UNIVERSITI MALAYSIA PAHANG

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JUDUL: MODAL ANALYSIS OF DISSIMILAR METAL (STEEL AND ALUMINIUM) JOINT BY SPOT WELDING

SESI PENGAJIAN: 2012/2013

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MODAL ANALYSIS OF DISSIMILAR METAL (STEEL AND ALUMINIUM) JOINT BY SPOT WLEDING

MOHD FADHLI BIN CHE ISMAIL

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

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FACULTY OF MECHANICAL ENGINEERING

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Dedicated to my father, Mr. Che Ismail bin Abd Rahman, my beloved mother, Mrs. Norashikin binti Ismail, and last but not least to all my fellow friends

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ABSTRACT

This project report deals with dynamic behaviour of joining between stainless steel and aluminium alloy by Spot welding using theoretical and experimental analysis method. The structural three-dimensional solid modelling of joining between stainless steel and aluminium alloy by welding was developed using the drawing software. The finite element model of the components was analysed 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 Spot 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. Experimental operating deflection shape also conducted and compare with calculation method to get a dominant mode shape when 53.3 Hz will give. Mode one show a dominant mode in ods. The result shows joining between aluminium and steel by Spot drawn to welding–brazing because of their difference in melting point and the natural frequency comparison shows the closeness of the result between experimental modal analysis and FEA.

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. Pemodelan struktur tiga-dimensi spiral wound gasket dilukis menggunakan perisian melukis. 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 Spot 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. Eksperimen bentuk pesongan operasi dijalankan dan di bandingkan dengan keputusan cara pengiraan untuk mendapatkan bentuk mod yang dominan apabila 53.3 Hz dikenakan. Mod pertama menunjukkan mod dominan apabila menbuat eksperimen bentuk pesongan. Hasil menunjukkan antara aluminium dan keluli oleh Spot tertarik dengan kimpalan pateri kerana perbezaan mereka dalam takat lebur dan perbandingan kekerapan semula jadi menunjukkan keakraban antara hasil analisis eksperimen modal dan FEA

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LIST OF SYMBOLS

ºC	Degree Celsius
Psi	Pounds per Square Inch
w	Watt
A	Ampere
mm	Millimetre
min	Minute
N	Newton
%	Per cent
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

RSW	Resistance Spot Welding
IMC	Intermetallic Compounds
NVH	Noise, 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
2D	Two Dimensional
3D	Three Dimensional
ASCII	American Standard Code for Information Interchange
SI	International System of Units
Br	Magnitude transfer function
Xr	Respond for spatial (couple)
Xpr	Respond in modal
Qpr	Force for modal
Q	Force

CHAPTER 1

INTRODUCTION

1.1 GENERAL INTRODUCTION

Steel and aluminium are the most important construction materials for the mass production of today's automotive structures. It is well known that metallurgical bonds between aluminium and steel are difficult to achieve with fusion welding because of the inherent discrepancies in electrical, thermal, and mechanical properties between the two materials. For fusion welding processes such as direct resistance spot welding (RSW), little or no mutual solubility of aluminium and steel exists. The most common application of spot welding is in the automobile industry used to weld the sheet metal form a body car and other parts.

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

1.2 PROJECT OBJECTIVE

The purpose of this research is to study the dynamic properties and behaviour of dissimilar metal (Steel and Aluminium) joint by spot welding using modal analysis and comparison with the finite element analysis.

1.3 PROJECT SCOPE

This project focuses on the following points:

i. Welding dissimilar metal with different thickness.
ii. The specimen product metal is created using SOLIDWORK.
iii. The theoretical data for dynamic analysis using FEA will be taken.
iv. To develop FEA analytical simulation method and experimental modal analysis to compare the result
v. Check dominant mode shape using Operating Deflection Shape

1.4 PROBLEM STATEMENT

Hybrid structures of aluminium alloy to stainless steel are suggested in spacecraft, airplane and automotive to improve the fuel efficiency, increase the fly range by reducing weight. Therefore, it is receiving a remarkable attention to joining aluminium alloy and stainless steel together. However, aluminium and steel are not compatible metals as far as fusion welding. Modal analysis was 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 spot 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.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents the review of the modal analysis of dissimilar metal (steel and aluminium) joint by using spot welding. This chapter begins with general review of processes by given a simple definition of the key terms and, the importance and to make a modal testing. Reviews of some of the previous works that are similar and related to this study are discussed in this chapter.

2.2 BASIC VIBRATION THEORY

Any system has certain characteristics that must be met before it will vibrate. In simple words, each system has a stable position in which all teams are equal, and when this balance is disturbed, the system will try to regain a stable position. To maintain a stable, vibration exhibits structure at different magnitudes when excited, the vibration varies from point to point (node to node), due to changes in the structure and dynamic response of the external force applied. Therefore, the vibration can also be described as the physical manifestation of the exchange between kinetic and potential energy (Silva, 2005).

All vibration is a combination of both forced and resonant vibration. Forced vibration can be due to,

· Internally generated forces.
· Unbalances.
· External loads.
· Ambient excitation.

Resonant vibration occurs when one or more of the resonances or natural modes of vibration of a machine or structure is excited. Resonant vibration typically amplifies the vibration response far beyond the level deflection, stress, and strain caused by static loading (Schwarz B.J and Richardson M.H, 1999)

2.3 MODAL TESTING

Modal testing is a formalized method for identification of natural frequencies and mode shapes of structures. It utilizes dedicated modal test equipment, and requires a formalized procedure for disturbing, e.g., rapping, the structure into motion, and then recording the distribution of the resulting motions throughout the structure. The end results of a modal test are the various natural frequencies, mode shapes, and impedance data of the structure. These data are identified from the digitized input signals using efficient curve-fitting routines. The results are subsequently displayed as impedance plots and mode shapes. (Rieger N.F, 2003)

Modal testing is used to rapidly identify these modes and their natural frequencies, and to provide the structural matrices, which govern the modes and natural frequencies. The advantages of modal analysis that are a modal test provides the most rapid and effective procedure available for the acquisition of data on the dynamic properties of a structure. Second advantage, modal analysis is an effective analytical procedure for the solution of large sets of structural dynamics equations because it reduces coupled matrix equations to a set of independent linear equations. Modal solutions can therefore be obtained directly, without further numerical operations. These solutions are then re-combined to form the complete solution to the structural response problem in question. It should here be noted that solutions to harmonic, transient, and random forced vibration problems can all be obtained using this modal analytical procedure. (Rieger N.F, 2003)

According (Rieger N.F, 2003), the output from modal testing consists of natural frequencies, mode shapes, modal stiffness, modal damping, and modal mass matrices. The main assumption involved in the acquisition of this information is that the structural system is linear, i.e., structural displacements are directly proportional to applied loads. In practical structures this condition is not always met. Structural systems may be non-linear to some degree, due to those causes listed below. Nonlinearities complicate the extraction of modal data and, where their effect is strong; they may invalidate the results obtained by linear analysis. Non-linear effects may be present in a structural system due to several causes:

i. The material properties may be non-linear, e.g., composite structures, viscoelastic materials, elastic-plastic materials, where displacement is non-linearly related to force.

ii. Where large amplitudes are involved, the geometry may result in displacements, which are non-linearly related to load, e.g., large deflections of plate and shell-type structures.

iii. The structural boundary conditions may introduce nonlinearities, e.g., structures where the number of support points changes, or where the structure is a rotor mounted in fluid-film bearings experiencing relatively large whirl amplitudes.

Another limitation of modal testing is that it cannot, by itself, predict threshold conditions for structural stability problems, such as structural buckling, and rotor whirl stability in fluid-film bearings.

Again, the modal test structural matrix data from such problems can be developed for subsequent (linear) finite element analysis, such as the prediction of stability threshold conditions. However, the nonlinear limitation again applies to the post- threshold behaviour of such structures. Following the development of an unstable condition, e.g., buckling or rotor whirl, the structure characteristically undergoes large displacements until a new equilibrium condition is found. Such behaviour may be highly non-linear, and so beyond the capabilities of modal analysis, and of the structural matrices developed by modal testing. (Rieger N.F, 2003)

2.3.1 Parameters of Modal Testing

The parameters that describe each mode are:

i. natural frequency or resonance frequency
ii. (modal) damping
iii. 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. In addition, the model can subsequently be used to come up with possible solutions to individual problems. The modal parameters can be extracted from a set of Frequency Response Function (FRF) measurements between one or more reference positions and a number of measurement positions required in the model. A position is a point and a direction on the structure and is hereafter called a Degree of Freedom (DOF). The resonance frequencies and damping values can be found from any of the FRF measurements on the structure (except those for which the excitation or response DOF is in a nodal position, that is, where the mode shape is zero). These two modal parameters are therefore called ‘Global Parameters’. To accurately model the associated mode shape, frequency response measurements must be made over a sufficient number of DOFs to ensure enough detailed coverage of the structure under test. The extraction of the modal parameters from the FRFs can be done using a variety of mathematical curve-fitting algorithms. In order to calibrate (scale) the modal model, the driving-point measurement, the measurement where the excitation and the response is in the same DOF, needs to be included. (Herlufsen .H, Denmark)

2.4 WELDING

Aluminium and steel joined by fusion welding is difficult because the compound is a mixture of two compounds form a brittle intermetallic compounds (IMCs) in the joints. To control the formation of the IMC layer, the shape and size of the joint is very important. Joints have two features: the base, aluminium alloy metal with low melting weld together, mixed with molten filler metal to form a weld joint, while steel is a metal surface with a high melting point solder, which acts as the reaction with the filler metal liquid to form a solder layer interface formed solder joints. (Lin et al., 2009)

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

2.4.1 Consideration of Welding

i. Size installation: For a large gathering, welding is a more appropriate method. Larger gatherings require high heat during solder heating requires less heat, making it difficult to reach the required temperature filler metal flow.

ii. Thickness: To participate in a thin sheet, solder has the advantage of high heat such as welding can wrap or burn through that section. Instead, solder can help to avoid distortion.

iii. Form joints: more welding saves time and cost. In addition, the solder just as easily draw the filler metal into the weld configuration straight, curved or irregular.

iv. Type of material: welding solder soundly beats when joining dissimilar metals. As long as the filler material is compatible with both the base metal and melts at a lower temperature, solder 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.

2.5 SPOT WELDING

Resistance spot welding is one of the oldest electric welding processes in use by industry today, especially in the automotive industry. Welds made by a combination of heat, pressure, and time. As the name resistance welding implies, it is the resistance of the material to be welded to current flow causes localized heating in parts. The pressure exerted by the tongs and electrode tips, in which the current flows, holds the parts to be welded in intimate relationships before, during, and after the welding cycle. The amount needed during the course of time in the joint is determined by the thickness and type of material, the total running time, and the cross sectional area of the surface of the welding contact tip. (Handbook for Resistance Spot Welding, 2012)

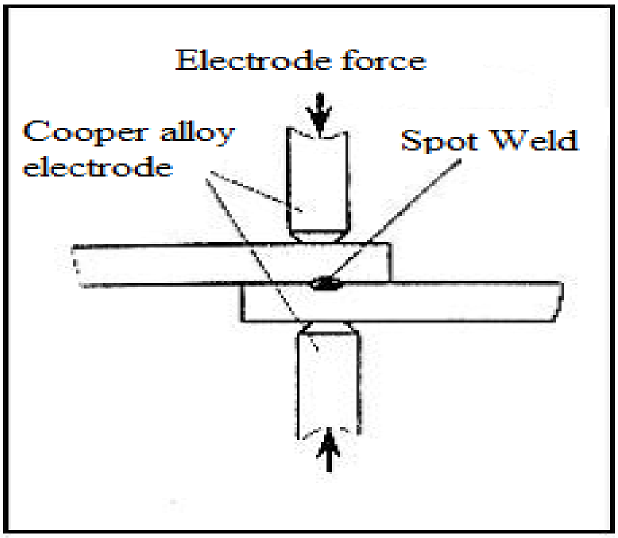


Figure 2.1: Schematic view of the spot welding process

Source: Thakur et al., (2010)

2.5.1 Principles of Spot Welding

Resistance welding is accomplished when current is caused to flow through electrode tips and the separate pieces of metal to be joined. The resistance of the base metal to electrical current flow causes localized heating in the joint, and the weld is made. The resistance spot weld is unique because the actual weld nugget is formed internally in relation to the surface of the base metal. (Handbook for Resistance Spot Welding, 2012)

In the spot welding process, two or three overlapped or stacked stamped components are welded together as a result of the heat created by electrical resistance. This is provided by the work pieces as they are weld together under pressure between two electrodes. Spot welding may be performed manually, robotically or by a dedicated spot welding machine. The similar spot welds having same property can be obtained in high production speeds by controlling welding current, electrode force and weld time automatically.

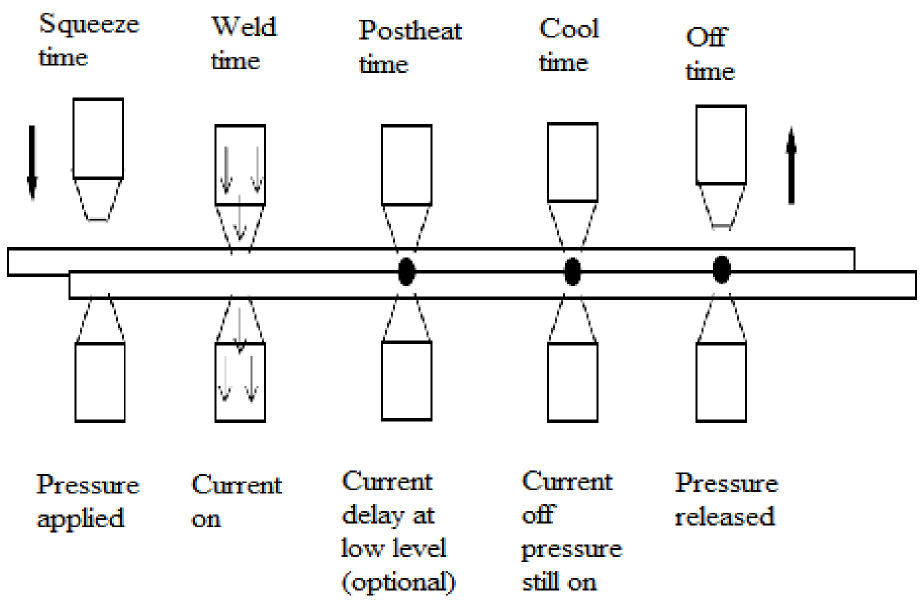


Figure 2.2: Cycle of Spot Welding

Source : (Walther Jenis 2009)

The processes in resistance spot welding have 5 cycle process as shown in the Figure 2.2. The first cycle is the squeeze time, where pressure from the electrode force is applied to the work piece. The second cycle is weld time, this process where the current is on and the welding current is applied in the metal sheets to melt the sheet metal for the welding process. Then, post heat time, the current delay at the low level. The fourth cycle is cool time. This cycle allow the melt nugget diameter to solidify before the releasing the welded parts and lastly the off time cycle, the electrode force applied on the sheets metal is released the welding process is done.

There are six major points of resistance in the work area. They are as follows:

i. The contact point between the electrode and top work piece.
ii. The top work piece.
iii. The interface of the top and bottom work pieces.
iv. The bottom work piece.
v. The contact point between the bottom work piece and the electrode.
vi. Resistance of electrode tips.

2.5.2 Advantages of Spot Welding

Spot welding is quick and easy. There is no need to use any fluxes or filler metal to create a join by spot welding, and there is no dangerous open flame. Spot welding can be performed without any special skill. Automated machines can spot weld in factories to speed up production. The machines used in car factories produce as many as 200 spot welds in six seconds. Spot welding can be used to join many different metals, and can join different types to each other. Sheets as thin as 1/4 inch can be spot welded and multiple sheets may be joined together at the same time. (Ambroziak A. and Korzeniowsk M., 2010)

2.5.3 Disadvantages of Spot Welding.

The electrodes have to be able to reach both sides of the pieces of metal that are being joined together. A particular spot welding machine will be able to hold only a certain thickness of metal--usually 5 to 50 inches--and although the position of the electrodes can be adjusted, there will be only a limited amount of movement in most electrode holders.

The size and shapes of the electrodes will determine the size and strength of the weld. The join forms only at the spot where the electrodes are in contact with the metal. If the current is not strong enough, hot enough or the metal is not held together with enough force, the spot weld may be small or weak.

Warping and a loss of fatigue strength can occur around the point where metal has been spot welded. The appearance of the join is often rather ugly, and there can be cracks. The metal may also become less resistant to corrosion. (Ambroziak A. and Korzeniowsk M., 2010).

2.6 MATERIAL

2.6.1 Aluminium Alloy 1100

Aluminium alloy 1100 contains at least 99% aluminium. It has excellent 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 normal to all aluminium alloys. Pieces of aluminium alloys have moderate strength and light weight. Aluminium alloy 1100 can be welded by gas welded or resistance welded, but the resulting joints are not strong or corrosion resistant as the inert gas welded joints. (Austral Bronze Crane Copper Limited, 2005)

According (Beneke Wire Company) it has at least 99.0% of aluminium, not heat treated alloy also known as commercially pure aluminium. This alloy combines excellent formability and corrosion resistance is very high to be used in many applications where high strength is not required. These alloys can be used in most any climate anywhere without worry. Anodizing very good finish can be obtained, especially with special finishes listed below.

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.Class austenitic stainless steel is generally considered be weld able by the common fusion and resistance techniques. Special consideration is required to avoid weld "hot cracking" to ensure the formation of ferrite in the weld deposit. Type 304 and 304L are generally considered to be most common alloy is class steel.

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

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.

In order to use the FEM model with confidence, it has been found necessary to verify the accuracy of the model by comparing the modal parameters (frequency, damping and mode shapes) are predicted by the model cap parameters identified by actually testing the structure. In fact, most progress in experimental modal test comes from demand to verify the accuracy of FEM model. (Ramsey K.A., 1983)

Finite element analysis used in this manner provides the dynamic properties of structures, including mode shapes and corresponding natural frequencies. (Rieger N.F. 2003). 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. (Rieger N.F. 2003). According to Ramsey (1983), the advantage of finite element is

i. The model can be “built and used before any prototype hardware is available.
ii. The model can predict a structure’s behaviour under real world dynamic operating conditions.
iii. An engineer can analytically modify the structure (via the FEM model) much cheaper, faster and easier than he can change actual hardware.

2.7.2 Disadvantages of Finite Element Analysis

Although the problem of linear structural dynamics may now complete accurately and economically, it is still expensive to solve most non-linear problems. Problem of repetitive geometry is quite common, for example, bladed turbo machinery structures, axisymmetric structure, the structure of the building, and many types of rotating machinery. Geometric often closes on its own structure ('ring' structure). Total structure matrix is still symmetric and three diagonal, but the dynamic matrix contains off-diagonal elements, which can significantly increase local bandwidth matrix. This causes a corresponding increase in computational time. Efficient Calculation of recurrent components have been implemented by a special finite difference procedure. (Rieger N.F. 2003). According to Ramsey (1983), the disadvantage of finite element is

i. FEM models can be very difficult and expensive to "build."
ii. Modelling is generally done by a skilled dynamics because of the complexities of the available FEM codes.
iii. A model can be, and indeed is often inaccurate.
iv. Models can be expensive to run, depending on the size of the model. They may also require a large computer for operation.
v. Many implementations because a user to wait hours before either plotted or printed results are available.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

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

This study begins with the problem statement, the project objectives, scopes, and literature review on previous work on joining by spot welding and modal analysis. After collect the information, the model of sheet metal joining by Spot welding is a sketch using SOLIDWORK software. Then a simulation is conducted to observe the dynamic properties of sheet metal joining by Spot welding such as natural frequency and mode shape. In this project, the simulation is performed using ANSYS Finite Element Analysis software. After that, joining between stainless steel and aluminium alloy by Spot 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 spot welding.

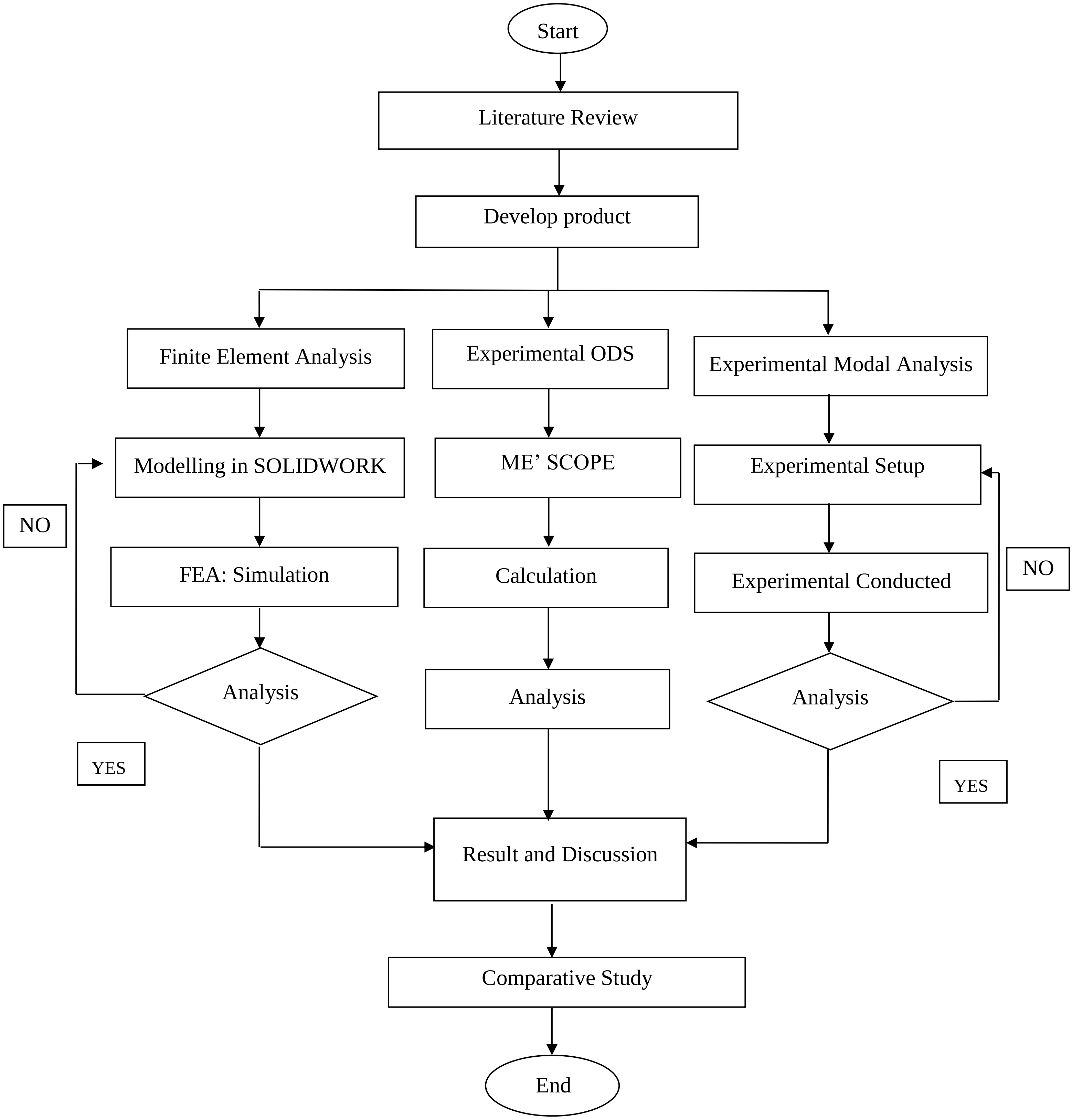


Figure 3.1: Flowchart methodology

3.2 MATERIAL

Material, size and thickness of the plate must be determined before the experiment. This is an important consideration to ensure the experiment and the simulation runs smoothly. The material used is aluminium alloy 1100 in a 3.0 mm thick stainless steel plate Sus304 2.0 mm in thickness. Both types of cut in mm plate size 150 x 100mm, and the surface cleaned by abrasive paper and acetone before the experiment. Material steel and aluminium will be attach at the end of each plate to weld together

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

Source : Foundry Laboratory, Faculty of Mechanical Engineering,Universiti Malaysia Pahang

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

Source : Foundry Laboratory, Faculty of Mechanical Engineering,Universiti Malaysia Pahang

3.3 METHOD WELDING

In this project, will joining stainless steel 2-millimeters thickness and aluminium alloy 3-millimeter thickness by Resistance Spot Welding (RSW). 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 overlap should be at least three times the thickness of the thinner plate.

Two stick electrodes placed on both sides plate, as shown in Fig. 3.2. Pressure is applied to the electrodes and maintained intervals known as squeeze time before further operation. Then the current through the electrodes. Time during the application known as the weld is measured in terms of number of cycles, each cycle corresponds to 20 m.sec. (1/line frequency). Pressure is maintained during this time as well. After the tide drops, the pressure is maintained for a short time known as hold time, so the metal is heated to solidify and form a weld block. After the hold time, the pressure will be released and out of time before starting another spot welding operations

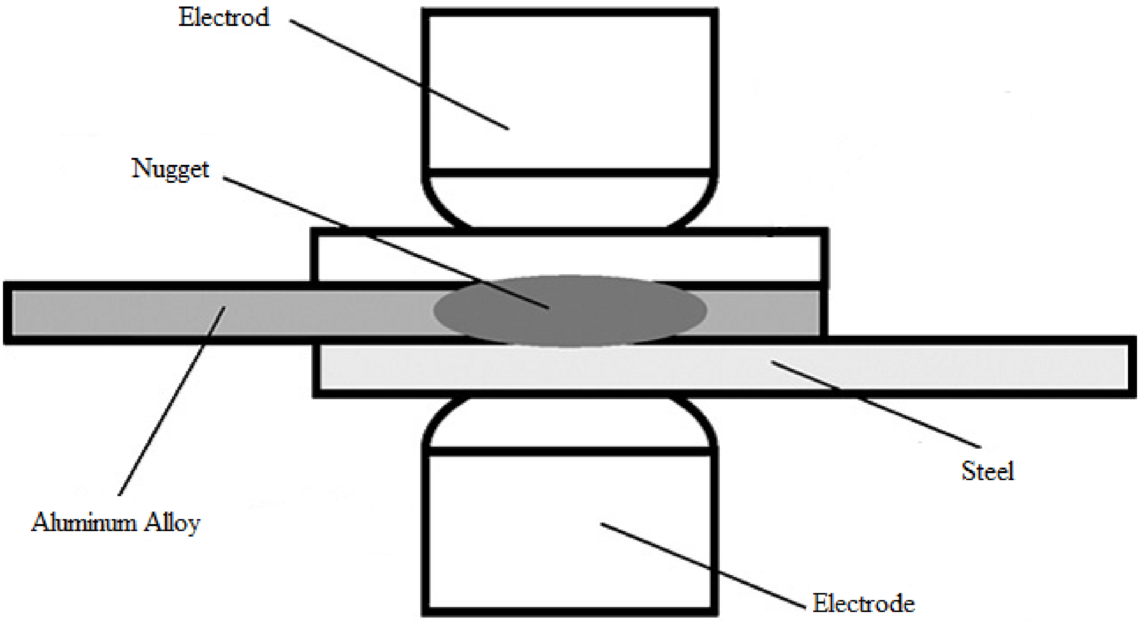


Figure 3.2: Schematic of aluminium–steel diagram spot welding

Source: Ranfeng Qiu (2010)

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 3.3 to 3.5. 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.

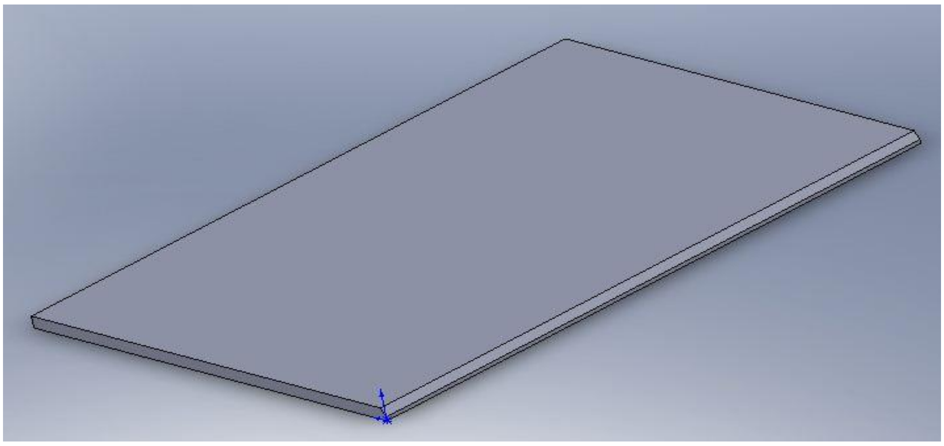


Figure 3.3: Isometric view of aluminium alloy plate

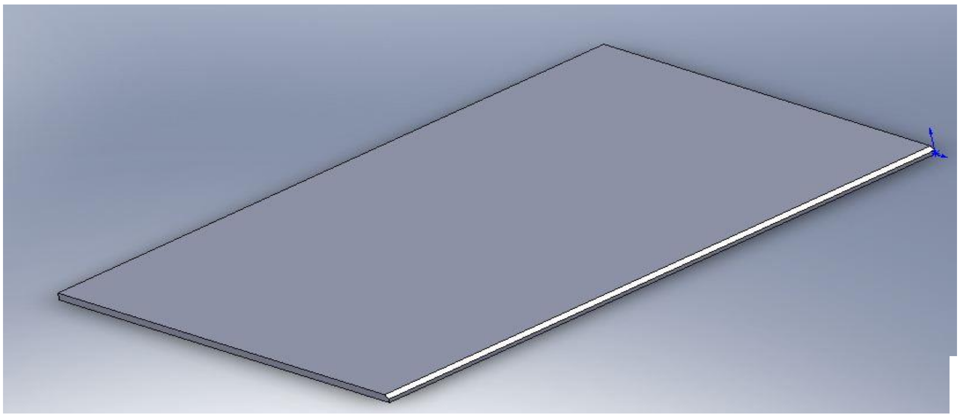


Figure 3.4: Isometric view of stainless steel plate

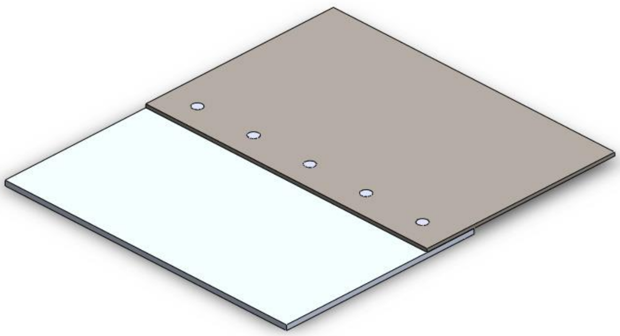


Figure 3.5: Isometric view of Assembly Part

3.5 SIMULATION

3.5.1 Simulation Method

The finite element analysis is carried out is using ANSYS. It 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.

ANSYS software is used to conduct the analyzing of joining aluminium alloy and stainless steel. ANSYS Finite Element Analysis (FEA) uses a complex system of point called nodes which make grid called mesh. Natural frequency (modal analysis) in ANSYS 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 Meshing

The mesh was constructed using three parts that represent the aluminium alloy plate, stainless steel plate and weld parts. The element type for the aluminium alloy plate inset of aluminium alloy 1100 H14, stainless steel plate insert to stainless steel SUS304 and set a value of current through at weld point as in figure 3.6. 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 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 3.6. The simulation is done part by part so then it can be compared to the experimental analysis later.

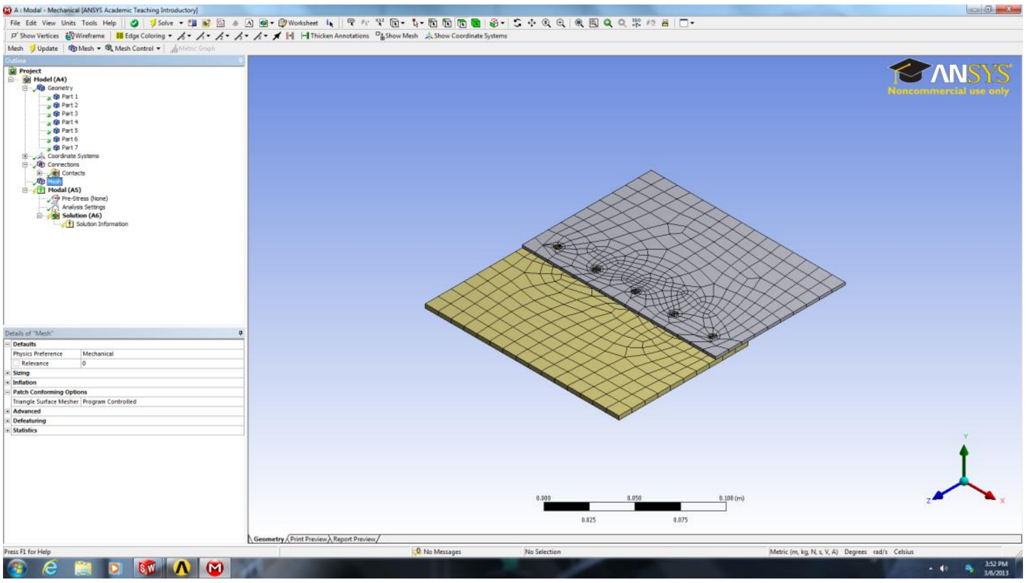


Figure 3.6: Mesh diagram of assembling parts

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 force spectrum can be customized to some extent through the use of hammer tips with various hardness's. A hard tip has a short pulse and excites a wide frequency range. Then, a soft tip has a long pulse and excites a narrow frequency range.

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 analysers.

3.6.3 Step of Experimental Modal Analysis

From Measurement & Automation software, accelerometer sensitivity and hammer will be established. This value is in the units you specify with the input sensitivity of this unit. Referring to box the sensor documentation to determine this value. Sensitivity hammer is 2:24 mvolts / g and acceleration sensitivity is 97.6 mvolts / g. Repeat this action to perform acceleration sensitivity on channel 2, it means that other x, y, z, y. Sensitivity settings are shown in Figure 3.7. This graph displays an analog signal derived or generated by the device. The experimental modal analysis is carried out is using DASYlab 10.0 software.

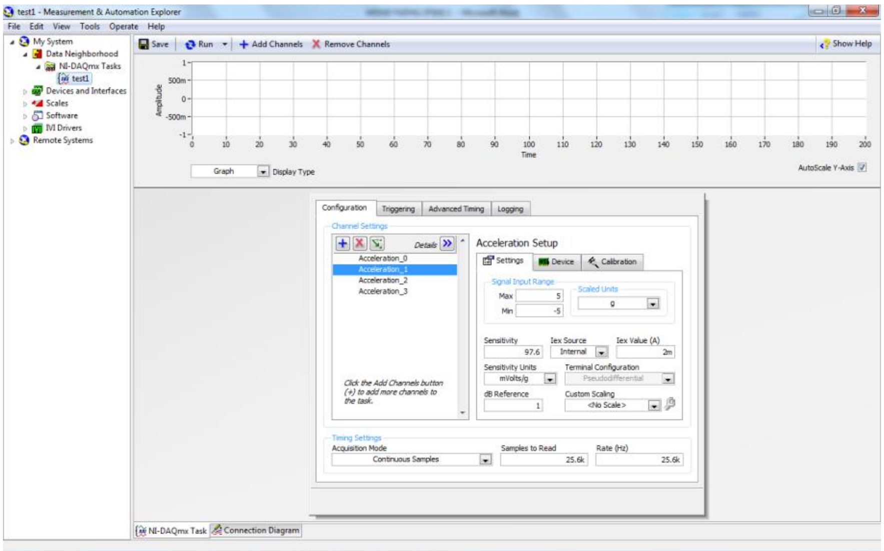


Figure 3.7: Setting of sensitivity

The data experimental modal analysis from DASYlab 10.0 is carried out is using ME'scope software. With using ME' scope, it will produce a mode shape of experimental at plate. 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 4 points in the Global X direction and 175 mm with 8 points in the Global Y direction will be added to the plate. The setting of the dimension is shown in figure 3.8.

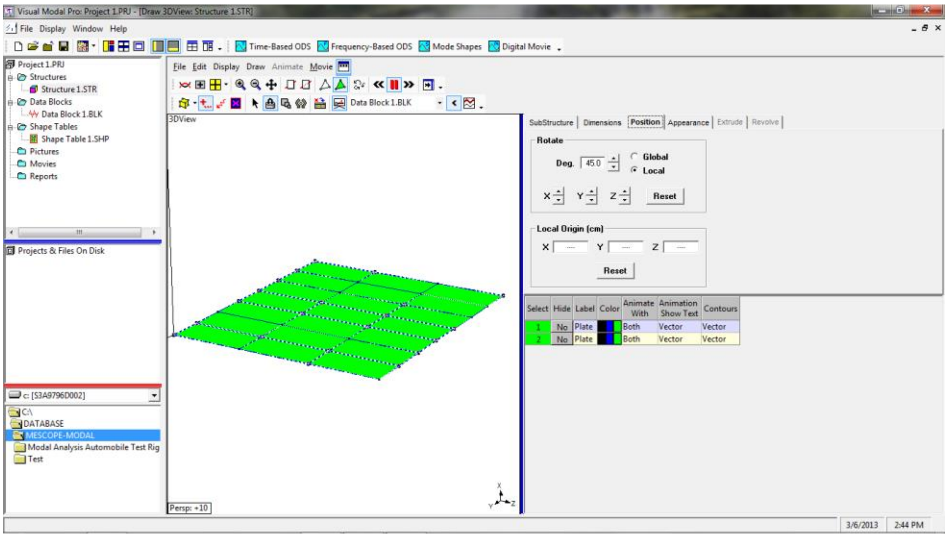


Figure 3.8: Dimension of plate

In ME'scope VES, 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 3.9 shows 3D views during point numbering.

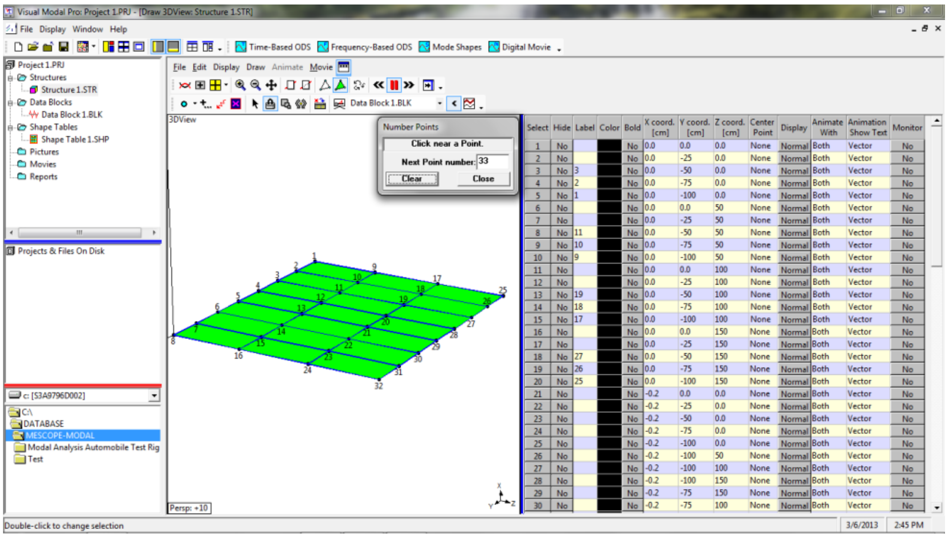


Figure 3.9: 3D View point numbering.

ME'scope VES contains SDOF (single mode), MDOF (multiple modes) and Multiple Reference curve fitting methods for estimating modal parameters from experimental data. Since ME'scope VES displays both ODS's & mode shapes, can see the differences and correlate the two. The figure 3.10 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.

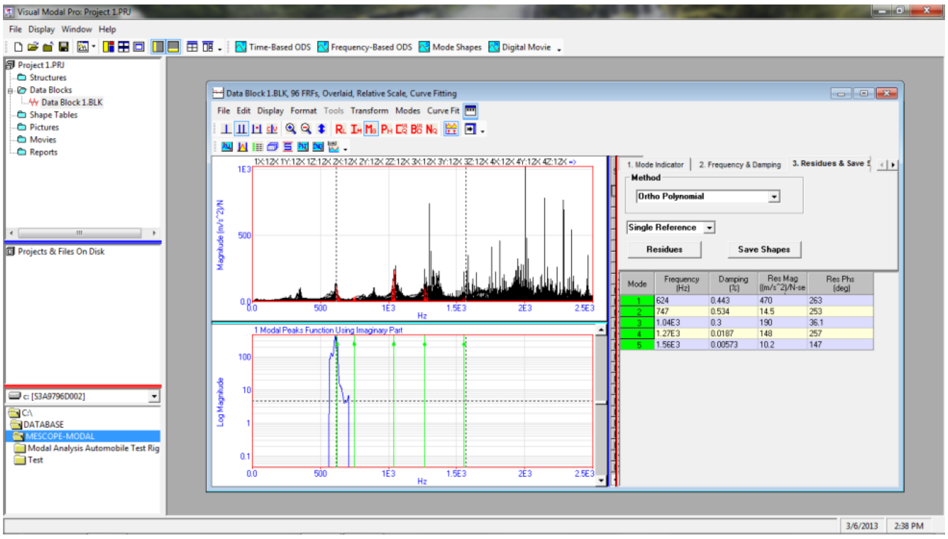


Figure 3.10: Curve fitting of number frequency

3.7 EXPERIMENTAL OPERATING DEFLECTION SHAPE

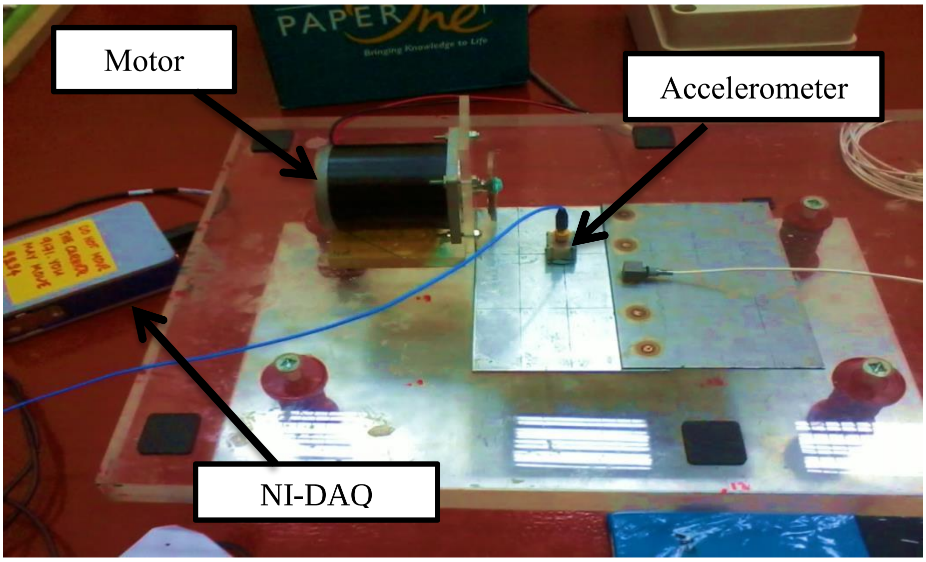
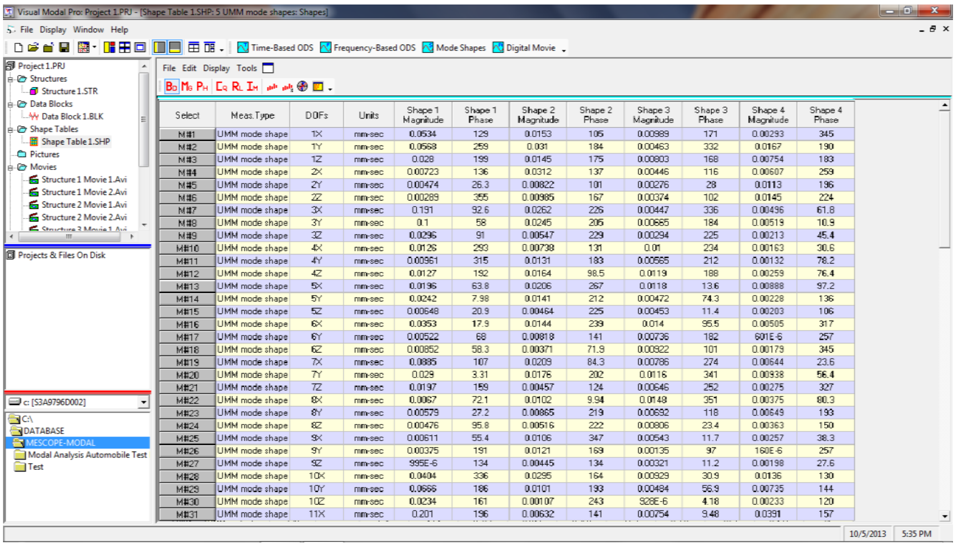


Figure 3.11: Setup experimental operating deflection shape (ODS)

Figure 3.11 above shows the process to do the experiment operating deflection shape (ODS). The weld plate between aluminium alloy and stainless steel placed on a test rig with padding at each end plate using rubber tik. And then, the motor have 55.3 Hz frequency and 3000 rpm put on the edge of the plate to create vibrations on the plate. The measurements were made using two accelerometers (one for the reference and one roving accelerometers). The reference accelerometer was maintained at a well-chosen point on the plate. Selection of reference points has a major impact the results of the measurements. It has to be placed such that all modes contribute to the reference accelerometer. Lastly, data after scaling unit modal mass will be taken to continue in calculation parts.



Select	Meas.Type	DOFs	Units	Shape 1 Magnitude	Shape 1 Phase	Shape 2 Magnitude	Shape 2 Phase	Shape 3 Magnitude	Shape 3 Phase	Shape 4 Magnitude	Shape 4 Phase
M#1	UMM mode shape	1X	mm-sec	0.0534	129	0.0153	105	0.00989	171	0.00293	345
M#2	UMM mode shape	1Y	mm-sec	0.0568	259	0.031	184	0.00463	332	0.0167	190
M#3	UMM mode shape	1Z	mm-sec	0.028	199	0.0145	175	0.00803	168	0.00754	183
M#4	UMM mode shape	2X	mm-sec	0.00723	136	0.0312	137	0.00446	116	0.00607	259
M#5	UMM mode shape	2Y	mm-sec	0.00474	26.3	0.00822	101	0.00276	28	0.0113	196
M#6	UMM mode shape	2Z	mm-sec	0.00289	355	0.00985	167	0.00374	102	0.0145	224
M#7	UMM mode shape	3X	mm-sec	0.191	92.6	0.0262	226	0.00447	336	0.00496	61.8
M#8	UMM mode shape	3Y	mm-sec	0.1	58	0.0245	205	0.00665	184	0.00519	10.9
M#9	UMM mode shape	3Z	mm-sec	0.0296	91	0.00547	229	0.00294	225	0.00213	45.4
M#10	UMM mode shape	4X	mm-sec	0.0126	293	0.00738	131	0.01	234	0.00163	30.6
M#11	UMM mode shape	4Y	mm-sec	0.00961	315	0.0131	183	0.00565	212	0.00132	78.2
M#12	UMM mode shape	4Z	mm-sec	0.0127	192	0.0164	98.5	0.0119	188	0.00259	76.4
M#13	UMM mode shape	5X	mm-sec	0.0196	63.8	0.0206	267	0.0118	13.6	0.00888	97.2
M#14	UMM mode shape	5Y	mm-sec	0.0242	7.98	0.0141	212	0.00472	74.3	0.00228	136
M#15	UMM mode shape	5Z	mm-sec	0.00648	20.9	0.00464	225	0.00453	11.4	0.00203	106
M#16	UMM mode shape	6X	mm-sec	0.0353	17.9	0.0144	239	0.014	95.5	0.00505	317
M#17	UMM mode shape	6Y	mm-sec	0.00522	68	0.00818	141	0.00736	182	601E-6	257
M#18	UMM mode shape	6Z	mm-sec	0.00852	58.3	0.00371	71.9	0.00922	101	0.00179	345
M#19	UMM mode shape	7X	mm-sec	0.0885	107	0.0209	84.3	0.00786	274	0.00644	23.6
M#20	UMM mode shape	7Y	mm-sec	0.029	3.31	0.0176	202	0.0116	341	0.00938	56.4
M#21	UMM mode shape	7Z	mm-sec	0.0197	159	0.00457	124	0.00646	252	0.00275	327
M#22	UMM mode shape	8X	mm-sec	0.0067	72.1	0.0102	9.94	0.0148	351	0.00375	80.3
M#23	UMM mode shape	8Y	mm-sec	0.00579	27.2	0.00865	219	0.00692	118	0.00649	193
M#24	UMM mode shape	8Z	mm-sec	0.00476	95.8	0.00516	222	0.00806	23.4	0.00363	150
M#25	UMM mode shape	9X	mm-sec	0.00611	55.4	0.0106	347	0.00543	11.7	0.00257	38.3
M#26	UMM mode shape	9Y	mm-sec	0.00375	191	0.0121	169	0.00135	97	160E-6	257
M#27	UMM mode shape	9Z	mm-sec	995E-6	134	0.00445	134	0.00321	11.2	0.00198	27.6
M#28	UMM mode shape	10X	mm-sec	0.0404	336	0.0295	164	0.00929	30.9	0.0136	130
M#29	UMM mode shape	10Y	mm-sec	0.0666	186	0.0101	193	0.00484	56.9	0.00735	144
M#30	UMM mode shape	10Z	mm-sec	0.0234	161	0.00107	243	928E-6	4.18	0.00233	120
M#31	UMM mode shape	11X	mm-sec	0.201	196	0.00632	141	0.00754	9.48	0.0391	157

Figure 3.12: Data from unit modal mass (UMM) table

3.7.1 Calculation for operating deflection shape (ODS)

Mode shapes and operating deflection shapes (ODS's) are related to one another. Traditionally, an ODS has been defined as the deflection of a structure at a particular frequency. However, an ODS can be defined more generally as any forced motion of two or more points on a structure. Specifying the motion of two or more points defines a shape. Stated differently, a shape is the motion of one point relative to all others. Motion is a vector quantity, which means that it has location and direction associated with it. With simple formula, it can calculate mode shape using equation.

$$B_r = \frac{1}{\sqrt{(Pr^2 - \omega^2)^2 + (2\sigma r\omega)^2}} \tag{3.1}$$

$$X_{pr} = Qpr \times Br\cos(\omega t - \text{Ø}) \tag{3.2}$$

$$X_r = \text{Ø}r \times Xpr \tag{3.3}$$

$$Q = m\omega^2 r \tag{3.4}$$

$$Q_{pr} = \text{Ø}r \times Q \tag{3.5}$$

Using the equation above, mode shape from calculation will find. Collect a data at unit modal mass table and choose only at x axis unit. In equation 3.1, radius (r) motor is 20 mm, mass (m) motor is 794 g and last omega (ω) is 336.77 rad/s. The value of σ get from damping table, where value each mode of damping divided 100% and multiply with a natural frequency. Table 3.3 show mode shape operating deflection shape with damping. Which have $m\omega^2 r$,it get find value in equation 3.4 and in equation 3.5, force for modal mode can calculate by force multiply matrix role. After that magnitude transfer function multiply force for modal mode to get a respond in modal. Lastly respond in modal will multiply matrix role to get respond for spatial and a result plot in excel graph.

Table 3.3: Natural frequency and damping ratio experimental operating deflection shape

Mode	Frequency (Hz)	Damping (%)
1	944	0.00726
2	1350	0.0446
3	2160	0.0107
4	2220	0.0336

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 ANSYS 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.

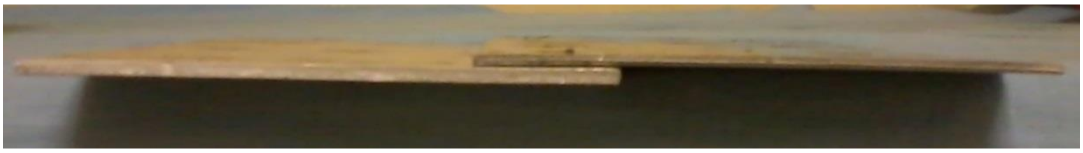
4.2 RESULT OF JOINING BETWEEN ALUMINIUM ALLOY AND STAINLESS STEEL (SPOT WELDING)

Joining between aluminium alloy and stainless steel was done by using Spot welding before doing the experimental modal analysis. The effect of welding on the joint characteristics of aluminium alloy and stainless steel with Spot welding is shown in the figure 4.1 below. From this figure right side is stainless steel and left side is aluminium alloy. This project use Spot welding with welding current at 7 kA and pressure 60 psi.

(a)

(b)

The figure 4.1 (a) and (b) shows the appearance of aluminium–steel lap joint made by Spot welding–brazing because of their difference in melting point. Melting point aluminium alloy 1100 about 645 ºC and stainless steel range of 1400-1450 °C. The joint has a good front and back and no crack appears on the welded seam/steel interface.



(c)

Figure 4.1: Result joining plate by Spot welding
(a) Front view (b) Back view (c) Side view

Figure 4.1 (c) show the side view the typical cross-section of aluminium–steel lap joint. Stainless steel plate is 2mm thickness while aluminium plate is 3mm thickness. 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 ANSYS 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 500Hz to 2000Hz

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	669.1	6530.7	13.1160
2	745.7	6994.6	4.8584
3	1015.3	6063.2	4.1015
4	1199.1	6226.2	9.3768
5	1523.4	6763.2	16.1800

4.3.2 Natural Frequency Of Experimental Modal Analysis

Experimental modal analysis was 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 was made within 42 points selected at the joining plate between aluminium alloy and stainless steel which consists of 20 points of the aluminium alloy area, 20 points of the stainless steel area and 8 points at welded between aluminium and stainless steel area. The table 4.2 shows Frequency and displacement of joining plate between stainless steel and aluminium alloy of each mode. Range of frequency between 300Hz to 2000Hz

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	624	4100	0
2	747	203	0
3	1040	6700	0
4	1270	238	0
5	1560	116	0

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 per cent of their errors in the different cases. Mode shape 2 had the lowest percentage error while mode 1 had the highest percentage error in the result.

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

Mode Shape	**Natural Frequency**		**Error (%)**
	Theoretical	**Experimental**	
1	669.1	624	6.74
2	745.7	747	0.17
3	1015.3	1040	2.43
4	1199.1	1270	5.91
5	1523.4	1560	2.40

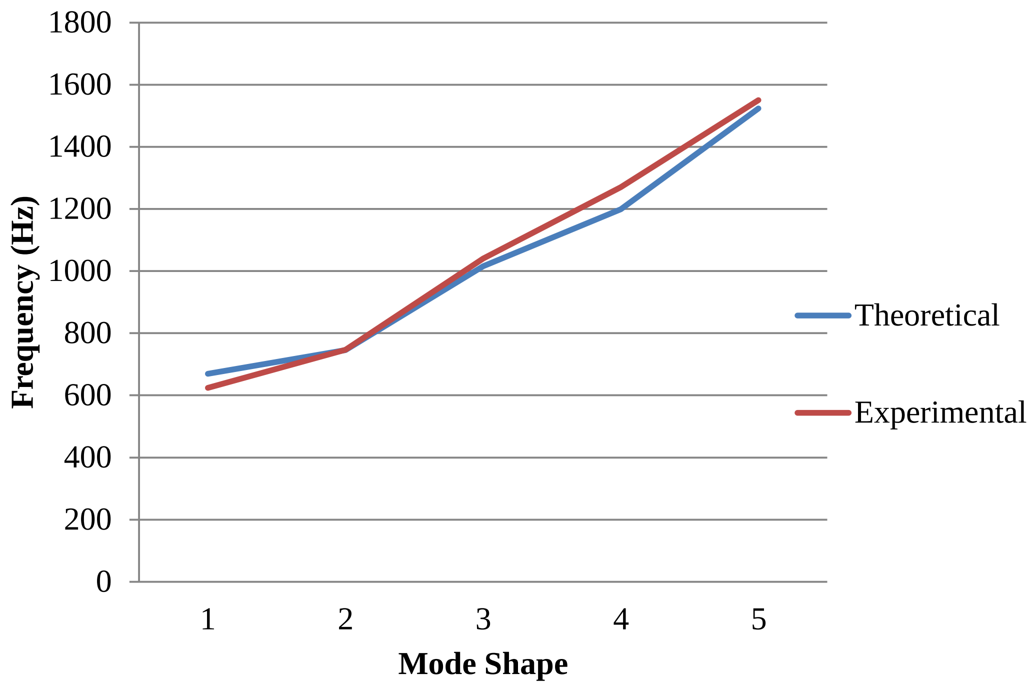


Figure 4.2: Graph of Comparison of natural frequency analysis

The graph in the figure 4.2 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 ANSYS Finite Element Analysis

Modal analysis is done by using ANSYS 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

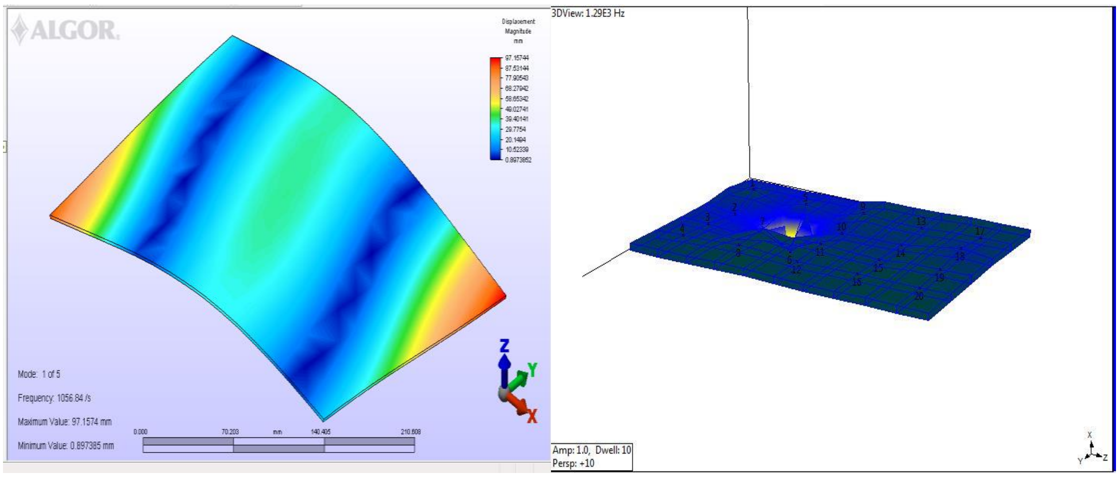
From the experimental analysis, a set data is collected during the impact hammer testing. The testing is made within 32 points selected at the joining plate between aluminium alloy and stainless steel which consists of 20 points of the aluminium alloy area, 20 points of the stainless steel area and 8 points at welded between aluminium and stainless steel area.

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. These deformation patterns are referred to as the mode shapes of the structure. Comparison starts with single plate first, stainless steel and aluminium alloy. Then result of welding plate will compare between experimental modal analysis and finite element analysis.

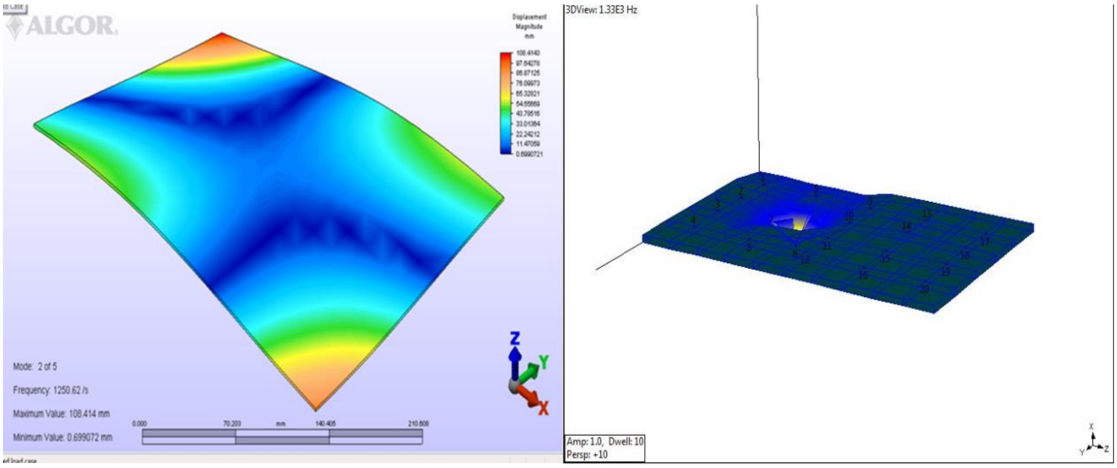
4.5.1 Result of Stainless Steel Plate



(a) (b)

Figure 4.3: First mode shape of stainless steel plate, (a) Finite element analysis, (b) Experimental modal analysis

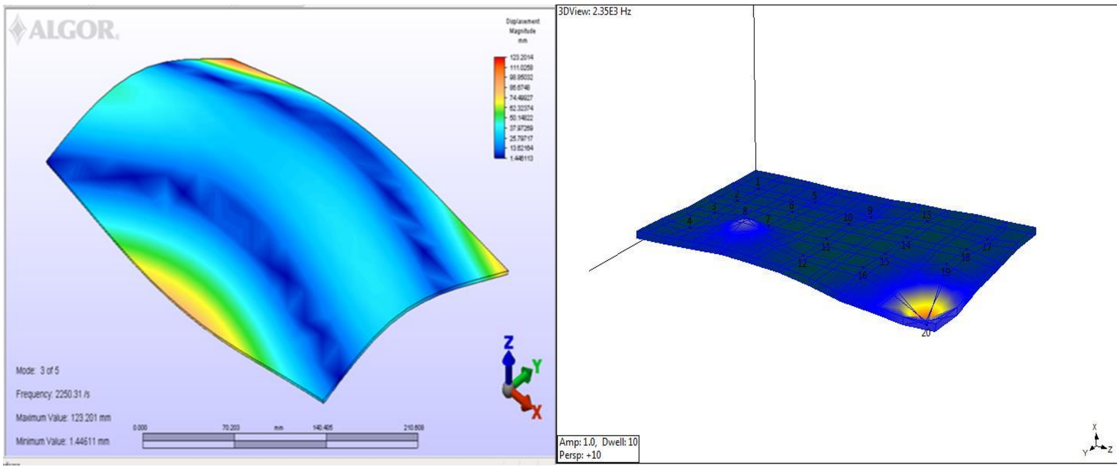
Figure 4.3 shows the first mode of stainless steel plate. The first mode was bending deformation pattern of the plate. The frequency of mode in finite element analysis (FEA) is 1056.84 Hz which the maximum shift mode is 97.1574 mm and minimum shift to 0.897385 mm. The frequency of mode in experimental modal testing is 1050 Hz which the maximum shift mode is 1.119 mm and minimum shift to 0 mm. The red colour represented as the maximum displacements occur in the mode and the colour blue is a minimum shift.



(a) (b)

Figure 4.4: Second mode shape of stainless steel plate, (a) Finite element analysis, (b) Experimental modal analysis

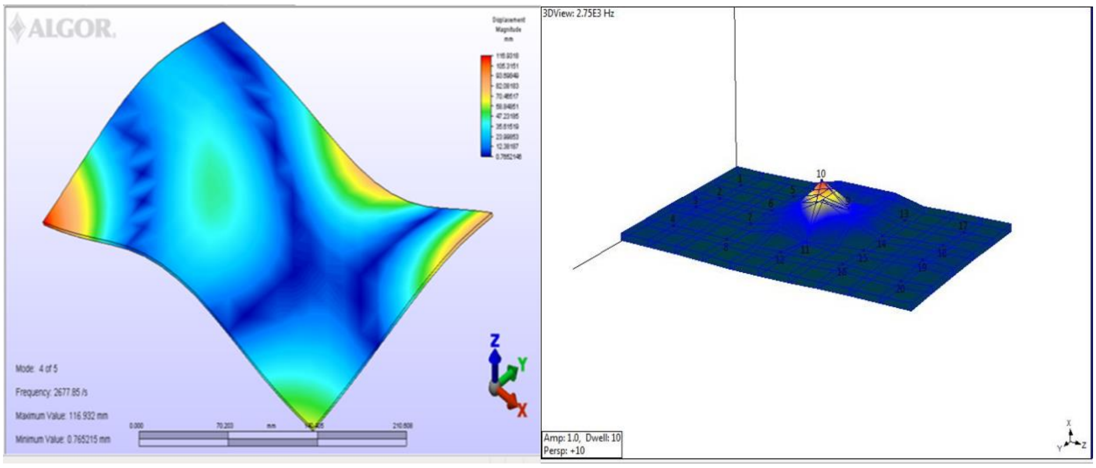
Figure 4.4 shows the second mode of stainless steel plate is twisting deformation pattern of the plate. The frequency of mode in finite element analysis (FEA) is 1250.62 Hz which the maximum shift mode is 108.414 mm and minimum shift to 0.699072 mm. The frequency of mode in experimental modal testing is 1330 Hz which the maximum shift mode is 1.8726 mm and minimum shift to 0 mm. The red colour represented as the maximum displacements occur in the mode and the colour blue is a minimum shift.



(a) (b)

Figure 4.5: Third mode shape of stainless steel plate, (a) Finite element analysis, (b) Experimental modal analysis

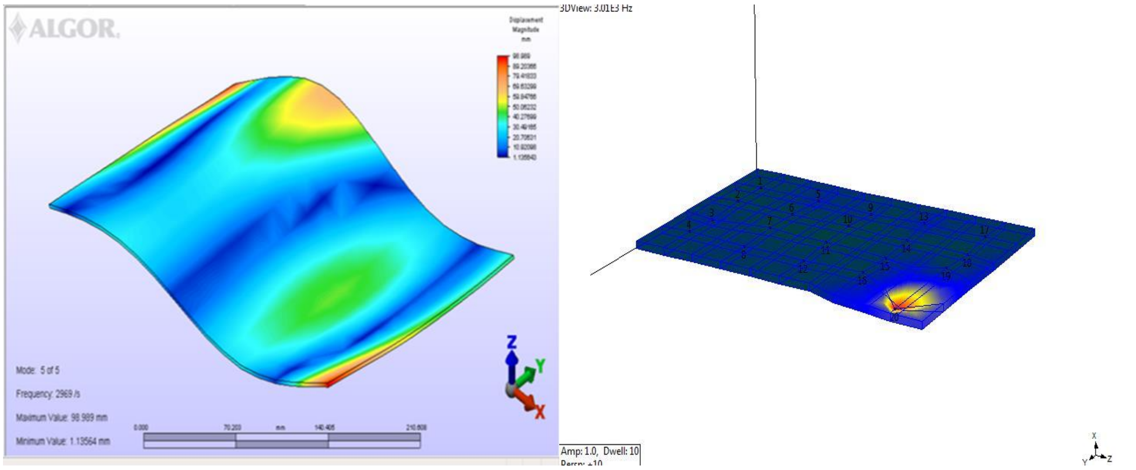
Figure 4.5 shows the third mode of stainless steel plate is bending deformation pattern of the plate. The frequency of mode in finite element analysis (FEA) is 2250.31 Hz which the maximum shift mode is 129.201 mm and minimum shift to 1.44611 mm. The frequency of mode in experimental modal testing is 2350 Hz which the maximum shift mode is 0.854 mm and minimum shift to 0 mm. The red colour represented as the maximum displacements occur in the mode and the colour blue is a minimum shift.



(a) (b)

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

Figure 4.6 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 2677.85 Hz which the maximum shift mode is 116.932 mm and minimum shift to 0.765215 mm. The frequency of mode in experimental modal testing is 2750 Hz which the maximum shift mode is 1.6244 mm and minimum shift to 0 mm. The red colour represented as the maximum displacements occur in the mode and the colour blue is a minimum shift.

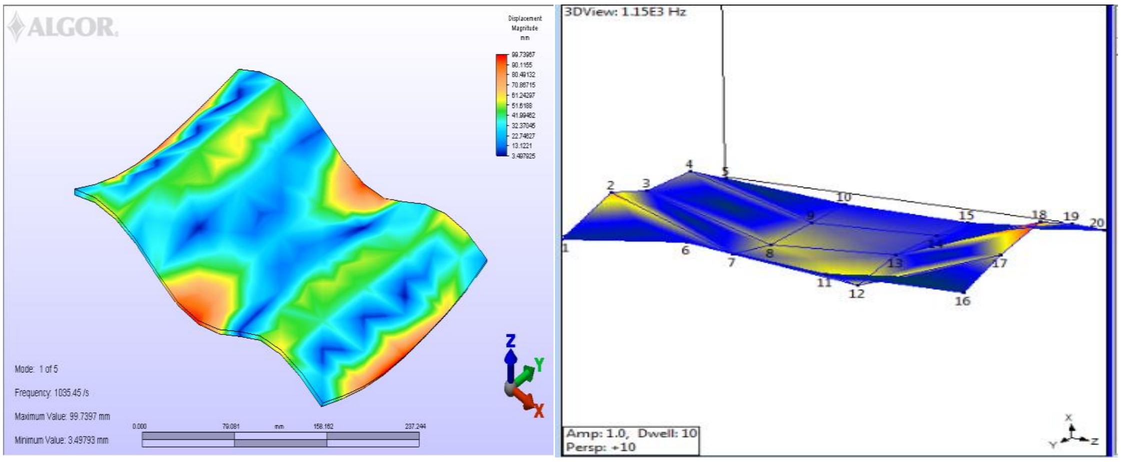


(a) (b)

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

Figure 4.7 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 2969 Hz which the maximum shift mode is 98.989 mm and minimum shift to 1.13564 mm. The frequency of mode in experimental modal testing is 3010 Hz which the maximum shift mode is 0.4833 mm and minimum shift to 0 mm. The red colour represented as the maximum displacements occur in the mode and the colour blue is a minimum shift.

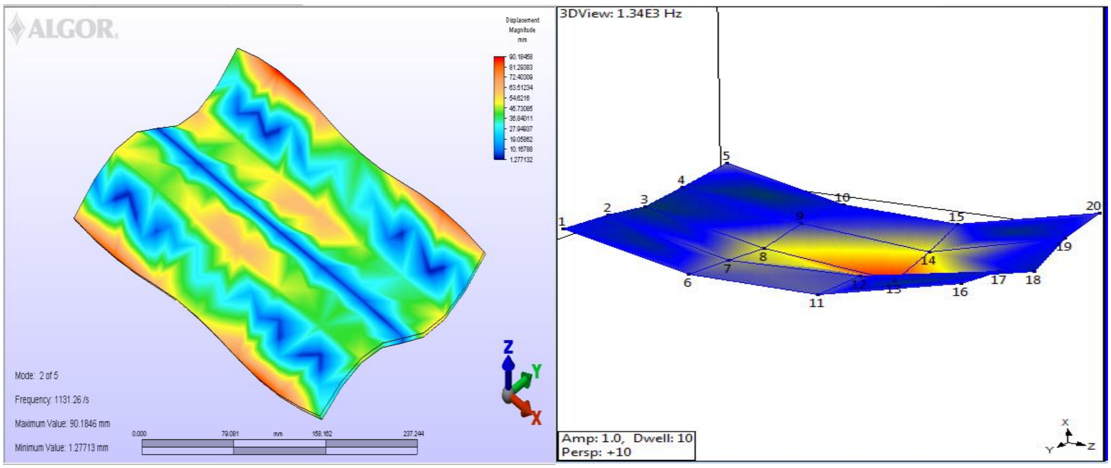
4.5.2 Result of Aluminium Alloy Plate



(a) (b)

Figure 4.8: First mode shape of aluminium alloy plate, (a) Finite element analysis, (b) Experimental modal analysis

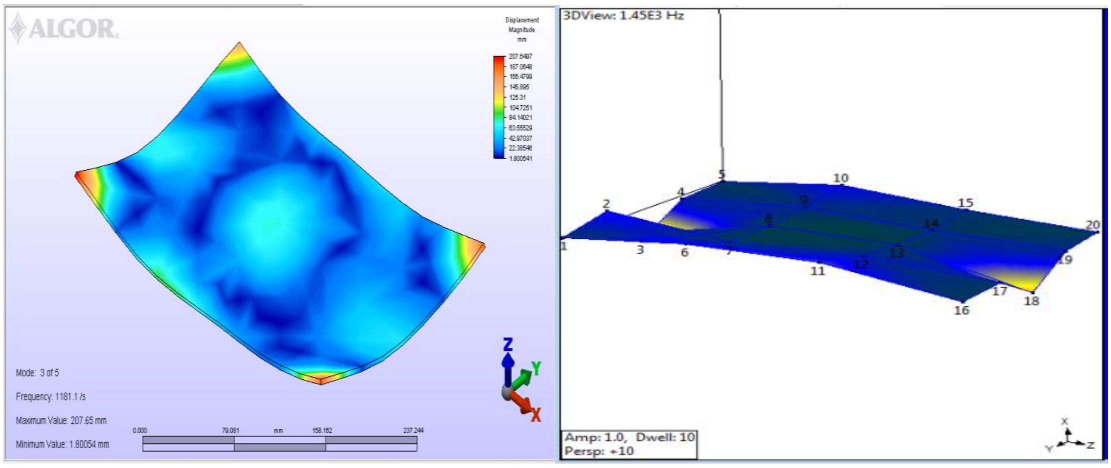
Figure 4.8 shows the first mode of aluminium alloy plate is bending deformation pattern of the plate. The frequency of mode in finite element analysis (FEA) is 1035.45 Hz which the maximum shift mode is 99.7397 mm and minimum shift to 3.49793 mm. The frequency of mode in experimental modal testing is 1150 Hz which the maximum shift mode is 0.7351 mm and minimum shift to 0 mm. 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: Second mode shape of aluminium alloy plate, (a) Finite element analysis, (b) Experimental modal analysis

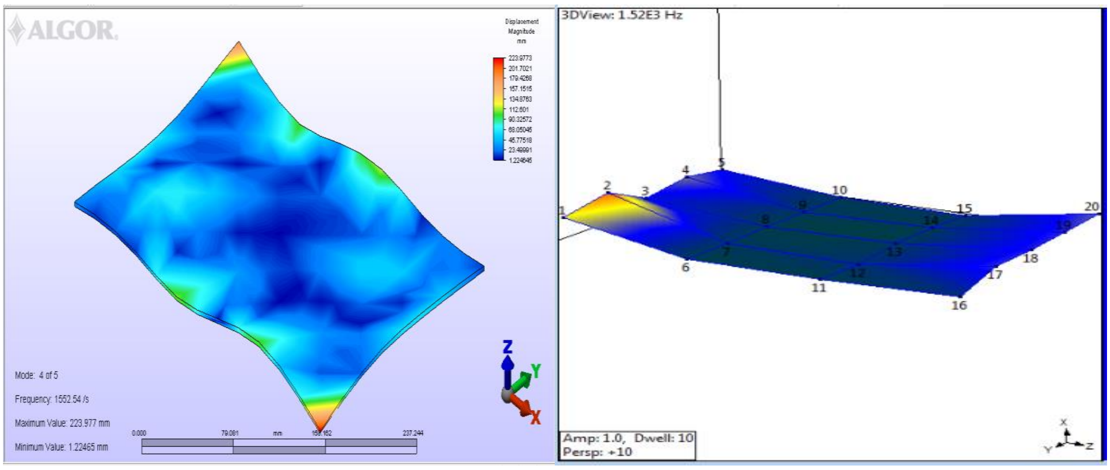
Figure 4.9 shows the first mode of aluminium alloy plate is twisting deformation pattern of the plate. The frequency of mode in finite element analysis (FEA) is 1131.26 Hz which the maximum shift mode is 90.1846 mm and minimum shift 1.27713 mm. The frequency of mode in experimental modal testing is 1340 Hz which the maximum shift mode is 1.371 mm and minimum shift to 0 mm. 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: Third mode shape of aluminium alloy plate, (a) Finite element analysis, (b) Experimental modal analysis

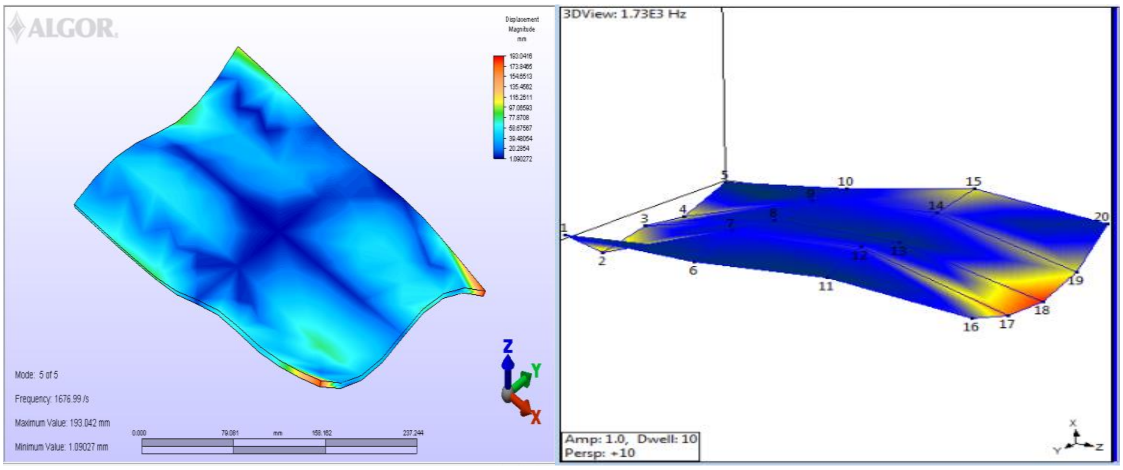
Figure 4.10 shows the third mode of aluminium alloy plate is bending deformation pattern of the plate. The frequency of mode in finite element analysis (FEA) is 1181.1 Hz which the maximum shift mode is 207.65 mm and minimum shift 1.80054 mm. The frequency of mode in experimental modal testing is 1450 Hz which the maximum shift mode is 0.8591 mm and minimum shift to 0 mm. The red colour represented as the maximum displacements occur in the mode and the colour blue is a minimum shift.



(a) (b)

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

Figure 4.11 shows the fourth mode of aluminium alloy plate is twisting deformation pattern of the plate. The frequency of mode in finite element analysis (FEA) is 1552.54 Hz which the maximum shift mode is 223.977 mm and minimum shift to 1.22465 mm. The frequency of mode in experimental modal testing is 1520 Hz which the maximum shift mode is 0.2802 mm and minimum shift to 0 mm. The red colour represented as the maximum displacements occur in the mode and the colour blue is a minimum shift.

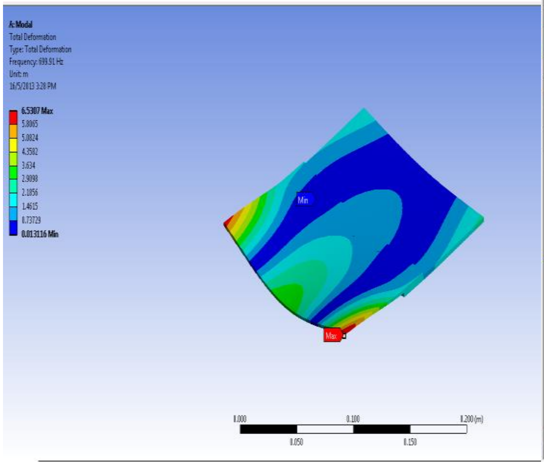


(a) (b)

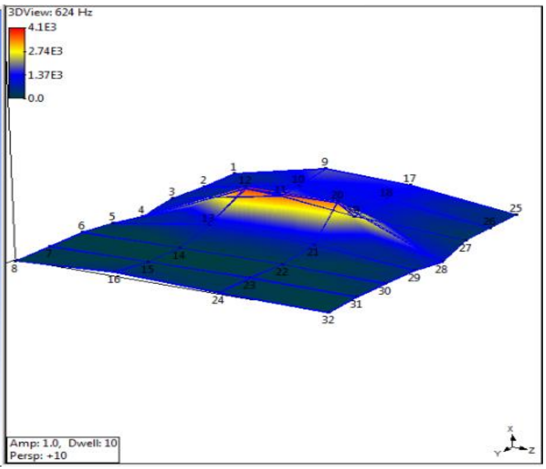
Figure 4.12: Fifth mode shape of aluminium alloy plate, (a) Finite element analysis, (b) Experimental modal analysis

Figure 4.12 shows the fifth mode of aluminium alloy plate is a bending deformation pattern of the plate. The frequency of mode in finite element analysis (FEA) is 1676.99 Hz which the maximum shift mode is 193.042 mm and minimum shift to 1.09027 mm. The frequency of mode in experimental modal testing is 1730 Hz which the maximum shift mode is 0.4627 mm and minimum shift to 0 mm. 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



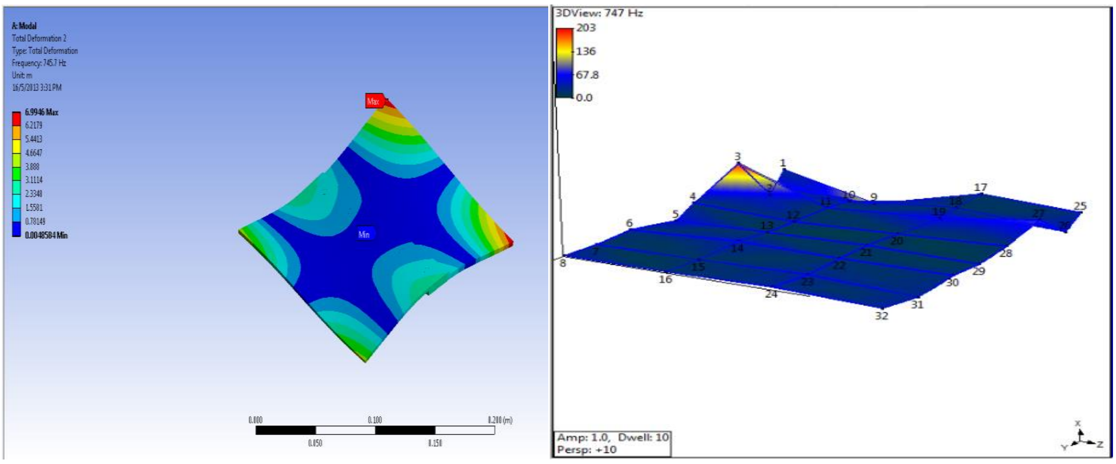
(a)



(b)

Figure 4.13: First mode shape of joining plate by Spot welding,
(a) Finite element analysis, (b) Experimental modal analysis

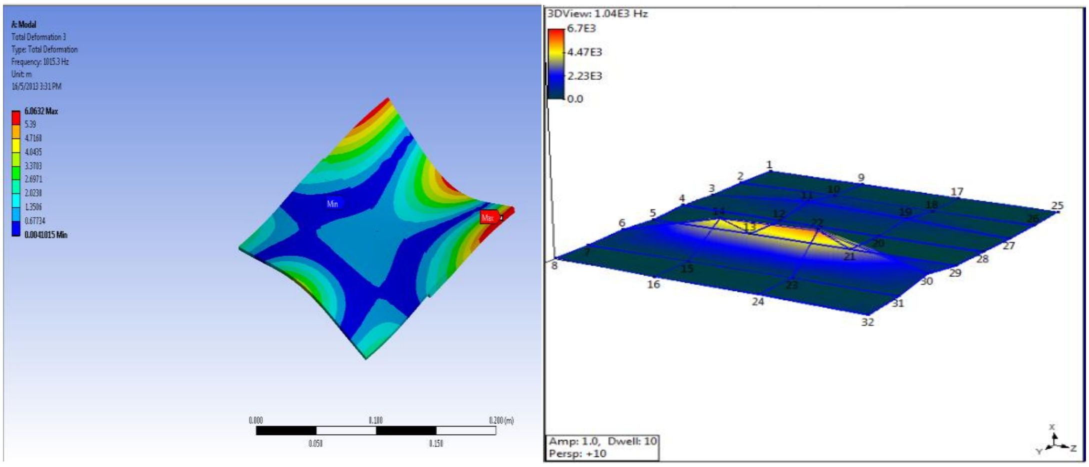
Figure 4.13 shows the first mode shape of joining aluminium alloy and stainless steel with weld, there is a first bending deformation pattern. For finite element analysis (FEA), the frequency of the mode is 666.91 Hz. The maximum displacement of the mode is 6530.7 mm and minimum displacement is 13.166 mm. For experimental modal testing, the frequency of the mode is 624 Hz. The maximum displacement of the mode is 4100 mm and minimum displacement is 0 mm. The red colour indicates the maximum displacement occurred in the mode and blue colour is minimum displacement.



(a) (b)

Figure 4.14: Second mode shape of joining plate by Spot welding,
(a) Finite element analysis, (b) Experimental modal analysis

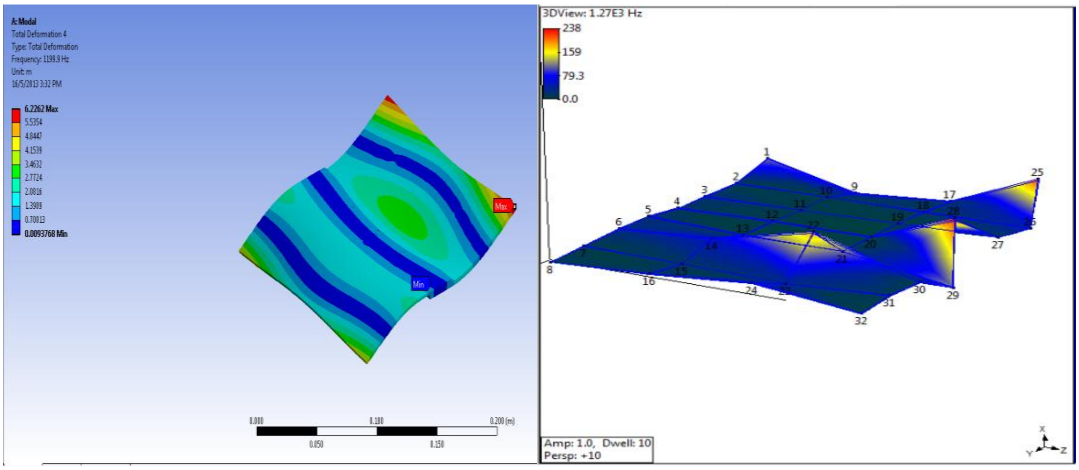
Figure 4.14 shows the second mode shape of joining aluminium alloy and stainless steel with weld, there is a first twisting deformation pattern. For finite element analysis (FEA), the frequency of the mode is 745.7 Hz. The maximum displacement of the mode is 6994.6 mm and minimum displacement is 4.8584 mm. For experimental modal testing, the frequency of the mode is 747 Hz. The maximum displacement of the mode is 203 mm and minimum displacement is 0 mm. The red colour indicates the maximum displacement occurred in the mode and blue colour is minimum displacement.



(a) (b)

Figure 4.15: Third mode shape of joining plate by Spot welding,
(a) Finite element analysis, (b) Experimental modal analysis

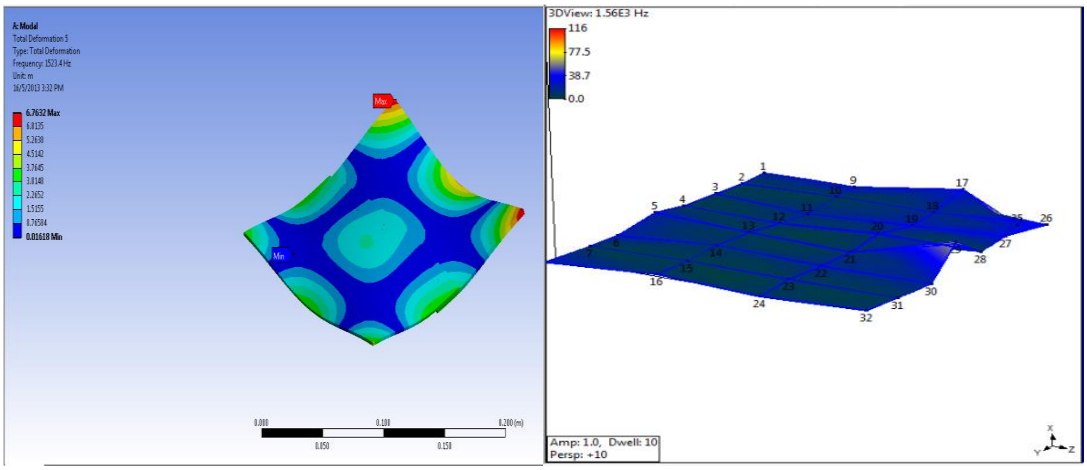
Figure 4.15 shows the third mode shape of joining aluminium alloy and stainless steel with weld, there is a first bending deformation pattern. For finite element analysis (FEA), the frequency of the mode is 1015.3 Hz. The maximum displacement of the mode is 6063.2 mm and minimum displacement is 41.105 mm. For experimental modal testing, the frequency of the mode is 1040 Hz. The maximum displacement of the mode is 6700 mm and minimum displacement is 0 mm. The red colour indicates the maximum displacement occurred in the mode and blue colour is minimum displacement.



(a) (b)

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

Figure 4.16 shows the fourth 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 1199.9 Hz. The maximum displacement of the mode is 6226.2 mm and minimum displacement 93.768 mm. For experimental modal testing, the frequency of the mode is 1270 Hz. The maximum displacement of the mode is 238 mm and minimum displacement 0 mm. The red colour indicates the maximum displacement occurred in the mode and blue colour is minimum displacement.

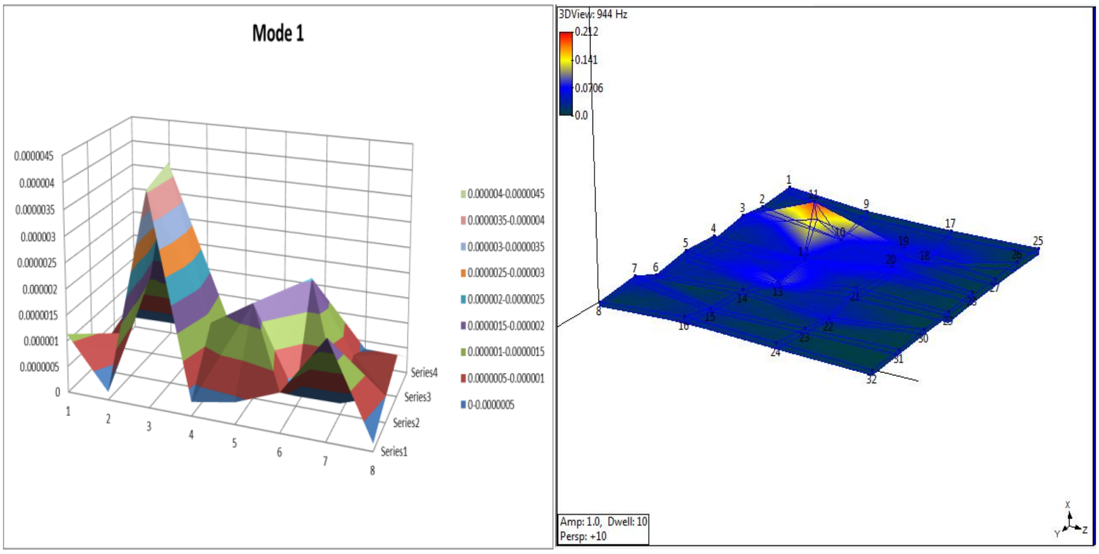


(a) (b)

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

Figure 4.17 shows the fifth 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 1523.4 Hz. The maximum displacement of the mode is 6763.2 mm and minimum displacement is 16.18 mm. For experimental modal testing, the frequency of the mode is 1560 Hz. The maximum displacement of the mode is 116 mm and minimum displacement is 0 mm. The red colour indicates the maximum displacement occurred in the mode and blue colour is minimum displacement.

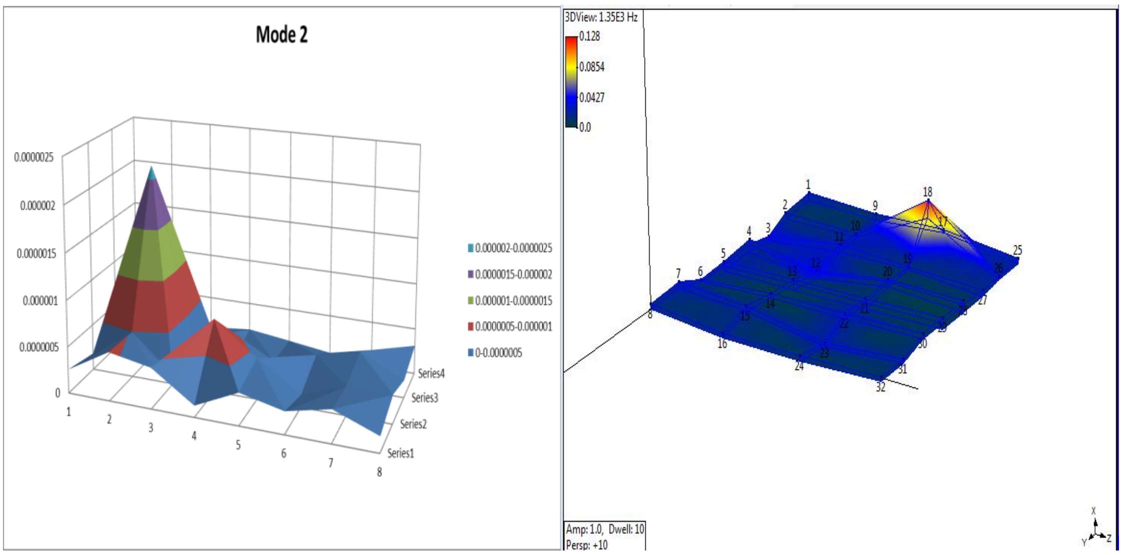
4.6 COMPARISON OF MODE SHAPES BETWEEN CALCULATION AND EXPERIMENTAL OPERATING DEFLECTION SHAPE



(a) (b)

Figure 4.18: First mode shape of Operating Deflection Shape, (a) Calculation, (b) ME Scope

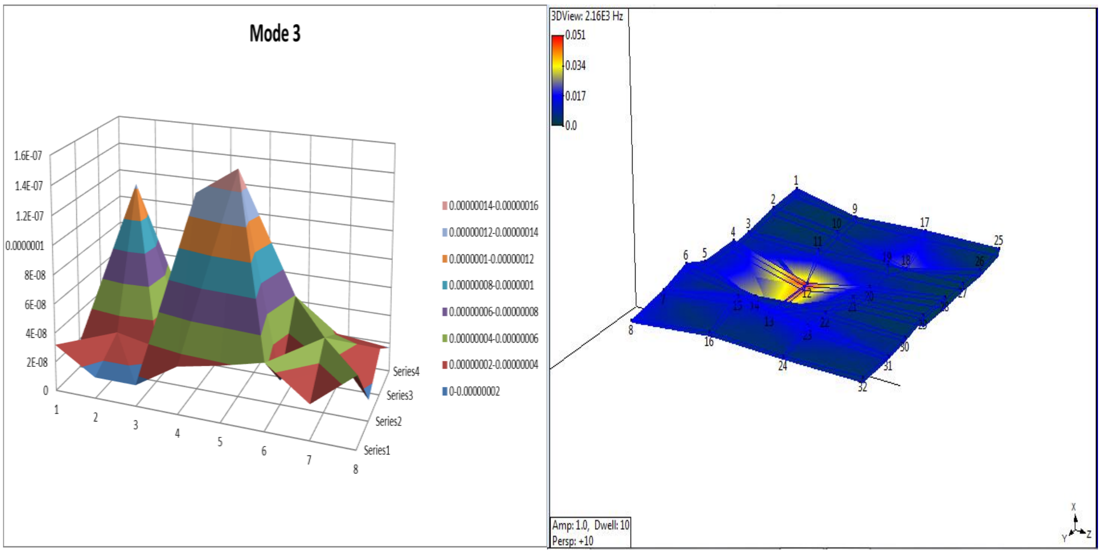
Figure 4.18 shows the first mode shape of joining aluminium alloy and stainless steel with weld, there is a bending deformation pattern. The red colour indicates the maximum displacement occurred in the mode and blue colour is minimum displacement in Me Scope. It shows a same shape where at point 11 have higher value both of them.



(a) (b)

Figure 4.19: Second mode shape of Operating Deflection Shape, (a) Calculation, (b) ME Scope

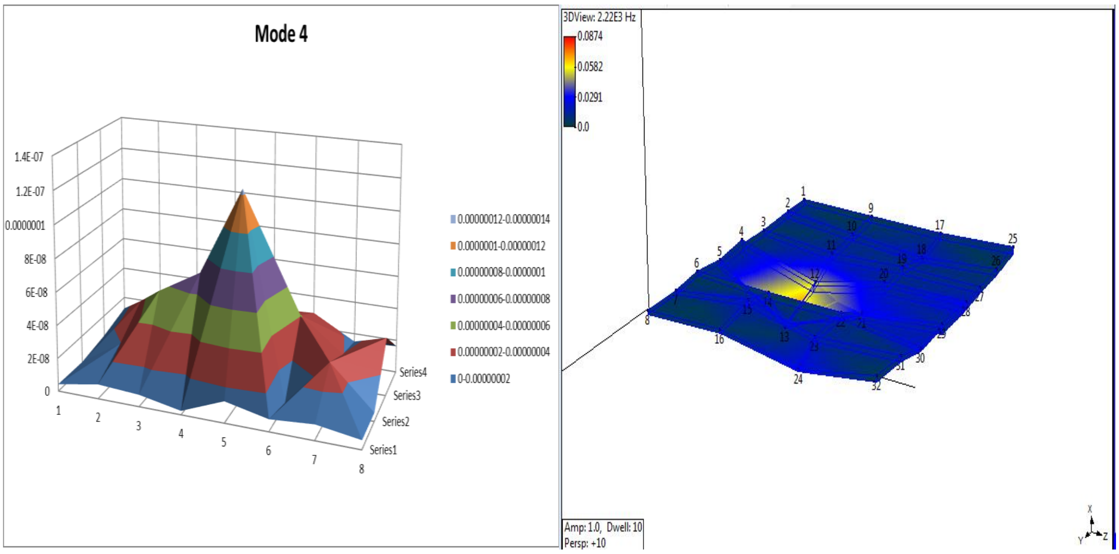
Figure 4.19 shows the first mode shape of joining aluminium alloy and stainless steel with weld, there is a bending deformation pattern. The red colour indicates the maximum displacement occurred in the mode and blue colour is minimum displacement in Me Scope. It shows a same shape where at point 18 have higher value both of them.



(a) (b)

Figure 4.20: Third mode shape of Operating Deflection Shape, (a) Calculation, (b) ME Scope

Figure 4.20 shows the first mode shape of joining aluminium alloy and stainless steel with weld, there is a bending deformation pattern. The red colour indicates the maximum displacement occurred in the mode and blue colour is minimum displacement in Me Scope. It shows a same shape where at points 12 and 18 have higher value both of them.



(a) (b)

Figure 4.21: Fourth mode shape of Operating Deflection Shape, (a) Calculation, (b) ME Scope

Figure 4.21 shows the first mode shape of joining aluminium alloy and stainless steel with weld, there is a bending deformation pattern. The red colour indicates the maximum displacement occurred in the mode and blue colour is minimum displacement in Me Scope. It shows a same shape where at point 13 have higher value both of them.

Lastly, all the result data from mode one until mode four will combine at one graph to check which one mode between one and four is a dominant mode when a motor with 53.3 Hz attach at the plate.

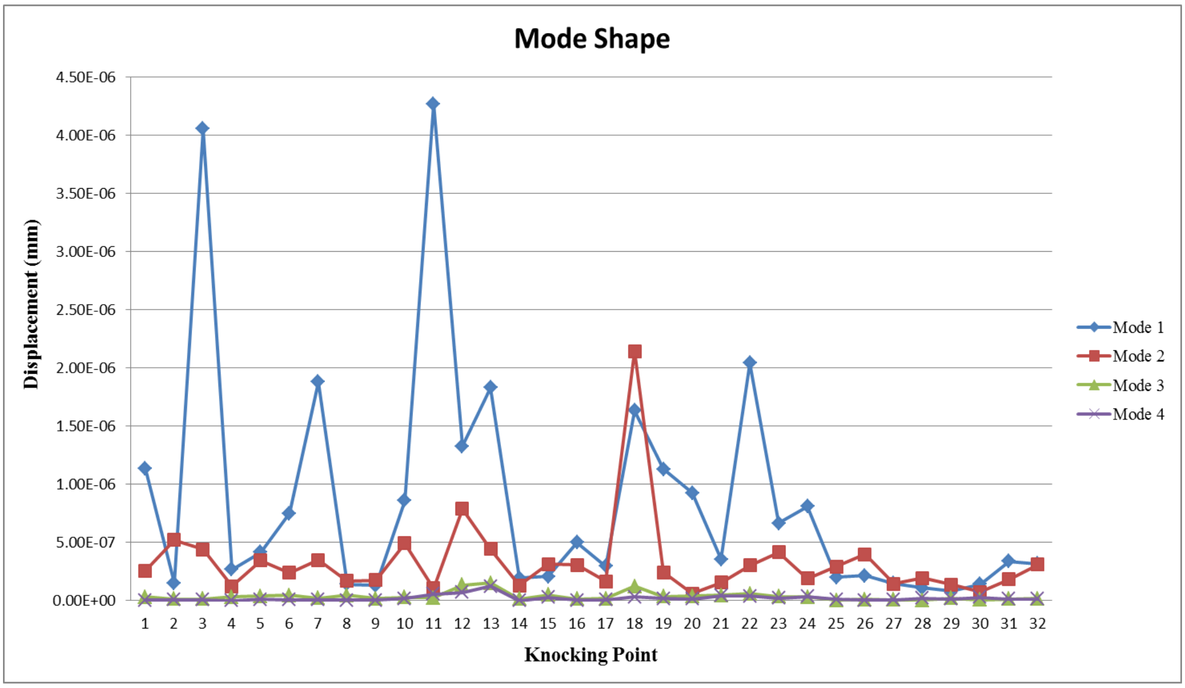


Figure 4.22: Graph comparison mode shape in operating deflection shape with calculation

From figure 4.22, line blue is represent mode one. The red colour represent mode two, green colour represent mode three and last purple colour represent mode four. When all result combines in one graph, mode shapes one which line blue colour have a higher value if compare another three mode shape. It can conclude that mode one is dominant mode when given 53.3 Hz of frequency.

4.7 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 results obtained from this study shows a comparison between the instructor and the experiment is completely 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 the study 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. ANSYS 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 is 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 INTRODUCTION

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 Spot welding using different thickness, other aspects of future work also will be discussed.

5.2 CONCLUSION

This project was achieve a main objective is to determine the dynamic properties and behaviour of dissimilar metal joint by Spot welding using different thickness using experimental modal analysis and comparison with the finite element analysis (FEA).

The result shows joining between aluminium and steel by Spot drawn to welding–brazing because of their difference in melting point. The joining between stainless steel and aluminium alloy were analysed in experimental modal analysis and compared with finite element analysis (FEA). Based on this study, the conclusion can be drawn as follows:

i. Joining by Spot welding between aluminium alloy and stainless steel has resulted the successful joining yet at the stainless steel side is brazing.

ii. Joining welding gave effect to dynamic properties (mode shape) of modal analysis especially mode 1 (bending pattern) and mode 4 (second bending)

iii. The natural frequency comparison shows the closeness of the result and mode shape between experimental and FEA is dissimilar.

iv. The percentage error is slightly high due to some errors during the experimental modal analysis. The experimental modal analysis was conducted with the fixed 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 factor as the higher percentage error.

5.3 RECOMMENDATION

There are few improvements could to be done for the future research. In order to improve the accuracy of the predicted dynamic properties of joining between stainless steel and aluminium alloy by welding, some recommendations made are as follows:

i. Use joining between stainless steel and aluminium alloy with large dimension as model of modal analysis

ii. Carry out the research in a completely soundproofed room and only allows the person who carrying out the experiment to be in the room in the meantime.

iii. When conducting experimental modal analysis, plate of joining between aluminium alloy and stainless steel should be suspended.

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APPENDIX A1

CHEMICAL COMPOSITION OF THE ALUMINIUM ALLOY 1100 H14 SHEETS

FOUNDRY LABORATORY
FACULTY OF MECHANICAL ENGINEERING
UNIVERSITI MALAYSIA PAHANG

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

Universiti Malaysia PAHANG

Chemical Results

Sample ID: Material: stainless steel

Customer: 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: 17/11/2012 Test by: Verify by:

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