FATIGUE ANALYSIS ON BONDING OF ALUMINIUM AND CARBON LAMINATE COMPOSITE

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DECLARATION

"I hereby declare this thesis is the results of my own research except as cited in the references"

Signature : .....

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APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quantity for the award of the degree of Bachelor of Mechanical Engineering (Structure & Materials).

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DEDICATION

To my beloved mother and father

ABSTRACT

Adhesive bonding at the structural component has become an alternative method in industries compared to other conventional methods and the adhesive used in this research was made up by the mixture of aluminium powder-epoxy adhesive. In this research, fatigue testing was conducted and analysed the fatigue life on bonding of aluminium and carbon laminate composite. Percentage of stress level influence the fatigue life of single lap joint between aluminium and carbon laminate composite. Experimental results showed that the higher percentage of stress level gives a small number of cycles to failure and the lower percentage of stress level gives a large number of cycles to failure. The fatigue life of single lap joint for 10% stress level is 1 229 323 cycles whereas the average life cycles for 80% stress level is 14 cycles. The type of bond failure can be identified as the specimens fail under the fatigue testing either it is an adhesion failure or cohesion failure.

ABSTRAK

Ikatan pelekat pada struktur komponen telah menjadi cara alternatif di dalam industri dibandingkan dengan cara konvensional yang lain dan pelekat yag digunakan di dalam penyelidikan adalah di buat daripada campuran serbuk aluminium-pelekat epoxy. Dalam penyelidikan ini, ujian kelesuan telah dilakukan dan jangka hidup kelesuan bagi ikatan aluminium dan karbon lamina komposit. Peratusan tahap tekanan mempengaruhi jangka hidup kelesuan antara gabungan tunggal aluminium dan karbon lamina komposit. Keputusan kajian menunjukkan bahawa kadar peratusan tahap tekanan yang tinggi akan menyebabkan jangka hidup kelesuan yang rendah dan kadar peratusan tahap tekanan yang rendah akan menyebabkan jangka hidup kelesuan yang tinggi. Jangka hidup kelesuan bagi gabungan tunggal untuk 10% tahap tekanan adalah 1 229 323 kitaran manakala purata jangka hidup kelesuan untuk 80% tahap tekanan adalah 14 kitaran. Jenis kegagalan ikatan dapat dikenal pasti setelah spesimen gagal pada ujian kelesuan sama ada kegagalan pelekat ataupun kegagalan kepaduan.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Fatigue is the most reason of failures in the mechanical structures and it is happen where the structure fail due to a cyclic load or repeated load applied on it. Fatigue failure is happen to all structure such as automobile, aircraft and turbine. As world of technologies getting advanced, the usage of metal are also increases with more failure of structures are recorded due to the repeated load. The high strength material with a higher performance was current demand for the manufacturer and users today to avoid the structural fatigue and increase the life time of the structures from failures.

An axial test machines is capable for tension and compression loading in both high cycle fatigue and low cycle fatigue ranges. This machine is closed-loop servohydraulically controlled and can be programmed with any desired fatigue spectrum. The present of frequency (f) in unit Hz influence the behaviour of fatigue with environmental effect such as temperature. Between 1852 and 1870, the German railway engineer August Wöhler's has conducted the first investigation on systematic fatigue. The data from Wöhler's are for Krupp axle steel were plotted in terms of nominal stress (S) versus number of cycles to failure (N), which has known as S-N diagram which is shown in Figure 1.1. (Anonymous, n.d)

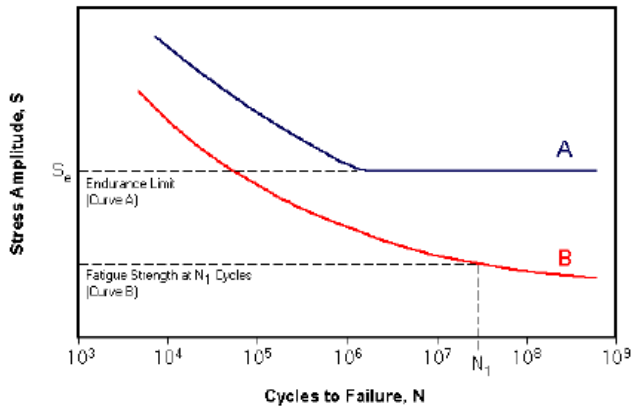

Figure 1.1: S-N Curves (Anonymous, n.d)

Aluminium is a metal and it is the third large element after oxygen and silicon. Aluminium is a silvery-white metal and has a very light density. The light weight of aluminium with high strength makes it as the most use in transportation industries. This material can be easily fabricated into different structure and shape. Besides, aluminium has high mechanical strength by alloying and heat treatments even though the tensile strength of pure aluminium is not high. Adhesive bonding of aluminium is successfully employed in many applications such as car bodies and aircraft components.

Carbon laminate composite are strong, high stiffness and lightweight materials. Composite material is a combination of materials which are made up of two or more materials to produce different structural properties. In this project, carbon laminate composite were chosen as the properties of the material are strong and light weight.

One of the matrix materials is epoxy. Epoxies will be used as the matrix materials in this studies, it is widely used in resins for structural adhesives. Epoxies have low levels of volatiles, good adhesion, low shrinkage and ease of processing. The curing of epoxies is quite slower which vary from room temperature to approximately 350ºF (180ºC). This type of adhesives can bond a wide variety of substrates with high strength such as attach aluminium skins to the struts of aircraft wings and tail sections (Anonymous, 2013). Plus, an aluminium powder is added on the neat epoxy adhesive to enhance the strength of the bonding.

Single lap joint is a joining of two materials with an overlapping bond. The joining of the materials can be done through the process of adhesive bonding which is the common type of bonding use nowadays especially in the aircraft industries or by the traditional

methods. Many types of materials can be joined together such as metal to metal, metal to composite, composite to composite and etc. There are also many types of joint such as double lap, double tapered strap lap and single strap lap.

1.2 Problem Statement

Nowadays, the usage of adhesive bonding in the industries such as automotive, aerospace, construction and marines are frequently been heard. Before the development of adhesives bonding, other traditional metal working methods have been used to attach the surface of structural, material and component of a substance. The examples are welding, bold and nut, fastener, rivets and brazing. Adhesives bonding on fatigue analysis have not been discovered deeply since before. In this study, I will do a research on adhesives bonding by fatigue analysis which the type of adhesives is epoxies with an addition of aluminium powder at the epoxy. The fatigue analysis will be determined by using S-N Curve, in terms of nominal stress (S) vs number of cycles to failure (N). The fatigue life is the number of cycles to failure at specified stress level and the fatigue strength is the stress below which failure does not occur. Only the fatigue life will be observed throughout this study.

1.3 Objectives

The objectives of this project are:

1) To conduct fatigue testing on bonding of aluminium and carbon laminate composite.
2) To determine fatigue life on bonding of aluminium and carbon laminate composite.

1.4 Scope of Project

The bonding of aluminium and carbon laminate composite will go through fatigue analysis under fatigue testing by using 25kN Universal Testing Machine (INSTRON-Model 8802). The scopes of this project are:

1) Literature review on fatigue, adhesive bonds, aluminium and carbon laminate properties.

2) The design of aluminium and carbon laminate composite is determine with suitable dimensions that can be fit at the testing machine.
3) Manufacturing of specimens which are aluminium by cutting the plate with require dimensions while carbon laminate by hand lay-up process.
4) Fatigue test is conduct by using 25kN Universal Testing Machine (INSTRON-Model 8802).

CHAPTER 2

LITERATURE REVIEW

As the technology of industries develop parallel with the transformation of revolution. The development gives an impact on automotive, aerospace, marine and construction industries to produce an advanced mechanisms or methods between the bonding of structure, material and component surface. In this study, adhesive bonding is the chosen method as the usage of the attachment by using adhesive bonding does not been fully discovered compare to traditional method. Fatigue test will be conducted to aluminium and carbon laminate composite in order to determine the fatigue life of bonding.

2.1 Material

2.1.1 Aluminium

Aluminium (Al) is a metal which are relatively soft, light and an abundant element of 8% on earth crust. The three main properties on which the application of aluminium are low density, high mechanical strength that can be achieved by alloying and heat treatments, and high corrosion resistance of the pure metal. Alloying constituents such as copper, magnesium, silicon, manganese, nickel and zinc were added to aluminium to increase the strength of pure aluminium. (Shakhashiri, 2008).

The 5000 series which is alloying between aluminium and magnesium (Al-Mg alloys) are used for structural and architectural applications. In this research, type of aluminium-5083 (Al-5083) was chosen. The aluminium-5083 is known for exceptional performance in extreme environments and highly resistant to seawater and industrial chemical environments (Ferrous, A, et.al, 2015). The applications of aluminium alloy 5083 are mostly used in vehicle bodies, shipbuilding and vehicle bodies. The chemical composition, physical properties and mechanical properties for aluminium alloy 5083 is shown in Table 2.1, Table 2.2 and Table 2.3 respectively.

Table 2.1: Chemical composition for aluminium alloy 5083 (Ferrous, A, et.al, 2015)

Element	% Present
Si	0.4
Fe	0.4
Cu	0.1
Mn	0.4-1.0
Mg	4.0-4.9
Zn	0.25
Ti	0.15
Cr	0.05-0.25
Al	Balance

Table 2.2: Physical properties of aluminium alloy 5083 (Ferrous, A, et.al, 2015)

Property	Value
Density	2650 kg/m^3
Melting Point	570°C
Modulus of Elasticity	72 GPa
Electrical Resistivity	0.058x10^{-6} Ω.m
Thermal Conductivity	121 W/m.K
Thermal Expansion	25x10^{-6} /K

Table 2.3: Mechanical properties for aluminium alloy 5083 (Ferrous, et.al, 2015)

BS EN 485-2:2008 Plate 6.3mm to 80mm Property	Value
Proof Stress	115 Min MPa
Tensile Strength	270 - 345 MPa
Hardness Brinell	75 HB

2.1.2 Composite

Composite materials are made up by combining of two or more materials which consists reinforcing elements, fillers and composite matrix binder. There are three types of geometry of reinforcements which are particle reinforced, fibre reinforced and structural. A particle reinforcement have dimensions that are equal in all directions with the orientation either random or with preferred orientation and fibrous reinforcement is characterized by its length. In single layer composites, there are long fibres and short fibres which called continuous fibre reinforced composites and discontinuous fibre composites respectively. Multilayered composites are another category of FRP, classified either as laminates or hybrids.

Laminate are composites in which layers of different materials are bonded together with adhesive, to give added strength and durability. The primary load of composite carrying material is fibre. The directions of fibre determine the strength and stiffness of the composite material. Unidirectional composites have predominant mechanical properties in one direction and are to be anisotropic, having mechanical or physical properties that vary with direction relative to natural reference axes inherent in the material (F.C, 2010).

Matrix is the constituent that is continuous and present on the greater quantity in the composite. The properties of matrix are improved by incorporating another constituent to produce a composite. Reinforcement is the second constituent in a composite system and it reinforces the mechanical properties of the matrix. Reinforcement is much harder, stronger and stiffer compare to matrix. The fibre orientation and fibre length affect the tensile strength of the composites.

The advantages of modern composite materials are light and strong. An appropriate combination of matrix and reinforcement material can forms a new requirement of a particular application. The flexibility of composite design can moulded them into complex shapes. An advanced composite material is made of a fibrous material embedded in a resin matrix, generally laminated with fibres oriented in alternating directions to give the material strength and stiffness (F.C, 2010). The advantages of composites are high strength and stiffness, low density, improved fatigue life, corrosion resistance and low cost. The applications of composite materials include transportation, sporting goods such as tennis racquets and marine goods.

The composite materials in this research are resin bisphenolic LP-1Q-EX and woven roving glass fibre reinforcement (200 g/m^2). The volume fraction of glass fibres is equal to 40% of the composite. The comparison between composites and metals are shown in Table 2.4.

Table 2.4: Composites versus metal comparison (F.C, 2010)

Condition	Comparative behavior relative to metals
Load-strain relationship	More linear strain to failure
Notch sensitivity	
Static	Greater sensitivity
Fatigue	Less sensitivity
Transverse properties	Weaker
Mechanical property variability	Higher
Fatigue strength	Higher
Sensitivity to hydrothermal environment	Greater
Sensitivity to corrosion	Much less
Damage growth mechanism	In-plane delamination instead of through thickness cracks

2.1.3 Design of Material

Single lap joints (SLJ) are widely used and a simple way to joined between two materials via an overlapping bond, refer to Figure 2.1 for the SLJ structural design. A single lap joint is an anti-symmetric structure of two materials which known as adherends, bonded via an overlap which is adhesives while double lap joints (DLJ) as shown in Figure 2.2 are lap joints with a step like interface (Lempke, M.P., 2013) An end tabs, cut from the same material as the adherend sections, were adhesively bonded to the specimen as shown in Figure 2.3 below. This type of tabs have been introduced to reduce the eccentricity of the load path that causes out of plane bending moments which resulting in high peel stresses and non-uniform shear stresses in the adhesive layer (Broughton, W.R., et.al, 1996)

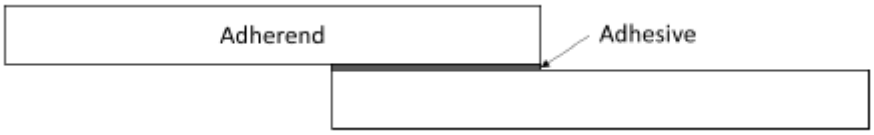

Figure 2.1: A single lap joint (Lempke, M.P., 2013)

Figure 2.2: A double lap joint (Lempke, M.P., 2013)

Figure 2.3: A single lap joint with an end tabs

Refer to Figure 2.3, when a single lap joint is loaded as shown in the direction of the arrows, the adhesive at the joint is subjected to primarily shear loads with an element of tensile loading.

2.2 Adhesive Bonding

Bonding is a joining of two or more surfaces whether metal to metal, non-metal to non-metal or metal to non-metal. There are various types of bonding and one of them is traditional method such as bold and nut, welding and fastener. Nowadays, industries tend to use an alternative method to mechanical joints in engineering applications as many advantages were provided.

An adhesive is a substance capable of holding materials together by surface attachment and have been use for thousand years. The first evidence of a substance being used as an adhesive dates back to 4000 B.C. Since before, there are various types of adhesives and their uses on daily life such as animal glues, fish glue, casein glue, starch, cellulose adhesive, rubber-based solvent cements, hot melt adhesives, RTV silicone adhesives, anaerobic adhesives and epoxies. The development of adhesive have change and improve the properties such as flexibility, toughness, temperature, curing and chemical resistance (Nicholson, C., et.al, 1991)

The joining of aluminium and carbon fibre called as joining dissimilar materials, and it is difficult than joining of same material. This type of joining processes is applicable by using adhesive bonding. The elements that need to be taken when designing a dissimilar material are joint design, material thickness, material combination and performance requirements.

2.2.1 Epoxy Adhesives

In this research, bonding by method of epoxy adhesives will be focus as it is widely used and the most diverse in term of variants available. Epoxies are made by polymerizing a mixture of two compound, resin and hardener. Epoxy resin is a combination with over 70 different curing agents from simple amines to complex anhydrides. Although there are variety of epoxies, the mechanisms of curing throughout all the variations is always the same. Epoxies can be functioning as adhesives, binding resins, coatings and an excellent of abrasion resistance and chemical resistance. The selection of an adhesive is important