SUPERVISOR DECLARATION

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of the Degree of Mechanical Engineering.

Signature : ……………………

Supervisor : Lee Giok Chui

Date : ……………………

INVESTIGATION ON THE SHEAR JOINTS FAILURE WITH TENSILE LOADING FOR ALUMINUM PINS

MOHD FIRDAUS BIN MOHD ZAID

A report submitted in partial fulfillment of the
requirements for the award of the degree of the
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Universiti Malaysia Pahang

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DECLARATION

I declared that this thesis entitled *Investigation on the Shear Joints Failure with Tensile Loading for Aluminum pins* is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ………………………………

Name : Mohd Firdaus Bin Mohd Zaid

ID Number : MA06068

Date : ………………………………

Dedicated to my beloved family and friends

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ABSTRACT

The use of pin joints is to connect two steel plates together and to support load together or alone. It has been extensively used in civil, mechanical and aircraft structures. Most of the available methods have been developed to estimate the loading capacity using side-edge distance but not the position of the pins using angle. In this paper, a research is developed to recommend the best position of pin group under in tensile loads based on the assumptions of angle and distance from centroid. The investigation is using Aluminum pins as connecter to joint two plates made of steel. The force applied on the side of plate and the Finite Element Analysis (ALGOR) as software to analysis the model. The analysis is use to find the lowest stress from four pins and that the first pins will fail. That means the pin can support lowest load than others pins. From the result, the pin closest to the load applied, not symmetry with other pin or alone and far from centroid axis are faster failed. As conclusion, The more close distance to centroid axis and other pins, to more higher maximum stress or the pin can support high load before it failed.

ABSTRAK

Kegunaan pin adalah untuk menyambung dua keping besi bersama-sama dan untuk menyokong beban bersama-sama atau sendirian. Ia digunakan secara menyeluruh di kejuruteaan awam, mekanikal dan struktur pesawat. Sebahagian besar kaedah yang sedia telah dibangunkan untuk menganggarkan beban yang boleh di tampung menggunakan jarak sisi-tepi tetapi tidak kedudukan pin menggunakan sudut. Dalam thesis ini, satu penyelidikan dibuat untuk mengesyorkan kedudukan terbaik kumpulan pin. Penyelidikan menggunakan pin Aluminium sebagai penyambung untuk bersama dua keping diperbuat daripada besi. Beban dikenakan dari sudut tepi dan finite Element Analysis (ALGOR) sebagai perisian untuk analisis model. Analisis ini digunakan untuk menentukan tekanan terendah daripada empat pin dan pin pertama akan gagal. Itu bererti pin yang pertama boleh menyokong beban terendah daripada pin yang lain. Daripada keputusan, pin paling dekat dengan beban yang dikenakan, tidak simetri dengan pin lain atau sendirian dan jauh dari paksi pusat lebih cepat gagal. Sebagai kesimpulan, Semakin dekat jarak paksi pusat dan pin yang lain, semakin tinggi beban yang boleh ditampung atau pin boleh menyokong beban yang tinggi sebelum gagal.

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D = Pin diameter
L = Length of plate
t = thickness of plate
W = width of plate
mm = milimeter
MPa = MegaPascal
% = Percent
N = Newton
σ = Stress
F = Force
A = Area
UTS = Ultimate Tensile Stress

CHAPTER 1

INTRODUCTION

1.1 Project Background

When a connection is desired that can be disassembled without destructive methods and that is strong enough to resist any load like tensile load, then the simple pins joint is a good solution but without a good design of joint can also be dangerous to people. The pinned connections are widely use in boilers, bridges, buildings and other structures but when they failure, it can be danger to human life unless it is properly designed and assembled by a trained mechanic.

In a pin joint with tensile loading, the pins are shared the load in shear, bearing in the pin, bearing in the member, and shear in the pin. When one pin is failed, another pins will begins to carry the load until they failed. The right location of pin must be correctly design to make all pins share same load when they subjected with load. It means, two pins with closed distance shared higher load or stress than one pin alone or the position one pin is far from another pins.

In this project, we want to design the best position of pins joint and investigation on the shear joints failure with tensile loading for Aluminum pins. We will investigate using Aluminum pins as connecter to joint two plates made of steel and testing in finite element analysis (ALGOR). The analysis is use to find the lowest stress from four pins and that the first pins will fail. That means the pin can support lowest load than others pins.

Thus, distance pins from load applied and distance pin to another pins also important.

1.2 Problem Statements

In this project, we want to model the best position of aluminum pins joint to support any load subjected and made investigate on shear joint failure on aluminum pins. The function of pin in this project is connecter between two slide steel plates. Example in aircraft industry or construction, pin joint are important to connect the wing of aircraft. If they failure during aircraft fly, it could be danger to people on the aircraft. So, the right locations of pins joint are very important to support highest load and prevent they failure.

1.3 Project Objectives

i. To recommend the best position of pins joint.
ii. Investigation on the shear joint failure with tensile loading for Aluminum pins.

1.4 Scopes

1. To model the best position of pins joint.
2. The pins are made from Aluminum.
3. Varying of the distance between pins.
4. Varying of angle between pins from centroid axis.

CHAPTER 2

Literature Review.

2.1 – Introduction

To determine safe, allowable loads for specification in design codes and standards, a considerable amount of research has been conducted on bolt joints. This research has primarily covered shear joint failure on aluminum rivets or pins. In practice, few bolt joints are used. Multiple bolts are required to provide a joint whose strength is matched to the strength of the members being joined and the forces carried by them.

Design recommendations for bolted joints were based on research by Trayer (1932). Examples design recommendations include the geometry of a multiple-bolt joint in terms of (a) the end and edge distances and fastener spacing (b) whether staggered boltrs can give a greater and more reliable ultimate load, and (c) whether there is a way to optimize the performance of a joint.

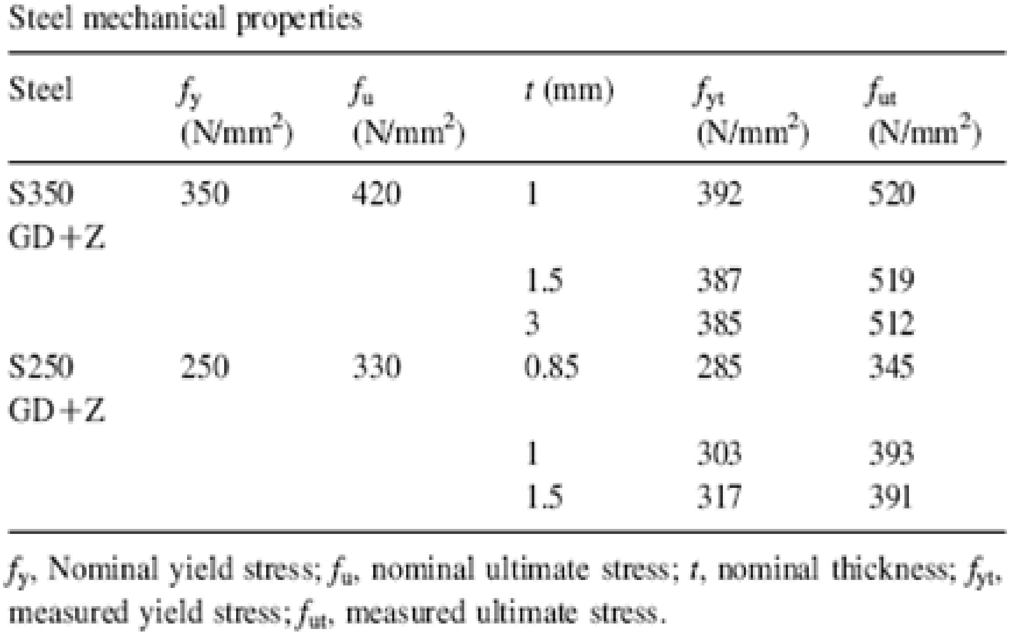
This report reviews past analytical and experimental research on bolted joints to determine our knowledge base about their performance and behavior under load. From this, future research areas are suggested.

2.2 Experimental Research

2.2.1 Experiment by Miquel Casafont (2006)

Miquel Casafont, Alfredo Arnedo, Francesc Roure and Antonio Rodrı´guez-Ferran (2006) tested of joints for seismic design of lightweight structures using steel grade S350 GDCZ or S250 GDCZ. Table 2.1 shows the nominal and measured mechanical properties of the steels. It should be noticed that the experimental fyt and fut are rather higher than the nominal fy and fu. Screws of two different diameters were used to connect the straps: 4.8 and 6.3 mm. The shaft length of the 4.8 mm diameter screws was always 10 mm (threaded part), and they could have either flat and square heads or hexagonal heads. The shaft of the 6.3 diameter screws, whose head was always hexagonal, could be 10 or 30 mm long (threaded part). The length of the steel straps ranged between 350 and 475 mm, depending on the number of screws of the joint. Their thickness was also variable from 0.85 to 3 mm, but their width was always the same, 100 mm. Figure 2.1 shows the position of the screws: the spacing and the longitudinal and transverse edge distances. The joint layout was identical for all the specimens. **Miquel Casafont, Alfredo Arnedo, Francesc Roure and Antonio Rodrı´guez-Ferran (2006)**

Table 2.1: The nominal and measured mechanical properties of the steels.



Steel mechanical properties

Steel	f_y (N/mm^2)	f_u (N/mm^2)	t (mm)	f_{yt} (N/mm^2)	f_{ut} (N/mm^2)
S350 GD+Z	350	420	1	392	520
			1.5	387	519
			3	385	512
S250 GD+Z	250	330	0.85	285	345
			1	303	393
			1.5	317	391

f_y, Nominal yield stress; f_u, nominal ultimate stress; t, nominal thickness; f_{yt}, measured yield stress; f_{ut}, measured ultimate stress.

- Source: Experimental testing of joints for seismic designof lightweight structures. Part 1. Screwed joints in straps*Miquel Casafont, Alfredo Arnedo, Francesc Roure, Antonio Rodrı´guez-Ferran,*

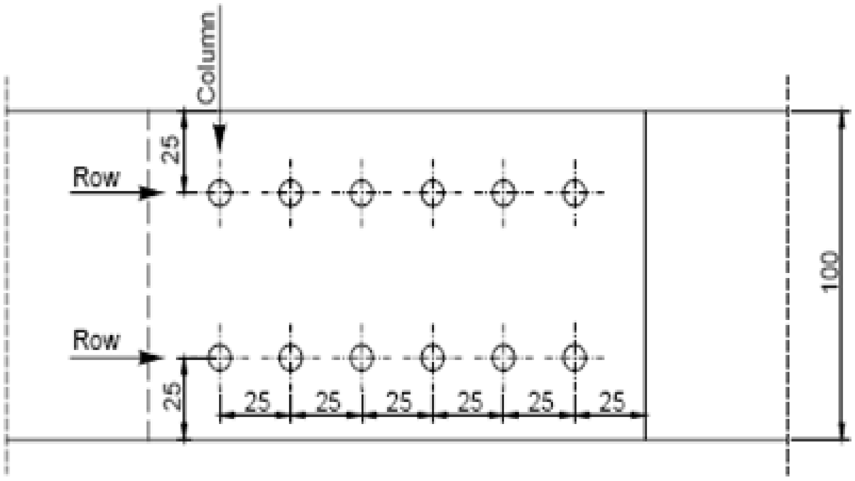


Figure 2.1: Joint layout

- Source: Experimental testing of joints for seismic designof lightweight structures. Part 1. Screwed joints in straps*Miquel Casafont, Alfredo Arnedo, Francesc Roure, Antonio Rodrı´guez-Ferran,*

2.2.2 Experiment by Doyle (1964)

Doyle (1964) tested a series of joints fabricated with eight bolts. The joints were three-member assemblies consisting of a three 6- by 190-mm (0.25 by 7.5 in.) two steel side plates with two rows of four bolts acting in double shear, and 12.5- and 19-mm (0.5- and 0.75-in.) bolts. Single-bolted joints were tested for comparison. Bolt spacings were either 75 or 114 mm (3 or 4.5 in.). One result from Doyle's research was that the ultimate stress per bolt in the eight-bolt connected joint was between 60% and 80% that of the single-bolt joints using 19-mm (0.75-in.) bolts. This lower ultimate bearing stress per bolt was attributed to factors such as tension parallel and perpendicular to the grain, splitting, shear along the grain, and nonuniform bearing of the bolts. The test results showed that the load per bolt when plotted against the joint slip for the multiple-connected joint was not nearly proportional to the strength of a single-bolt connection. **Doyle (1964)**

Specifically, Doyle concluded the following:

1) The bearing stress at the proportional limit for joints with two rows of four 19-mm (0.75-in.) bolts in laminated Douglas Fir members was about the same as for similar joints with one bolt, but the ultimate bearing stress was about a third less (Figure 2.2). Series A, 3 in (75 mm) bolt spacing; Series B, 4.5 in (114 mm) bolt spacing; Series C, stitch bolts; Series D, difference in densities; and E, tapered end. With 12.5-mm (0.50-in.) bolts, the bearing stress at the proportional limit and the ultimate bearing stress was about 15% less (Figure 2.3). Series F, 3 in (75 mm) bolt spacing; Series G, 4.5 in (114 mm) bolt spacing; Series H, difference in densities.

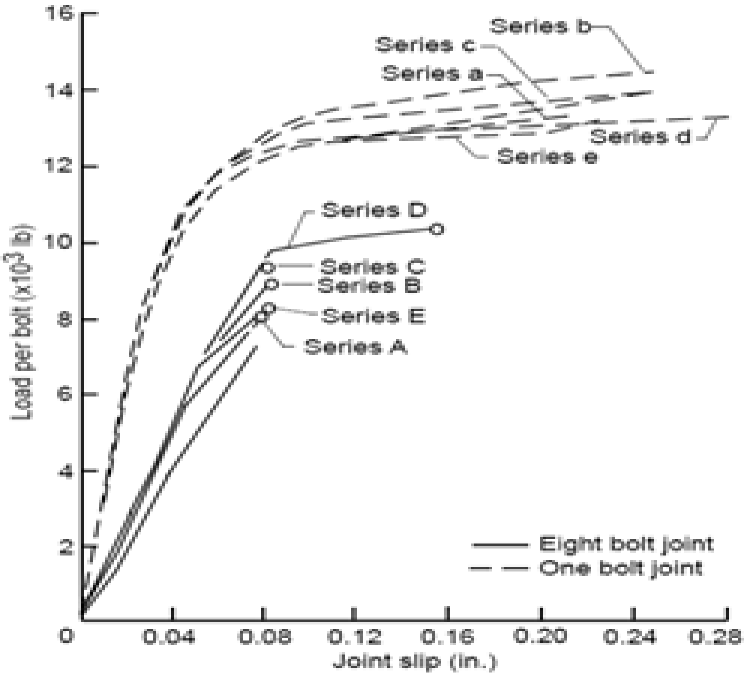


Figure 2.2: Load-curve slip curves for five series of joints with eight 19 mm (0.75—in) bolts in laminated Douglas fir members (series A through E) and their matching single-bolt control joints (series a through e)

- Source: Doyle, D.V. 1964. Performance of joints with eight bolts in laminated Douglas-fir.

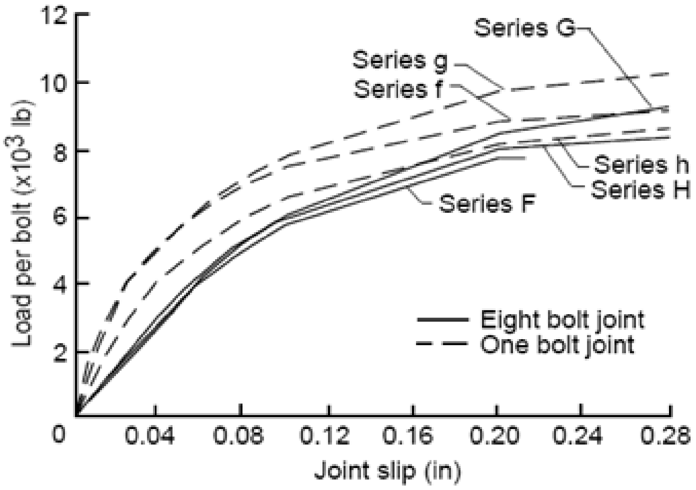


Figure 2.3: Load-slip curves for three series of joint with eight 12.5 mm (0.50-in) bolts in laminated Douglas Fir members (series F through H) and their matching single-bolt control joints (series f through h)

- Source: Doyle, D.V. 1964. Performance of joints with eight bolts in laminated Douglas-fir.

2) Joints with the eight bolts under tensile load slip had two to three times more slip at the proportional limit than did joints with a single bolt. However, joints with a single bolt had twice as much slip at ultimate load as did joints with eight bolts.

2.2.3 Experiment by Mettem and Page (1992)

Mettem and Page (1992) reported on tests conducted on both single- and multiple-bolted joints. The objective was to investigate how the load on a multiple-fastener bolted joint with steel sideplates and a central member would be distributed between the individual bolts. The tests were designed so that failure would occur in a pure embedment mode in the case of both single- and multiple-fastener joints. **Mettem and Page (1992)**

The thickness of the central member was 2.75 times the diameter of the fastener (i.e., *L/D* = 2.75), and the thickness of the steel sideplates was 0.83 times the bolt diameter. The bolts used had a 12-mm (0.5-in.) diameter; the European whitewood member was 33 mm (1.25 in.) thick with 10-mm- (0.375-in.-) thick steel sideplates. A special multiple embedment testing rig was used with strain-gauged sections to enable the load applied to each bolt to be measured. Tests were carried out for both tension and compression parallel to the grain, although only compression was carried out perpendicular to the grain. Bolts were spaced at 5*D* parallel or perpendicular to the grain. The end distances were 7*D* parallel to the grain and 4*D* perpendicular to the grain; the edge distances were 4*D* parallel to the grain and 2.1*D* perpendicular to the grain. These spacings and distances conformed with the Eurocode 5, April 1992, recommendations. **Mettem and Page (1992)**

The test procedure was to drill the bolt holes immediately before each test to a diameter of 12.2 mm (0.5 in.), with the intention of eliminating possible fabrication effects, misfit, shrinkage, swelling between holes. The bolt holes were positioned to avoid gluelines in the laminated material.

For single-bolt specimens, loading was carried to failure after the elastic stiffness had been measured. For the four-bolt embedment tests, loading was not continued until failure because the intention was only to measure load distribution within the elastic range.

The mean values of the four-bolt embedment tests (Figure 2.4) showed some variation from the value of 0.25 corresponding to the bolts sharing the load equally. These results relate only to elastic embedment and do not reflect the likely distribution at failure.

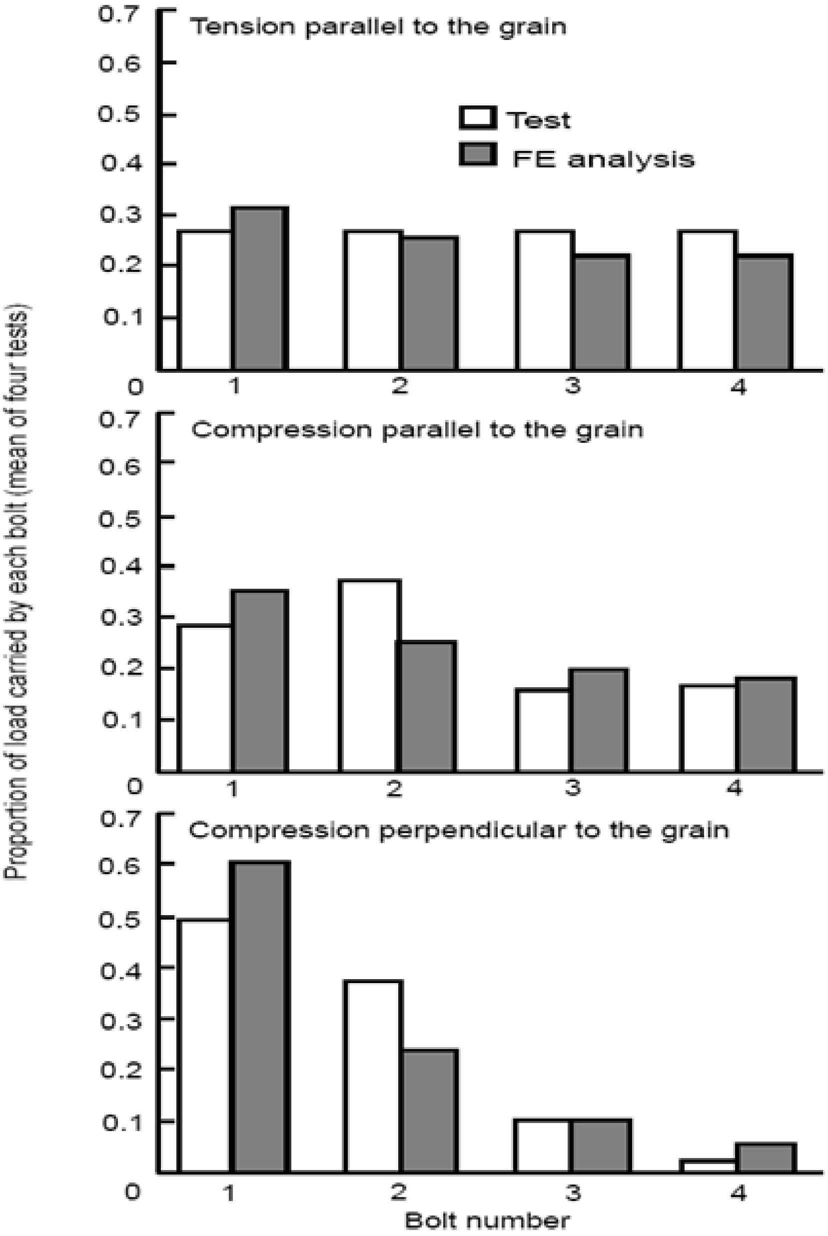


Figure 2.4 : Proportion of load carried by each in a four-bolt joint

- Source: Mettem, C.J.; Page, A.V. 1992. Load distributions in multi-fastener bolted joints in European whitewood with steel sideplates. Paper 25–7–12, CIB W18, Åhus, Sweden.

2.2.4 Experiment by Kuwamara (2001)

Experimental research regarding two types of bolted connections: single shear and double shear connections, fabricated from thin-walled stainless steel (austenitic stainless steel type; SUS304) using 1.5 or 3.0mm thick plate and 12 mm/15mm diameter bolt (A2-50; SUS common bolt or 10T-SUS; SUS high tensioned bolt) were carried out by Kuwamura et al. (2001). Figure 2.5 display geometry of test specimens and test set-up of specimen (series SA). The both ends of test specimens were gripped through chucks onto a tensile test machine (Amsler typed Universal Testing Machine) by which a tensile force was applied gradually to the test specimen in monotonic displacement control. It should be noted that the experimental data are very important since they can be used for calibration and implementation of numerical analysis. In this FE analysis, Only the thinner plate (1.5 or 3.0mm thick) out of single-shear connection with both test plates (1.5 or 3.0mm thick) and rigid plate (6.0mm thick). A total of eight test results which constitute three specimens with 1.5mm thick plate and five specimens with 3.0mm thick plate is summarized in Table 2.2. The object specimens were designed for the following parameters: (1) thickness of plane plate (t): 1.5 and 3.0 mm, (2) 12mm diameter (d) common bolt and 0.5mm bolt clearance, (3) 30mm pitch (p) and gage distance (g), (4) end distance (e) from the center of a bolt hole to the adjacent end of plate in the direction of load; 12, 18, 30 or 60mm and edge distance (b) perpendicular to the direction of load (fixed values according to all bolt arrangement), (5) three bolt arrangements (Series SA single bolt; Series SB: two bolts; Series SC: four bolts). **Kuwamara (2001)**

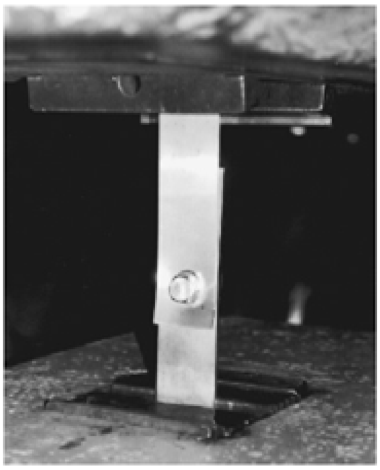
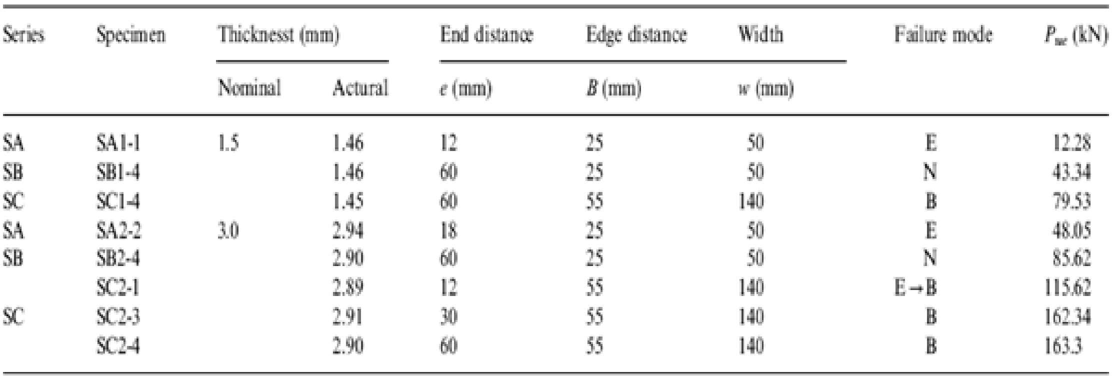


Figure 2.5: Test set up for specimen (Series SA)

- Source: Kuwamura H, Isozaki A. Ultimate behavior of fastener connections of thin stainless steel plates. Journal of Structural and Construction Engineering (Transactions of Architectural Institute of Japan) 2002;556:159–66.

Table 2.2: Test specimens and test result



Series	Specimen	Thicknesst (mm)		End distance	Edge distance	Width	Failure mode	P_{ue} (kN)
		Nominal	Actural	*e* (mm)	*B* (mm)	*w* (mm)		
SA	SA1-1	1.5	1.46	12	25	50	E	12.28
SB	SB1-4		1.46	60	25	50	N	43.34
SC	SC1-4		1.45	60	55	140	B	79.53
SA	SA2-2	3.0	2.94	18	25	50	E	48.05
SB	SB2-4		2.90	60	25	50	N	85.62
	SC2-1		2.89	12	55	140	E→B	115.62
SC	SC2-3		2.91	30	55	140	B	162.34
	SC2-4		2.90	60	55	140	B	163.3

- Source: Kuwamura H, Isozaki A. Ultimate behavior of fastener connections of thin stainless steel plates. Journal of Structural and Construction Engineering (Transactions of Architectural Institute of Japan) 2002;556:159–66.

2.3 Behavior of Joints with Misaligned Holes

Come into bearing and the fasteners generally offer further resistance to the slip movement. A series of small slips have been observed to develop at load levels considerably above the normal slip resistance. These partial slips bring more bolts into bearing and result in geometric self-adjustment of the joint elements as the applied loads force alignment of the joint. The joint tends to pivot around fasteners already in bearing, and eventually this result in more bolts in bearing. Tests have indicated that the slip resistance of a misaligned bolted joint is equal to or exceeds the slip resistance of a joint without misalignment. This is visually apparent in Figure 2.6. As the misaligned condition was made more severe, there was not as much rigid body motion possible. No significant change in joint stiffness was apparent until the applied loads were nearly twice as large as the load that caused major slip to develop with good alignment. Comparable results have been observed with more complex joints where misalignment is more probable. Misaligned holes always result in less movement between the connected plies. The joint stiffness is improved, and full hole slip is not possible.

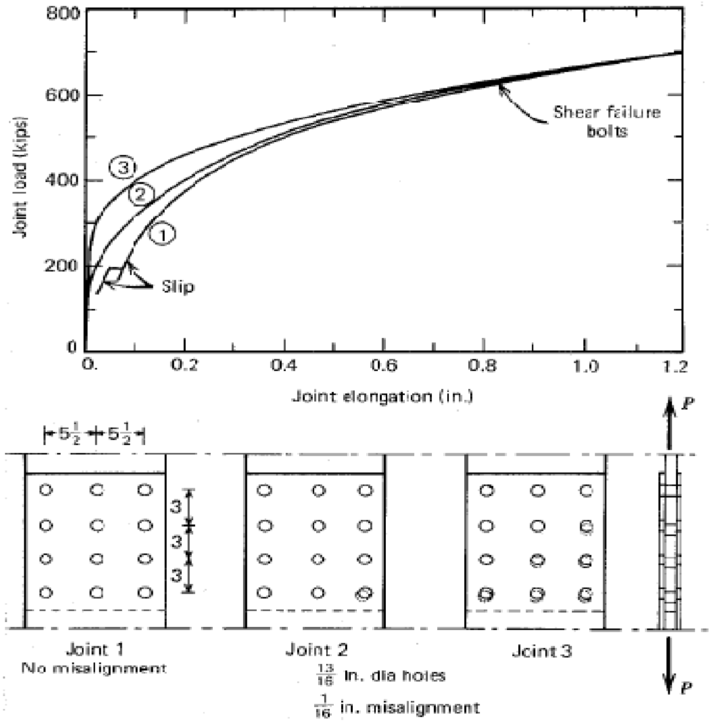


Figure 2.6: Load- elongation curve of a misaligned bolted joint is equal to or exceeds the slip resistance of a joint without misalignment

- Source: Guide to Design Criteria for Bolt and Riveted Joints, Second Edition, Geoffrey L. Kulak, John W. Fisher and John H. A. Struik (1987)

2.4 DESIGN RECOMMENDATIONS

The amount of misalignment in a joint depends largely on the joint geometry as well as on fabrication tolerances and erection procedures. Since bolt holes are generally 1/16 in. in excess of the nominal bolt diameter, some adjustment possibility is provided. Available test results do not indicate any adverse effect of misalignment resulting from hole clearance on either the slip resistance or the ultimate strength of the joint. Hence, the usual misalignment that may result from erection or fabrication tolerances does not affect the design of joints. Since the deformation capacity of the fasteners and plate material are of prime importance in the readjustment capacity of bolted joints with misaligned holes, the degree of tolerance will decrease when higher strength materials with lower ductility are used.

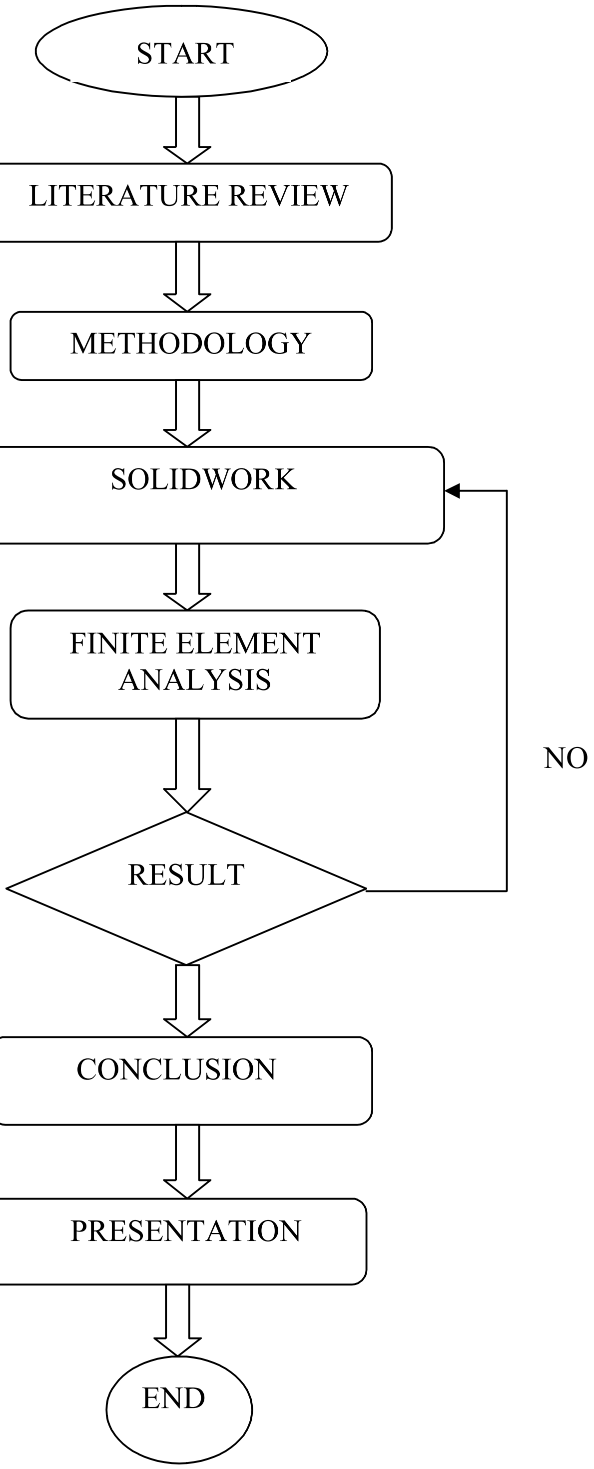
CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, we will further study about shear joint failure for pins made from aluminum by doing analysis using finite analysis software (ALGOR). This chapter also will explain about specimen preparation using solidwork and methodology will be used to make sure this project will success. In specimen preparation, there are many position are made after consideration by using distance of diameter between pins and angles from centroid for all pins. In this methodology, we also explain about flow chart, specimen, software for analysis and graph. The use of pin joints is to connect two steel plates together and to support load together or alone. In this paper, a research is developed to recommend the best position of pin group under in tensile loads based on the assumptions of angle and distance from centroid. The force applied on the side of plate and the Finite Element Analysis (ALGOR) as software to analysis the model. ALGOR's is software to design, analysis and simulation tools that allow engineers to virtually test and predict real-world behavior of new and existing product designs. These tests help engineers reduce the time to market and make better, safer products at a lower cost.

3.2 FLOW CHART OF THE PROCESSING METHOD



3.3 Specimen

Tests were performed on pin connections between two plates, where the pins are made from aluminum and plates are made from steel.

Pin diameter, D = 2 mm.
The length of the steel plates, L = 100 mm
The thickness of the steel plates, t = 3 mm
The width of the steel plates, W =50 mm.

Table 3.1: table for different angle

Position	**Angles pins from centroid**				**Distance between pin holes diameter (mm)**		**Distance all pin from centroid**
	1	**2**	**3**	**4**	**1 and 2**	**3 and 4**	
1	15	30	195	210	13	13	15
2	30	60	210	240	25	25	15
3	45	135	225	315	71	71	15
4	60	120	210	330	43	43	15
5	75	165	260	345	71	71	15
6	90	180	270	360	71	71	15

From table 3.1, we use difference angle but the distance all pin from centroid are same. We use difference angle from axis because we want find the best angle for right position of pins to give highest load. The increment angle is 15°.

From Table 3.1:

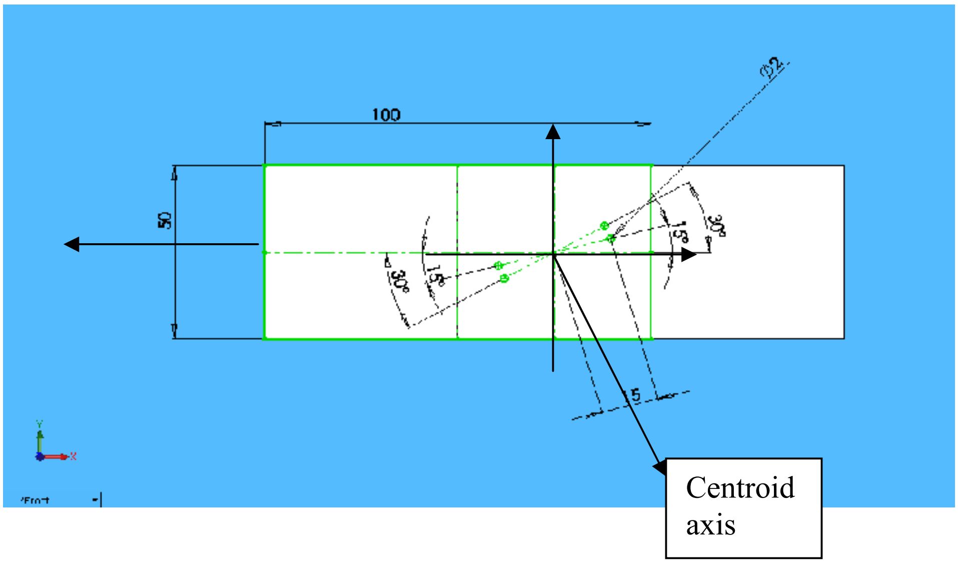


Figure 3.1: Position 1

For position 1, the location of all pins is distance 15 mm from centroid. First pin angle is 15º, second pin angle is 30º, third pin angle is 195º and fourth pin angle is 210º. The force will be applied at edge of plate.

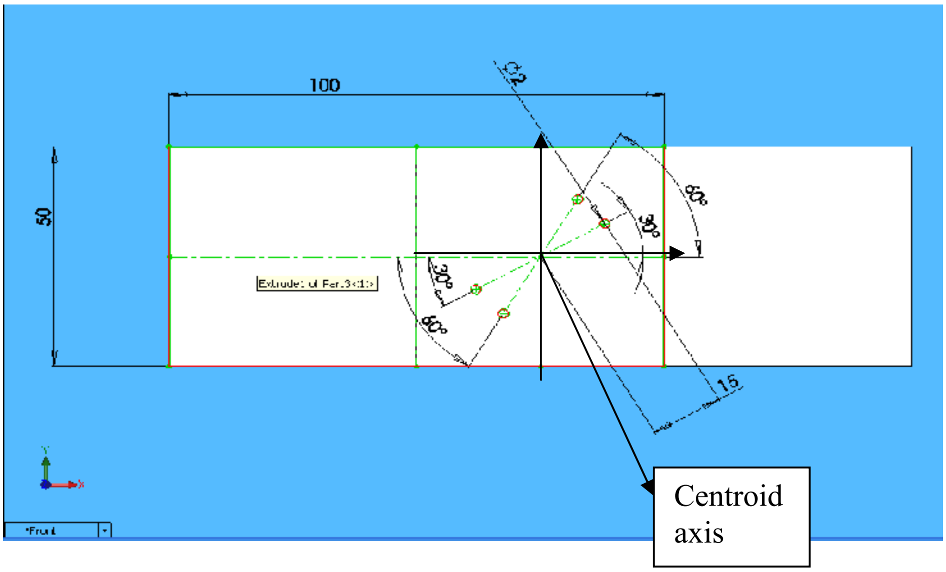


Figure 3.2: Position 2

For position 2, the location of all pins is distance 15 mm from centroid. First pin angle is 30º, second pin angle is 60º, third pin angle is 210º and fourth pin angle is 240º. The force will be applied at edge of plate.

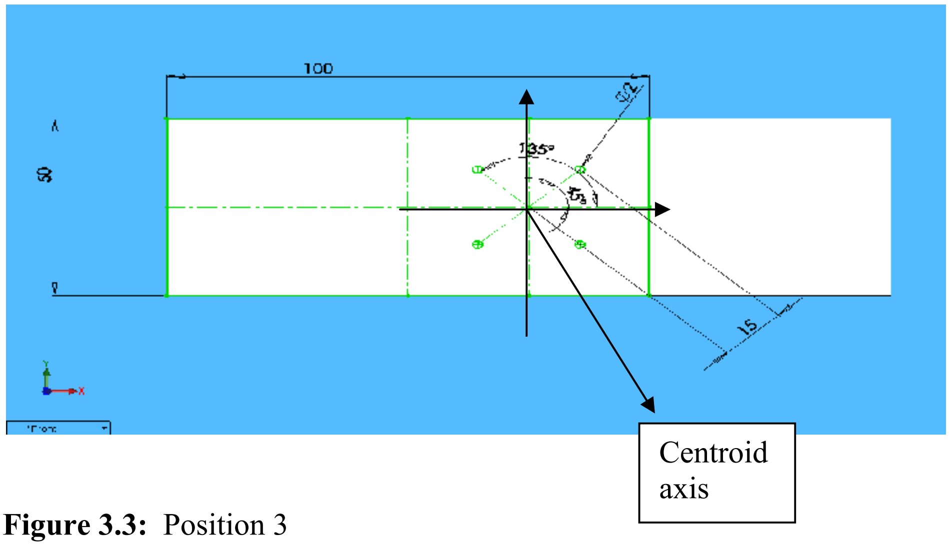


Figure 3.3: Position 3

For position 3, the location of all pins is distance 45 mm from centroid. First pin angle is 45º, second pin angle is 135º, third pin angle is 225º and fourth pin angle is 315º. The force will be applied at edge of plate.

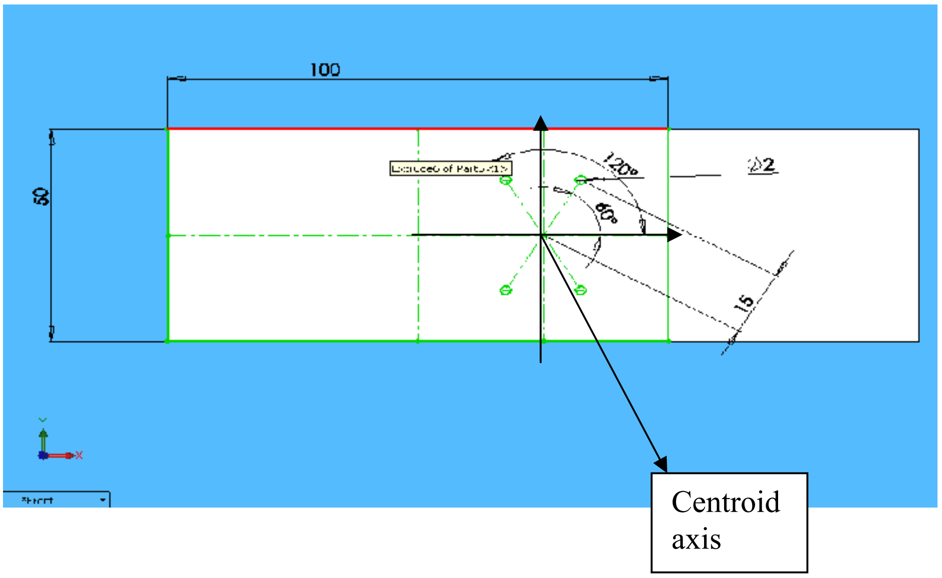


Figure 3.4: Position 4

For position 4, the location of all pins is distance 15 mm from centroid. First pin angle is 60º, second pin angle is 120º, third pin angle is 210º and fourth pin angle is 330º. The force will be applied at edge of plate.

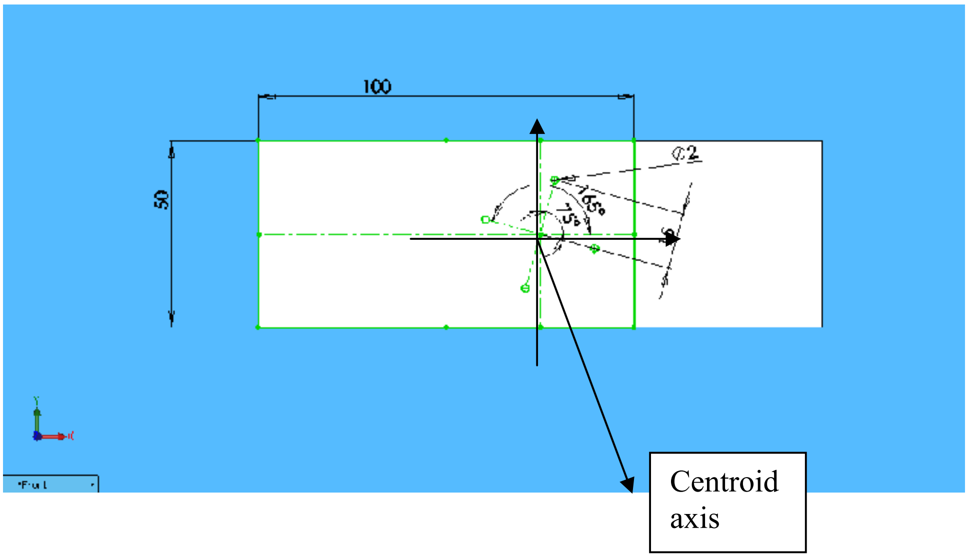


Figure 3.5: Position 5

For position 5, the location of all pins is distance 15 mm from centroid. First pin angle is 75º, second pin angle is 165º, third pin angle is 260º and fourth pin angle is 345º. The force will be applied at edge of plate.

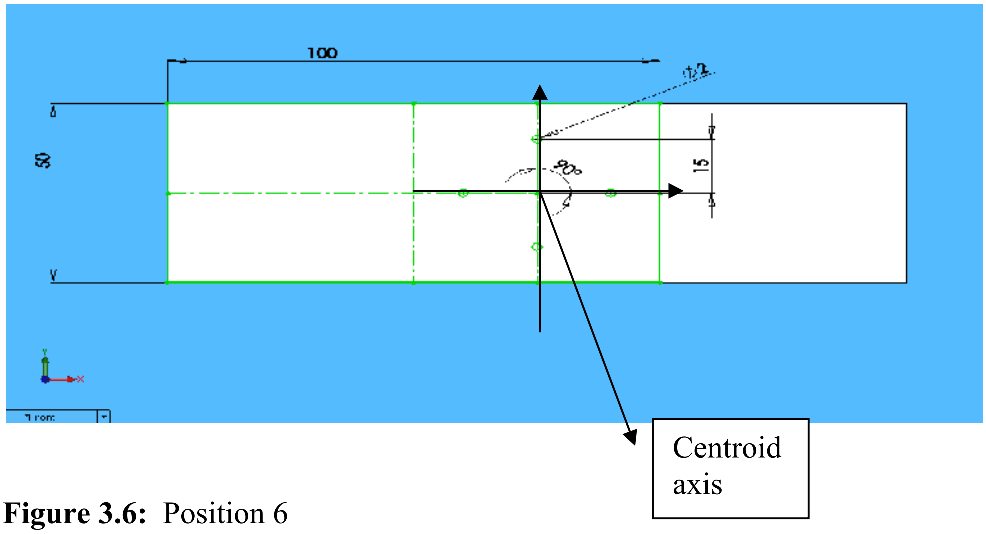


Figure 3.6: Position 6

For position 6, the location of all pins is distance 15 mm from centroid. First pin angle is 90º, second pin angle is 180º, third pin angle is 270º, and fourth pin angle is 360º. The force will be applied at edge of plate.

Table 3.2: same angle with difference distance from centroid

Position	**Angles pins from centroid**				**Distance between pin holes diameter (mm)**		**Distance all pin from centroid (mm)**
	1	**2**	**3**	**4**	**1 and 2**	**3 and 4**	
1	45	135	225	315	14.14	14.14	10
2	45	135	225	315	28.28	28.28	20

From table 3.2, we use same angle but distance pin from centroid difference because we want the best distance for pins to give a highest load. Will also compared use position 3 with same angle but the distance from centroid is 15 mm. The analysis for table 3.2 is same like table 3.1 but we assume that position 3 is the best because that are 2 pin can support load at the same time.

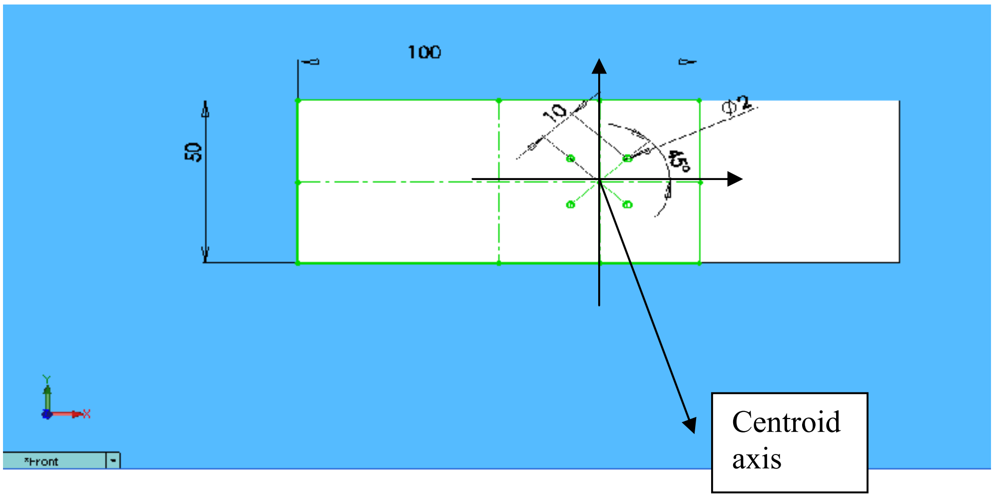
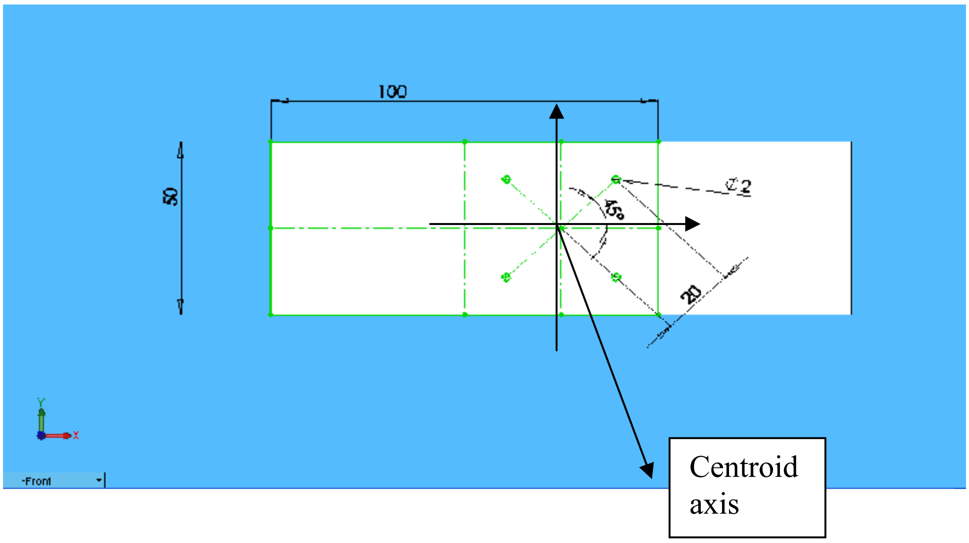


Figure 3.7: Position 7

For position 7, the location of all pins is distance 10 mm from centroid. First pin angle is 45º, second pin angle is 135º, third pin angle is 225º and fourth pin angle is 315º. The force will be applied at edge of plate.



Centroid axis

Figure 3.8: Position 8

For position 8, the location of all pins is distance 20 mm from centroid. First pin angle is 45º, second pin angle is 135º, third pin angle is 225º and fourth pin angle is 315º. The force will be applied at edge of plate.

3.4 Finite Element Analysis (ALGOR)

Finite Element Analysis (FEA), ALGOR provides services for mechanical and civil engineers in industries such as automotive, aerospace, medical, consumer products, military, electric power, petroleum, large structures, MEMS and more.

ALGOR's is software to design, analysis and simulation tools that allow engineers to virtually test and predict real-world behavior of new and existing product designs. These tests help engineers reduce the time to market and make better, safer products at a lower cost.

Our wide range of simulation capabilities includes static stress and Mechanical Event Simulation (MES) with linear and nonlinear material models, linear dynamics, fatigue, steady-state and transient heat transfer, steady and unsteady fluid flow, electrostatics, and full multi-physics. These analysis capabilities are all available within FEMPRO, an easy-to-use single user interface that supports most CAD solid modelers and includes sketching, modeling and meshing tools.

For this project, ALGOR V22 will be used to obtain the value of ultimate stress and compare the result with all position. The modeling can be done by using Solidwork software and analyze it using ALGOR.

3.5 SolidWorks 2006

SolidWorks is a 3D mechanical CAD (computer-aided design) program that runs on Microsoft Windows and was developed by Dassault Systèmes SolidWorks Corp.SolidWorks is a parasolid-based solid modeler, and utilizes a parametric feature-based approach to create models and assemblies.

Parameters refer to constraints whose values determine the shape or geometry of the model or assembly. Parameters can be either numeric parameters, such as line lengths or circle diameters, or geometric parameters, such as tangent, parallel, concentric, horizontal or vertical, etc. Numeric parameters can be associated with each other through the use of relations, which allows them to capture design intent. Design intent is how the creator of the part wants it to respond to changes and updates.

Features refer to the building blocks of the part. They are the shapes and operations that construct the part. Shape-based features typically begin with a 2D or 3D sketch of shapes such as bosses, holes, slots, etc. This shape is then extruded or cut to add or remove material from the part. Operation-based features are not sketch-based, and include features such fillets, chamfers, shells, applying draft to the faces of a part

Building a model in SolidWorks usually starts with a 2D sketch (although 3D sketches are available for power users). The sketch consists of geometry such as points, lines, arcs, conics (except the hyperbola), and splines. Dimensions are added to the sketch to define the size and location of the geometry. Relations are used to define attributes such as tangency, parallelism, perpendicularity, and concentricity. The parametric nature of SolidWorks means that the dimensions and relations drive the geometry, not the other way around. The dimensions in the sketch can be controlled independently, or by relationships to other parameters inside or outside of the sketch.

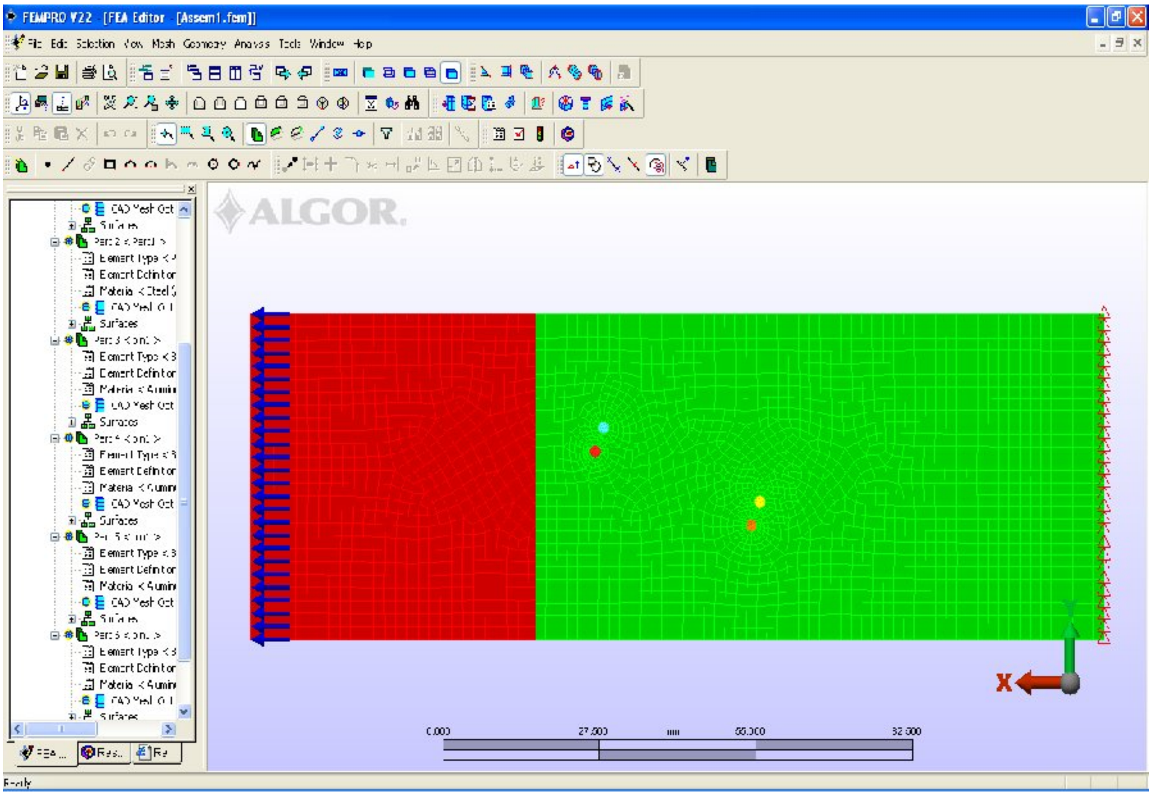
3.6 Procedure

3.6.1 Solidwork Sofware.

1. Firstly, open Solidwork software. Then, create a new part.
2. In a new file, choose front angle and create rectangle with dimension 100×50 mm. Then, create 4 circles on the rectangle with diameter 2 mm.
3. Make a point of centroid is 25×25 mm from the edge of rectangle. For all circle's distance is 15 mm from centroid.
4. Set the dimension for the angle first circle is 15°, second circle angle is 30°, third circle angle is 195° and fourth circle angle is 210°.
5. Select Extrude, and make thickness is 3mm.
6. Now, save the plate as part 1.
7. Open new part, then make a circle with diameter 2 mm and extruded with thickness 8 mm.
8. Save as Pin.
9. Open a new file and choose assembly part. Assembly all part.
10. Choose IGS. File and save as Position 1.
11. Repeat step 2 until 10 with different angles based on table 1 and 2.

3.6.2 Finite Element Analysis (ALGOR)

1. First step, Open file IGS with FEA (Algor).
2. Choose analysis type as statics stress with linear material models.
3. Set element type part 1 and part 2 as plate.
4. Part 1 and part 2 material as steel (ASTM-36)
5. Set element type part 3,4,5 and 6 as brick.
6. Part 3,4,5 and 6 as aluminum.



7. Then set model setting mesh with 75% close to fine.
8. Select side plate and add fix in Nodal Boundary condition.
9. Select other side and add force 5026.548N.
10. Run the analysis.
11. Repeat step 1 until 10 with all position.

From the data, we plot graph maksimum stress (MPa) vs closest distance pin to applied force (mm), graph ultimate stress (first failed) vs position and graph ultimate stress (first failed) vs distance from centroid.

For graph maksimum stress (MPa) vs closest distance pin to applied force (mm), we want to check either that the pin's distance to force applied has effect or not on stress to the pin.

For graph ultimate stress (first failed) (MPa) vs position, we want find the best location for pins based on angle from centroid to support highest stress.

For graph ultimate stress (first failed) (MPa) vs distance from centroid (mm) for table 2, we want find the best distance for pins based on angle from centroid to support highest.

3.7 Calculation

Ultimate Stress, $= —$

Force, $= 4\ (—)$

Ultimate stress for steel ASTM-A36 = 400MPa

D=0.002

F = 5026.548 N

Force will applied at the edge of plate is 5026.548 N.

3.8 Material Properties

Table 3.3: Aluminum 2024-O

Ultimate stress	186MPa
Mass Density	0.00000000278 N·s²/mm/mm³
Modulus of Elasticity	73100 N/mm²
Poisson's Ratio	0.33
Shear Modulus of Elasticity	28000 N/mm²
Thermal Coefficient of Expansion	2.320000E-005 1/°C

Table 3.4: Steel (ASTM - A36) –Plate

Stress ultimate	400Mpa
Mass Density	0.0000000078548 N·s²/mm/mm³
Modulus of Elasticity	199950 N/mm²
Poisson's Ratio	0.29
Thermal Coefficient of Expansion	0.0000117 1/°C
Shear Modulus of Elasticity	77221 N/mm²