CLOSED-FORM SOLUTIONS AND STRESS ANALYSIS OF STAINLESS STEEL/ALUMINUM HYBRID JOINT

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by

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LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
UTM	Universal testing machine
PE A	Orthophtalic polyester resins
PE B	Orthophtalic polyester resins
VE I	Vinylester resin
EPO	Epoxy system
ANSYS	engineering simulation software (computer-aided engineering)
FE	Finite element
FEM	Finite element method
FEA	Finite element analysis

LIST OF SYMBOLS

j	Material been used (aluminum/stainless steel)
$E^{(j)}$	Young modulus of the adherent j in MPa
G	Coulomb modulus of the adhesive in MPa
$u_i^{(j)}$	Longitudinal displacement in mm of the adherent j in the bay i
b	Transversal pitch in mm
d_i	Abscissa of the fastener i
	(d: edge distance in mm; s: longitudinal pitch in mm)
E	Thickness of the adhesive in mm
$e^{(j)}$	Thickness of the adherent j
L	Length of the lap mm
L_g	Length of the left bar not bonded in mm
L_d	Length of the right bar not bonded in mm
X_p	Length of the plastic region in mm
T_p	Plastic adhesive shear stress in MPa
N	Normal force in N
T	Adhesive shear stress in MPa

Peryelesaian Tertutup dan Analisis Tegasan untuk Gabungan Hibrid Keluli Tahan Karat/ Aluminium

ABSTRAK

Gabungan hibrid ialah gabungan antara ikatan perekat dan juga pengikat mekanikal yang mampu untuk menggabungkan kelebihan kedua-dua jenis gabungan. Hari ini, gabungan hybrid menarik untuk digunakan dalam aplikasi automotif kerana teknik ini boleh menawarkan banyak faedah semasa pembuatan. 3 mm plat nipis aluminium dan keluli tahan karat digunakan sebagai bahan merekat dan perekat yang digunakan adalah berprestasi tinggi iaitu perekat araldite. Penyelidikan ini mempertimbangkan keluli tahan karat/aluminum hybrid yang akan diuji dalam dua cara. Cara pertama mengunakan perisian ANSYS dimana ia telah digunakan untuk berdepan dengan tegangan analisis hibrid tidak serupa mengunakan kaedah elemen hingga. Hibrid tidak serupa telah direka dan mempunyai lima ketebalan yang berlainan iaitu 0.4 mm, 0.8 mm, 1.2 mm, 1.6 mm dan 2.0 mm. Kesan ketabalan setiap perekat dianalisis mengunakan ANSYS. Berbagai ketebalan perekat memberikan nilai yang berbeda untuk tegasan maksimum von Mises. Hal ini ditemukan bahawa hasil ketebalan yang lebih besar menyebabkan tegasan maksimum yang lebih tinggi. Selain itu, berbagai ketebalan perekat juga menghasilkan nilai yang berbeda ubah bentuk. Hal ini menunjukkan bahawa lebih ubah bentuk terjadi ketika ketebalan perekat meningkat. Analisis ini membuktikan bahwa peningkatan ketebalan perekat mengurangi kekuatan gabungan, terutama karana agihan tegasan meningkat pada permukaan perekat. Sebelum melanjutkan ke pendekatan kedua, perbandingan antara eksperimen dan ANSYS telah dilakukan. Tujuan perbandingan ini adalah untuk membuktikan bahwa analisis ANSYS mirip dengan eksperimen dan hasilnya dapat digunakan. Pendekatan kedua adalah untuk merumuskan persamaan baru menggunakan perisian MATLAB untuk analisis agihan tegasan ricih tegangan geser sepanjang garis ikatan di bawah pengaruh nisbah ketebalan bahan merekat dan nisbah modulus Young. Solusinya disusun berdasarkan analisis Paroissien Eric. Kekuatan dalam sendi dapat dicapai dengan nisbah yang sesuai ketebalan dan modulus Young dari bahan merekat. Hasil dari kedua cara ANSYS dan model analitik dibandingkan dan hasilnya adalah sama, yang bererti bahwa model analitik ini dapat digunakan setidaknya untuk konfigurasi yang dipertimbangkan dalam penelitian ini.

Closed-Form Solutions and Stress Analysis of Stainless Steel/Aluminum Hybrid

ABSTRACT

Hybrid joints are a combination of adhesive bonding and mechanical fastening that are able to combine the advantages of both joint types. Today, hybrid joining is attractive in automotive applications as the technique can offer various benefits during manufacturing. A 3 mm thin plate of Aluminium A7075 and stainless steel 304 were used as the adherend material for experimental test and the adhesive used was high performance Araldite Epoxy adhesive. This research examines stainless steel/aluminium hybrid joints to be tested in two ways. First is by using ANSYS software application where it was employed to deal with stress analysis of the adhesive bonding of hybrid dissimilar joints using the finite element method. Hybrid dissimilar joint specimens were fabricated having five bond thicknesses; *t* (i.e., 0.4 mm, 0.8 mm, 1.2 mm, 1.6 mm and 2.0 mm). The effect of bond thickness was investigated by using the commercial finite element package in ANSYS. Various thicknesses of adhesive give different values of maximum von Mises stress. It is found that greater thickness results in higher maximum stress. Moreover, various thicknesses of adhesive also result in different values of deformation. This shows that more deformation occurs when the thickness of adhesive is increased. This analysis proves that increasing adhesive thickness reduces the joint strength, mainly because stress distribution is increased on adhesive surfaces. Before proceed to second approach, comparison between experiment and ANSYS was done. The purpose for this comparison is to prove that ANSYS analysis is similar with experiment and the result can be use. The second approach is to formulate a new equation using MATLAB tools for analysis of shear stress distribution along the bond line under effect of adherend thickness ratio and adherend Young's modulus ratio. The solution is formulated based on the analysis of Paroissien Eric. The least stress intensities in the joint could be achieved with a suitable ratio of thickness and Young's modulus of adherends. Result from both method ANSYS and analytical model were compared and the results were in agreement, which means that the analytical model can be used at least for the configuration considered in this study.

CHAPTER 1

INTRODUCTION

1.1 Project Background

The joining of stainless steel/aluminum is normally accomplished by adhesive bonding, mechanical fastening or a mix of both methods. The blend of adhesive bonding and mechanical fastening is often employed as a safe guard against defects within the adhesive layer that may prompt untimely or calamitous disappointment. Forecast of the joint fatigue life and the susceptibility of the adhesive/interface to environmental attack are additional uncertainties that have resulted in hybrid joint designs applied in practice. Hybrid joining is the combination of two or more joining techniques to produce joints with improved properties additional to those obtained from a single technique. The most common types of hybrid joint are used for joining sheet materials and involve an adhesive in conjunction with a point joint such as a fastener (rivet or threaded device), a clinched joint or a resistance spot weld. The hybrid joining technique is attractive in automotive applications because it offers benefits during part manufacturing. Other examples of hybrid joints include a combination of two different fusion processes (e.g. MIG/MAG augmented laser welding) or a combination of two different types of adhesive (e.g. tape combined with paste).The bolts can be utilized as a way to adjust and attach different structural parts to each other, and give fixation during adhesive cure. Furthermore, hybrid joints can offer improved performance in correlation to adhesive bonded joints during crash loading where part detachment is frequently undesirable. Moreover, hybrid joints can offer improved performance in examination to adhesive bonded joints during crash loading where part separation is offen undesirable. It was recently shown (Kelly, 2006) that hybrid composite single-lap joints can be outlined where the bolt transfers a significant part of the load. The joint geometry and adhesive mechanical properties were observed to be significant parameters governing the load transfer distribution in the joint.

Adhesive bonding was commercially applied in industry due to some advantages such as, high corrosion resistance, high fatigue resistance, crack retardance and good damping. In adhesive bonding, adhesive serves as a medium for a load to transmit from one adherent to another(Kinloch, 1987; Lucic, Stoic, & Kopac, 2006). When transmitting a load, the adhesive layer starts deforming due to shear and tensile stress. However, adhesive bonding can utilize stress more uniformly than other bonding such as welding and dissemination bonding. Stress concentration within the adhesive layer can be modified by changing geometry properties such as overlap length, adherent's thickness and Young's modulus. Therefore, accurate analysis of adhesive bonding is becoming more crucial than ever, since the ability of an adhesive joint to spread a load over a large loading area leads to less stress concentration. There are various types of joints such as butt, lap and strap joints. Designers need to consider many different factors when choosing a suitable type of joint for application.

Single lap joints are the most widely used adhesive joints because they are practical, simple and give good stress distribution over the bonded area. When applying loads to the end of the adherents, the adherents are pulled in the eccentricity of the load path, which produces a bending moment, causing the joint to rotate. Consequently, the adhesive layer will deform due to shear and peel stress.

Besides, five types of stress can be found in adhesive joints such as shear, peel, compression, tension and cleavage stress. Any combination of these stresses maybe encountered in adhesive bonding applications. In Fig. 1.1, τ_p represents the shear stresses that are caused by moving parts, whereas τ_d represents the shear stresses that are caused by the deformation of the adhesive layer. Both shear stresses are parallel to the bonded area. The stresses perpendicular to the bonded area are tensile stresses caused by bending moments (Lucic et al., 2006). Among these stresses, tensile stresses are the most significant in the deforming adhesive layer and adherent. If the yield strength of an adhesive is greater than the adherent, adherents will fail due to tensile stress.

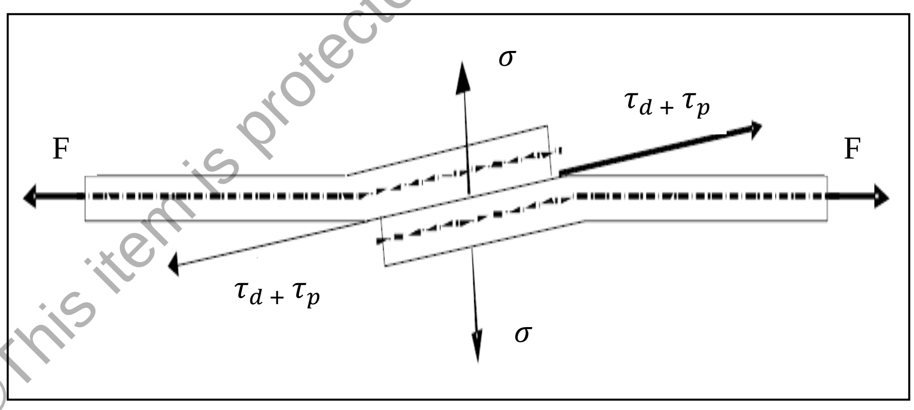

Figure 1.1: Stresses in single lap joint (Lucic et al., 2006).

1.2 Problem Statements

(a) Many researchers so far only consider using adhesively bonded similar joint to study effect of different adhesives thickness on joint strength and literature for dissimilar material is limited. The study of hybrid dissimilar material is vital as well. Besides, bonding similar and dissimilar adherents can bring different effect to the strength of joint.

(b) Most automotive industry used adhesive bonding and fastener to assembly part. However the comparison between FEA modeling and experiment results of adhesive, fastener and hybrid joint strength is still lacking.

(c) Previous researchers using two fasteners and same adherent to form analytical model for hybrid joint.

(d) There is no analytical model for load transfer within hybrid joint has been developed. Based on studies, no one has compared hybrid joint performance using FEA and analytical model.

1.3 Objectives

The main objectives of this research are listed as follows:

(a) To investigate the effects of different adhesive thicknesses on joint strength of stainless steel/aluminum hybrid joint.

(b) To compare the joint strength obtained from finite element analysis (FEA) and experiment for adhesive, huck bolt and hybrid joint.

(c) To form an analytical model and investigate adhesive load transfer displacement under the effect of different rigidities of the Huck bolt for stainless steel/aluminum hybrid joint.

(d) To validate load displacement curve between the FEA and the analytical model.

1.4 Scopes

The scope has been defined based on the following points:

(a) Baseline drawing for stainless steel/aluminum hybrid joint with geometry, dimension and material.

(b) Conduct static analysis in FEA to simulate different thicknesses of adhesive

(c) Conduct static analysis in FEA to simulate linearized equivalent stress in three different paths.

(d) Conduct static analysis in FEA and testing experiment in three different joint (bonded joint, bolted joint and hybrid joint)

(e) The tensile load and size of the specimen are governed by the mounting on the Universal testing machine (UTM) (Shimadzu Autograph AG-IS, 2002)

(f) Employ the MATLAB tool to formulate an analytical model for stainless steel/aluminum hybrid joint to investigate adhesive load transfer displacement under the effect of different rigidities of the Huck bolt.

1.5 Significance of Study

The main contribution of this study is to provide additional research such as effects of different adhesive thicknesses on strength of stainless steel/aluminum hybrid joint, difference in strength between an finite element analysis (FEA) and an experiment for adhesive, huck bolt and hybrid joint and to form an analytical model and investigate adhesive load transfer displacement under the effect of different rigidities of the Huck bolt for stainless steel/aluminum hybrid joint. This research is expected to obtain the highest stress concentration which is highest adhesives thickness and the result for analytical model for stainless steel/aluminum hybrid joint. Since stainless steel/aluminum hybrid joint will be more efficient with the application of adhesives, it can be used as the improvement structure for the application in industry, military, automotive or manufacturing. Thus, the main objective are to study about effect adhesive using different material and to form analytical model with different material.

Besides that, the effects of using different thickness for adhesive can be observed in this study. Furthermore, the study on using various kind of different method such as by using FE software ANSYS, MATLAB and comparison with real experiment, will help to provide a design guideline for the engineers, researchers and designers to create the most efficient stainless steel/aluminum hybrid joint. In addition, the results of using different rigidity of Huck bolt also presented in this study.