that objects was designated with a certain natural frequency and is not slightly different from a distance, but the distance was counted from the two ends, which mean the value of frequency on one end is the same with the other end and is same with another point that is mirror to the other side.

4.4 RESULT OF MODE SHAPES

Mode shapes were deformation patterns at resonant frequencies. At these resonant frequencies take on a variety of different shapes depending on the excitation force frequency. These deformation patterns are referred to as the structure’s mode shapes.

4.4.1 Mode Shapes of ALGOR Finite Element Analysis

Modal analysis is done by using ALGOR finite element analysis (FEA) to determine mode shape of joining aluminium alloy and stainless steel with weld bead. From the mode shapes, resonance in the system can be neglected. Hence, it will save a lot of cost from shutting down. The figure shows the deformation patterns that will result when the excitation coincides with one of the natural frequencies of the system.

4.4.2 Mode Shapes of Experimental Analysis

From the experimental analysis, a set data is collected during the impact hammer testing. The testing is made within 42 points selected at the joining plate between aluminium alloy and stainless steel which consist of 18 points of the aluminium alloy area, 18 points of the stainless steel area and 6 points at welded area. Number of points from 1 to 24 represent by the aluminium plate and point 19 to 42 represent by stainless steel plate.

This pattern deformation referred to as mode shape structure. That ‘not actually perfectly corrects from the standpoint of pure mathematics but for a brief discussion here, this pattern of deformation very close to the mode shapes, from a practical point of view.

4.5 COMPARISON OF MODE SHAPES BETWEEN FEA AND EXPERIMENTAL MODAL ANALYSIS

Accelerometers distributed on the plate and measure the amplitude of the response of the plate with different excitation frequencies. The figure 4.5 shows the deformation patterns that will result when the excitation coincides with one of the natural frequencies of the system. At the first natural frequency, there is a first bending deformation pattern in the plate shown in blue (mode 1). At the second natural frequency, there is a first twisting deformation pattern in the plate shown in red (mode 2). When dwell at the third and fourth natural frequencies, the second bending and second twisting deformation patterns are seen in green (mode 3) and magenta (mode 4), respectively. These deformation patterns are referred to as the mode shapes of the structure. In this project, the result of pattern deformation in mode shape valid with Peter Avitabile, University of massachusetts Lowell.

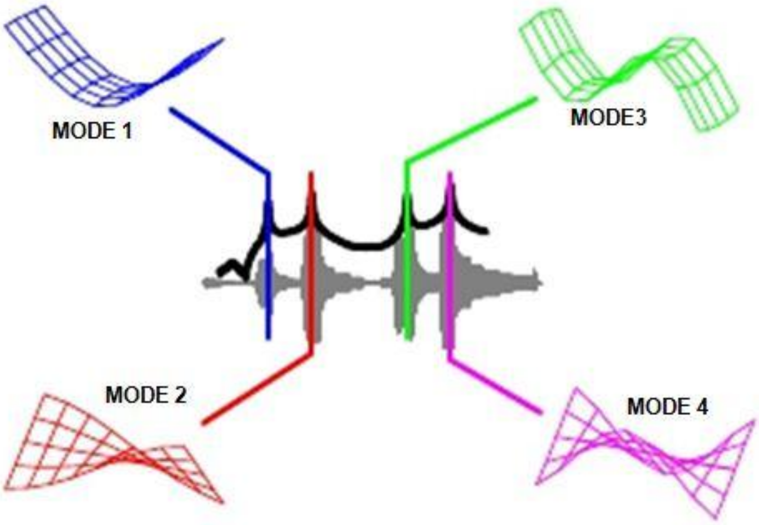
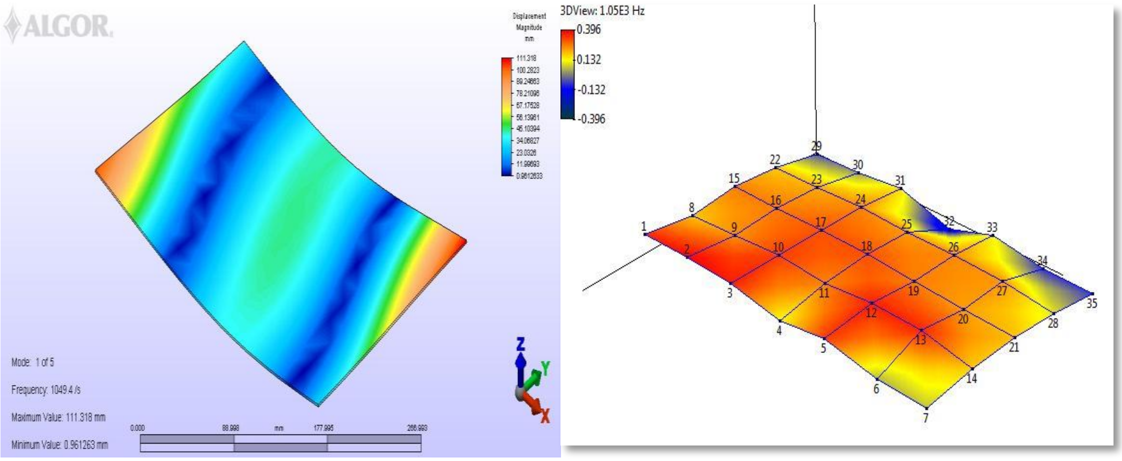


Figure 4.5: Simple plate sine dwell response

Source: modal analysis and controls laboratory
University of massachusetts lowell

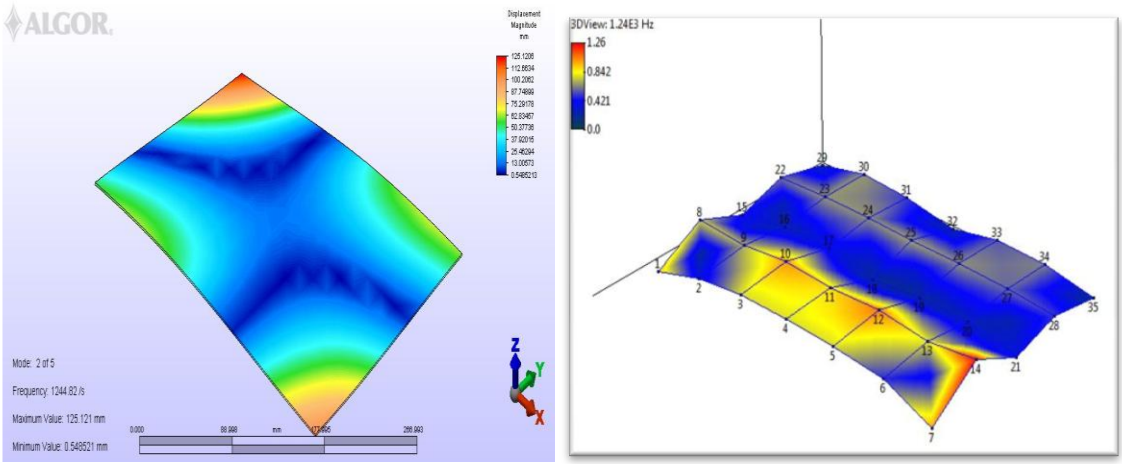
4.5.1 Result of Stainless Steel Plate



(a) (b)

Figure 4.6: First mode shape of stainless steel plate, (a) Finite element analysis, (b) Experimental modal analysis

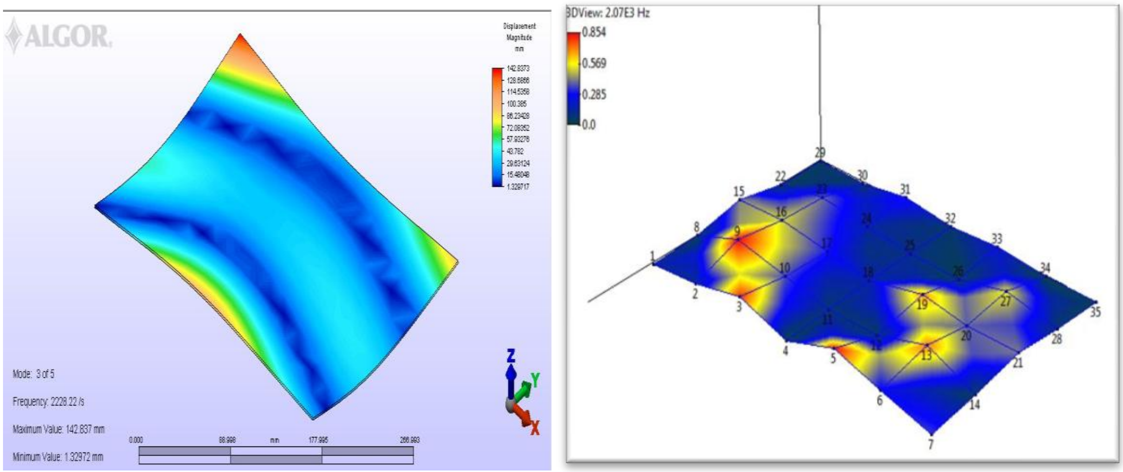
Figure 4.6 shows the first mode of stainless steel plate. The first mode is bending deformation pattern of the plate. The frequency of mode in finite element analysis (FEA) is 1049.4 Hz which the maximum shift mode is 111.31mm and minimum shift 0.961263mm. The frequency of mode in experimental modal testing is 1050 Hz which the maximum shift mode is 0.396mm and minimum shift -0.396mm.The red colour represented as the maximum displacements occur in the mode and the colour blue is a minimum shift.



(a) (b)

Figure 4.7: Second mode shape of stainless steel plate, (a) Finite element analysis, (b) Experimental modal analysis

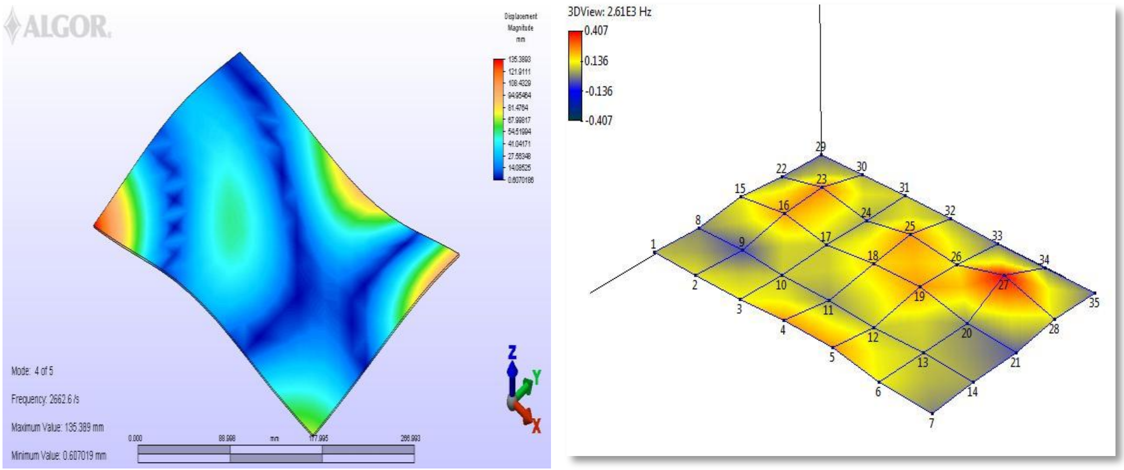
Figure 4.7 shows the second mode of stainless steel plate is twisting deformation pattern of the plate. The frequency of mode in finite element analysis (FEA) is 1244.82 Hz which the maximum shift mode is 125.121mm and minimum shift 0.548521mm. The frequency of mode in experimental modal testing is 1240 Hz which the maximum shift mode is 1.26mm and minimum shift 0mm.The red colour represented as the maximum displacements occur in the mode and the colour blue is a minimum shift.



(a) (b)

Figure 4.8: Third mode shape of stainless steel plate, (a) Finite element analysis, (b) Experimental modal analysis

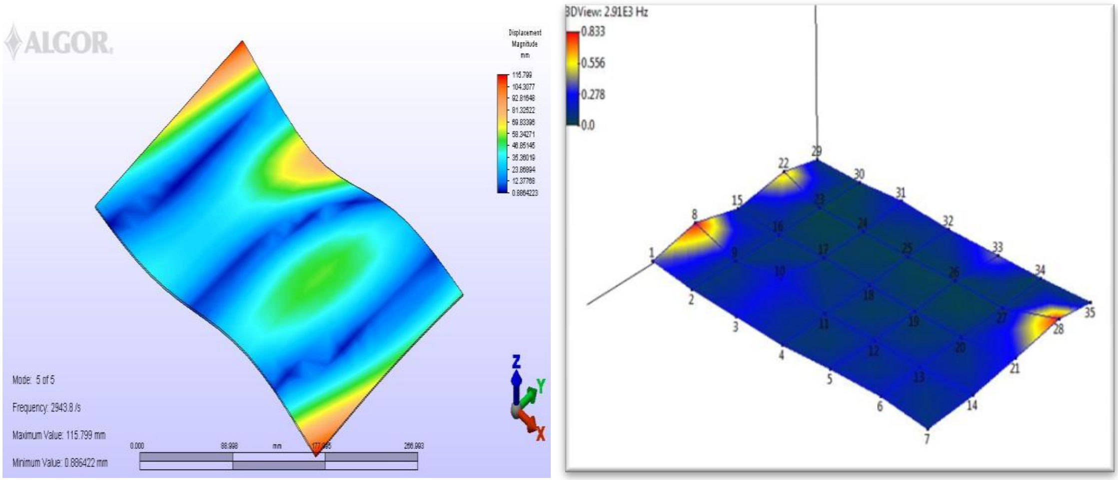
Figure 4.8 shows the third mode of stainless steel plate is bending deformation pattern of the plate. The frequency of mode in finite element analysis (FEA) is 2228.22 Hz which the maximum shift mode is 142.837mm and minimum shift 1.32972mm. The frequency of mode in experimental modal testing is 2070 Hz which the maximum shift mode is 0.854mm and minimum shift 0mm.The red colour represented as the maximum displacements occur in the mode and the colour blue is a minimum shift.



(a) (b)

Figure 4.9: Fourth mode shape of stainless steel plate, (a) Finite element analysis, (b) Experimental modal analysis

Figure 4.9 shows the fourth mode of stainless steel plate is twisting deformation pattern of the plate. The frequency of mode in finite element analysis (FEA) is 2662.6 Hz which the maximum shift mode is 135.389mm and minimum shift 0.607019mm. The frequency of mode in experimental modal testing is 2610 Hz which the maximum shift mode is 0.407mm and minimum shift -0.407mm.The red colour represented as the maximum displacements occur in the mode and the colour blue is a minimum shift.

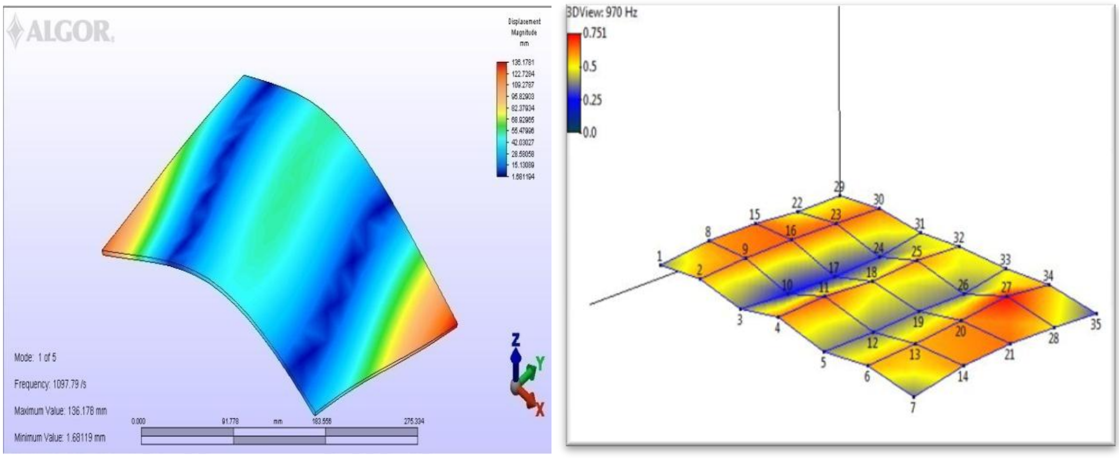


(a) (b)

Figure 4.10: Fifth mode shape of stainless steel plate, (a) Finite element analysis, (b) Experimental modal analysis

Figure 4.10 shows the fifth mode of stainless steel plate is a second bending deformation pattern of the plate. The frequency of mode in finite element analysis (FEA) is 2943.8 Hz which the maximum shift mode is 115.799mm and minimum shift 0.886422mm. The frequency of mode in experimental modal testing is 2910 Hz which the maximum shift mode is 0.833mm and minimum shift 0mm.The red colour represented as the maximum displacements occur in the mode and the colour blue is a minimum shift.

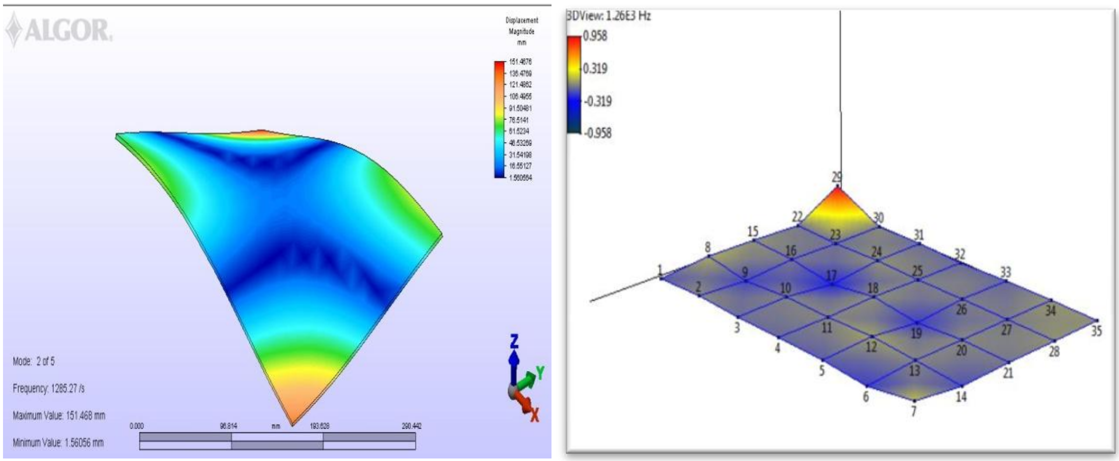
4.5.2 Result of Aluminium Alloy Plate



(a) (b)

Figure 4.11: First mode shape of aluminium alloy plate, (a) Finite element analysis, (b) Experimental modal analysis

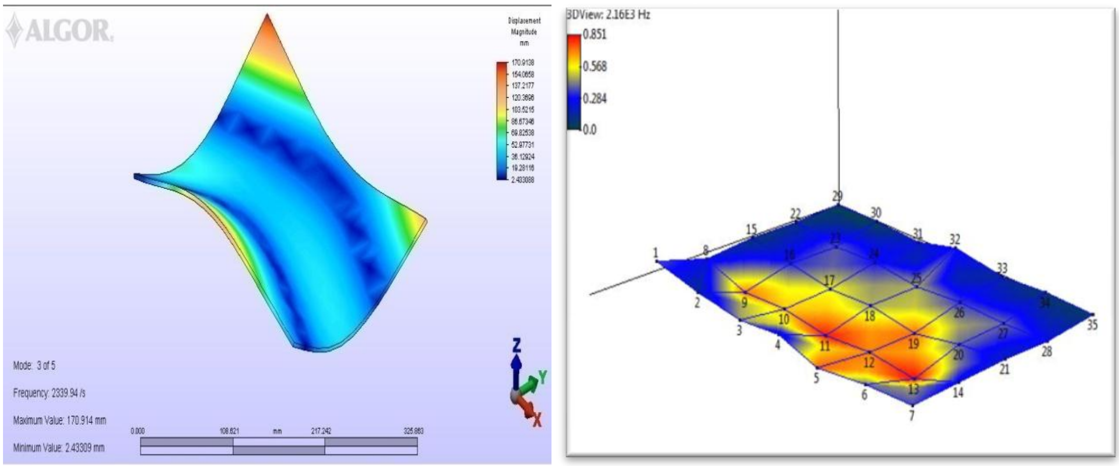
Figure 4.11 shows the first mode of aluminium alloy plate is bending deformation pattern of the plate. The frequency of mode in finite element analysis (FEA) is 1097.79 Hz which the maximum shift mode is 136.788mm and minimum shift 1.68119mm. The frequency of mode in experimental modal testing is 970 Hz which the maximum shift mode is 0.751mm and minimum shift 0mm.The red colour represented as the maximum displacements occur in the mode and the colour blue is a minimum shift.



(a) (b)

Figure 4.12: Second mode shape of aluminium alloy plate, (a) Finite element analysis, (b) Experimental modal analysis

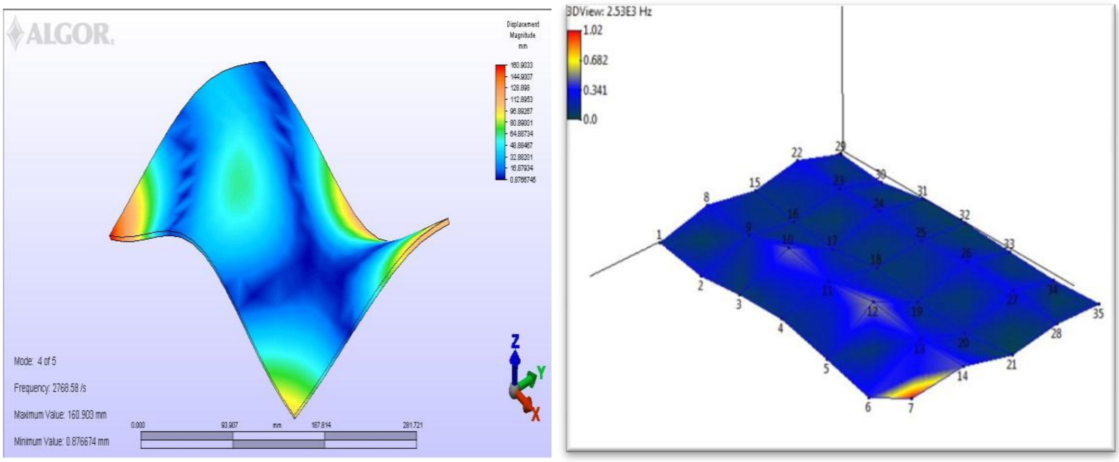
Figure 4.12 shows the first mode of aluminium alloy plate is twisting deformation pattern of the plate. The frequency of mode in finite element analysis (FEA) is 1285.27 Hz which the maximum shift mode is 151.418mm and minimum shift 1.56056mm. The frequency of mode in experimental modal testing is 1260 Hz which the maximum shift mode is 0.958mm and minimum shift -0.958mm.The red colour represented as the maximum displacements occur in the mode and the colour blue is a minimum shift.



(a) (b)

Figure 4.13: Third mode shape of aluminium alloy plate, (a) Finite element analysis, (b) Experimental modal analysis

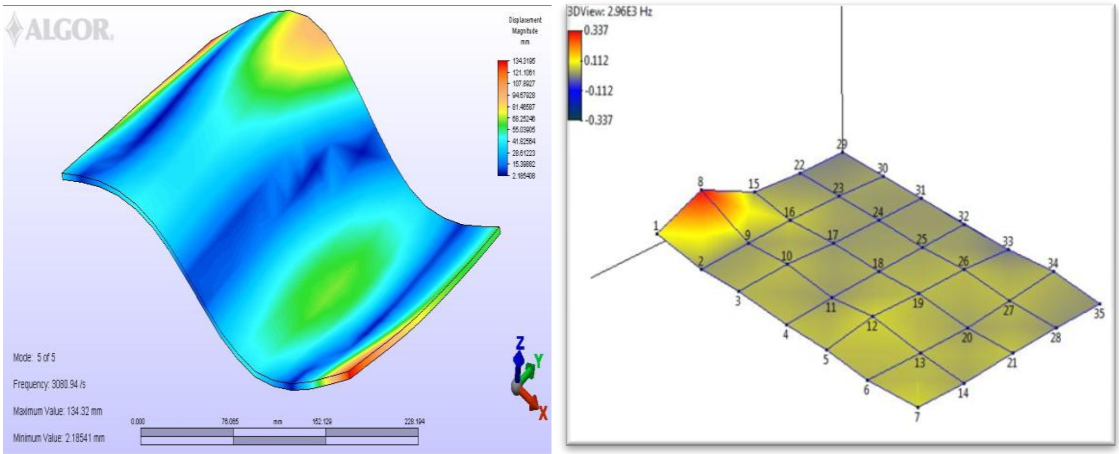
Figure 4.13 shows the third mode of aluminium alloy plate is bending deformation pattern of the plate. The frequency of mode in finite element analysis (FEA) is 2339.94 Hz which the maximum shift mode is 170.914mm and minimum shift 2.43309mm. The frequency of mode in experimental modal testing is 2160 Hz which the maximum shift mode is 0.851mm and minimum shift 0mm.The red colour represented as the maximum displacements occur in the mode and the colour blue is a minimum shift.



(a) (b)

Figure 4.14: Fourth mode shape of aluminium alloy plate, (a) Finite element analysis, (b) Experimental modal analysis

Figure 4.14 shows the fourth mode of aluminium alloy plate is second twisting deformation pattern of the plate. The frequency of mode in finite element analysis (FEA) is 2768.58 Hz which the maximum shift mode is 160.903mm and minimum shift 0.876674mm. The frequency of mode in experimental modal testing is 2530 Hz which the maximum shift mode is 1.02mm and minimum shift 0mm.The red colour represented as the maximum displacements occur in the mode and the colour blue is a minimum shift.

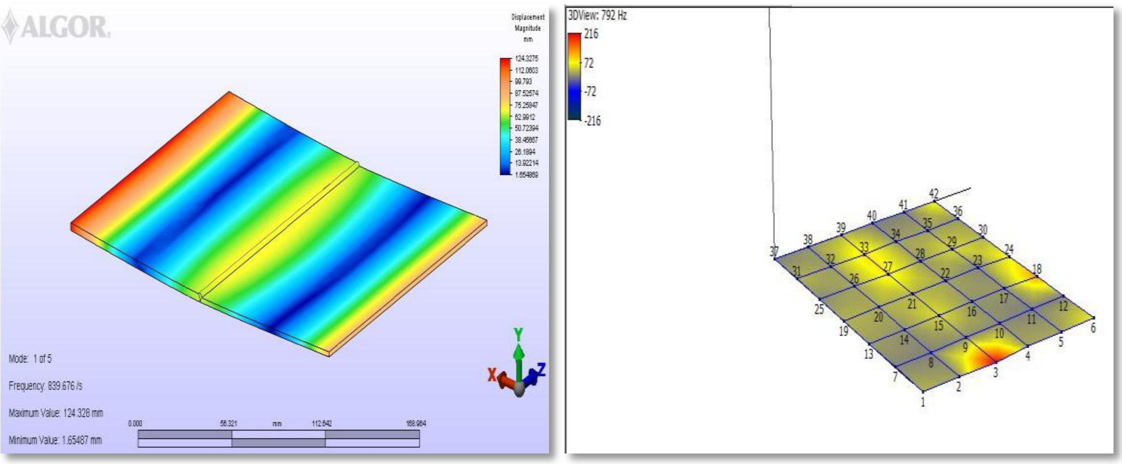


(a) (b)

Figure 4.15: Fifth mode shape of aluminium alloy plate, (a) Finite element analysis, (b) Experimental modal analysis

Figure 4.15 shows the fifth mode of aluminium alloy plate is a second bending deformation pattern of the plate. The frequency of mode in finite element analysis (FEA) is 3080.94 Hz which the maximum shift mode is 134.32mm and minimum shift 2.18541mm. The frequency of mode in experimental modal testing is 2960 Hz which the maximum shift mode is 0.337mm and minimum shift -0.337mm.The red colour represented as the maximum displacements occur in the mode and the colour blue is a minimum shift.

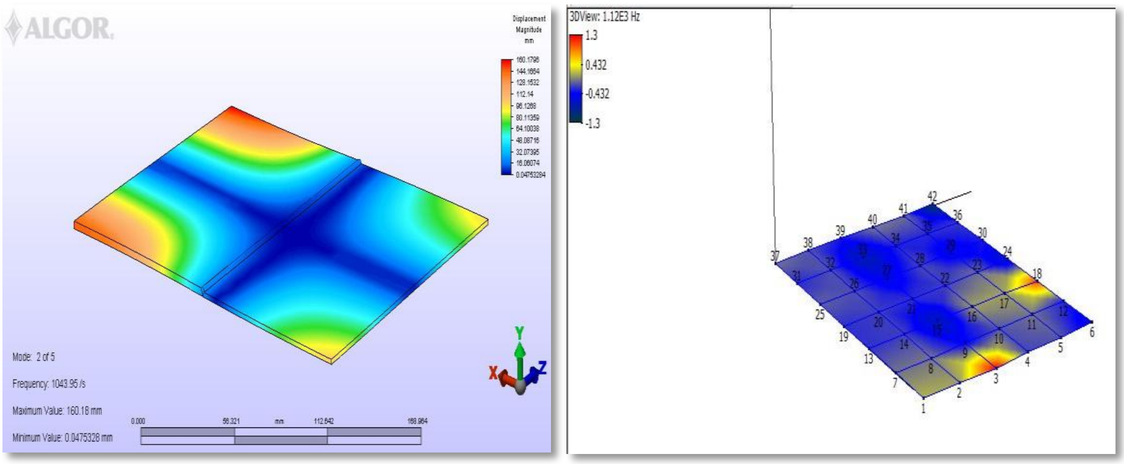
4.5.3 Result of Joining Plate between Stainless Steel and Aluminium Alloy



(a) (b)

Figure 4.16: First mode shape of joining plate by MIG welding, (a) Finite element analysis, (b) Experimental modal analysis

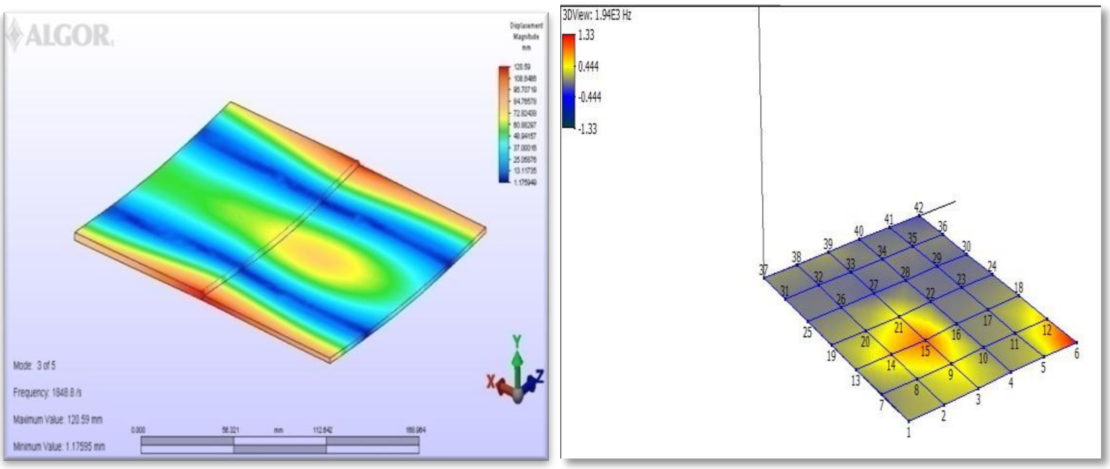
Figure 4.16 shows the first mode shape of joining aluminium alloy and stainless steel with weld, there is a first bending deformation pattern. For finite element analysis (FEA), the frequency of the mode is 839.676 Hz. The maximum displacement of the mode is 124.328 mm and minimum displacement is 1.65487mm. For experimental modal testing, the frequency of the mode is 792 Hz. The maximum displacement of the mode is 216 mm and minimum displacement is -216 mm. The red colour indicates the maximum displacement occurred in the mode and blue colour is minimum displacement.



(a) (b)

Figure 4.17: Second mode shape of joining plate by MIG welding,
(a) Finite element analysis, (b) Experimental modal analysis

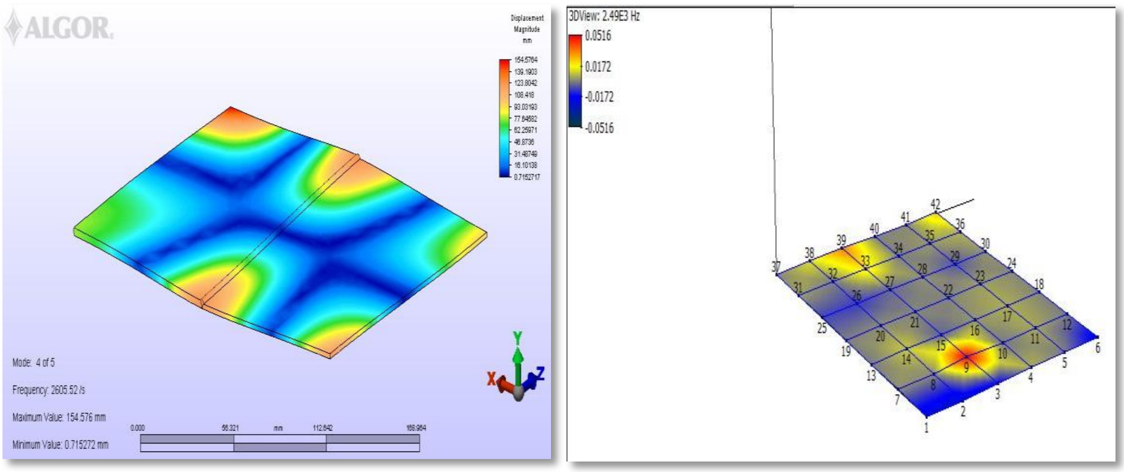
Figure 4.17 shows the second mode shape of joining aluminium alloy and stainless steel with weld, there is a first twisting deformation pattern. For finite element analysis (FEA), the frequency of the mode is 1043.95 Hz. The maximum displacement of the mode is 160.18 mm and minimum displacement is 0.0475328 mm. For experimental modal testing, the frequency of the mode is 1120 Hz. The maximum displacement of the mode is 1.3 mm and minimum displacement is -1.3 mm. The red colour indicates the maximum displacement occurred in the mode and blue colour is minimum displacement.



(a) (b)

Figure 4.18: Third mode shape of joining plate by MIG welding, (a) Finite element analysis, (b) Experimental modal analysis

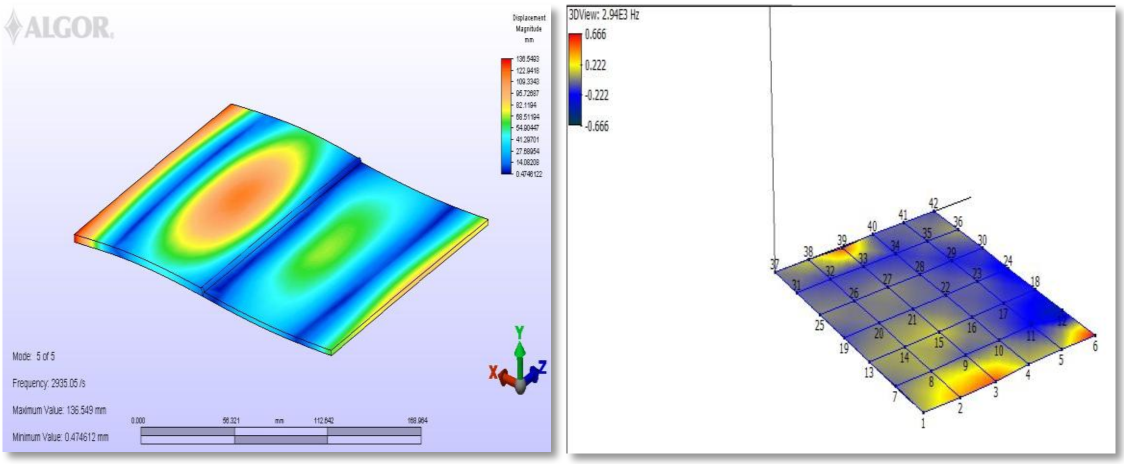
Figure 4.18 shows the third mode shape of joining aluminium alloy and stainless steel with weld, there is a first bending deformation pattern. For finite element analysis (FEA), the frequency of the mode is 1848.8 Hz. The maximum displacement of the mode is 120.59 mm and minimum displacement is 1.17595 mm. For experimental modal testing, the frequency of the mode is 1940 Hz. The maximum displacement of the mode is 1.33 mm and minimum displacement is -1.33 mm. The red colour indicates the maximum displacement occurred in the mode and blue colour is minimum displacement.



(a) (b)

Figure 4.19: Fourth mode shape of joining plate by MIG welding,
(a) Finite element analysis, (b) Experimental modal analysis

Figure 4.19 shows the fourth mode shape of joining aluminium alloy and stainless steel with weld, there is a second twisting deformation pattern. For finite element analysis (FEA), the frequency of the mode is 2605.52 Hz. The maximum displacement of the mode is 154.576 mm and minimum displacement is 0.715272 mm. For experimental modal testing, the frequency of the mode is 2490 Hz. The maximum displacement of the mode is 0.0516 mm and minimum displacement is -0.0516 mm. The red colour indicates the maximum displacement occurred in the mode and blue colour is minimum displacement.



(a) (b)

Figure 4.20: Fifth mode shape of joining plate by MIG welding,
(a) Finite element analysis, (b) Experimental modal analysis

Figure 4.20 shows the fifth mode shape of joining aluminium alloy and stainless steel with weld, there is a second bending deformation pattern. For finite element analysis (FEA), the frequency of the mode is 2935.05 Hz. The maximum displacement of the mode is 136.549 mm and minimum displacement is 0.474612 mm. For experimental modal testing, the frequency of the mode is 2940 Hz. The maximum displacement of the mode is 0.666 mm and minimum displacement is -0.666 mm. The red colour indicates the maximum displacement occurred in the mode and blue colour is minimum displacement.

4.6 DISCUSSION OF COMPARISON

The objective of modal analysis in structural mechanics is to determine the natural mode shapes and frequencies of an object or structure during free vibration. From the obtained result of this study it showed the comparison between FEA and experimental is totally different. The current result of comparison between FEA and experimental has been compared by research study from Willian S. Land II, Vibration Laboratory Modal Analysis. In research by Willian, there are some of the factors that result in two methods is different and we related this reason in this project. Finite element methods (FEM) were linear analysis which provides an act can be trusted of a variety of cases. FEM is commonly used to perform this analysis because the object being analyzed can have arbitrary shape and the results of the calculations are acceptable.

Experimental modal analysis utilizing the concept of normal mod suggestion and also is more accurate than the finite element analysis because modal analysis is a nonlinear dynamic system in which the structure of certain systems in which the focus of work is aligned. Nonlinearity is a frequent occurrence in real-life applications. Although the concept of nonlinear normal mode of vibrations is well established for general vibratory nonlinear structural systems use in structural dynamics is restricted to very particular motions. Vibration frequency region joins aluminium alloy and stainless steel by welding higher vibration frequency in the solid area because they made from different element. Medium Frequency of joining of plate is that low at the edge and of the plate’s angles because the smaller cross sectional area compared with other areas.

The frequencies of the experimental modal analysis are a bit different with the frequencies of the FEA. This general trend can be justified through the modelling of the joining plate stiffness. ALGOR FEA code assumed the ideal stiffness for the joining plate, and then applied that rigidity joining plate during virtual model. The actual joining plate stiffness vary from this assumed stiffness, and is actually not constant throughout the plate.

The percentage error levels for all the parts are within the accepted range and the high error in some of them might be referred to the boundary condition specification, because it is not easy to simulate the realistic boundary condition for such complicated system and it is impossible to imitate the perfect free boundary condition in the experiment. This condition can only be approximated in the laboratory with reasonable accuracy. Another reason that may be causing the high percentage error levels in the comparative study is the experimental modal analysis is conducted with fix condition of the joining plate between aluminium alloy and stainless steel by welding and the effect of damping which effect test rig by using polystyrene as a base of the plate while in simulation, the plate was free condition and no effect of damping. Since the condition is different, there will be a slight error in the result.

While doing the experiment, the room is also not completely silent. Even though the room is soundproofed, but the door is left open and there will be noise come from the outside by accident and affect the result of the experiment.

CHAPTER 5

CONCLUSION

5.1 INRODUCTION

This chapter will conclude the project and briefly discussed about the recommendation that can be applied in the future work. The conclusion obtained according to the result from chapter 4. In order to study the dynamic properties and behaviour of dissimilar metal joint by MIG welding using different thickness, other aspects of future work also will be discussed.

5.2 CONCLUSION

The aim of this project is to determine the dynamic properties and behaviour of dissimilar metal joint by MIG welding using different thickness using experimental modal analysis and comparison with the finite element analysis (FEA).

In this project, joining between stainless steel and aluminium alloy using MIG welding show the result is similar with result of the journal from Song et al (2009). The result shows joining between aluminium and steel by MIG, welding–brazing because different melting point. Experimental modal analysis made using joining between stainless steel and aluminium alloy to be compared with finite element analysis (FEA). Based on this study, the following conclusion can be drawn.

i. Result joining by MIG welding between aluminium alloy and stainless steel is successfully joining however at stainless steel side is brazing.

ii. Joining welding give effect to dynamic properties (mode shape) of modal analysis especially mode 1,3 (bending pattern) and mode 4 (second twisting)
iii. Comparison natural frequency shows the closeness of the result and mode shape between experimental and FEA is dissimilar.
iv. The percentage error is bit high because there are some errors occur during the experimental modal analysis. The experimental modal analysis is conducted with fix condition of the joining plate between aluminium alloy and stainless steel by welding and the effect of damping which effect test rig by using polystyrene as a base of the plate is a factors as the higher percentage error.

5.3 RECOMMENDATION

There are few improvements need to be done for the future research. This is to improve the accuracy of the predicted dynamic properties of joining between stainless steel and aluminium alloy by welding. Some of the recommendations are:

i. Use joining between stainless steel and aluminium alloy by tungsten inert gas (TIG) welding as model of modal analysis.
ii. Change filler wire aluminium 4043 two aluminium 5356
iii. The research is carried out in a completely soundproofed room and only the person doing the experiment is allowed to be in the room while doing the experiment.
iv. Plate of joining between stainless steel and aluminium alloy suspended when conducting experimental modal analysis.

REFERENCES

Aleš FRANC (2010). Heterogeneous Joints Between Steel And Aluminium Made By Modified MIG Process. 18. - 20. 5. 2010.

Alexandre Mathieua,Ã et al (2007). Dissimilar material joining using laser (Aluminium to steel using zinc-based filler wire). (2007) 652–661

Allemang, R.J., Rost, R.W., Brown, D.L.: Dual Input Estimation of Frequency Response Functions for Experimental Modal Analysis of Aircraft Structures. Proceedings, IMAC. 1982

De-Guang Shang *et.al* (2003). Effect of fatigue damage on the dynamic response frequency of spot-welded joints. 25 (2003) 311–316.

Harri Katajisto (2000). Big Wheel Modal Analysis Using FEM. July 25. 2000 Tob-Note 00. 4

Herlufsen H, Brüel & Kjær. Modal Analysis using Multi-reference and Multiple-Input Multiple-Output Techniques

Herlufsen, H.: Dual Channel FFT Analysis Part 1 & 2. Brüel & Kjær Technical Review No.1 & 2 1984. BV 0013-11 & BV 0014-11

Husain N A et al. (2009). Finite-element modelling and updating of laser spot weld joints in a top-hat structure for dynamic analysis. 10.1243/09544062JMES1787

Jiang W.C.(2011). Finite element analysis of the effect of welding heat input and layer number on residual stress in repair welds for a stainless steel clad plate. 32 (2011) 2851-2857

Kenneth A. Ramsey (1983). Experimental Modal Analysis, Structural Modifications and FEM Analysis on a Desktop Computer. February 1983

Lin S.B. et.al (2010). Brazability of dissimilar metals tungsten inert gas butt welding–brazing between aluminium alloy and stainless steel with Al–Cu filler metal. 31 (2010) 2637–2642.

Matteo Palmonella a (2005). Finite element models of spot welds in structura dynamics: review and updating. 83 (2005) 648–661

Mehdi Batel et al. Ambient Response Modal Analysis on A Plate Structure. Brüel & Kjær Sound & Vibration Measurement A/S, Denmark

Neville F. Rieger. (2003). The Relationship Between Finite Elemen Analysis And Modal Analysis. 79 (2003) 405

Niw Chang Chee And Abd Rahim Abu Bakar (2007). Finite Element Modeling Of Arc Welded Joints. *June 2007, No. 23, 15 – 30*

Peter Avitabile. Modal Analysis and Controls Laboratory Mechanical Engineering Department University of Massachusetts Lowell. Lowell, Massachusetts USA

Ramesh Kolar*a*. Modal Analysis and Damage Assessment of Cracked Plates Department of Aeronautics & Astronautics, Naval Postgraduate School, 699 Dyer Road, Bldg 234, Rm 245, Monterey, CA 93943, U.S.A.

Rattana Borrisutthekul (2010). Feasibility of using TIG welding in dissimilar metal between steel/aluminium alloys. 82-86, 2010

Song J.L. (2009). Spreading behaviour and microstructure characteristics of dissimilar metals TIG welding–brazing of aluminium alloy to stainless steel. A 509 (2009) 31–40.

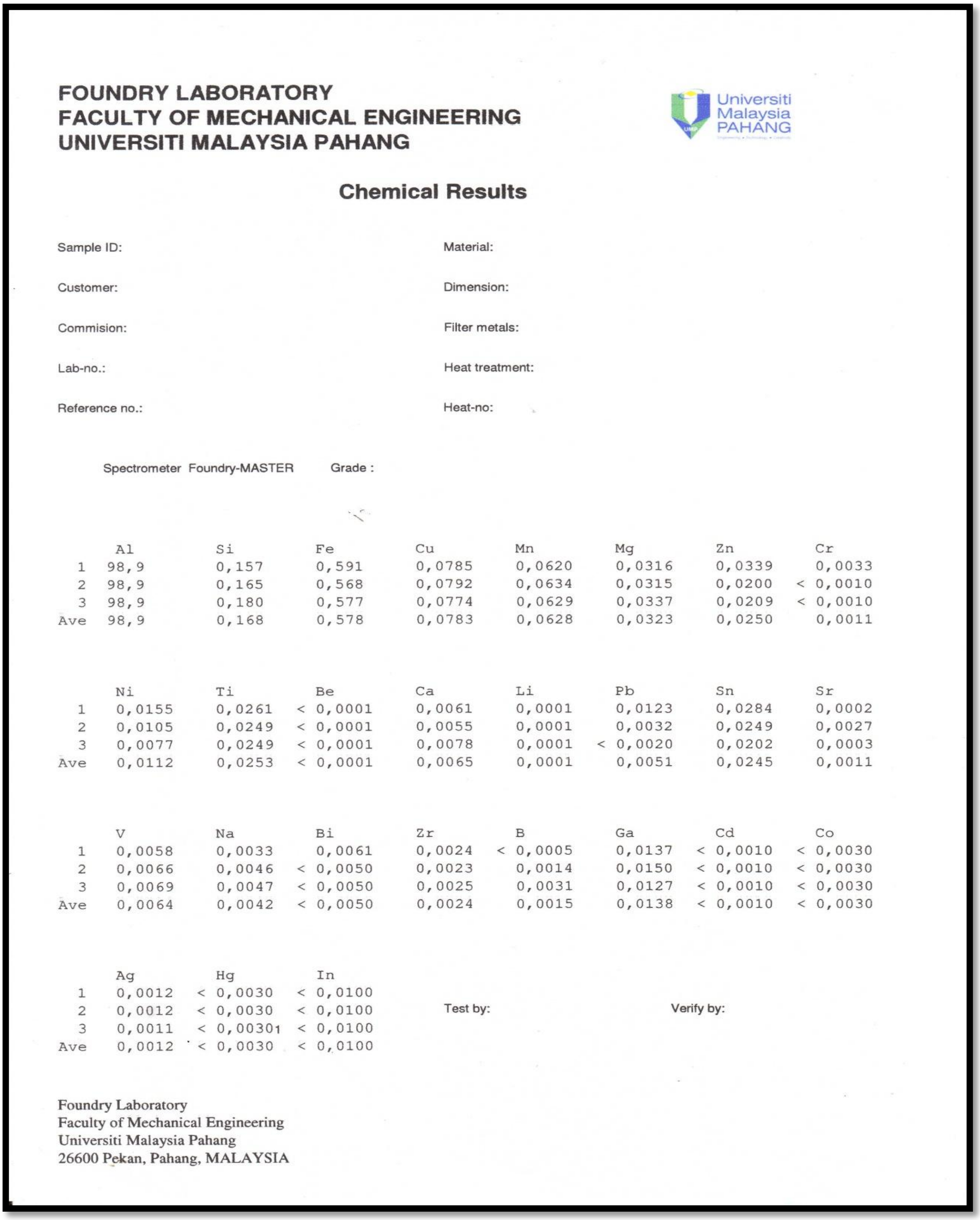
Sun X. and M. A. Khaleel (2004). Resistance Spot Welding of Aluminum Alloy to Steel with Transition Material —Part II: Finite Element Analyses of Nugget Growth. July 2004

Thomy C and F Vollertsen. (2009). Laser-MIG Hybrid Welding Of Aluminium To Steel - Effect Of Process Parameters On Joint Properties. XII-1958-09

Willian S. Land II (2010). Vibration Laboratory Lab Report Modal Analysis.18.11.2010.

APPENDIX A1

CHEMICAL COMPOSITION OF THE ALUMINIUM ALLOY 1100 H14 SHEETS



FOUNDRY LABORATORY
FACULTY OF MECHANICAL ENGINEERING
UNIVERSITI MALAYSIA PAHANG

Chemical Results

Sample ID:

Material:

Customer:

Dimension:

Commision:

Filter metals:

Lab-no.:

Heat treatment:

Reference no.:

Heat-no:

Spectrometer Foundry-MASTER Grade :

	Al	Si	Fe	Cu	Mn	Mg	Zn	Cr
1	98,9	0,157	0,591	0,0785	0,0620	0,0316	0,0339	0,0033
2	98,9	0,165	0,568	0,0792	0,0634	0,0315	0,0200	< 0,0010
3	98,9	0,180	0,577	0,0774	0,0629	0,0337	0,0209	< 0,0010
Ave	98,9	0,168	0,578	0,0783	0,0628	0,0323	0,0250	0,0011

	Ni	Ti	Be	Ca	Li	Pb	Sn	Sr
1	0,0155	0,0261	< 0,0001	0,0061	0,0001	0,0123	0,0284	0,0002
2	0,0105	0,0249	< 0,0001	0,0055	0,0001	0,0032	0,0249	0,0027
3	0,0077	0,0249	< 0,0001	0,0078	0,0001	< 0,0020	0,0202	0,0003
Ave	0,0112	0,0253	< 0,0001	0,0065	0,0001	0,0051	0,0245	0,0011

	V	Na	Bi	Zr	B	Ga	Cd	Co
1	0,0058	0,0033	0,0061	0,0024	< 0,0005	0,0137	< 0,0010	< 0,0030
2	0,0066	0,0046	< 0,0050	0,0023	0,0014	0,0150	< 0,0010	< 0,0030
3	0,0069	0,0047	< 0,0050	0,0025	0,0031	0,0127	< 0,0010	< 0,0030
Ave	0,0064	0,0042	< 0,0050	0,0024	0,0015	0,0138	< 0,0010	< 0,0030

	Ag	Hg	In
1	0,0012	< 0,0030	< 0,0100
2	0,0012	< 0,0030	< 0,0100
3	0,0011	< 0,0030	< 0,0100
Ave	0,0012	< 0,0030	< 0,0100

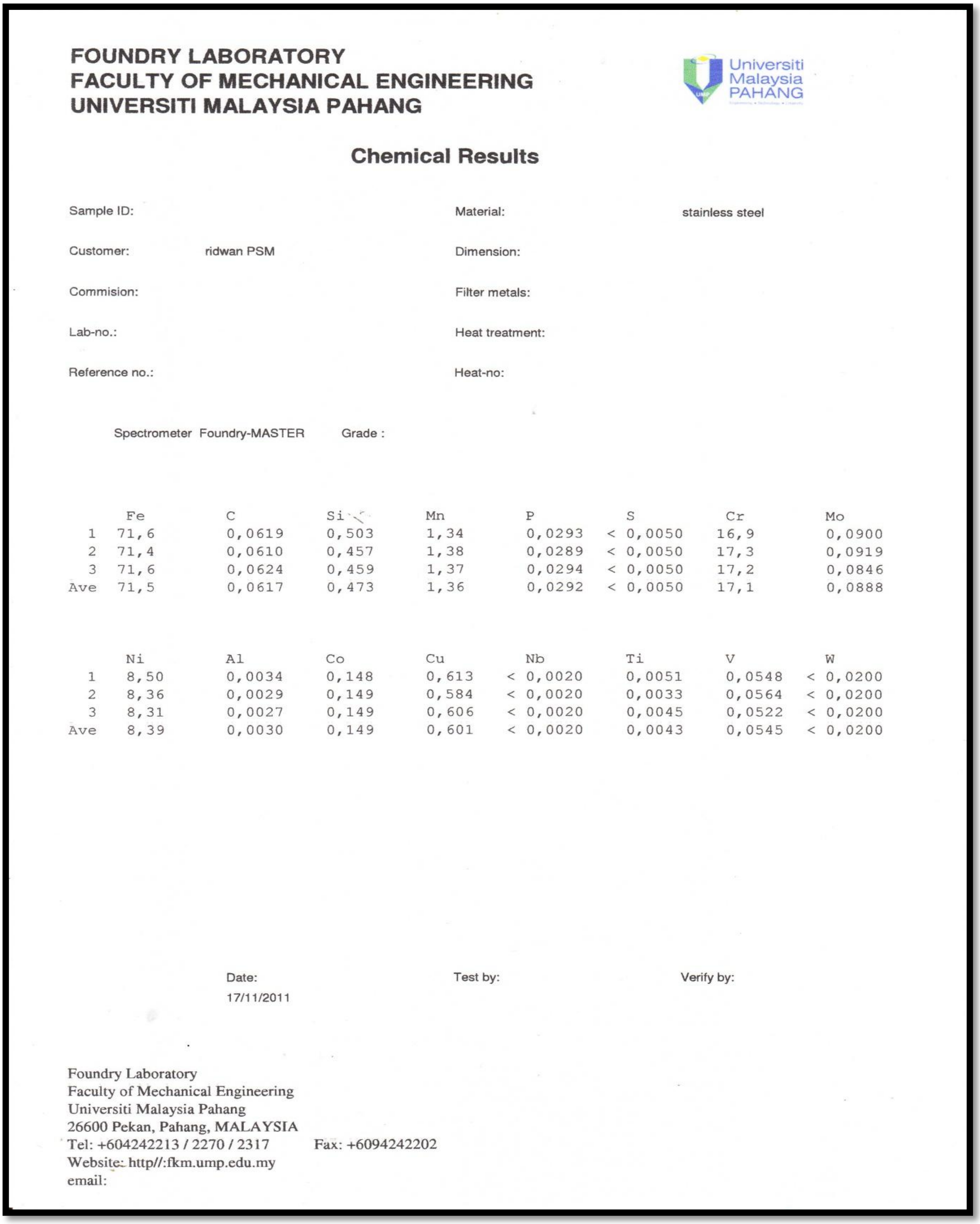
Test by:

Verify by:

Foundry Laboratory
Faculty of Mechanical Engineering
Universiti Malaysia Pahang
26600 Pekan, Pahang, MALAYSIA

APPENDIX A2

CHEMICAL COMPOSITION OF THE STAINLESS STEEL AISI 304 SHEETS



FOUNDRY LABORATORY
FACULTY OF MECHANICAL ENGINEERING
UNIVERSITI MALAYSIA PAHANG

Chemical Results

Sample ID:		Material:	stainless steel
Customer:	ridwan PSM	Dimension:	
Commision:		Filter metals:	
Lab-no.:		Heat treatment:	
Reference no.:		Heat-no:	

Spectrometer Foundry-MASTER Grade :

	Fe	C	Si	Mn	P	S	Cr	Mo
1	71,6	0,0619	0,503	1,34	0,0293	< 0,0050	16,9	0,0900
2	71,4	0,0610	0,457	1,38	0,0289	< 0,0050	17,3	0,0919
3	71,6	0,0624	0,459	1,37	0,0294	< 0,0050	17,2	0,0846
Ave	71,5	0,0617	0,473	1,36	0,0292	< 0,0050	17,1	0,0888

	Ni	Al	Co	Cu	Nb	Ti	V	W
1	8,50	0,0034	0,148	0,613	< 0,0020	0,0051	0,0548	< 0,0200
2	8,36	0,0029	0,149	0,584	< 0,0020	0,0033	0,0564	< 0,0200
3	8,31	0,0027	0,149	0,606	< 0,0020	0,0045	0,0522	< 0,0200
Ave	8,39	0,0030	0,149	0,601	< 0,0020	0,0043	0,0545	< 0,0200

Date: 17/11/2011	Test by:	Verify by:

Foundry Laboratory
Faculty of Mechanical Engineering
Universiti Malaysia Pahang
26600 Pekan, Pahang, MALAYSIA
Tel: +604242213 / 2270 / 2317 Fax: +6094242202
Website: http//:fkm.ump.edu.my
email: