BMM87 BEARING LOAD ON A BRASS PIN WITH ALUMINIUM PLATES

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BMM87 BEARING LOAD ON A BRASS PIN WITH ALUMINIUM PLATES

MOHD NUR HILMI BIN MOHD NAZIH

Thesis submitted in fulfillment of the requirements
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FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled " *BMM 87 Bearing Load on a Brass Pin with Aluminium Plates* " is written by *Mohd Nur Hilmi Bin Mohd Nazih*. I have examined the final copy of this project and in my opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering in I herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering.

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

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Special thanks to my parents on their support and cares.

En. Mohd Nazih Bin Embong

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Mr. Lee Giok Chui

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ABSTRACT

The investigation is about the bearing load on a brass pin joined with Aluminium thin plates of variables thickness. The experiment had done using various dimensions of the specimens which is pin diameter, plates thickness and plate thickness to diameter ratio, t/D. The specimens were tested using universal tensile testing machine. The movement for upper crosshead of the testing machine is stopped when the specimen is break. For each specimen, the bearing load was taken and determined from the load vs. displacement graph which is obtained from the Trapezium software in computer that connects with the universal tensile testing machine. The differences dimensions of the specimens give different value of bearing load. By t/D ratio increasing, the higher load pin can support. The higher bearing load is obtained from 5mm brass pin diameter which is 3898.84 N. The finite element analysis ALGOR is use to compare the bearing stress value with experimental test, to choose the more accurate method for other investigation. Finally, the graph of bearing load vs. pin diameter can be used to design brass rivet in the future.

ABSTRAK

Kajian adalah mengenai beban galas yang dikenakan keatas pin tembaga yang bergabung dengan plat Aluminium yang nipis yang berlainan ketebalan. Eksperimen ini dijalankan menggunakan model yang berlainan saiz iaitu diameter pin, ketebalan plat dan nisbah ketebalan plat kepada diameter pin, t/D. Spesimen diuji dengan menggunakan mesin ujian tegangan universal. Gerakan untuk kepala pemegang bahagian atas mesin uji akan berhenti apabila specimen telah gagal atau pin tercabut daripada plat. Untuk setiap specimen, nilai beban yang menyebabkan kegagalan diambil dan ditentukan daripada graf beban melawan sesaran yang diperolehi dari perisian Trapezium dalam computer yang disambung pada mesin ujian tegangan universal. Perbezaan dimensi pada setiap spesimen memberikan nilai yang berbeza untuk beban kegagalan. Dengan nisbah t/D yang meningkat, lebih besar beban yang dapat ditanggung oleh pin. Beban galas paling tinggi diperolehi pada 5mm diameter pin tembaga ialah 3898.84 N. Analisis unsur terhingga oleh ALGOR digunakan untuk membandingkan nilai tegasan galas dengan ujikaji eksperimen, untuk memilih kaedah yang lebih tepat untuk kajian lain. Akhir sekali, graf untuk beban galas melawan diameter pin boleh digunakan untuk merekabentuk rivet tembaga pada masa hadapan.

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LIST OF SYMBOLS

L	Length of the plate, mm
P	Load by Universal Testing Machine, N
E	Distance between centre of hole and edge of the plate, mm
W	Width of the plate, mm
D	Diameter of the pin, mm
t	Thickness of the plate, mm
W/D	Width to Diameter ratio
E/D	Edge to Diameter ratio
t/D	Thickness to Diameter ratio
σ_b	Bearing stress, N/mm^2
τ	Shear stress, N/mm^2

LIST OF ABBREVIATIONS

FEA	: Finite Element Analysis
Al	: Aluminum
Br	: Brass
UTS	: Ultimate Tensile Strength

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Joints are primary sources of weakness in a structure. The mechanically connected structures using fasteners and bolted or pinned joints are a common occurrence in most engineering designs. Design procedures for pins joints have been developed and generally lead to successful applications and safe structures. The pin joint usually use in the applications where light weight and high strength are critical such as the joining structures of aircraft and aerospace vehicles. But, this type of joining have a possibility of serious failure can occur such as bearing stress and crack due to stress concentration and very danger to human. This can be avoided within it is properly designed and assembled by a trained mechanic. In practical structural connections, failure which may occur as a result of this interaction manifests itself as either pin shear, plate net-tension, plate shear-out tension or pin bearing against the plate in the direction of loading.

Bearing mode of failure occurred is due to the bearing stress. Bearing stress is caused by one component acting directly on another. The bearing stress is computed by dividing the load applied to the pin, which bears against the edge of the hole, by the bearing area. This failure can be investigated by apply load to the single shear plate joined by pin under tensile loading. Thus, the pin will be share the load in shear, bearing in the pin and the member, and shear in the pin. Pin joints are unavoidable in complex structures because of their low cost, simplicity, and facilitation of disassembly for repair. It is important therefore to determine the bearing load that pin can withstand in the connections and failure mode occurred.

In this project, we want to investigate the bearing load on a brass pin with Aluminium thin plates of variable thickness. The designing two flat Aluminium plate join by using brass pin, possibly failure might occur on the joints caused by bearing stress. This investigation used at least three set of the same thickness of Aluminium plates and three set of different thickness of Aluminium plates. Brass pin is been machined to many sizes to act as pins. Tensile machine is used to test the specimens and FEA software is used to speed up the investigation. Thus, the analysis from graph of bearing load versus diameter of pins could be used for future designed of rivet.

1.2 PROBLEM STATEMENT

In this project, we want to investigate the bearing load on a brass pin with thin Aluminium plates of variable thickness. The brass pins will act as a connector for two slide Aluminium plates. If bearing failure occurs, it will less cause in harm or disaster, as example in aerospace vehicles or construction. So, the right choice of pin diameter size is important, for it not to break off before its reach its maximum load.

1.3 PROJECT OBJECTIVES

i) To investigate the bearing load for different diameters of brass pin joined with Aluminium thin plates of variable thickness.

1.4 SCOPES

1) Using Aluminium plates thickness of 1mm, 2mm and 3mm.

2) Brass pin diameter of 3mm, 4mm and 5mm.

3) Investigation was limited to the size of the jaw of the Universal Tensile Testing Machine.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The main disadvantage of pin joints is the formation of high stress concentration zones at the locations of pin holes, which might lead to a premature failure of the joint due to net-section, shear-out, or bearing failures, or their combinations. In common case, design of pin connections can be realized according to standard design rules which is the pin and the plate thickness are designed according to their geometrical dimensions, geometry or dimensions of the plate is designed on the basis of its thickness. Some difficulties may occur in case of minimization of dimensions of connection plates or in the case of load carrying capacity determination of an existing pin connection. Scientists and engineers had been carefully analyzed the failed component to determine the cause of failure in most cases. The information gained is used to advance safe performance and minimize the possibility of failure through improvements in design, materials synthesis and selection.

2.2 STRENGTH OF MATERIALS

The strength of a material refers to the ability of a structure to resist loads without failure because of excessive stress or deformation. The applied stress may be tensile, compressive, or shear. Strength of materials is a subject which deals with loads, deformations and the forces acting on a material. A load applied to a mechanical member will induce internal forces within the member called stresses. The stresses acting on the material cause deformation of the material. Deformation of the material is called strain, while the intensity of the internal forces is called stress. The strength of any material relies on three different types of analytical method which is strength, stiffness and stability, where strength refers to the load carrying capacity, stiffness refers to the deformation or elongation and stability refers to the ability to maintain its initial configuration. Strength can be expressed in terms of compressive strength, tensile strength and shear strength. The ultimate strength refers to the point on the engineering stress-strain curve corresponding to the stress that produces fracture. Typical points of interest when testing a material including the ultimate tensile strength (UTS), offset yield strength (OYS) which represents a point just beyond the onset of permanent deformation and the rupture (R) or fracture point where the specimen separates into pieces.

2.2.1 Ultimate Strength

Ultimate strength or tensile strength is a shortened word from ultimate tensile strength. It is the maximum stress that a material can withstand while being stretched or pulled before necking, which is when the specimen's cross-section starts to significantly contract. The value can be found by drawing a horizontal line from the maximum point on the stress-strain curve to the stress axis. The stress where this line intersects the stress axis is called ultimate tensile strength. If the specimen develops a localized decrease in cross sectional area, the engineering stress will decrease with further strain until fracture occurs since the engineering stress is determined by using the original cross sectional area of the specimen. The more ductile a metal is, the more the specimen will neck before fracture and hence the more decrease in the stress on the stress-strain curve beyond the maximum stress. The ultimate strength is not used much in engineering design for ductile alloys since too much plastic deformation takes place before it is reached. It is an intensive property, therefore its value does not depend on the size of the test specimen, it is dependent on other factors, such as the preparation of the specimen, the presence or otherwise of surface defects, and the temperature of the test environment and material (William et al., 2009).

2.2.2 Offset Yield Strength (OYS)

The yield strength or yield point of a material is defined in engineering and materials science as the stress at which a material begins to deform plastically. Once the yield point is passed, some fraction of the deformation will be permanent and non-reversible. Because there is no definite point on the stress-strain curve where elastic strain ends and plastic strain begins, the yield strength is chosen to be that strength when a definite amount of plastic strain has occurred. For American engineering structural design, the yield strength is chosen when 0.2 percent plastic strain has taken place. The 0.2 percent yield strength, also called the 0.2 percent offset yield strength, is determined from the engineering stress-strain diagram. It is the stress that corresponds to the point of intersection of a stress-strain diagram and a line parallel to the straight line portion of the diagram. Offset refers to the distance between the origin of the stress-strain diagram, and the point of intersection of the parallel line and the zero stress axes. Offset yield strength is arbitrary approximation of elastic limit. Knowledge of the yield point is vital when designing a component since it generally represents an upper limit to the load that can be applied.

2.2.3 Bearing Strength

Bearing strength is defined as the point where a bearing load does not cause plastic deformation. Most commonly this term is used in the analysis of bolts or pins where said members are placed in shear, thus resulting in the pin or bolt exerting a force or pressure against one side of the hole it passes through. In plastic industry, it is use to denote the ability of sheets to sustain edgewise loads that are applied by pins, rods or rivets used to assemble the sheets to other articles. Analyzing bearing strength, it is the load divided by the area it is acting against. For a pin or bolt, that area is the bolt shank diameter times the thickness of the material (Yi et al., 2005).

2.2.4 Shear Strength

Shear strength in engineering is a term used to describe the strength of a material or component against the type of yield or structural failure where the material or component fails in shear. A shear load is a force that tends to produce a sliding failure on a material along a plane that is parallel to the direction of the force. In structural and mechanical engineering the shear strength of a component is important for designing the dimensions and materials to be used for the manufacture or construction of the component.

2.2.5 Stress-Strain Relations

During tensile testing of a material sample, the stress–strain curve is a graphical representation of the relationship between stress, derived from measuring the load applied on the sample, and strain, derived from measuring the deformation of the sample. The slope of a stress-strain curve is known as Young's Modulus, or the Modulus of Elasticity. The Modulus of Elasticity can be used to determine the stress-strain relationship in the linear-elastic portion of the stress-strain curve. Elasticity is the ability of a material to return to its previous shape after stress is released. In many materials, the relation between applied stresses is directly proportional to the resulting strain, and a graph representing those two quantities is a straight line. Plasticity or plastic deformation is the opposite of elastic deformation and is defined as unrecoverable strain. Plastic deformation is retained after the release of the applied stress.

2.3 MECHANICAL FAILURE

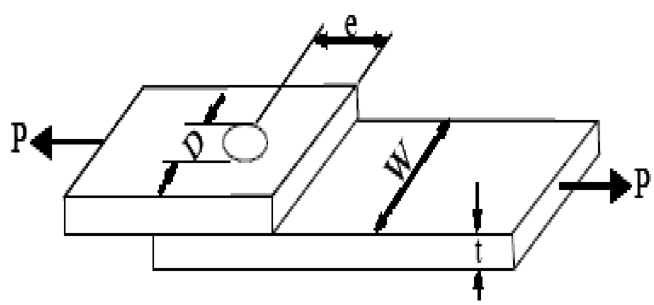
Mechanical failure might be defined as any change in the size, shape or material properties of a structure, machine or machine part that renders it incapable of satisfactorily performing its intended function. The three key for classifications of mechanical failure are the mechanisms, cause, and mode. These keys give the engineer a key view in understanding how and why a part failed and what can be done to prevent a failure in the future. Engineers are deeply aware of the possibility of fracture in load-bearing components and its potentially detrimental effect on productivity, safety and other economic issues. As a result all design, manufacturing and materials engineers use safety factors in their initial analysis to reduce the possibility of fracture by essentially overdesigning the component or the machine. It is imperative to understand that mechanical parts, like most other items, do not survive indefinitely without maintenance (William et al., 2009).

2.3.1 Ultimate Failure

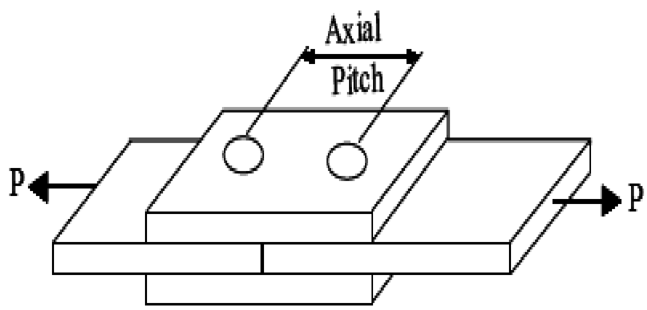
In mechanical engineering, ultimate failure describes the breaking of a material. In general there are two types of failure which are fracture and buckling. Buckling occurs when compressive loads are applied to the material and instead of cracking the material bows. This is undesirable because most tools that are designed to be straight will be inadequate if curved. If the buckling continues, it will create tension on the outer side of the bend and compression on the inner side, potentially fracturing the material. Fracture of a material occurs when either an internal or external crack elongates the width or length of the material. In ultimate failure this will result in one or more breaks in the material. There are two different types of fracture which are brittle and ductile. Each of these types of failure occurs based on the material's ductility. Brittle failure occurs with little to no plastic deformation before fracture. While applying a tensile stress to a ductile material, instead of immediately breaking the material will instead elongate. The material will begin by elongating uniformly until it reaches the yield point, then the material will begin to neck. When necking occurs the material will begin to stretch more in the middle and the radius will decrease. Once this begins the material has entered a stage called plastic deformation. Once the material has reached its ultimate tensile strength it will elongate more easily until it reaches ultimate failure and breaks.

2.4 MECHANICALLY FASTENED JOINTS

Mechanical joints are used when repeated disassembly and reassembly is required or when surface preparation is not practical. Mechanical joints can be readily inspected before assembly and while in service. Examples of two typical joints are the single lap joint and double lap joints as shown in **Figure 2.1**. The single lap joint is the simplest and most weight efficient but the load results in a moment due to off-set load. The double lap joint will eliminate the moment but adds additional weight from the straps and additional fastener. Mechanical fasteners are used in assemblies for their strength, reusability and appearance. A fastener is defined as an act of bringing together, connecting or uniting to becoming one or a unit. It also can be classified a hardware device that mechanically joins or affixes two or more objects together. It will hold the part of a structure together by transferring load from one component to another. There are many types of fasteners widely use, for example, bolts, rivets, nails, screws and pins.



(a)



(b)

Figure 2.1: Basic types of mechanical joints. (a) Single lap joint, (b) double lap joint

2.4.1 Pins

Pin can divide into two categories which is fasteners and fixture pins. Pin joints represent either 3D double shear or 2D single shear joints that are applied in many engineering structures from the skeletal frameworks to the outer skin of aircraft, automobiles, buildings and pressure vessels. The stresses and slips in the vicinity of contact regions determine the static strength, plasticity, frictional damping and vibration levels, and affect the structural performance. Stress will occur on fasteners due to the load applied. Two important types of stress in fasteners are bearing stress and shear stress.

2.4.1.1 Bearing Stress

Bearing stress is caused by one component acting directly on another or the contact pressure between the separate bodies. It is corresponding to average force intensity. It can be calculated by dividing the bearing force to the projected area of the fasteners. For cylindrical fasteners, the projected area is a rectangle. It differs from compressive stress, as it is an internal stress caused by compressive forces.

$$\sigma_b = \frac{F}{Dt} \tag{2.1}$$

2.4.1.2 Shear Stress

Shear stress is the result of two opposite transverse forces being applied on either side of a plane of a component. It is arises from the force vector component parallel to the cross section. For shear strength, it is the material's ability to endure the applied stress. If enough stress is applied to a body it may not return to its original shape. For a component under single shear, the average shear stress (τ) is the applied load (P) divided by the cross-sectional area (A) of the component, or τ = P/A. For fastener, the average shear stress, (τ), is the shear force transferred divided by the cross-sectional area, which is generally a circle.

$$\tau = \frac{P}{\pi D^2/4} \tag{2.2}$$

2.4.2 Mechanical Fastened Joint Failure Mode

It has been observed experimentally that mechanical fastened joints fail under three basic mechanisms which are net-tension, shear-out and bearing. Typical damage caused by each mechanism is shown in **Figure 2.2**. Net-tension failure or normal failure involves a fracture across the width of the joint and normally occurs when the width distance to diameter ratio (W/D) is small. For shear-out failure, it is occurs when a plug of material separates from the laminate ahead of the pin and normally occurs when the edge distance to diameter ratio (E/D) is small. Shear-out failure can therefore occur after some bearing damage has initiated. If bearing failure occurs, it will less cause in harm or disaster. Bearing failure is defined as local crushing of the material adjacent to the hole and normally occurs when E/D and W/D ratios are large (Taner et al., 2007).

(a) (b) (c)

Figure 2.2: Types of damage failure mode samples after pin loading experiments. (a) net-tension failure type, (b) shear-out failure type, (c) Bearing failure type.

- Source: Taner et al. (2007)

2.5 MATERIALS

2.5.1 Aluminum

Aluminum is an abundant metallic chemical element which is widely used and the third most common element in the Earth's crust and it is the most common metallic element on Earth. Pure Aluminium (99%) is soft, ductile, corrosion resistant and has a high electrical conductivity. It is one of the lightest engineering metals, having a high strength to weight ratio superior to steel. Aluminium is well suited to cold environments because its' tensile strength increases with decreasing temperature while retaining its toughness. It has excellent resistance to most acids but less resistant to alkalis. It cause by the Aluminium oxide layer form instantaneously when exposed to air. Aluminium can be severely deformed without failure. This allows Aluminium to be formed by rolling, extruding, drawing, machining and other mechanical processes. The ultimate tensile strength of Aluminum 1050-H14 use in this investigation is 110Mpa and yield tensile strength is 103Mpa. Aluminium is most commonly alloyed with copper, zinc, magnesium, silicon, manganese and lithium. These alloys are used in construction, airplane and automobile structures, traffic signs, heat dissipative, storage deposits, bridges and kitchen utensils. It also uses in chemical process plant equipment, food industry containers, pyrotechnic powder, architectural flashings, lamp reflectors and cable sheathing.

2.5.2 Brass

Brass is an alloy of copper and zinc. Typically it is more than 50% copper and from 5 to 20% zinc, in comparison to bronze which is principally an alloy of copper and tin. It is usually use for applications where low friction is required such as locks, gears, and bearings. Brass has higher malleability than bronze or zinc. Combinations of iron, aluminum, silicon and manganese make brass stronger and corrosion resistant. It resists corrosion especially seawater corrosion and metal fatigue better than steel and also conducts heat and electricity better than most steels. It is susceptible to stress cracking when exposed to ammonia. These investigations use the red brass having relatively low melting point of 990 to 1025°C. This brass contains 85% of copper and 15% of zinc. By varying the proportions of copper and zinc, the properties of the brass can be changed, allowing hard and soft brasses. The density of the brass is 8750 kg/m^3 which is equivalent to $8.75 g/cm^3$. The ultimate tensile strength is 345 N/mm^2 and 275 N/mm^2 for its yield tensile strength.

2.6 PREVIOUS STUDIES

2.6.1 A study of the effects of various geometric parameters on the failure strength of pin loaded woven-glass-fiber reinforced epoxy laminate

The aim of this study is to examine the effects of woven fiber, specimen width-to-hole diameter ratio (W/D), and the ratio of edge distance to holes diameter (E/D) on the bearing strength of woven laminated composites. Single-hole pin-loaded specimens were tested for their tensile response and W/D and E/D ratios evaluated. Using glass/epoxy material, bearing strengths are compared for various geometries. It can be seen that critical E/D ratio is 2. The effects of E/D ratio on the pin bearing strength of the composite are shown in **Figure 2.3**. The mode of failure changed from the bearing to net-tension or shear-out with decreasing E/D. This mode change is associated with a considerable drop in load-carrying capacity. The effect of W/D ratio on the pin bearing strength is presented in **Figure 2.4**. As can be seen, pin-loaded strength decreases with decreasing W/D ratio. As the width of the specimen decreases, there is a point where the mode of failure changes from the bearing to net tension. From this research, ultimate load capacity of the all different configurations of the pin connections increased by increasing the geometric dimensions. It was found that increasing the E/D ratio beyond 2 had an insignificant effect on the ultimate load capacity of the connection. When the value of W/D is smaller than 3, specimens are said to be weak. In addition, when the width was increased, the specimens that had small end distances failed in the shear-out modes. When the end distance was increased, bearing failure developed in addition to shear-out failure. For short end distances, failure extended very rapidly. As conclusion, increasing the E/D ratio beyond 2 and increasing the W/D ratio beyond 3 have an insignificant effect on the ultimate load capability of the connection (Buket et al., 2001).

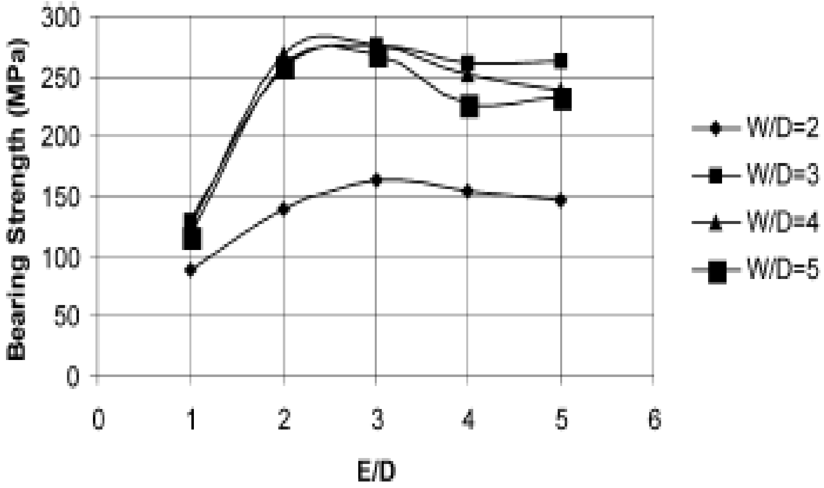


Figure 2.3: The effect of edge distance to diameter ratio on the bearing strength.

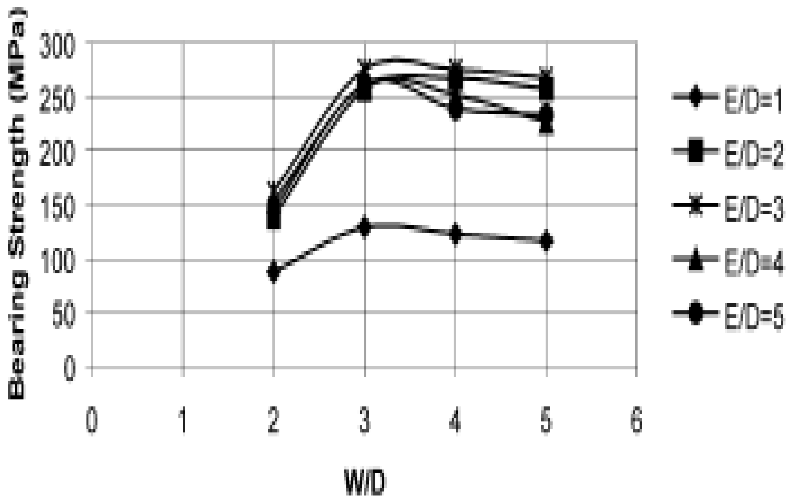


Figure 2.4: The effect of width distance to diameter ratio on the bearing strength.

- Source: Buket et al. (2001)

2.6.2 Failure analysis of pin-loaded aluminum–glass–epoxy sandwich composite plates

The aim of this study was to investigate failure load and failure mode in an aluminum–glass–epoxy sandwich composite plate, with a circular hole, which are subjected to a traction force by a pin. Parametric studied was performed experimentally to evaluate the effects of joint geometry and fiber orientation (0˚) on the failure strength and failure mode. One layer of woven fiber-glass epoxy (epoxy mixed with hardened was spread equally to two sides of the woven fiber-glass) and two layer of aluminum plates was cut with same dimensions and each layer of aluminum and glass–epoxy are of 0.5 mm and 0.6 mm thicknesses, respectively, which made the total thickness is 1.6 mm. The constant diameter drilled is 5mm. The pin location was studied by varying the width to diameter (W/D) and edge distance to diameter (E/D) ratios, from 1 to 5 and 2 to 5, respectively for 0˚. This experiment was carried out in tension mode on the Instron-1114 Tensile Machine by using crosshead speed of 0.5 mm/min. The specimens was stretching by the lower edge of the specimen was clamped and loaded from the steel pin. Three composite joint with pin was loaded until the tear occurred and the general behavior of the composite was obtained from the load versus displacement curves below.

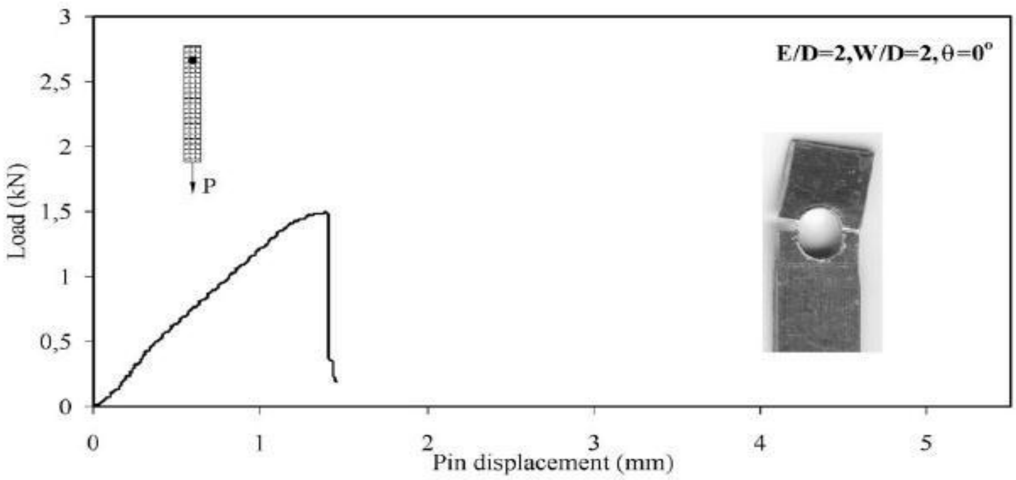


Figure 2.5: Net-tension mode

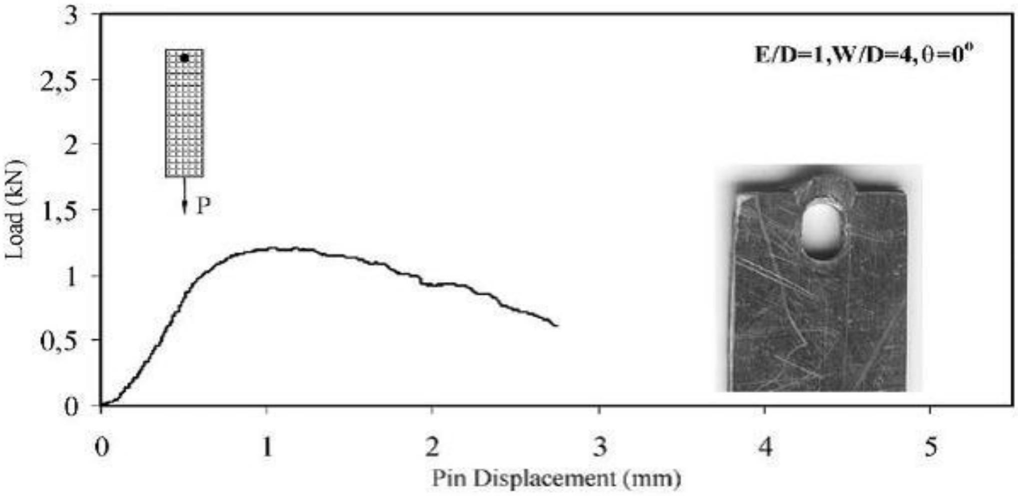


Figure 2.6: Shear-out mode

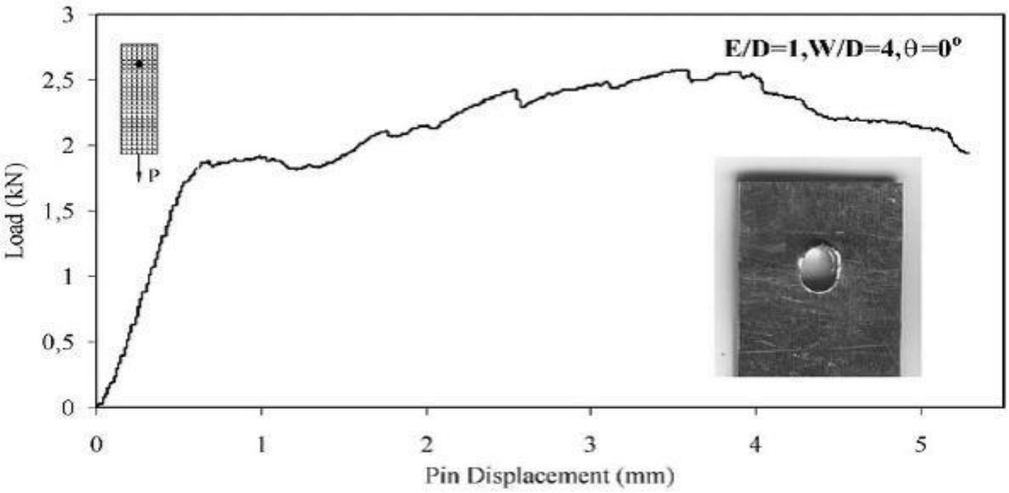


Figure 2.7: Bearing mode

- Source: Bulent et al. (2003)

From **Figure 2.5**, the edge and width distance use is 10 mm respectively. The failure mode occurred is net-tension at maximum load value of 1.5kN. For shear-out mode, the maximum value of failure load appeared at 1.3kN refer to **Figure 2.6**. The size for this specimen is 5mm for edge distance and 20mm for width. For bearing-mode failure, the size is same as shear-out mode specimen, but the maximum failure load is different, approximately 2kN, but it increase as the increasing pin displacement until the pin break as shown in **Figure 2.7**. As conclusion, the plate size and edge distance from hole for this project must be design correctly because different diameter pin give different value of maximum failure load.

2.6.3 Pin and bolt bearing strength of fibreglass/aluminium laminates

An experimental investigation was carried out on a fibreglass/aluminium (FGA) laminate in order to characterize its behavior under pin and bolt-bearing conditions. In pin bearing, the limit width-to-diameter and edge distance-to-diameter ratios necessary to avoid unsafe failure modes were lower than those usually quoted for classical laminates. The fibreglass/aluminium (FGA) is made of 7475 T7351 aluminium alloy 0.3 mm in thickness and S2-glass fibre/epoxy. It was tested under pin and bolt bearing conditions as illustrated in **Figure 2.8**. In order to induce different failure modes during the bearing tests, the ratios E/D and W/D were varied by suitably choosing the specimen width (W=10–30 mm), edge distance (E=8–30 mm), and hole diameter (D=5–8 mm). From the data in **Figure 2.9**, the transition from net tension to true bearing occurs for a limit W/D value approximately equal to 2. Further, the true pin-bearing strength, indicated by σ_{tb} in the following, is substantially unaffected by the hole diameter. This implies that σ_{tb} is dependent on the ratio W/D, rather than on the W and D values separately. Similarly to **Figure 2.9**, the graph in **Figure 2.10** shows the effect of the E/D ratio on the transition from cleavage to true bearing. Due to the lack of experimental data, the limit value of E/D, beyond which cleavage is suppressed, cannot be precisely individuated. However, it is evident that the limit value of E/D is in the range 1 (cleavage failure, white symbols) to 1.6 (first true bearing failure, black symbols). As a conclusion, true bearing was achieved when sufficiently large width-to-diameter (W/D) and edge distance-to-diameter (E/D) ratios were adopted. Only in the case of true bearing a safe behavior was observed, with the joint being able to support significant load after first failure.

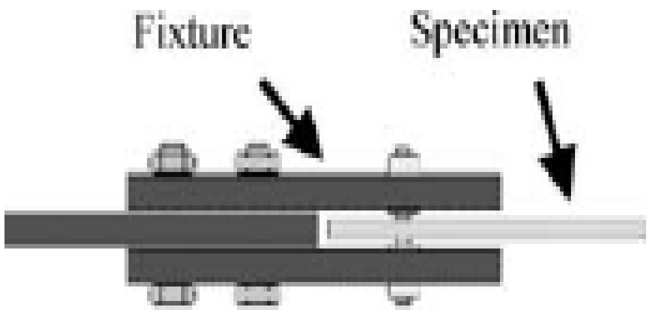


Figure 2.8: Test set-up for pin-bearing tests

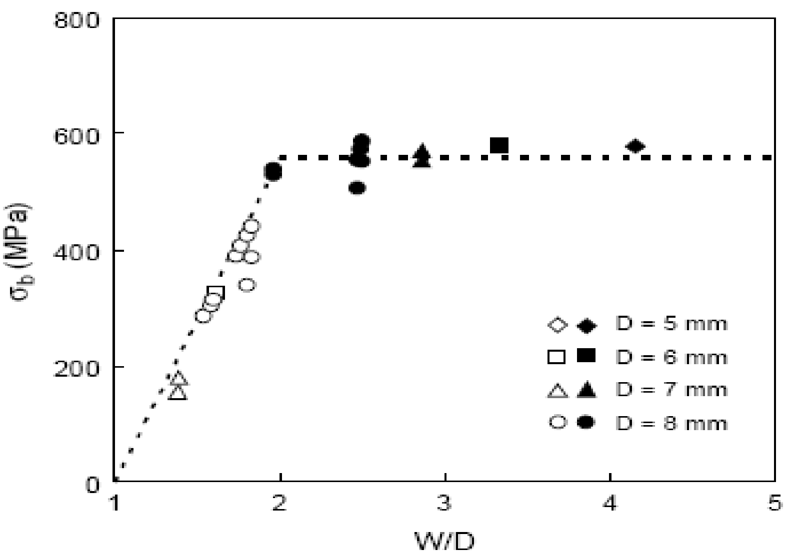


Figure 2.9: Pin-bearing strength against the ratio W/D of the specimen. White symbols: net tension failure; black symbols: bearing failure.

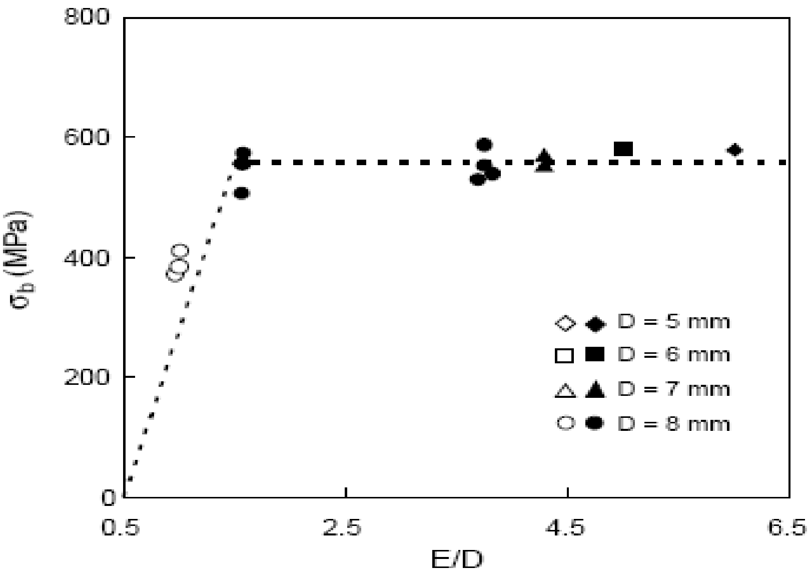


Figure 2.10: Pin-bearing strength against the ratio E/D of the specimen. White symbols: cleavage failure; black symbols: bearing failure.

- Source: G. Caprino et al. (2005)

2.6.4 Three-dimensional Size Effects in Composite Pin Joints

This study was to investigate the three-dimensional size affects in composite (different thickness) pin joints. The composite material used in this study was made of S-2 glass fabrics and a phenolic matrix. Composite laminates of 8-ply (n =2), 24-ply (n = 6) and 40-ply (n = 10) was prepared in this study. The 8-ply, 24-ply and 40 ply composite laminates had thicknesses of 1.96mm, 5.97mm and 9.40mm. The geometric elements of the joints, such as width W, hole diameter D, thickness H and the distance between hole center and specimen end E, and the associated geometric ratios, such as W/D, E/D and H/D, were important parameters in studying mechanical fastening. To ensure bearing failure, instead of a net-section or a shear-out failure, all laminates had W/D = 4 and E/D > 2.66. To assembly of the composite joints, steel pin was used of variable diameter. From this research, based on **Figure 2.11** outcome, they found that, the combination of a small-diameter pin and a large-thickness composite resulted in a non-uniform pin-hole contact through the laminate thickness. For the combination of a large-diameter pin and a small-thickness composite, the result showed a relatively uniform pin-hole contact through the laminate thickness. Otherwise, it can be seen that the bearing strengths increase as the thickness scale increases while the pin diameters decrease. However, as the thickness increased, the risk of pin bending also increased. The failure mode was occurred for different thicknesses which are net-tension, shear-out and bearing mode.

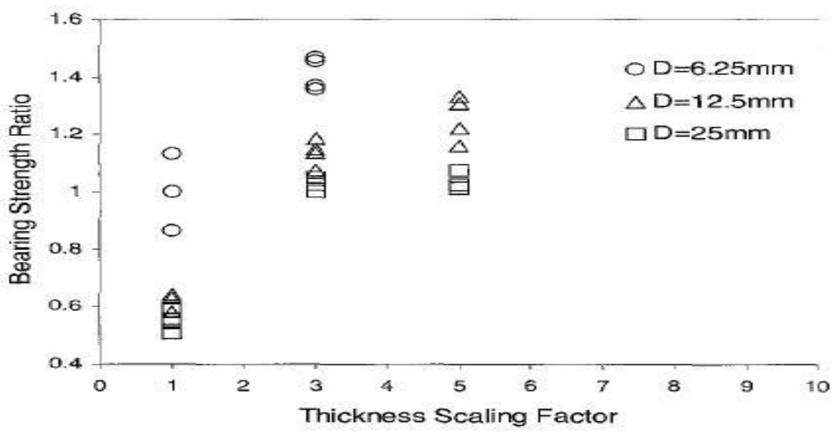


Figure 2.11: Bearing strength ratios due to thickness scaling (1=1.96mm, 3=5.97mm and 5=9.40mm)

- Source: D. Liu et al. (2002)

2.6.5 Summary of Other Studies

Table 2.1: Title and Summary of others studies.

Title and Author	Summary
Behavior and modeling of a bolt bearing on a single plate, Journal of Structural engineering, Clinton O. Rex and W. Samuel Easterling (2003).	• The plate width would not have a significant effect on the load-deformation behavior, as the plate width is reduced, the failure mode will eventually be a net section tension rupture rather than a bolt bearing/tear-out failure. • Shearing rather than sawing plates does appear to have a negative effect on the nominal strength. This effect seems to be influenced by end distance and steel strength.
Combined in-plane and through the thickness analysis for failure prediction of bolted composite joints, American Institute of Aeronautics and Astronautics, V.Kradinov, E.Madenci and D.R.Ambur (2004).	• Proves that the ply load distribution in a laminate is significantly influenced near the bolt by the bolt bending deformations. The distribution is dependent on the plate thickness and laminate lay-up, and it is different for single and double lap bolted joints.
An investigation of pin bearing strength on composite materials, Dustin Troutman and Jeremy Mostoller.	• Prove that as the hole diameter for a given pin size increased the ultimate bearing strength decreased. • The oversize hole diameter has a large influence on the structural efficiency of the connection.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter will further describe the designing of experiment for the tension/bearing loading on a brass pin join with Aluminium plates by using the Universal Tensile Testing Machine and using finite element analysis ALGOR software. The designing experiment has been made based on the objective for this experiment. From the research has been done, the factors can affect the strength of joint are the edge distance, width distance and thickness of plates, the diameter and type of material for pin. The illustration joint for FEA software will be explained more in this chapter. There are several step must be followed to make sure the objective can be achieved start from literature finding until submit the final report. The steps will briefly explain into flow chart schematic diagram.

3.2 PROJECT FLOW CHART

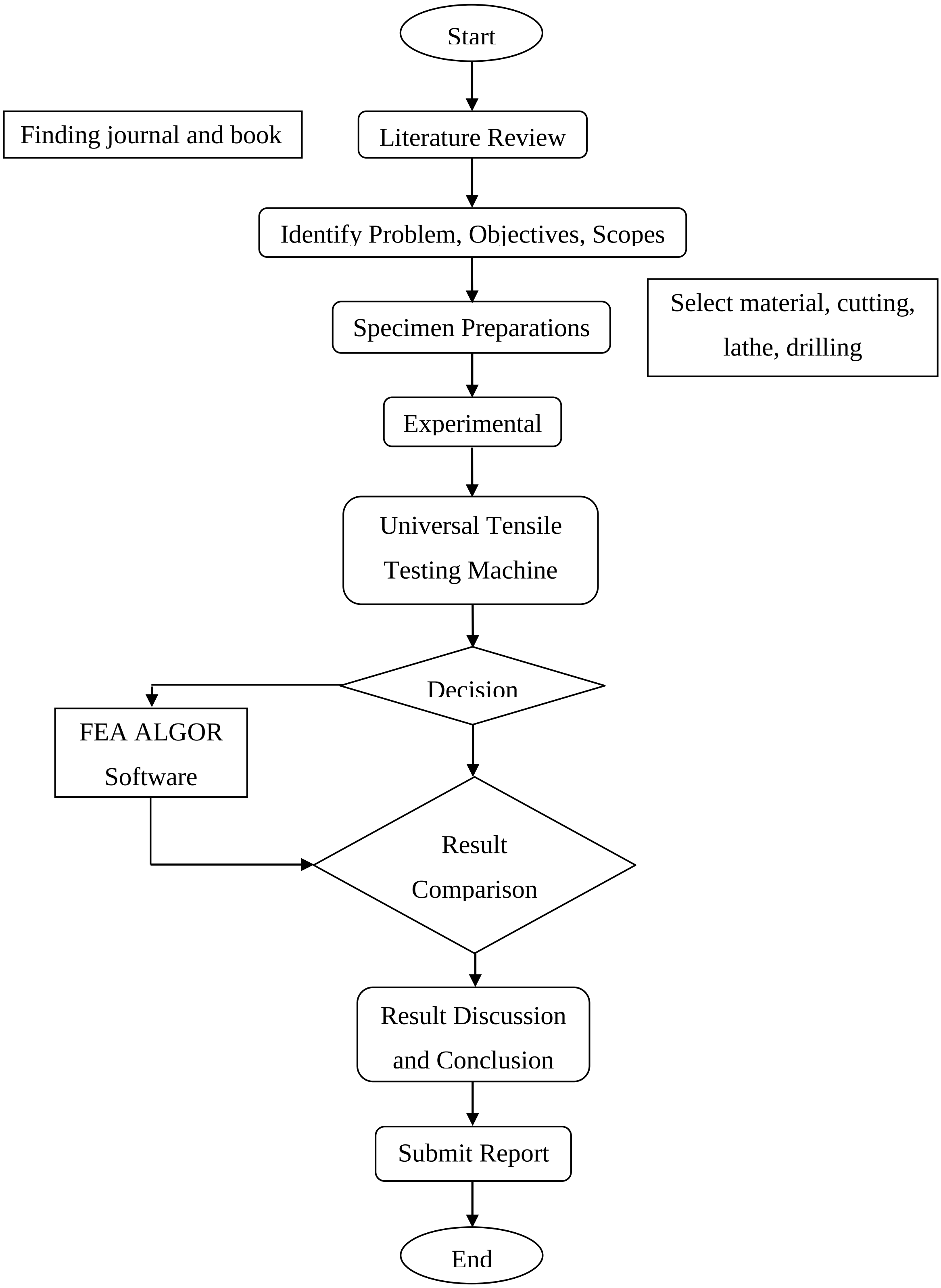


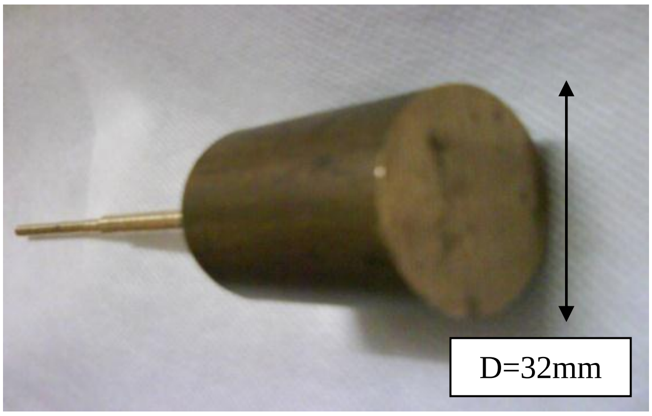
Figure 3.1: Flow chart of the project

3.3 PREPARATION OF SPECIMENS

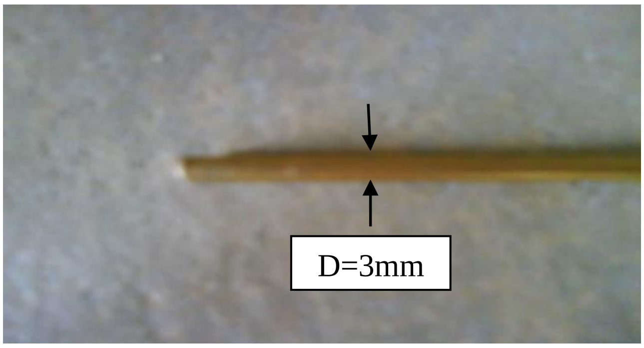
3.3.1 Pin

The material use for pin is brass. The shape of the brass obtained from the mechanical store is in the form of rod. Its initial diameter is 32mm. For this investigation, the diameter of pin I use is in 3mm, 4mm and 5mm. The pin size use is practical and used in manufacturing such as for joining small structure. The brass rod was machined to form the diameter needed by using lathe machine as shown in **Figure 3.2**. Cutting speed for brass is 90 meter per minute. So, the revolution per minute (RPM) use in lathe machine to form the needed diameter is estimated to be 990 rpm because the exact value of 895 rpm is not available on the machine. The calculation for RPM is shown below.

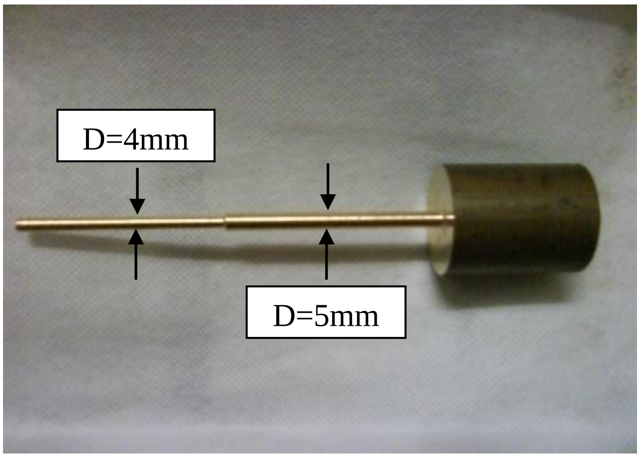
$$\text{RPM} = \frac{cutting\ speed}{\pi\ x\ initial\ diameter} = \frac{90m/min}{\pi\ x\ 32mm\ (\frac{1m}{1000mm})} = 895\text{ rpm} \approx 990\text{ rpm}$$



(a)



(b)

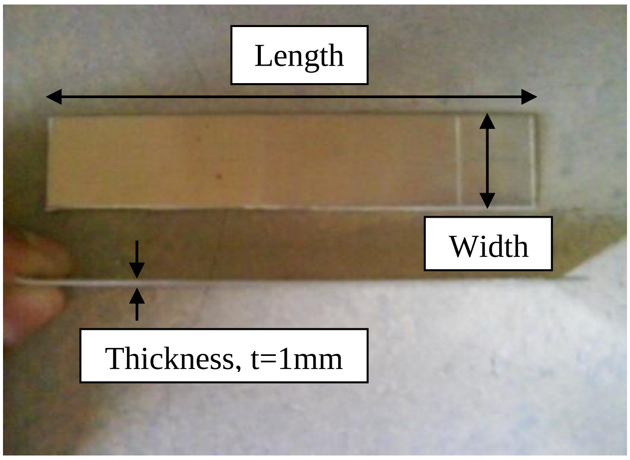


(c)

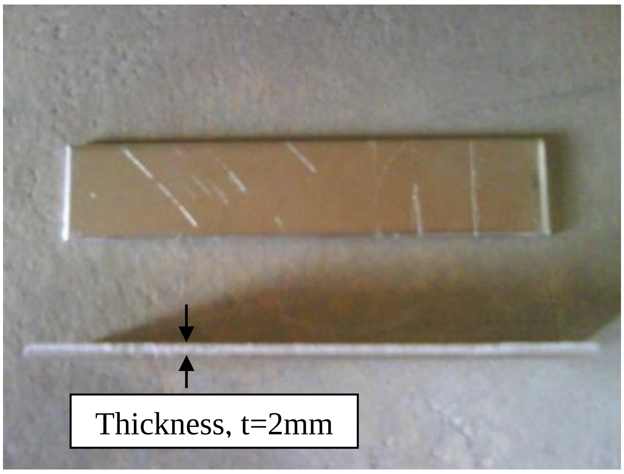
Figure 3.2: Brass rod after lathe machined. (a) Initial diameter of 32mm, (b) diameter of 3mm, (c) diameter of 4mm and 5mm.

3.3.2 Plate

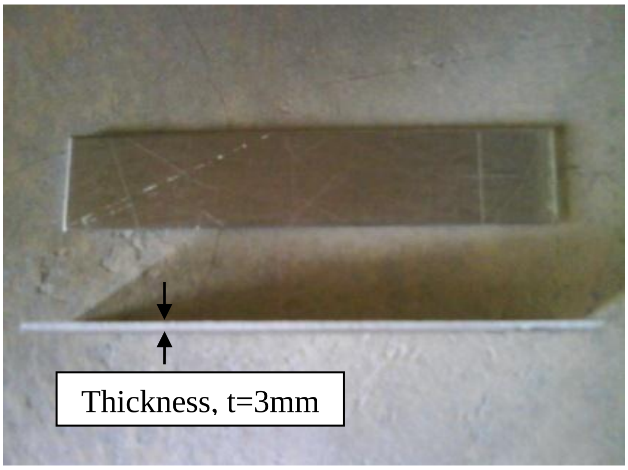
The material use for plates is Aluminium plate. The available thickness of plate obtained from mechanical store is in 1mm, 2mm and 3mm. Every each of plate thickness is cut into same dimensions, 20mm for width and 100mm for length as shown in **Figure 3.3**. For this investigation, six pieces for each different plate thickness is used.



(a)



(b)



(c)

Figure 3.3: Plates dimension (a) plate thickness of 1mm, (b) plate thickness of 2mm, (c) plate thickness of 3mm.

For every six pieces of each plate thickness is drill to form a hole of 3mm, 4mm and 5mm diameter as in **Figure 3.6**. Drill machine is used to make holes by using exactly sizes of twist drill bit, 3mm, 4mm and 5mm as shown in **Figure 3.5**. High speed steel twist drill bit is used to drill Aluminium because it is much more resistant to heat and can withstand higher temperatures without losing its temper. The brass pin is insert into the hole. The center of hole diameter is 15mm from edge distance and 10mm in between width distance. This is the hole center position for every plate. More understanding of the diagram can refer to **Figure 3.4**.

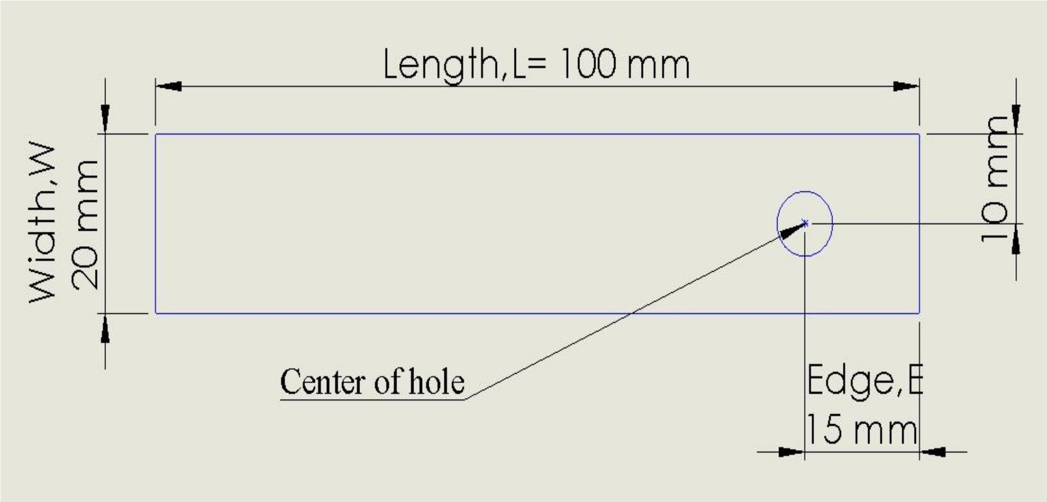


Figure 3.4: Geometry of Aluminium plate with center of holes position

Figure 3.5: Diameter high speed steel twist drill bit for 3mm, 4mm and 5mm

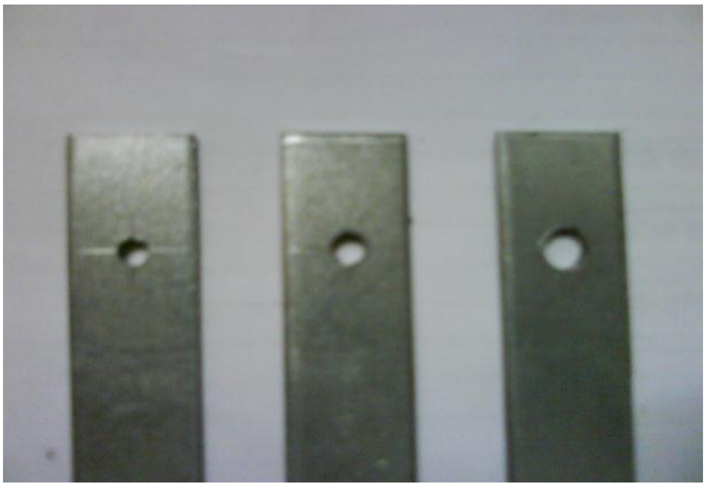


Figure 3.6: 3mm, 4mm and 5mm holes diameter of Aluminium plates

3.3.3 Joining

The Aluminium plates will be joined as a single lap joint. The brass pin will act as fastener to join the plate. The brass pin was inserted to the hole. Different diameter of brass pin is used to investigate its optimum load can withstand with different plate thickness pull by using universal testing machine. The each value of edge distance to hole diameter ratio (E/D) and width to hole diameter ratio (W/D) for every specimens is exceeds of 2 and 3 based on previous study because if it less than the ratios given can cause different failure mode. Bearing failure is the preferred failure mode since the joined members are not catastrophically separated. But, different of plate thickness and different diameter of pin also give effects for maximum load and failure mode.

3.4 UNIVERSAL TENSILE TESTING MACHINE

Universal testing machine is used in this experiment for testing the strength of the pin joints. Universal testing machine otherwise known as a materials testing machine or test frame is used to test the tensile and compressive properties of material. It can perform the entire test like compression, bending, and tension to examine the material in all mechanical properties. In this experiment, tensile test is conducted on the different diameter of pin joint design. Shimadzu Autograph AG-X Series is the machine used to obtain the testing.

Figure 3.7: Tensile Machine test Shimadzu AG-X series

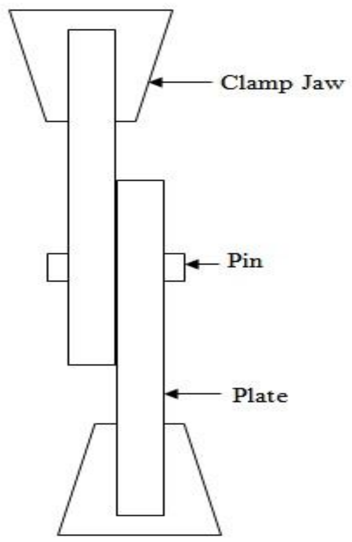


Figure 3.8: Experimental setup for the pin joint fixture

Machine setting for this experiment:

- Full scale load range: 50 kN
- Humidity: 50 %
- Cross head speed: 1 mm/min
- Temperature: 26 ˚C
- Proceed until the specimens break.
- Obtain a graph of Maximum Load vs. Displacement.
- Obtain a graph of Maximum Stress vs. Maximum Strain.

3.5 FINITE ELEMENT ANALYSIS (ALGOR)

This section described the procedure to design and analyze the investigation. SolidWork 2008 is used to design the plates and pins. Then, it is exported to ALGOR. ALGOR software will do the finite element analysis of the joint by inserted the load value obtains from calculation using ultimate tensile strength value of brass to find the bearing stress. The value of bearing stress from experimental and simulation been compared.

Procedure for SolidWork 2008 software:

1) Open solidwork and choose create a new part.
2) Select top plane and choose sketch in design tree.
3) Select corner rectangular and create rectangular with length of 100mm and width 20mm. Click on features, choose the extruded boss/base to extrude this rectangular to thickness of 1mm.
4) Select line and draw 15mm from left middle edge into inside on the rectangular.
5) The end point of 15mm line inside the rectangular will be centroid for joint.
6) Draw one circle of diameter 3mm on the centroid for joint.
7) Click on features, choose the extruded cut to extrude the circle to 1mm thickness.
8) Save the part as shown in **Figure 3.10** as plate 1mm thickness with 3mm hole.
9) Repeat step 1 until 8 to create plate of 1mm thickness with hole of 4mm and 5mm each. Then, repeat step 1 until 8 to create plate of 2mm and 3mm thickness with hole of 3mm, 4mm and 5mm each.
10) Create new part.
11) Select top plane and choose sketch.
12) Draw a circle of 3mm diameter. Choose the extruded boss/base to extrude this circle to 8mm thickness.
13) Save part as shown in **Figure 3.9** as pin 3mm.
14) Repeat step 10 until 13 to create pin of 4mm and 5mm diameter.
15) Open new file and create new assemble.
16) Assemble the all part as shown in **Figure 3.11** and save as *igs format with name of Diameter3mm Thickness1mm.
17) Repeat step 15 and 16 for another pin diameter and plate thickness.

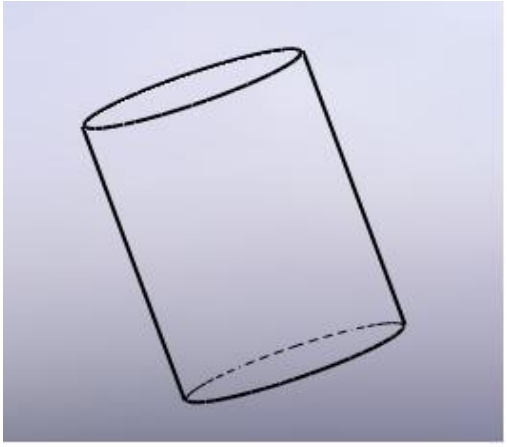


Figure 3.9: Pin

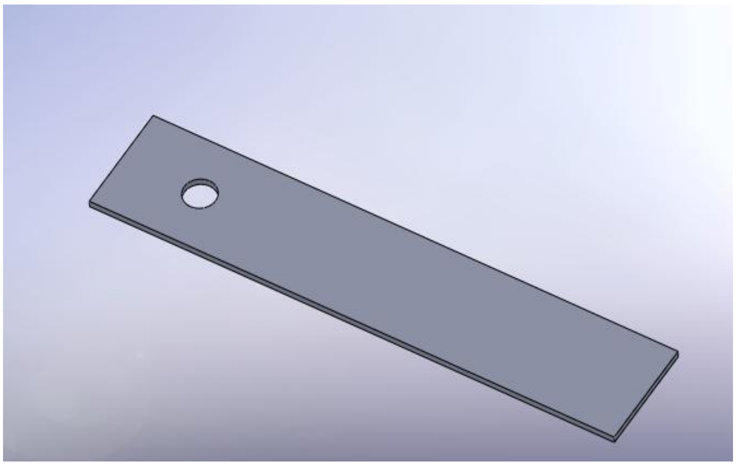


Figure 3.10: Plate with hole

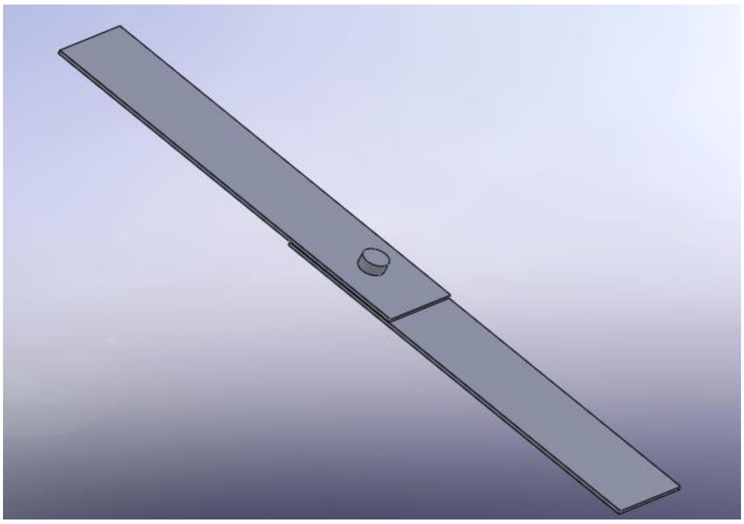


Figure 3.11: Plates assemble with pin

Procedure for Finite Element Analysis (ALGOR):

1) Open IGS file with AlgorFempro software.
2) Choose analysis type as static stress with linear material models.
3) Meshing the models with 100% fine.
4) Set the element type for part 1 and part 2 as plate.
5) Select material for part 1 and part 2 as Aluminum 1050-H14.
6) Set the thickness as 1mm for part1 and part 2 in the element definition.
7) Select the material for part 3 as Brass, Red.
8) Select the left side edge of plate and add fixed in Nodal Boundary Condition.
9) Select right side edge of plate and add nodal force according to value of load obtain from below calculation example (magnitude is equal to maximum load value divide by number of nodes). This all step can refer to **Figure 3.12.**
10) Choose the analysis to analyze the model.
11) Repeat step 1 until 10 for another specimens.

Example calculation to find input load for specimen of single lap joint 3mm Aluminium plate thickness with 5mm Brass pin diameter:

Diameter, D=5mm

Plate thickness, t=3mm

σ_b = ultimate tensile strength of brass=345N/mm^2

$$\sigma_b = \frac{F/2}{Dt}$$

$F = 2(\sigma_b \text{ x } Dt)$= 2(345 x 5 x 3) =10350 N

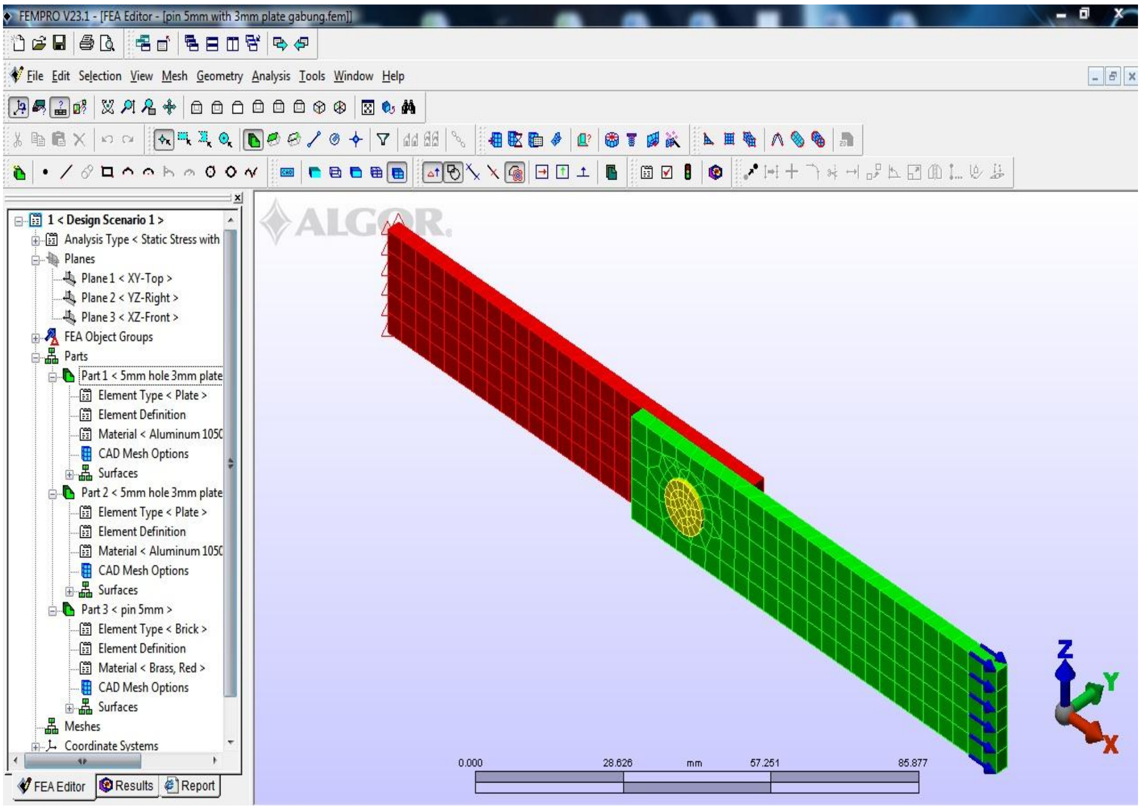


Figure 3.12: Design of AlgorFempro software

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

The purpose of this chapter is to discuss the result that has been obtained after doing the experiment. This chapter may give further discussion for every analysis of the specimen's based on tensile test experimental and finite element analysis by using ALGOR software. The tensile test is done to investigate the bearing load on a brass pin in single lap joint Aluminium plates. Besides that, finite element analysis ALGOR is done to find the bearing stress by using the load value from the calculation. The result of bearing stress from experimental and software analyze will be compare.

4.2 ANALYZING THE TENSILE TEST EXPERIMENTAL RESULTS

The two plates Aluminium of same thickness was joined by each of three different diameter of brass pin and the test is done to evaluate the bearing load. This test uses three different thickness of Aluminium plate which varied at the t/D ratio. Thus, the type of specimen failure is obtained. The calculation of bearing stress is done by using below formula where F is bearing load, D is pin diameter and t is plate thickness.

$$\sigma_b = \frac{F}{Dt} \tag{4.1}$$

4.2.1 Brass Pin (D=3mm) with Aluminium Plates (t=1mm)

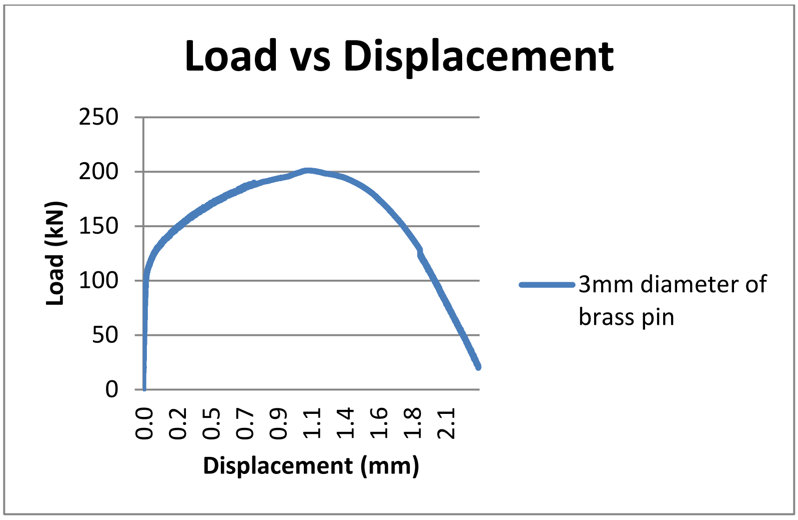


Figure 4.1 : Graph 1 : Load (kN) versus Displacement (mm)

Bearing load : 201.178 N

Bearing stress : 67.06 N/mm^2

Figure 4.2 : Specimen and Failure Occur

Graph 1 shows the load versus displacement for Brass Pin (D=3mm) with Aluminium Plates (t=1mm) with t/D ratio is 0.7. The pin is placed at 15mm from edge distance and 10mm in between width as illustrated in **Figure 3.4**. The load the brass pin can withstand is 201.178 N and bearing stress is 67.06 N/mm^2. The **Figure 4.2** shows the plate's holes fail in bearing mode and pin does not break off.

4.2.2 Brass Pin (D=3mm) with Aluminium Plates (t=2mm)

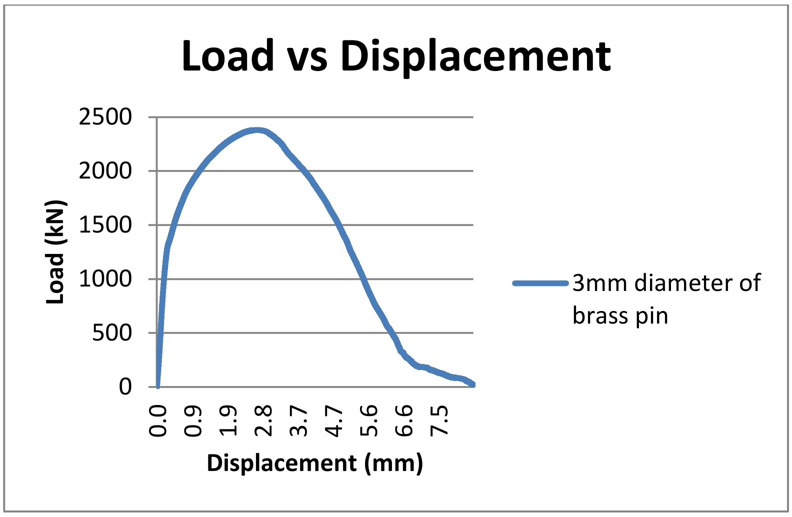


Figure 4.3 : Graph 2 : Load (kN) versus Displacement (mm)

Bearing load : 2380.07 N

Bearing stress : 396.68 N/mm^2

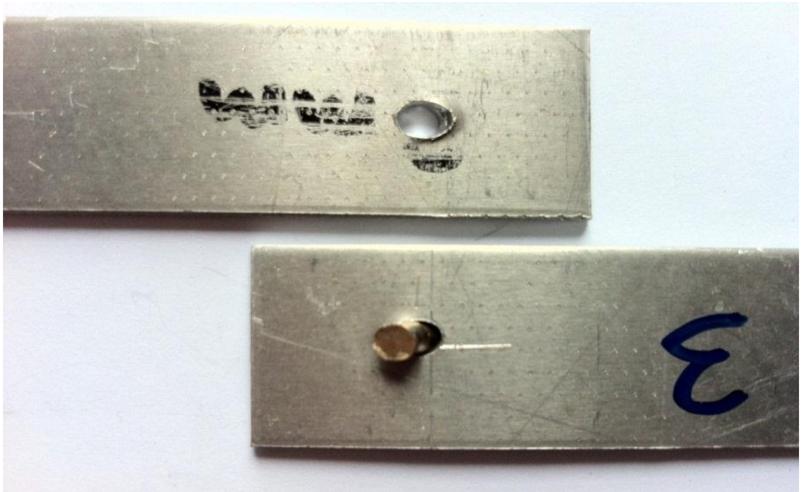


Figure 4.4 : Specimen and Failure Occur

Graph 2 shows the load versus displacement for Brass Pin (D=3mm) with Aluminium Plates (t=2mm) with t/D ratio is 1.3. The pin is placed at 15mm from edge distance and 10mm in between width as illustrated in **Figure 3.4**. The load the brass pin can withstand is 2380.07 N and bearing stress is 396.68 N/mm^2. The **Figure 4.4** shows the plate's holes fail in bearing mode and pin does not break off.

4.2.3 Brass Pin (D=3mm) with Aluminium Plates (t=3mm)

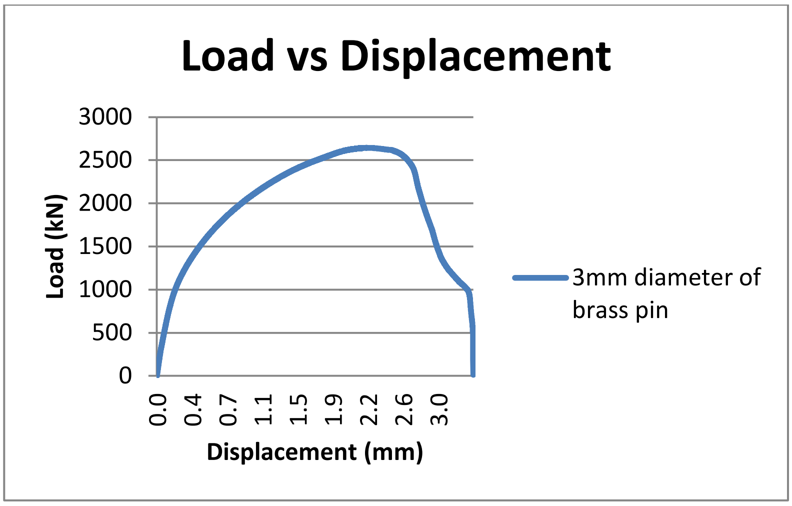


Figure 4.5 : Graph 3 : Load (kN) versus Displacement (mm)

Bearing load : 2644.60 N

Bearing stress : 293.84 N/mm^2

Figure 4.6 : Specimen and Failure Occur

Graph 3 shows the load versus displacement for Brass Pin (D=3mm) with Aluminium Plates (t=3mm) with t/D ratio is 2.0. The pin is placed at 15mm from edge distance and 10mm in between width as illustrated in **Figure 3.4**. The load the brass pin can withstand is 2644.60 N and bearing stress is 293.84 N/mm^2. The **Figure 4.6** shows the plate's holes fail in bearing mode and pin does not break off.

4.2.4 Brass Pin (D=4mm) with Aluminium Plates (t=1mm)

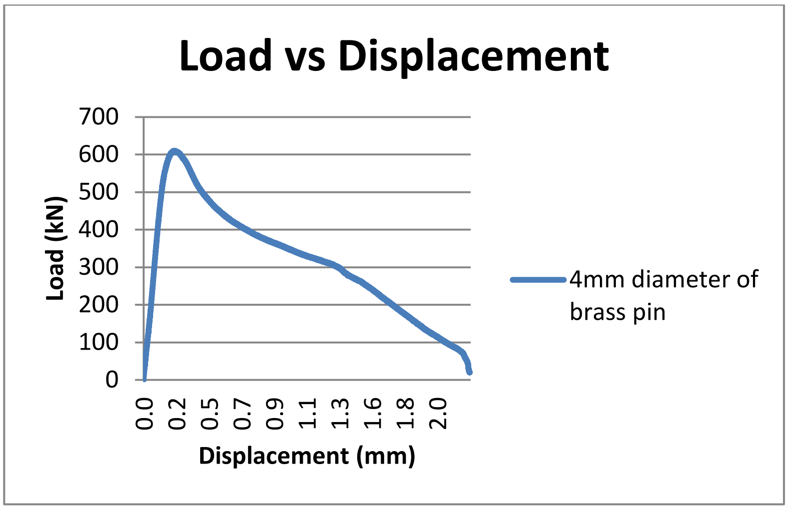


Figure 4.7 : Graph 4 : Load (kN) versus Displacement (mm)

Bearing load : 609.350 N

Bearing stress : 152.34 N/mm^2

Figure 4.8 : Specimen and Failure Occur

Graph 4 shows the load versus displacement for Brass Pin (D=4mm) with Aluminium Plates (t=1mm) with t/D ratio is 0.5. The pin is placed at 15mm from edge distance and 10mm in between width as illustrated in **Figure 3.4**. The load the brass pin can withstand is 609.350 N and bearing stress is 152.34 N/mm^2. The **Figure 4.8** shows the plate's holes fail in bearing mode and pin does not break off.

4.2.5 Brass Pin (D=4mm) with Aluminium Plates (t=2mm)

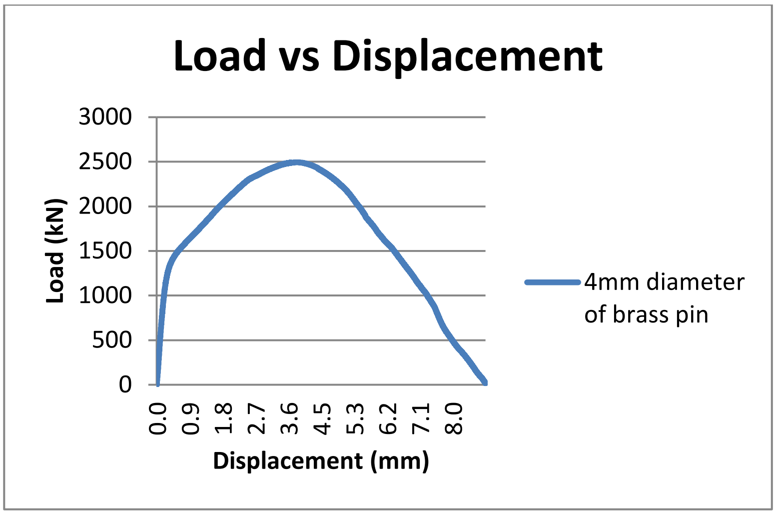


Figure 4.9 : Graph 5 : Load (kN) versus Displacement (mm)

Bearing load : 2491.95 N

Bearing stress : 311.49 N/mm^2

Figure 4.10 : Specimen and Failure Occur

Graph 5 shows the load versus displacement for Brass Pin (D=4mm) with Aluminium Plates (t=2mm) with t/D ratio is 1.0. The pin is placed at 15mm from edge distance and 10mm in between width as illustrated in **Figure 3.4**. The load the brass pin can withstand is 2491.95 N and bearing stress is 311.49 N/mm^2. The **Figure 4.10** shows the plate's holes fail in bearing mode and pin does not break off.

4.2.6 Brass Pin (D=4mm) with Aluminium Plates (t=3mm)

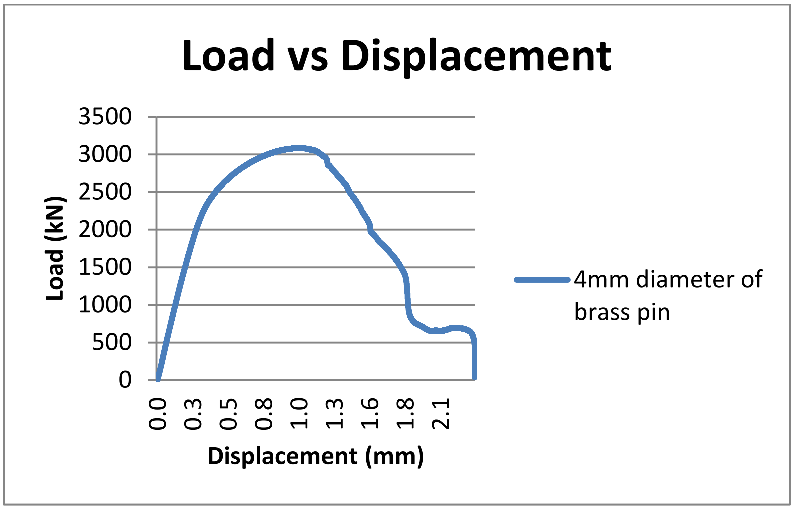


Figure 4.11 : Graph 6 : Load (kN) versus Displacement (mm)

Bearing load : 3086.09 N

Bearing stress : 257.17 N/mm^2

Figure 4.12 : Specimen and Failure Occur

Graph 6 shows the load versus displacement for Brass Pin (D=4mm) with Aluminium Plates (t=3mm) with t/D ratio is 1.5. The pin is placed at 15mm from edge distance and 10mm in between width as illustrated in **Figure 3.4**. The load the brass pin can withstand is 3086.09 N and bearing stress is 257.17 N/mm^2. The **Figure 4.12** shows the plate's holes fail in bearing mode and pin does not break off.

4.2.7 Brass Pin (D=5mm) with Aluminium Plates (t=1mm)

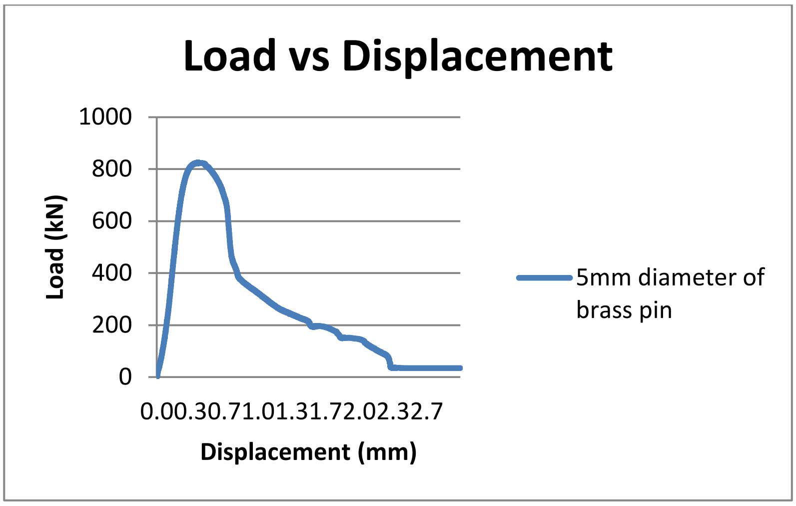


Figure 4.13 : Graph 7 : Load (kN) versus Displacement (mm)

Bearing load : 824.754 N

Bearing stress : 164.95 N/mm^2

Figure 4.14 : Specimen and Failure Occur

Graph 7 shows the load versus displacement for Brass Pin (D=5mm) with Aluminium Plates (t=1mm) with t/D ratio is 0.4. The pin is placed at 15mm from edge distance and 10mm in between width as illustrated in **Figure 3.4**. The load the brass pin can withstand is 824.754 N and bearing stress is 164.95 N/mm^2. The **Figure 4.14** shows the plate's holes fail in bearing mode and pin does not break off.

4.2.8 Brass Pin (D=5mm) with Aluminium Plates (t=2mm)

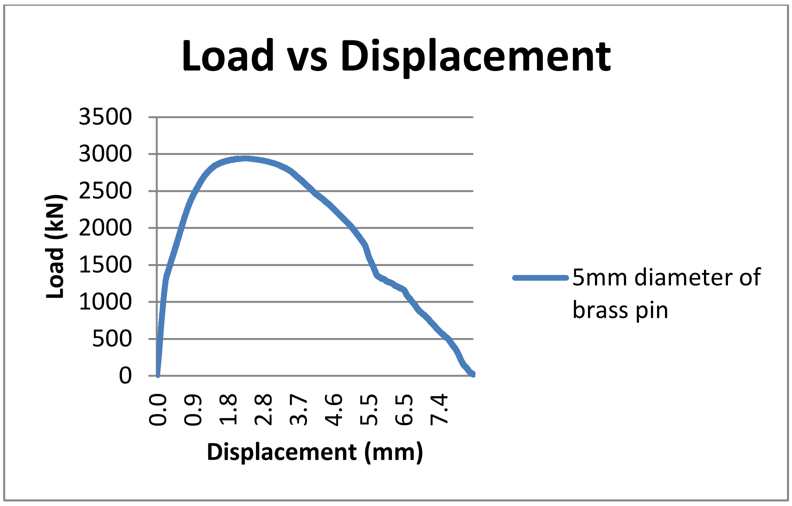


Figure 4.15 : Graph 8 : Load (kN) versus Displacement (mm)

Bearing load : 2939.57 N

Bearing stress : 293.96 N/mm^2

Figure 4.16 : Specimen and Failure Occur

Graph 8 shows the load versus displacement for Brass Pin (D=5mm) with Aluminium Plates (t=2mm) with t/D ratio is 0.8. The pin is placed at 15mm from edge distance and 10mm in between width as illustrated in **Figure 3.4**. The load the brass pin can withstand is 2939.57 N and bearing stress is 293.96 N/mm^2. The **Figure 4.16** shows the plate's holes fail in bearing mode and pin does not break off.

4.2.9 Brass Pin (D=5mm) with Aluminium Plates (t=3mm)

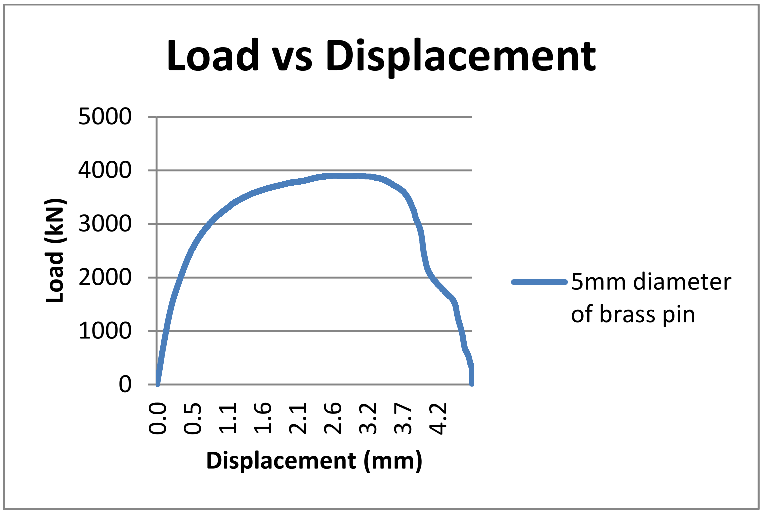


Figure 4.17 : Graph 9 : Load (kN) versus Displacement (mm)

Bearing load : 3898.84 N

Bearing stress : 259.92 N/mm^2

Figure 4.18 : Specimen and Failure Occur

Graph 9 shows the load versus displacement for Brass Pin (D=5mm) with Aluminium Plates (t=3mm) with t/D ratio is 1.2. The pin is placed at 15mm from edge distance and 10mm in between width as illustrated in **Figure 3.4**. The load the brass pin can withstand is 3898.84 N and bearing stress is 259.92 N/mm^2. The **Figure 4.18** shows the plate's holes fail in bearing mode and pin does not break off.

4.3 ANALYZING USING FINITE ELEMENT ANALYSIS ALGOR

The value of load for each specimen used in FEA analysis is finding by using ultimate tensile strength of brass which is $345N/mm^2$. The example for calculation of the load can be referred below which is based on plate thickness and pin diameter of specimens. The area for bearing stress occurs on specimens was marked by the red colour.

Example for load calculation:

Brass pin diameter, D=5mm

Aluminium plate thickness, t=3mm

σ_b = ultimate tensile strength of brass=$345N/mm^2$

$$\sigma_b = \frac{F/2}{Dt}$$

$F = 2(\sigma_b \text{ x } Dt)$= 2(345 x 5 x 3) =10350 N

4.3.1 Brass Pin (D=3mm) with Aluminium Plates (t=1mm)

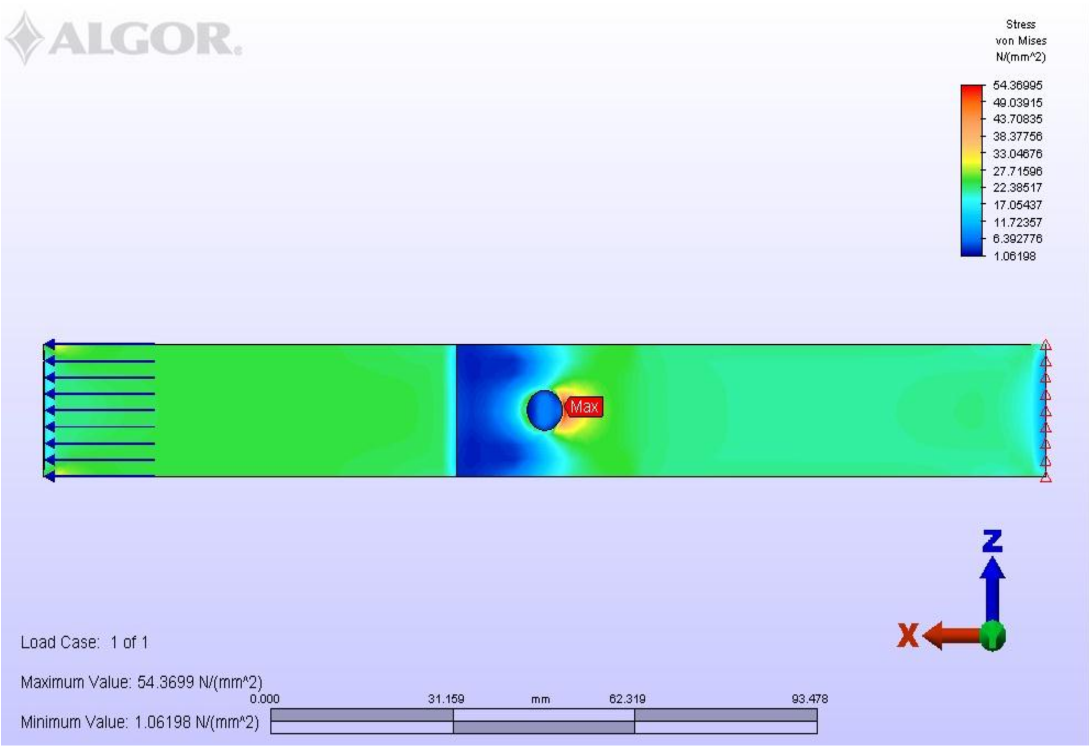


Figure 4.19 : Area of Bearing Stress Occur

Bearing stress : 54.37 N/mm^2

Input Load : 2070 N

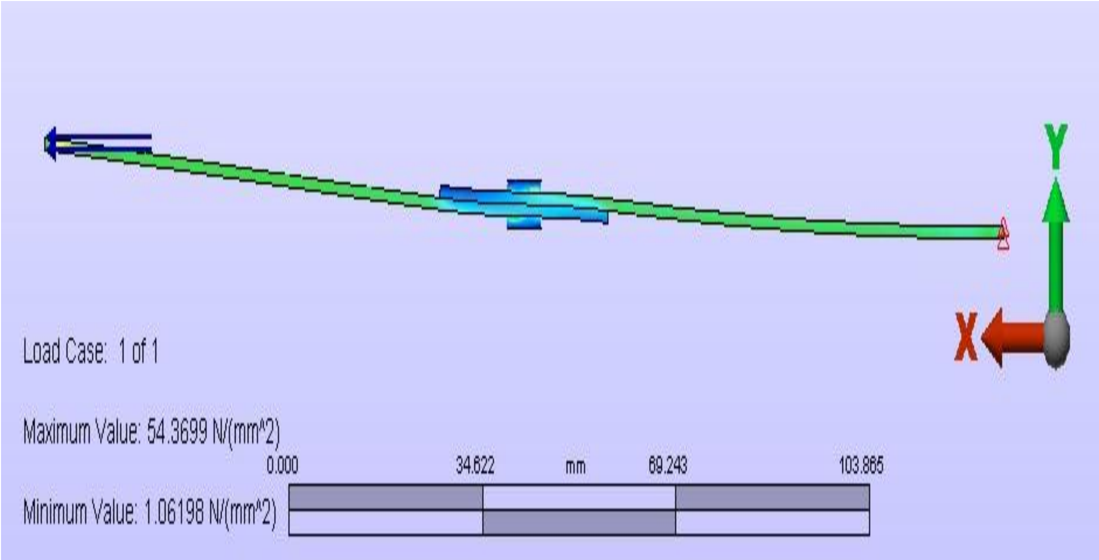


Figure 4.20 : Formation of Pin and Plates After Applied Load

The **Figure 4.19** shows the area of bearing stress occur on the specimen. The input load for this specimen analysis is 2070 N. The bearing stress obtained from the analysis is 54.37 N/mm^2. **Figure 4.20** shows the deformation of pin and plates after applied load. The pin does not break off and plates been bent.

4.3.2 Brass Pin (D=3mm) with Aluminium Plates (t=2mm)

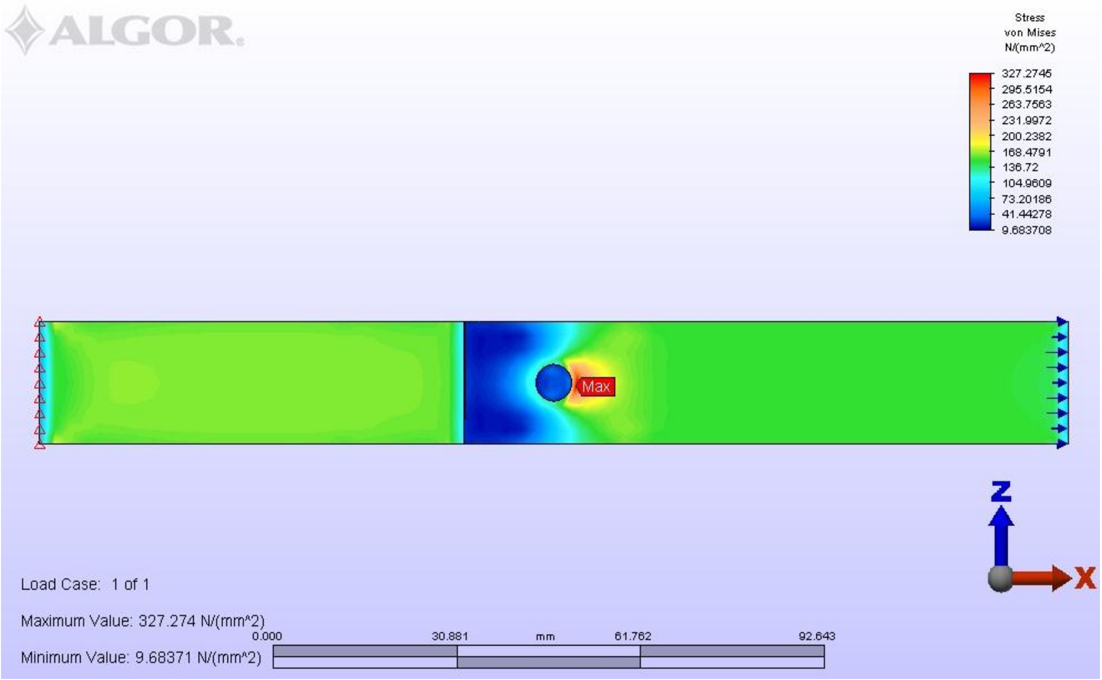


Figure 4.21 : Area of Bearing Stress Occur

Bearing stress : 327.27 N/mm^2

Input Load : 4140 N

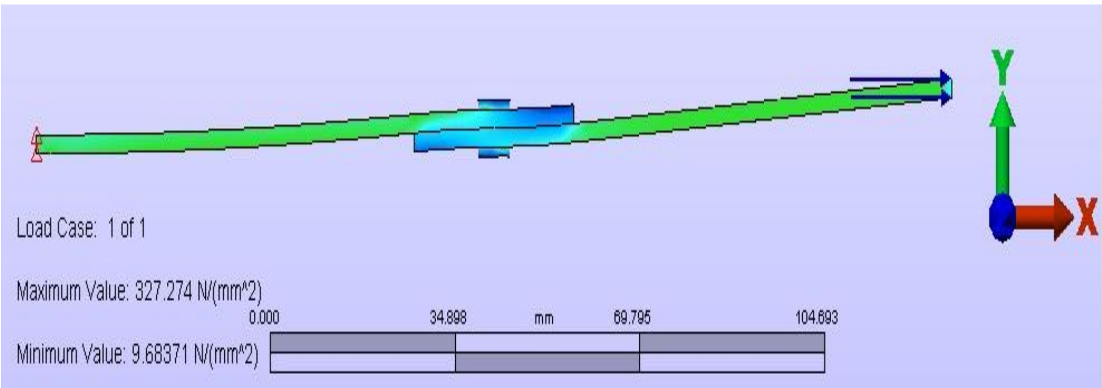


Figure 4.22 : Formation of Pin and Plates After Applied Load

The **Figure 4.21** shows the area of bearing stress occur on the specimen. The input load for this specimen analysis is 4140 N. The bearing stress obtained from the analysis is 327.27 N/mm^2. **Figure 4.22** shows the deformation of pin and plates after applied load. The pin does not break off and plates been bent.

4.3.3 Brass Pin (D=3mm) with Aluminium Plates (t=3mm)

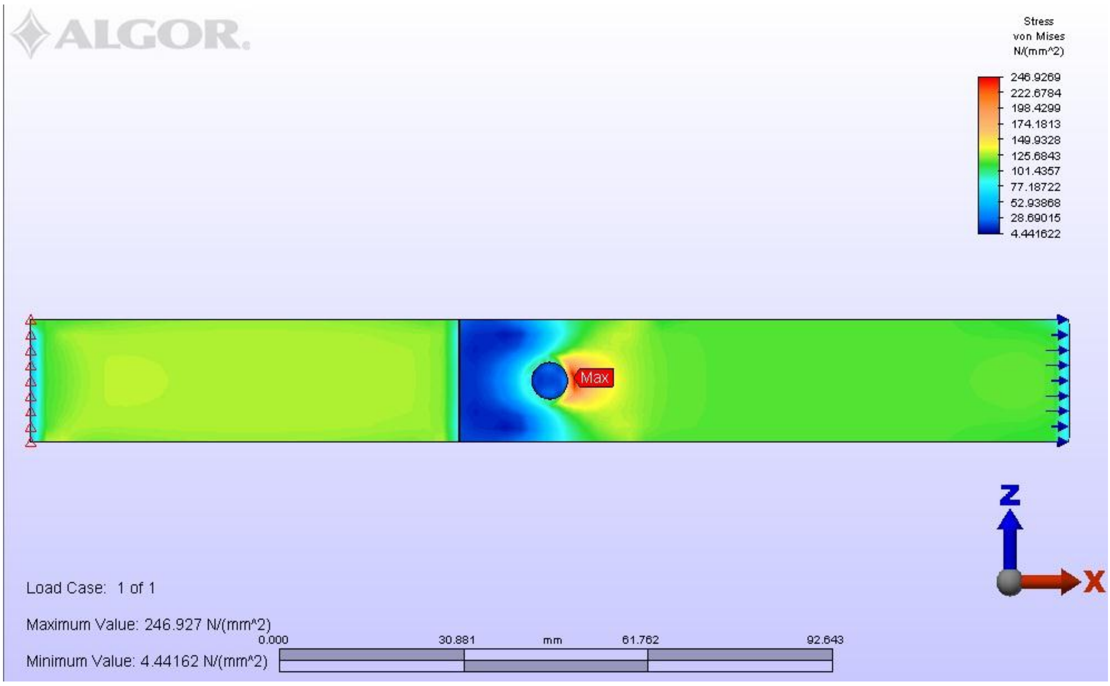


Figure 4.23 : Area of Bearing Stress Occur

Bearing stress : 246.93 N/mm^2

Input Load : 6210 N

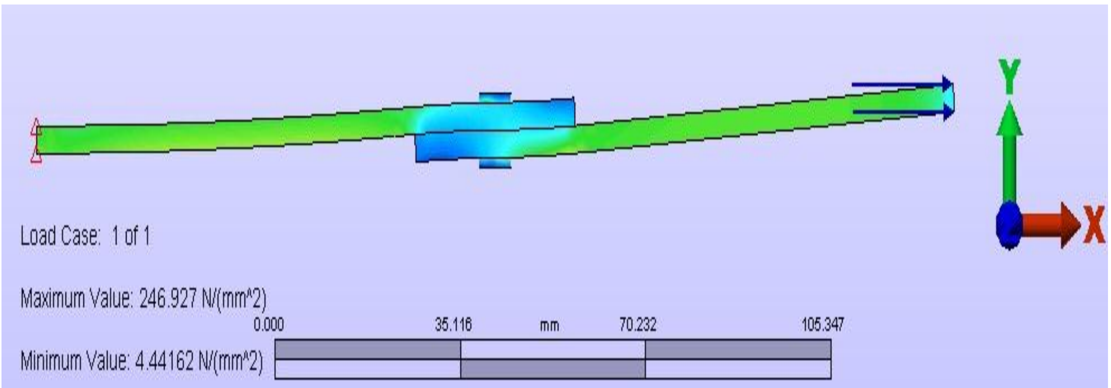


Figure 4.24 : Formation of Pin and Plates After Applied Load

The **Figure 4.23** shows the area of bearing stress occur on the specimen. The input load for this specimen analysis is 6210 N. The bearing stress obtained from the analysis is 246.93 N/mm^2. **Figure 4.24** shows the deformation of pin and plates after applied load. The pin does not break off and plates been bent.

4.3.4 Brass Pin (D=4mm) with Aluminium Plates (t=1mm)

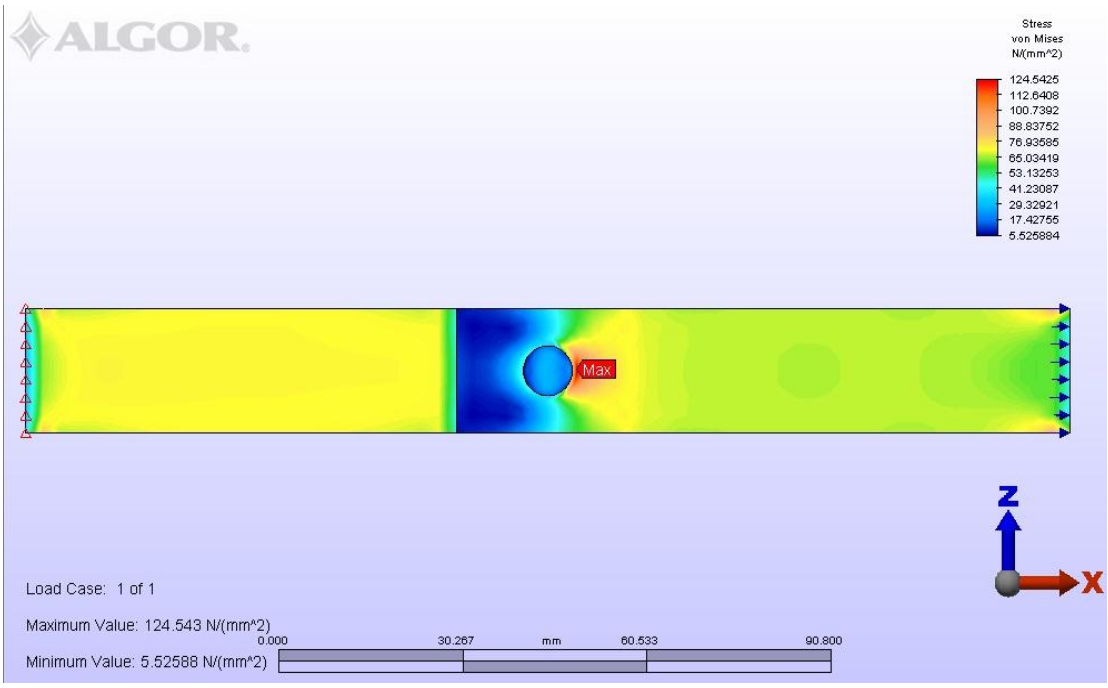


Figure 4.25 : Area of Bearing Stress Occur

Bearing stress : 124.54 N/mm^2

Input Load : 2760 N

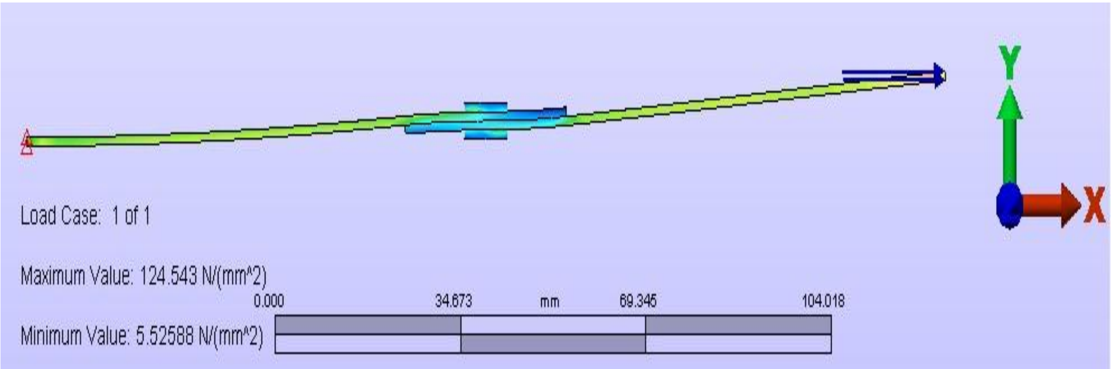


Figure 4.26 : Formation of Pin and Plates After Applied Load

The **Figure 4.25** shows the area of bearing stress occur on the specimen. The input load for this specimen analysis is 2760 N. The bearing stress obtained from the analysis is 124.54 N/mm^2. **Figure 4.26** shows the deformation of pin and plates after applied load. The pin does not break off and plates been bent.

4.3.5 Brass Pin (D=4mm) with Aluminium Plates (t=2mm)

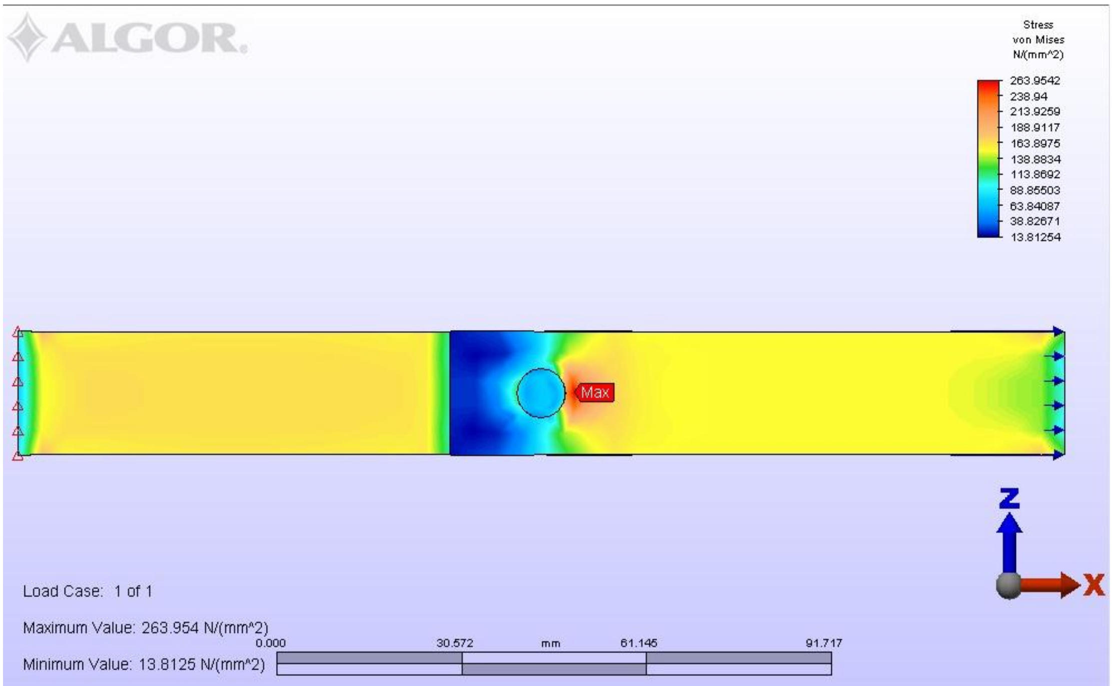


Figure 4.27 : Area of Bearing Stress Occur

Bearing stress : 263.95 N/mm^2

Input Load : 5520 N

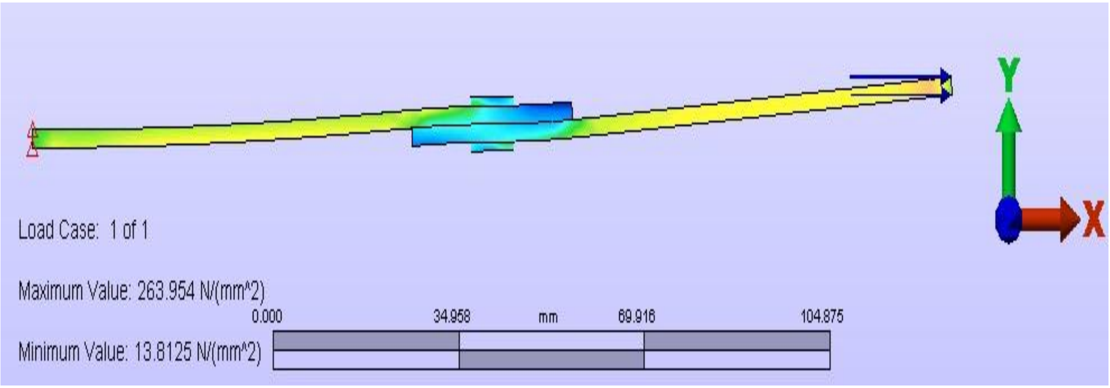


Figure 4.28 : Formation of Pin and Plates After Applied Load

The **Figure 4.27** shows the area of bearing stress occur on the specimen. The input load for this specimen analysis is 5520 N. The bearing stress obtained from the analysis is 263.95 N/mm^2. **Figure 4.28** shows the deformation of pin and plates after applied load. The pin does not break off and plates been bent.

4.3.6 Brass Pin (D=4mm) with Aluminium Plates (t=3mm)

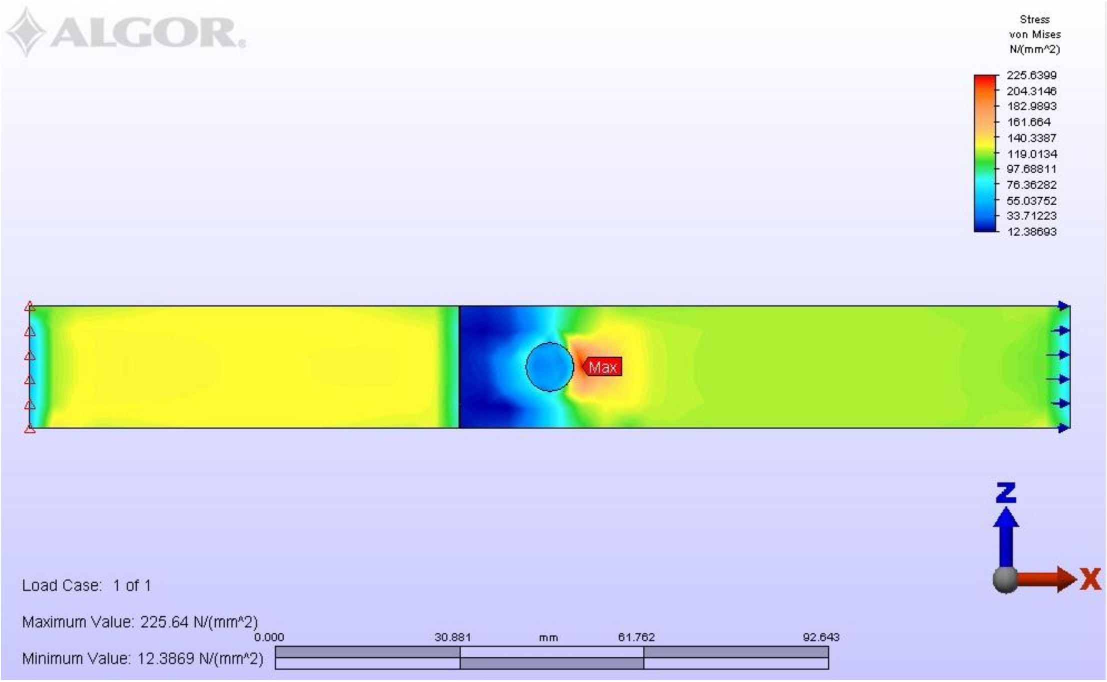


Figure 4.29 : Area of Bearing Stress Occur

Bearing stress : 225.64 N/mm^2

Input Load : 8280 N

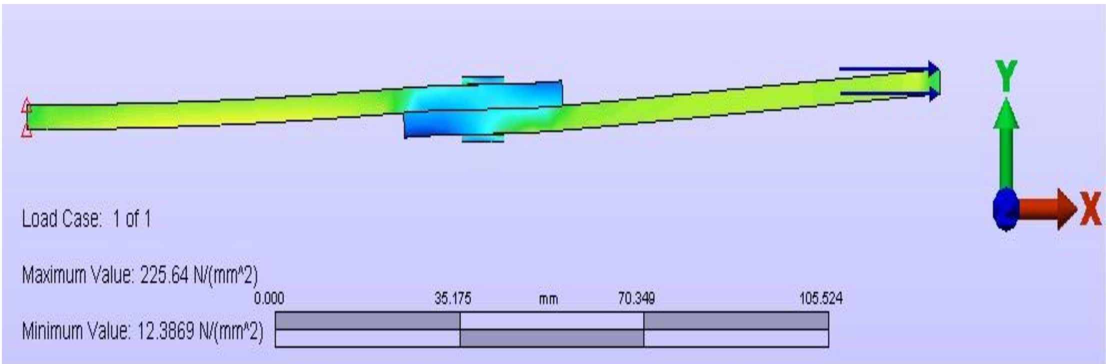


Figure 4.30 : Formation of Pin and Plates After Applied Load

The **Figure 4.29** shows the area of bearing stress occur on the specimen. The input load for this specimen analysis is 8280 N. The bearing stress obtained from the analysis is 225.64 N/mm^2. **Figure 4.30** shows the deformation of pin and plates after applied load. The pin does not break off and plates been bent.

4.3.7 Brass Pin (D=5mm) with Aluminium Plates (t=1mm)

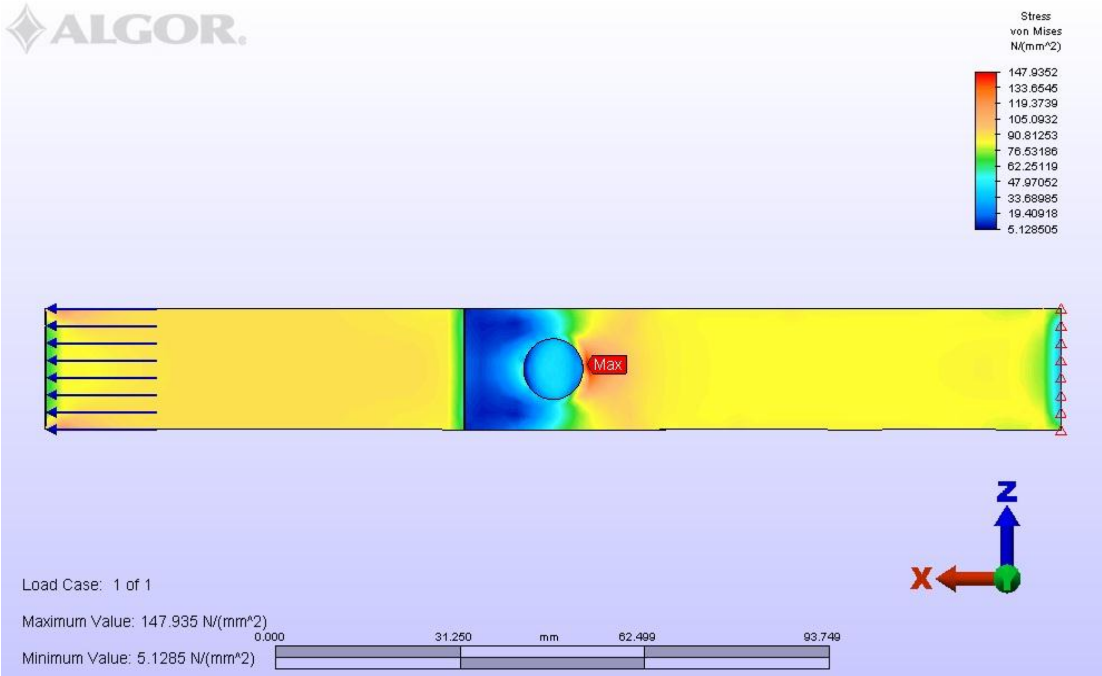


Figure 4.31 : Area of Bearing Stress Occur

Bearing stress : 147.94 N/mm^2

Input Load : 3450 N

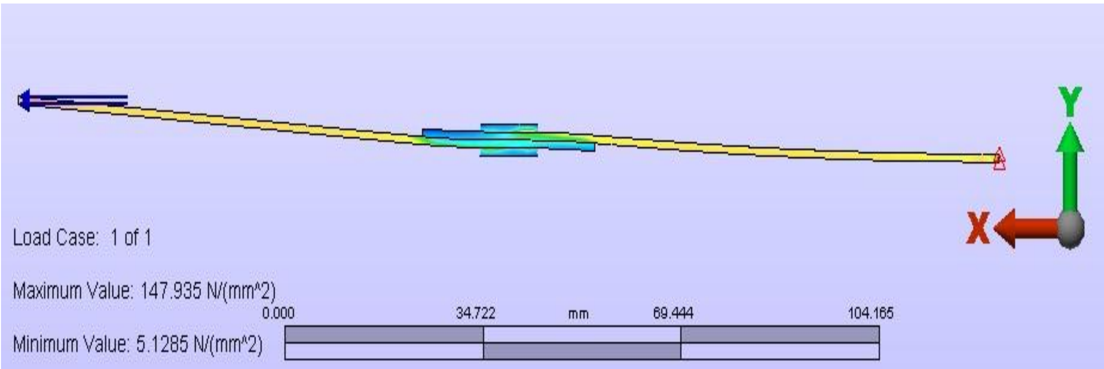


Figure 4.32 : Formation of Pin and Plates After Applied Load

The **Figure 4.31** shows the area of bearing stress occur on the specimen. The input load for this specimen analysis is 3450 N. The bearing stress obtained from the analysis is 147.94 N/mm^2. **Figure 4.32** shows the deformation of pin and plates after applied load. The pin does not break off and plates been bent.

4.3.8 Brass Pin (D=5mm) with Aluminium Plates (t=2mm)

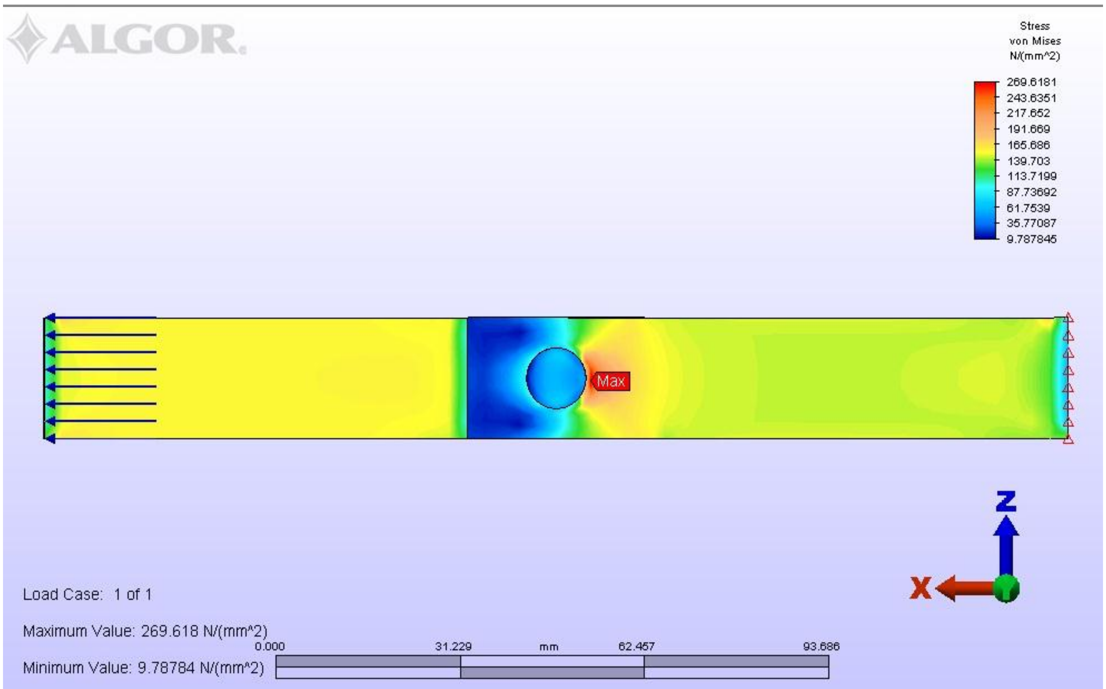


Figure 4.33 : Area of Bearing Stress Occur

Bearing stress : 269.62 N/mm^2

Input Load : 6900 N

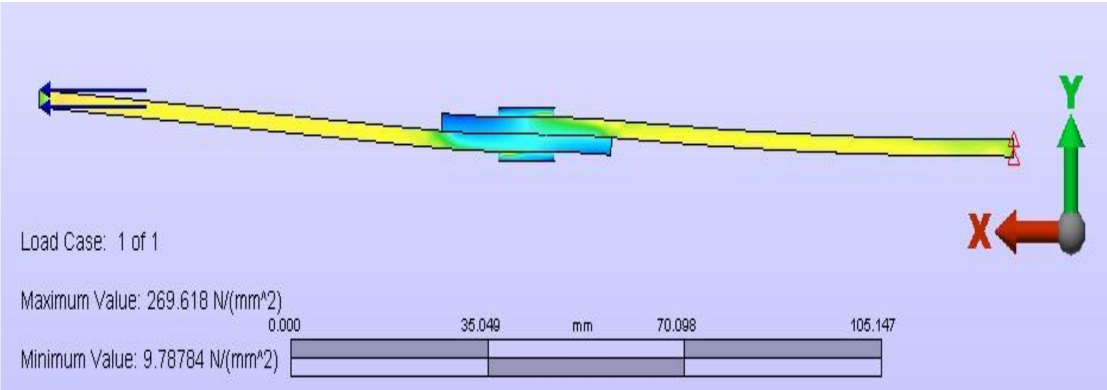


Figure 4.34 : Formation of Pin and Plates After Applied Load

The **Figure 4.33** shows the area of bearing stress occur on the specimen. The input load for this specimen analysis is 6900 N. The bearing stress obtained from the analysis is 269.62 N/mm^2. **Figure 4.34** shows the deformation of pin and plates after applied load. The pin does not break off and plates been bent.

4.3.9 Brass Pin (D=5mm) with Aluminium Plates (t=3mm)

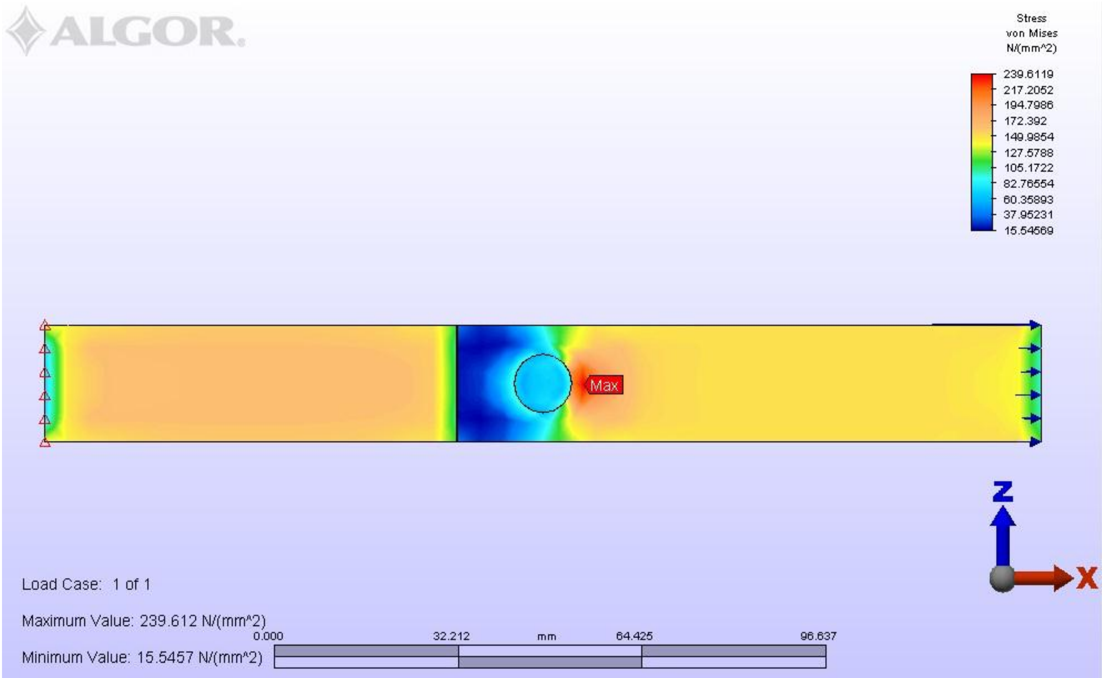


Figure 4.35 : Area of Bearing Stress Occur

Bearing stress : 239.61 N/mm^2

Input Load : 10350 N

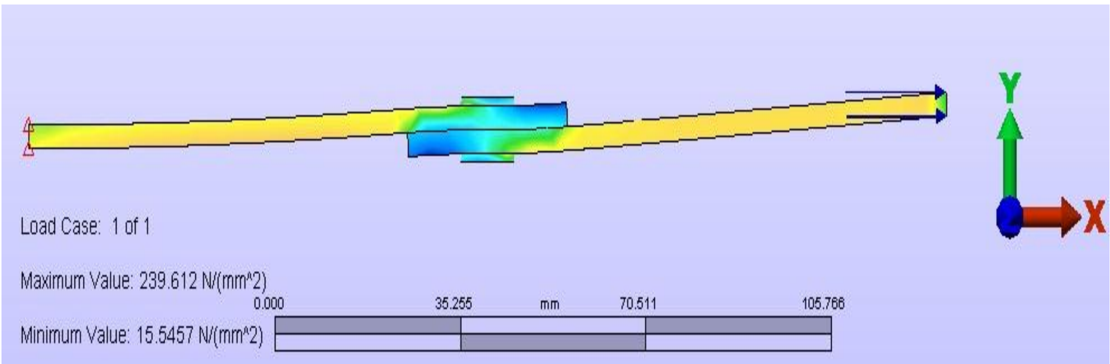


Figure 4.36 : Formation of Pin and Plates After Applied Load

The **Figure 4.35** shows the area of bearing stress occur on the specimen. The input load for this specimen analysis is 10350 N. The bearing stress obtained from the analysis is 239.61 N/mm^2. **Figure 4.36** shows the deformation of pin and plates after applied load. The pin does not break off and plates been bent.

4.4 RESULT

4.4.1 Bearing Test Experimental Result

Table 4.1 : Result for Different Diameter of Brass Pin from Experimental

Brass Pin Diameter (mm)	Aluminium Plates Thickness (mm)	Plate thickness to pin diameter ratio, t/D	Bearing Load (N)	Bearing Stress (N/mm^2)
3	1	0.3	201.178	67.06
	2	0.7	2380.07	396.68
	3	1.0	2644.60	293.84
4	1	0.25	609.350	152.34
	2	0.5	2491.95	311.49
	3	0.8	3086.09	257.17
5	1	0.2	824.754	164.95
	2	0.4	2939.57	293.96
	3	0.6	3898.84	259.92

4.4.2 Finite Element Analysis ALGOR Result

Table 4.2 : Result for Different Diameter of Brass Pin from Simulation

Brass Pin Diameter (mm)	Aluminium Plates Thickness (mm)	Input Load (N)	Bearing Stress (N/mm^2)
3	1	2070	54.37
	2	4140	327.27
	3	6210	246.93
4	1	2760	124.54
	2	5520	263.95
	3	8280	225.64
5	1	3450	147.94
	2	6900	269.62
	3	10350	239.61

4.5 DISCUSSION

From experimental data, the bearing load for each specimen can be determined. The value of bearing load was located at the top point from the graph load versus displacement. The summary for all bearing load are plotted into graph of bearing load versus pin diameter. The graph was plotted by following the Aluminium thickness used which is 1mm, 2mm and 3mm. The graphs will be discussed.

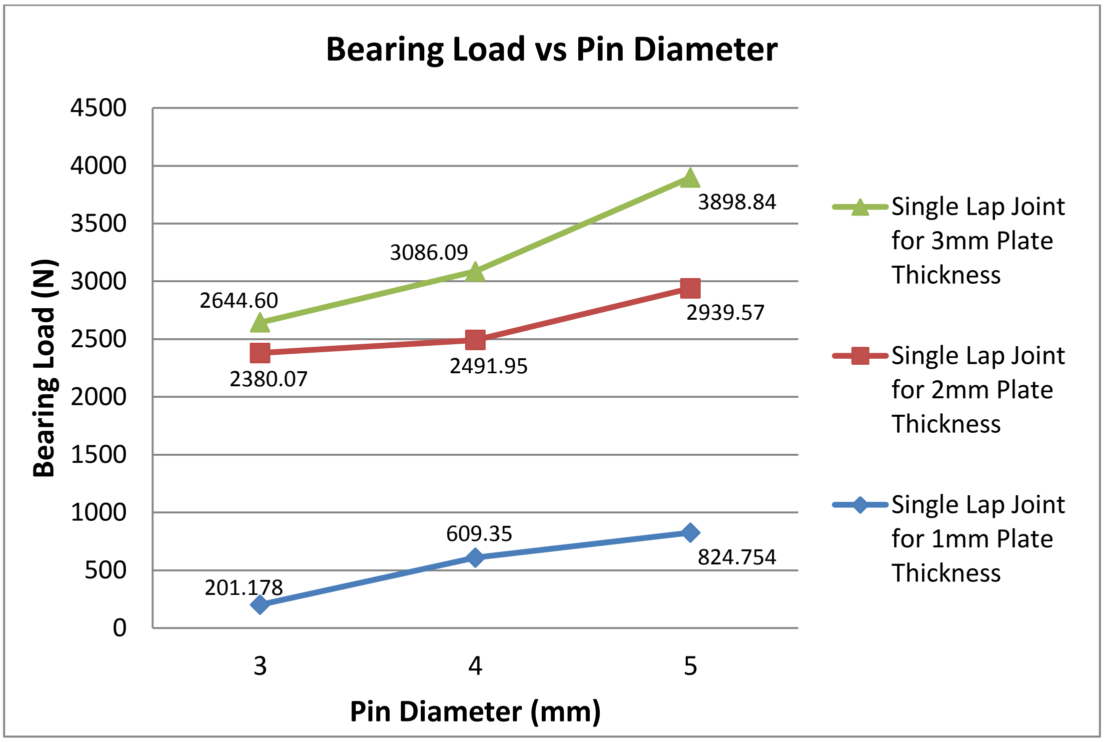


Figure 4.37 : Graph 10 : Summary Graph of Bearing Load versus Pin Diameter

From the **Graph 10**, it shows the bearing load for pin can withstand for different plates thickness. The value bearing load is different and increase as the pin diameter is bigger. The strength and bearing load for pin is based on its diameter for this investigation. If two plates Aluminium of same thickness will be joined by using 3mm diameter brass pin, the plates and pin did not last long. The pin size could only survive with a small burden imposed by the plates until the joint broke. This is different for others pin diameter. As seen through the graph, the highest value bearing load is for 5mm pin diameter. This means, the pin size is the better choice than others, because, it can withstand higher load with different plates thickness. By increase the pin diameter, decrease the plate thickness, caused the value bearing load for pin can withstand increased based on this investigation.

As shown through the **Figure 4.2** until **Figure 4.18**, the failure for each specimen is same which is pin does not break off and plates holes fail in bearing mode. These have been proved that (Buket et al., 2001), if W/D and E/D ratio is higher, it cause the bearing failure mode occurred. As can see, the bearing failure for two pieces of 3mm plate thickness joined with 3mm, 4mm and 5mm pin diameter are more significant than the other plates. It caused by the higher value bearing load imposed on the plates by pin. Thus, the time for the joint plate and pin to break is longer than others specimen. The lower plate thickness and pin diameter, the joint will fail and broke in a short time. The relationship of plate thickness to pin diameter, t/D ratio as shown in **Table 4.1** also can be used to estimate the maximum or minimum load of some joint can withstand. As the t/D ratio increase, the load for joint can support is higher.

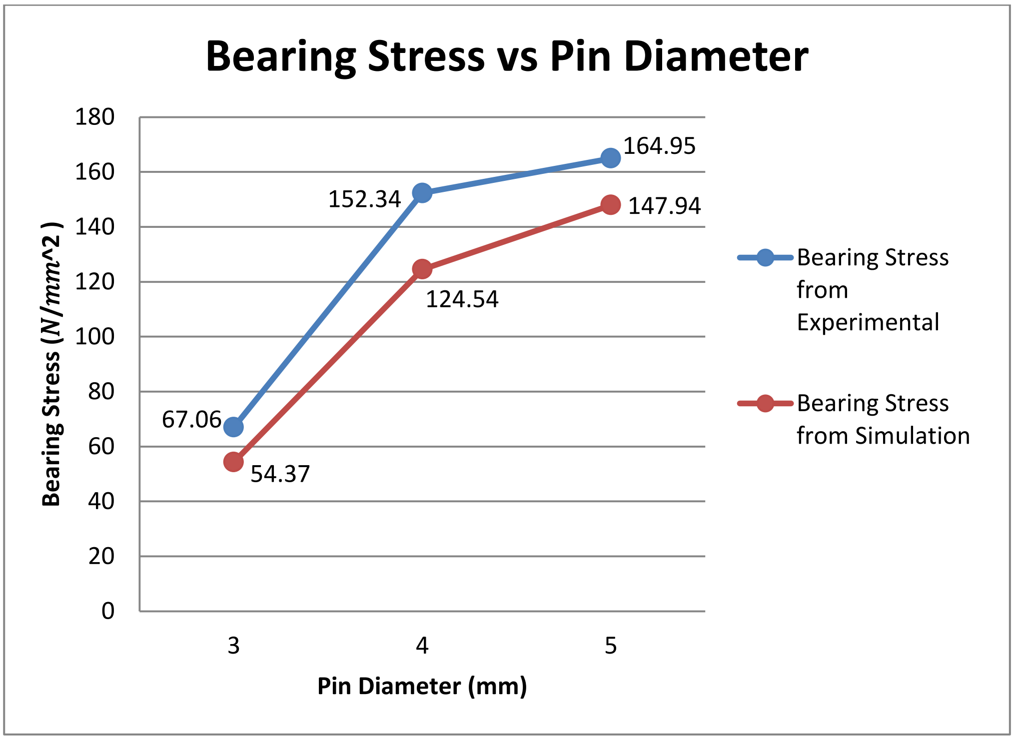


Figure 4.38 : Graph 11 : Bearing Stress versus Pin Diameter for Single Lap Joint of 1mm Aluminium plates thickness between Experimental and Simulation

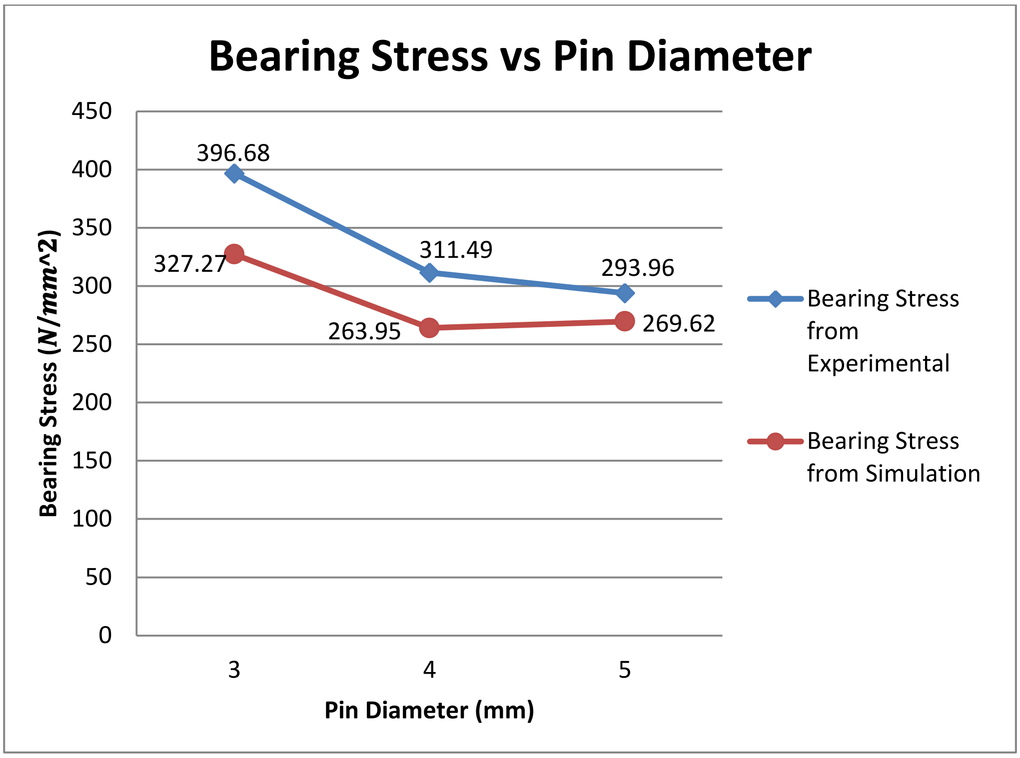


Figure 4.39 : Graph 12 : Bearing Stress versus Pin Diameter for Single Lap Joint of 2mm Aluminium plates thickness between Experimental and Simulation

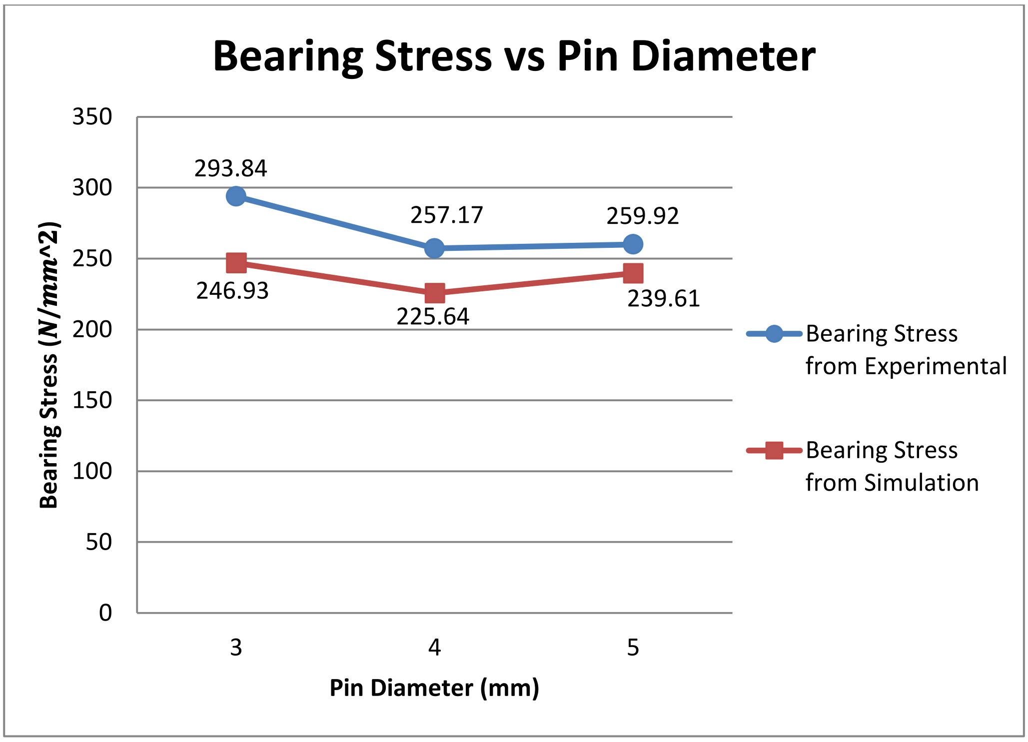


Figure 4.40 : Graph 13 : Bearing Stress versus Pin Diameter for Single Lap Joint of 3mm Aluminium plates thickness between Experimental and Simulation

Table 4.3 : Percentage Error (%) of Bearing Stress for Experimental vs Simulation

Brass Pin Diameter (mm)	**Aluminium Plates Thickness (mm)**	**Bearing Stress from Experimental (N/mm^2)**	**Bearing Stress from Simulation (N/mm^2)**	**Percentage Error (%)**
3	1	67.06	54.37	18
	2	396.68	327.27	17
	3	293.84	246.93	15
4	1	152.34	124.54	18
	2	311.49	263.95	15
	3	257.17	225.64	12
5	1	164.95	147.94	10
	2	293.96	269.62	8
	3	259.92	239.61	7

Average Percentage Error = 20 %

$$\text{Percentage error, \%} = \frac{\begin{pmatrix}\text{Bearing Stress Value}\\ \text{from Experimental}\end{pmatrix} - \begin{pmatrix}\text{Bearing Stress Value}\\ \text{from Simulation}\end{pmatrix}}{\text{Bearing Stress Value from Experimental}} \text{ X } 100$$

The bearing stress for this investigation is obtained as shown in **Table 4.1** and **Table 4.2**. **Table 4.3** show the bearing stress percentage error between experimental and simulation. The percentage error will clearly tell whether result of experiment can be accepted or not. The purpose of finding the percentage of error is to determine how large the region between experiment result and simulation result is. The low value of percentage error is better because the result for experiment is close to simulation. The bearing stress value was plotted into a graph as can see through **Figure 4.38** to **Figure 4.40** according to different Aluminium plate thickness. As seen, the graph of bearing stress value obtained from experimental is closely to the graph of bearing stress value from simulation. The different value is small for both. For example, the percentage error between bearing stress value of 259.92 N/mm^2 and 239.61 N/mm^2 is 7 %. For others value, the percentage error is less than 20%. The average percentage error for all specimens is 20 %. Virtually, all the bearing stress value for different pin diameter according to plate thickness obtained from experimental is closely to simulation value. The small different value of bearing stress obtained could be due to errors occurred either in experimental or simulation works.

An experimental can be characterized as an investigative activity that involves intervening on a system in order to see how properties of interest of the system change, if at all, in light of that intervention. A computer simulation is a sequence of states undergone by a digital computer, with that sequence representing the sequence of states that some real or imagined system did, will or might undergo. For this investigation, there are some errors can be considered from experimental that cause the bearing stress value differ from simulation. From the viewpoint of specimens' physical, the possibilities of both sides surface of the plate are not closely connected and pin loose. Hole on the plates for pin connection may also slightly damaged cause by the drill bit and hole size increases when the connection pin is completed. This can be overcome by using the accurate size of drill bit that can make a hole on the plate as exactly of needed size. Precautions is needed when to connect the pin into plate hole to assure the specimen not damage or misalignment. Another error could occur is from tensile instrumental. Proper alignment of the grips and the specimen when clamped in the grips is important. The offsets in alignment maybe occurred that will create bending stresses and tower tensile stress readings. It may even cause the specimen to fracture outside the gage length and the force given not balanced to entire area of specimens. The value of gage length that key in into trapezium software could be not same as value of manual measurement on between the clamps jaw that can cause miscalculation for the results. This can be overcome by make a marking on the specimen as mark point to make sure the specimen is clamped to the grip centered. The tolerance values for pin diameter also not as exactly of 3mm, 4mm and 5 mm, thus it gives effects on failure load and stress value of pin. The pin needed to be machined by using other machine such as CNC machine as it automatically work that will produce accurate pin size.

For simulation by ALGOR Fempro, there are several error can be considered that the value of bearing stress is differ from the experimental value. As can see, from **Figure 4.2** until **Figure 4.35**, the located area of bearing stress occurs for experimental are almost the same as shown by simulation software analysis. That means, the physical effect as seen in real world can be the same as simulation, but the internal effect could be significantly different. The meshing for the models maybe not accurate, plus the material properties in ALGOR software could be slightly differ with actual material. This can be overcome by define by our own for the material properties in the simulation.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

In this study, the bearing load on 3 different diameter brass pin joined with an Aluminium thin plate of variable thickness had been determined. It was found that, the bigger pin diameter size, the higher load that pin can withstand. For example, the 5mm brass pin diameter has the highest bearing load of 3898.84 N. But, that depends on the plate thickness. The pin diameter size to be used must be greater than the thickness of the plates to be joined because it can leads to bearing failure mode. Previous study concludes, the bearing failure mode as example shown in **Figure 4.12** is safest failure than others. Moreover, it can reduce the risk of pin to break. So, a joint will be able to last longer if the plates fail first in bearing mode and is higher risk if the pin first broken in a joint.

Another conclusion can be made is, both either the experimental or the simulation is best accurate method. This is because of the different value bearing stress for experimental is closely to simulation by software as shown in **Table 4.1** and **Table 4.2** with average percentage error of 20 %. As can see, from **Figure 4.2** until **Figure 4.35**, the located area of bearing stress occurs for experimental are almost the same as shown by simulation software analysis. That means, the physical effect as seen in real world can be the same as simulation, but the internal effect could be significantly different. Experiments can be more accurate than simulations in the sense that they are performed under real-world conditions, and believe about how things work in the real world. Thus, some of a complex studies shows the results from experimental and simulation software are the same.

5.2 RECOMMENDATIONS

There are some recommendations in order to get the better bearing load and the best software for simulation.

a) Using the plate from other material type and higher strength than the brass such as mild steel or stainless steel. The different brass pin diameter will be broken, thus the bearing load and stress can be obtained.
b) Use the CNC machine to produce accurate size of small brass pin diameter. It can control the motions of the work piece or tool, the input parameters such as feed, depth of cut, speed, and the functions such as turning spindle on/off, turning coolant on/off to produce a better product.
c) Use ANSYS software that providing access to virtually any field of engineering simulation. Could get the better value bearing stress or others stress that could be same with experimental results.
d) Do not use the recycled materials or rusty specimens. This possibly can affect the actual load or specimens become easier to crack.

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APPENDICES

Result data for Brass Pin (D=3mm) with Aluminium Plates (t=1mm) from tensile experiment.

Time	Force	Stroke			
sec	N	mm	67.01	201.0981	1.116292
			67.02	201.1299	1.116458
66.66	200.9869	1.110438	67.03	201.1299	1.116625
66.67	201.0186	1.110604	67.04	201.1299	1.116792
66.68	201.0186	1.110771	67.05	201.1299	1.116958
66.69	201.0186	1.110958	67.06	201.1299	1.117125
66.7	201.0186	1.111104	67.07	201.1299	1.117292
66.71	201.0186	1.111271	67.08	201.1299	1.117458
66.72	201.0186	1.111458	67.09	201.1299	1.117625
66.73	201.0186	1.111604	67.1	201.1299	1.117792
66.74	201.0504	1.111771	67.11	201.1299	1.117958
66.75	201.0504	1.111938	67.12	201.1299	1.118125
66.76	201.0504	1.112104	67.13	201.1299	1.118292
66.77	201.0504	1.112271	67.14	201.1299	1.118458
66.78	201.0504	1.112458	67.15	201.1299	1.118625
66.79	201.0504	1.112625	67.16	201.1299	1.118792
66.8	201.0504	1.112792	67.17	201.1299	1.118958
66.81	201.0504	1.112958	67.18	201.1299	1.119125
66.82	201.0504	1.113125	67.19	201.1299	1.119292
66.83	201.0504	1.113292	67.2	201.1299	1.119458
66.84	201.0504	1.113458	67.21	201.1299	1.119625
66.85	201.0504	1.113625	67.22	201.1299	1.119792
66.86	201.0504	1.113792	67.23	201.1299	1.119958
66.87	201.0504	1.113958	67.24	201.1299	1.120125
66.88	201.0504	1.114125	67.25	201.1776	1.120292
66.89	201.0504	1.114292	67.26	201.1776	1.120458
66.9	201.0663	1.114458	67.27	201.1776	1.120625
66.91	201.0981	1.114625	67.28	201.1776	1.120792
66.92	201.0981	1.114792	67.29	201.1776	1.120958
66.93	201.0981	1.114958	67.3	201.1776	1.121125
66.94	201.0981	1.115125	67.31	201.1776	1.121292
66.95	201.0981	1.115292	67.32	201.1776	1.121458
66.96	201.0981	1.115458	67.33	201.1776	1.121625
66.97	201.0981	1.115625	67.34	201.1776	1.121792
66.98	201.0981	1.115792	67.35	201.1776	1.121958
66.99	201.0981	1.115958	67.36	201.1776	1.122125
67	201.0981	1.116125	67.37	201.1299	1.122292

Result data for Brass Pin (D=3mm) with Aluminium Plates (t=2mm) from tensile experiment.

Time sec	Force N	Stroke mm	Time sec	Force N	Stroke mm
159.48	2379.99	2.657458	159.83	2380.021	2.663292
159.49	2379.99	2.657625	159.84	2380.021	2.663458
159.5	2379.99	2.657792	159.85	2380.021	2.663625
159.51	2379.99	2.657958	159.86	2380.021	2.663792
159.52	2379.99	2.658125	159.87	2380.021	2.663958
159.53	2379.99	2.658271	159.88	2380.021	2.664125
159.54	2379.99	2.658437	159.89	2380.021	2.664292
159.55	2380.021	2.658625	159.9	2380.021	2.664458
159.56	2380.021	2.658792	159.91	2380.021	2.664625
159.57	2380.021	2.658958	159.92	2380.069	2.664792
159.58	2380.021	2.659125	159.93	2380.069	2.664958
159.59	2380.021	2.659271	159.94	2380.021	2.665125
159.6	2380.021	2.659437	159.95	2380.021	2.665292
159.61	2380.021	2.659604	159.96	2380.021	2.665458
159.62	2380.021	2.659771	159.97	2380.021	2.665625
159.63	2380.021	2.659937	159.98	2380.021	2.665792
159.64	2380.021	2.660125	159.99	2380.021	2.665958
159.65	2380.021	2.660271	160	2380.021	2.666125
159.66	2380.021	2.660458	160.01	2380.021	2.666292
159.67	2380.021	2.660604	160.02	2380.021	2.666458
159.68	2380.021	2.660771	160.03	2380.021	2.666625
159.69	2380.021	2.660938	160.04	2380.021	2.666792
159.7	2380.021	2.661125	160.05	2380.021	2.666958
159.71	2380.021	2.661271	160.06	2380.021	2.667125
159.72	2380.021	2.661458	160.07	2380.021	2.667292
159.73	2380.021	2.661604	160.08	2380.021	2.667458
159.74	2380.021	2.661771	160.09	2380.021	2.667625
159.75	2380.021	2.661937	160.1	2380.021	2.667792
159.76	2380.021	2.662104	160.11	2380.021	2.667958
159.77	2380.021	2.662271	160.12	2380.021	2.668125
159.78	2380.021	2.662437	160.13	2380.021	2.668292
159.79	2380.021	2.662604	160.14	2380.021	2.668458
159.8	2380.021	2.662792	160.15	2380.021	2.668625
159.81	2380.021	2.662958	160.16	2380.021	2.668792
159.82	2380.021	2.663125	160.17	2379.99	2.668958
			160.18	2379.99	2.669125
			160.19	2379.99	2.669292

Result data for Brass Pin (D=3mm) with Aluminium Plates (t=3mm) from tensile experiment.

Time	Force	Stroke			
sec	N	mm	132.82	2643.267	2.213104
			132.83	2643.347	2.213271
132.47	2643.14	2.207292	132.84	2643.553	2.213438
132.48	2642.87	2.207458	132.85	2643.235	2.213604
132.49	2642.377	2.207625	132.86	2643.108	2.213771
132.5	2641.932	2.207792	132.87	2643.124	2.213938
132.51	2642.25	2.207958	132.88	2643.267	2.214104
132.52	2642.822	2.208125	132.89	2643.442	2.214271
132.53	2642.886	2.208292	132.9	2643.172	2.214437
132.54	2642.743	2.208458	132.91	2643.315	2.214604
132.55	2643.267	2.208625	132.92	2643.697	2.214771
132.56	2642.345	2.208792	132.93	2643.251	2.214937
132.57	2642.187	2.208958	132.94	2643.156	2.215104
132.58	2642.345	2.209125	132.95	2643.506	2.215271
132.59	2643.315	2.209292	132.96	2643.363	2.215437
132.6	2643.569	2.209458	132.97	2642.775	2.215604
132.61	2642.806	2.209625	132.98	2642.838	2.215771
132.62	2642.266	2.209792	132.99	2642.552	2.215937
132.63	2642.489	2.209958	133	2642.457	2.216104
132.64	2642.584	2.210125	133.01	2642.997	2.216271
132.65	2644.157	2.210292	133.02	2643.824	2.216458
132.66	2643.665	2.210458	133.03	2643.538	2.216625
132.67	2643.395	2.210625	133.04	2643.887	2.216792
132.68	2643.728	2.210792	133.05	2643.538	2.216938
132.69	2643.331	2.210958	133.06	2643.331	2.217104
132.7	2642.584	2.211125	133.07	2644.348	2.217292
132.71	2643.299	2.211292	133.08	2644.603	2.217458
132.72	2642.934	2.211458	133.09	2643.792	2.217625
132.73	2643.092	2.211604	133.1	2643.092	2.217792
132.74	2643.967	2.211792	133.11	2643.665	2.217958
132.75	2642.981	2.211958	133.12	2643.808	2.218125
132.76	2643.204	2.212125	133.13	2643.697	2.218292
132.77	2642.918	2.212292	133.14	2643.855	2.218458
132.78	2642.791	2.212458	133.15	2643.776	2.218625
132.79	2643.474	2.212625	133.16	2643.808	2.218792
132.8	2643.538	2.212771	133.17	2643.665	2.218958
132.81	2643.013	2.212938			

Result data for Brass Pin (D=4mm) with Aluminium Plates (t=1mm) from tensile experiment.

Time	Force	Stroke			
sec	N	mm	12.55	607.7289	0.208625
12.21	606.2985	0.202958	12.56	608.0151	0.208792
12.22	606.5051	0.203104	12.57	608.2694	0.208958
12.23	607.0773	0.203271	12.58	607.6972	0.209125
12.24	607.0455	0.203438	12.59	608.3171	0.209292
12.25	607.5065	0.203625	12.6	608.921	0.209458
12.26	607.6336	0.203792	12.61	607.9197	0.209625
12.27	607.0137	0.203938	12.62	607.5541	0.209792
12.28	606.7276	0.204104	12.63	607.5065	0.209958
12.29	607.0296	0.204271	12.64	608.2853	0.210125
12.3	606.8071	0.204458	12.65	609.2866	0.210292
12.31	606.8865	0.204625	12.66	609.1595	0.210458
12.32	607.268	0.204771	12.67	608.4601	0.210625
12.33	607.9356	0.204938	12.68	608.6509	0.210792
12.34	607.4905	0.205104	12.69	608.4919	0.210958
12.35	606.9343	0.205271	12.7	608.1422	0.211125
12.36	607.1885	0.205438	12.71	608.5078	0.211292
12.37	606.5845	0.205604	12.72	608.6349	0.211458
12.38	607.1727	0.205771	12.73	608.3647	0.211625
12.39	607.7766	0.205938	12.74	609.0323	0.211792
12.4	607.7289	0.206104	12.75	609.2866	0.211958
12.41	607.4111	0.206271	12.76	608.3329	0.212125
12.42	607.8243	0.206438	12.77	608.2375	0.212292
12.43	607.8879	0.206625	12.78	608.0309	0.212458
12.44	607.5223	0.206771	12.79	608.0627	0.212625
12.45	607.2203	0.206958	12.8	608.7144	0.212771
12.46	607.8879	0.207104	12.81	608.4124	0.212958
12.47	608.2694	0.207292	12.82	608.6509	0.213125
12.48	607.4587	0.207458	12.83	609.0482	0.213292
12.49	606.966	0.207625	12.84	609.3502	0.213458
12.5	607.6177	0.207792	12.85	608.5873	0.213625
12.51	608.1104	0.207958	12.86	608.3965	0.213792
12.52	608.8575	0.208125	12.87	608.619	0.213958
12.53	609.08	0.208292	12.88	608.3329	0.214125
12.54	608.4283	0.208458	12.89	607.7766	0.214292
			12.9	607.5223	0.214458

Result data for Brass Pin (D=4mm) with Aluminium Plates (t=2mm) from tensile experiment.

Time	Force	Stroke
sec	N	mm
227.99	2491.872	3.799292
228	2491.872	3.799458
228.01	2491.872	3.799625
228.02	2491.872	3.799792
228.03	2491.872	3.799958
228.04	2491.872	3.800125
228.05	2491.872	3.800292
228.06	2491.872	3.800458
228.07	2491.872	3.800625
228.08	2491.872	3.800792
228.09	2491.872	3.800958
228.1	2491.872	3.801125
228.11	2491.872	3.801292
228.12	2491.903	3.801458
228.13	2491.919	3.801625
228.14	2491.919	3.801792
228.15	2491.919	3.801958
228.16	2491.919	3.802125
228.17	2491.919	3.802292
228.18	2491.919	3.802458
228.19	2491.919	3.802625
228.2	2491.919	3.802792
228.21	2491.919	3.802958
228.22	2491.919	3.803125
228.23	2491.919	3.803292
228.24	2491.919	3.803458
228.25	2491.919	3.803625
228.26	2491.919	3.803792
228.27	2491.919	3.803958
228.28	2491.919	3.804125
228.29	2491.919	3.804292
228.3	2491.919	3.804458
228.31	2491.919	3.804625
228.32	2491.919	3.804792
228.33	2491.919	3.804958
228.34	2491.919	3.805125
228.35	2491.919	3.805292
228.36	2491.919	3.805458
228.37	2491.919	3.805625
228.38	2491.919	3.805792
228.39	2491.919	3.805958
228.4	2491.919	3.806125
228.41	2491.935	3.806292
228.42	2491.951	3.806458
228.43	2491.951	3.806625
228.44	2491.951	3.806792
228.45	2491.951	3.806958
228.46	2491.951	3.807125
228.47	2491.951	3.807292
228.48	2491.951	3.807458
228.49	2491.951	3.807625
228.5	2491.951	3.807792
228.51	2491.951	3.807958
228.52	2491.951	3.808125
228.53	2491.951	3.808292
228.54	2491.951	3.808458
228.55	2491.951	3.808625
228.56	2491.951	3.808792
228.57	2491.951	3.808958
228.58	2491.951	3.809125
228.59	2491.951	3.809292
228.6	2491.951	3.809458
228.61	2491.951	3.809625
228.62	2491.951	3.809792
228.63	2491.935	3.809958
228.64	2491.919	3.810125
228.65	2491.919	3.810292
228.66	2491.919	3.810458
228.67	2491.919	3.810604
228.68	2491.919	3.810792
228.69	2491.919	3.810937

Result data for Brass Pin (D=4mm) with Aluminium Plates (t=3mm) from tensile experiment.

Time	Force	Stroke
sec	N	mm
61.3	3083.77	1.021125
61.31	3083.642	1.021292
61.32	3083.706	1.021458
61.33	3083.928	1.021625
61.34	3084.008	1.021792
61.35	3084.294	1.021958
61.36	3084.405	1.022125
61.37	3084.517	1.022292
61.38	3084.119	1.022458
61.39	3083.992	1.022625
61.4	3084.326	1.022792
61.41	3084.405	1.022958
61.42	3083.69	1.023125
61.43	3083.69	1.023292
61.44	3084.119	1.023458
61.45	3084.803	1.023625
61.46	3084.389	1.023792
61.47	3084.262	1.023958
61.48	3084.803	1.024125
61.49	3084.962	1.024292
61.5	3085.327	1.024458
61.51	3085.375	1.024625
61.52	3085.025	1.024792
61.53	3084.977	1.024958
61.54	3085.566	1.025125
61.55	3084.453	1.025292
61.56	3084.977	1.025458
61.57	3085.136	1.025625
61.58	3085.438	1.025792
61.59	3084.993	1.025958
61.6	3085.168	1.026125
61.61	3084.612	1.026292
61.62	3084.024	1.026458
61.63	3083.992	1.026625
61.64	3084.548	1.026792
61.65	3085.057	1.026958
61.66	3084.691	1.027125
61.67	3084.85	1.027292
61.68	3084.962	1.027458
61.69	3084.803	1.027625
61.7	3085.025	1.027792
61.71	3084.93	1.027958
61.72	3084.787	1.028125
61.73	3084.517	1.028292
61.74	3084.532	1.028458
61.75	3084.357	1.028625
61.76	3085.216	1.028792
61.77	3085.025	1.028958
61.78	3084.898	1.029125
61.79	3084.564	1.029292
61.8	3084.199	1.029458
61.81	3085.152	1.029625
61.82	3085.423	1.029792
61.83	3085.423	1.029958
61.84	3085.406	1.030125
61.85	3084.707	1.030292
61.86	3084.803	1.030458
61.87	3084.993	1.030625
61.88	3084.866	1.030792
61.89	3085.041	1.030958
61.9	3085.645	1.031125
61.91	3085.47	1.031292
61.92	3084.993	1.031458
61.93	3085.152	1.031625
61.94	3085.073	1.031792
61.95	3084.866	1.031958
61.96	3086.09	1.032125
61.97	3085.47	1.032292
61.98	3085.009	1.032458
61.99	3085.582	1.032625
62	3085.438	1.032792
62.01	3084.898	1.032958
62.02	3085.311	1.033125

Result data for Brass Pin (D=5mm) with Aluminium Plates (t=1mm) from tensile experiment.

Time	Force	Stroke
sec	N	mm
23.59	823.2276	0.392625
23.6	822.6871	0.392792
23.61	822.7984	0.392938
23.62	822.4805	0.393104
23.63	822.6554	0.393271
23.64	823.7044	0.393458
23.65	823.1004	0.393625
23.66	823.2911	0.393792
23.67	823.2435	0.393958
23.68	823.1163	0.394125
23.69	823.4978	0.394292
23.7	823.5137	0.394458
23.71	823.2117	0.394625
23.72	822.6713	0.394792
23.73	823.005	0.394958
23.74	823.2911	0.395125
23.75	823.8157	0.395292
23.76	823.6091	0.395458
23.77	824.0859	0.395625
23.78	824.3084	0.395792
23.79	824.372	0.395958
23.8	824.1335	0.396125
23.81	824.213	0.396292
23.82	823.6249	0.396458
23.83	823.7998	0.396625
23.84	823.7362	0.396792
23.85	824.3561	0.396958
23.86	823.7521	0.397125
23.87	823.5931	0.397292
23.88	823.5772	0.397458
23.89	823.7362	0.397625
23.9	822.9415	0.397792
23.91	823.466	0.397958
23.92	823.8315	0.398125
23.93	824.3561	0.398292
23.94	824.0859	0.398458
23.95	824.372	0.398625
23.96	823.7203	0.398792
23.97	823.911	0.398958
23.98	823.7521	0.399125
23.99	823.5613	0.399292
24	823.466	0.399458
24.01	823.5772	0.399625
24.02	824.0699	0.399792
24.03	822.9891	0.399958
24.04	823.3706	0.400125
24.05	824.2766	0.400292
24.06	823.1163	0.400458
24.07	823.307	0.400625
24.08	823.4342	0.400792
24.09	823.4342	0.400958
24.1	823.7679	0.401125
24.11	824.0541	0.401292
24.12	823.1957	0.401458
24.13	822.9891	0.401625
24.14	823.7203	0.401792
24.15	823.3547	0.401958
24.16	823.5772	0.402125
24.17	823.1957	0.402292
24.18	823.5613	0.402458
24.19	823.7839	0.402625
24.2	823.8475	0.402792
24.21	824.1971	0.402958
24.22	824.1971	0.403125
24.23	823.5613	0.403292
24.24	823.7044	0.403458
24.25	824.0223	0.403625
24.26	824.213	0.403792
24.27	823.7044	0.403958
24.28	823.2117	0.404125
24.29	824.372	0.404292
24.3	824.7535	0.404458
24.31	823.8157	0.404625
24.32	823.3865	0.404792
24.33	823.2593	0.404958

Result data for Brass Pin (D=5mm) with Aluminium Plates (t=2mm) from tensile experiment.

Time	Force	Stroke
sec	N	mm
138.62	2939.494	2.309792
138.63	2939.494	2.309958
138.64	2939.494	2.310125
138.65	2939.494	2.310292
138.66	2939.494	2.310458
138.67	2939.51	2.310625
138.68	2939.542	2.310792
138.69	2939.542	2.310958
138.7	2939.542	2.311125
138.71	2939.542	2.311292
138.72	2939.542	2.311458
138.73	2939.542	2.311625
138.74	2939.542	2.311792
138.75	2939.542	2.311958
138.76	2939.542	2.312125
138.77	2939.542	2.312292
138.78	2939.542	2.312458
138.79	2939.542	2.312625
138.8	2939.542	2.312792
138.81	2939.542	2.312958
138.82	2939.542	2.313125
138.83	2939.542	2.313292
138.84	2939.542	2.313458
138.85	2939.542	2.313625
138.86	2939.542	2.313792
138.87	2939.542	2.313958
138.88	2939.542	2.314125
138.89	2939.542	2.314292
138.9	2939.542	2.314458
138.91	2939.542	2.314625
138.92	2939.542	2.314792
138.93	2939.542	2.314958
138.94	2939.542	2.315125
138.95	2939.542	2.315292
138.96	2939.542	2.315458
138.97	2939.542	2.315625
138.98	2939.542	2.315792
138.99	2939.574	2.315958
139	2939.574	2.316125
139.01	2939.574	2.316292
139.02	2939.574	2.316458
139.03	2939.574	2.316625
139.04	2939.574	2.316792
139.05	2939.574	2.316958
139.06	2939.574	2.317125
139.07	2939.574	2.317292
139.08	2939.574	2.317458
139.09	2939.574	2.317625
139.1	2939.574	2.317792
139.11	2939.574	2.317958
139.12	2939.542	2.318125
139.13	2939.542	2.318292
139.14	2939.542	2.318458
139.15	2939.542	2.318625
139.16	2939.542	2.318812
139.17	2939.542	2.318958
139.18	2939.558	2.319125
139.19	2939.574	2.319292
139.2	2939.574	2.319479
139.21	2939.574	2.319646
139.22	2939.542	2.319813
139.23	2939.542	2.319958
139.24	2939.542	2.320125
139.25	2939.542	2.320292
139.26	2939.542	2.320458
139.27	2939.542	2.320625
139.28	2939.542	2.320792
139.29	2939.542	2.320958
139.3	2939.542	2.321125
139.31	2939.542	2.321292
139.32	2939.542	2.321458
139.33	2939.542	2.321625
139.34	2939.542	2.321792

Result data for Brass Pin (D=5mm) with Aluminium Plates (t=3mm) from tensile experiment.

Time	Force	Stroke			
sec	N	mm	181.8	3898.827	3.029458
181.41	3898.462	3.022958	181.81	3898.843	3.029625
181.42	3898.478	3.023125	181.82	3898.843	3.029792
181.43	3898.509	3.023292	181.83	3898.843	3.029958
181.44	3898.509	3.023458	181.84	3898.843	3.030125
181.45	3898.525	3.023625	181.85	3898.843	3.030292
181.46	3898.541	3.023792	181.86	3898.843	3.030458
181.47	3898.541	3.023958	181.87	3898.843	3.030625
181.48	3898.589	3.024125	181.88	3898.843	3.030792
181.49	3898.589	3.024292	181.89	3898.843	3.030958
181.5	3898.589	3.024458	181.9	3898.843	3.031125
181.51	3898.621	3.024625	181.91	3898.843	3.031292
181.52	3898.621	3.024792	181.92	3898.843	3.031458
181.53	3898.621	3.024958	181.93	3898.843	3.031625
181.54	3898.621	3.025125	181.94	3898.843	3.031792
181.55	3898.652	3.025292	181.95	3898.843	3.031958
181.56	3898.652	3.025458	181.96	3898.843	3.032125
181.57	3898.652	3.025625	181.97	3898.843	3.032292
181.58	3898.684	3.025792	181.98	3898.843	3.032458
181.59	3898.7	3.025958	181.99	3898.843	3.032625
181.6	3898.7	3.026125	182	3898.843	3.032792
181.61	3898.7	3.026292	182.01	3898.843	3.032958
181.62	3898.7	3.026458	182.02	3898.843	3.033125
181.63	3898.7	3.026625	182.03	3898.843	3.033292
181.64	3898.732	3.026792	182.04	3898.843	3.033458
181.65	3898.732	3.026958	182.05	3898.843	3.033625
181.66	3898.732	3.027125	182.06	3898.843	3.033792
181.67	3898.732	3.027292	182.07	3898.811	3.033958
181.68	3898.78	3.027458	182.08	3898.811	3.034125
181.69	3898.78	3.027625	182.09	3898.811	3.034292
181.7	3898.78	3.027792	182.1	3898.811	3.034458
181.71	3898.78	3.027958	182.11	3898.811	3.034625
181.72	3898.78	3.028125	182.12	3898.811	3.034792
181.73	3898.78	3.028292	182.13	3898.811	3.034958
181.74	3898.78	3.028458	182.14	3898.811	3.035125
181.75	3898.795	3.028625	182.15	3898.78	3.035292
181.76	3898.811	3.028792	182.16	3898.78	3.035458
181.77	3898.811	3.028958	182.17	3898.78	3.035625
181.78	3898.811	3.029125	182.18	3898.78	3.035792
181.79	3898.811	3.029292	182.19	3898.78	3.035958
			182.2	3898.764	3.036125