UNIVERSITI PUTRA MALAYSIA

PEEL STRENGTH AND OTHER RELATED MECHANICAL PROPERTIES OF COMPOSITE SANDWICH STRUCTURES

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By

ZAHURIN BINTI HALIM

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Doctor of Philosophy

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To My Husband,Parents, Family and Friends

Thank you for being my inspiration and motivator….

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chairman: Professor ShahNor Bin Basri, Ph.D, PEng

Faculty: Engineering

An experimental and numerical investigation of the peel strength and other mechanical properties of composite sandwich structures were conducted. The composite sandwich structure consists of carbon fibre and aramid fibre as facings with either a honeycomb or foam core.

The peel strength of both types of composite sandwich structure for use at the flap and aileron was studied. The peel tests showed that the composite sandwich structure with a honeycomb core is stronger than the composite sandwich structure with a foam core. The modes of failures or possible path of crack propagation were also studied. The most critical modes of failure were the adhesion failure to the facing and the adhesion failure to the core.

A peel modelling was developed using interface elements and the effect of various modes of failures on the strain energy release rate was evaluated by finite element analysis using LUSAS, a commercial finite element code. A numerical scheme called

virtual crack closure scheme was used to calculate the strain energy release rate at the peel front in a peel test specimen.

To complement the results on the peel strength, investigations on other related mechanical properties were conducted and comparisons were made with previous works in the reference. The important parameters studied were bending, shear and compression as all of them has a static condition. The results show that experimental, numerical and validations with parametric studies agree well. The tensile test was also conducted experimentally to obtain modulus of elasticity that was required in the computational calculations.

Abstrak tesis dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

KEKUATAN LEKANG DAN SIFAT-SIFAT MEKANIKAL YANG BERKAITAN UNTUK STRUKTUR KOMPOSIT TERAPIT

Oleh

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Pengerusi: **Profesor ShahNor Bin Basri, Ph.D, PEng**

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Kajian eksperimen dan berangka telah dijalankan ke atas kekuatan lekang struktur komposit terapit. Struktur komposit terapit tersebut terdiri daripada gentian karbon dan gentian aramid sebagai permukaan atas dan samada busa atau indung madu sebagai teras. Dua bahagian yang paling dipengaruhi oleh kesan lekang di dalam sesebuah kapalterbang adalah aileron dan kepak dan kajian terperinci ke atas kedua-dua bahagian dijalankan.

Ujian lekang telah menunjukkan bahawa struktur komposit terapit dengan teras indung madu adalah lebih kuat daripada struktur komposit terapit dengan teras busa. Mod kegagalan atau laluan yang mungkin bagi perambatan retak juga telah diselidiki. Mod kegagalan yang paling kritikal adalah kegagalan rekatan pada permukaan atas serta kegagalan rekatan pada teras.

Model baru untuk proses lekang dengan menggunakan elemen antaramuka telah di bangunkan dan kesan pelbagai mod kegagalan ke atas kadar pelepasan tenaga terikan telah dinilai dengan menggunakan kaedah analisis unsur terhingga dengan

menggunakan kod komersil analisis unsur LUSAS. Skim berangka yang dipanggil skim penutupan retak maya digunakan untuk mengira kadar pelepasan tenaga terikan pada permukaan hadapan lekang dalam spesimen ujian lekang.

Kajian ke atas sifat-sifat mekanikal yang lain dijalankan untuk mensahihkan model lekang dan perbandingan dibuat dengan kajian-kajian terdahulu dalam rujukan. Parameter penting yang dikaji adalah lenturan, ricihan dan mampatan. Daripada keputusan yang diperolehi, ianya menunjukkan bahawa kajian eksperimen, kajian berangka dan kajian sifat-sifat mekanikal untuk pengsahihan adalah sepakat. Ujian tegangan juga dijalankan secara eksperimen untuk memperolehi modulus elastik yang diperlukan dalam pengiraan berangka.

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LIST OF ABBREVIATIONS

A_f	net cross-sectional area of fibre
A_i	cross-sectional area of lamina i
A_m	net cross-sectional area of matrix
D	flexural rigidity
E	modulus of elasticity
E_{11}	longitudinal elastic modulus of composite facings
E_c	modulus of elasticity of the core
E_f	modulus of elasticity of the facings
E_{fi}	fibre Young's Modulus
E_i	modulus of elasticity of lamina I
E_m	matrix Young's Modulus
E_x	modulus of elasticity of lamina at distance x from neutral axis
$F(\sigma)$	yield surface
$F_1(\sigma)$	limited tension criterion
$F_2(\sigma)$	Mohr-Coulomb criterion
F_o	load required to overcome resisting load
F_p	average load required to bend and peel adherend
G	strain energy release rate
G_c	shear modulus of core
I	second moment of area
I_i	second moment of area of lamina I about neutral axis

L	beam length
M	bending moment
N	shear stiffness of core
N_i, ξ, η	element shape function
P	peel strength
$\underline{P}$	vector of internal forces
$\underline{P}_b$	vectors of the bottom displacements
P_{cr}	critical buckling load
P_{ec}	edge compressive load
P_p	point load
$\underline{P}_t$	vectors of the top displacements
P_t	tensile force
Q	shear force
S	first moment of area
U	strain energy in the facing at the strain ε_{11}
U, V	the nodal degrees of freedom
W	work
W_k	mid-ordinate integration weights
$\underline{\underline{B}}$	strain displacement
$\underline{\underline{B'}}$	local strain global displacement
$\underline{\underline{D}}$	stiffness matrix
$\underline{\underline{D'}}$	matrix of elastic properties

$\underline{\underline{H}}$	shape function matrix
$\underline{\underline{J}}$	Jacobian matrix
$\underline{\underline{K}}$	element stiffness matrix
$\underline{R}$	load vector
$\bar{x}$	neutral axis location
1/R	curvature
$\underline{a}$	global displacement
a	spacing between points of honeycomb core support for the facings
b	width of beam
c	thickness of the core
c_s	cohesive strength
d	distance between the centre lines of the upper and lower facings
f	thickness of the facing
h	overall depth of the beam
h_k	thickness of the k^{th} layer
k_b, k_s	constants dependent on the beam loading
k_d	theoretical or experimental dimpling coeffecient
k_w	theoretical or empirical buckling coefficient
r_i	radius of drum
r_o	radius of flange
t	the total thickness of the shell
$\underline{u}$	displacement field
$\underline{u}_b$	bottom displacement

$\underline{u}_t$	top displacement
v_f	fibre volume fraction
v_m	matrix volume fraction
w	width of the facing
z	depth below the centroid of the cross-section
α	peel angle
δ	deflection
ε_{11}	tensile strain in fibre direction in the facing
ε_c	longitudinal strain in composite
ε_m	longitudinal strain in matrix
$\underline{\varepsilon}, \underline{\sigma}$	total strains and stresses
$\underline{\varepsilon}', \underline{\sigma}'$	local strain and stress vector
$\underline{\varepsilon}_o, \underline{\sigma}_o$	initial strains and stresses
ϕ	friction angle
λ	an angle of orthotrophy
ν	Poisson's ratio
ν_c	Poisson ratio of core
ν_f	Poisson ratio of faces
σ_{11}	tensile stress in fibre direction in the facing
σ_{co}	average tensile stress in the composite
σ_{fi}	fibre stress
σ_m	matrix stress
σ	bending stress

σ'_c	compressive stress in core
σ'_f	compressive stress in faces
σ_c	bending stress in core, at extreme fibre
σ_f	bending stress in faces
σ_n	compressive stress in core
σ_t	threshold strength
σ_w	wrinkling of compressive force
τ	shear stress
τ_c	shear stress of the core
ξ, η, ζ	parent coordinates in a mapped element
ξ_k	within the k_{th} layer of an element
$\underline{\Psi}$	residual force vector

CHAPTER 1

INTRODUCTION

1.1 Background

Structural materials can be divided into four basic categories: metals, polymers, ceramics and composites. Composites, which consist of two or more separate materials combined in a macroscopic structural unit, are made from various combinations of the three materials. For over 60 years, composite materials have proven to be very successfully utilized in structural applications. They are used in stiffness-critical aerospace structures, offshore structures, marine, automotive industries and also in medical, sports and electrical applications.

Composite materials can be divided into two main groups i.e. particle composites and fibre-reinforced composites. The detailed types of composite construction are shown in Figure 1.1[1]. In this present work only composite sandwich structures will be discussed thoroughly. The American Society for Testing and Materials (ASTM) defines for a composite sandwich structure as a construction which consists of high strength composite facing sheets bonded to a lightweight foam or honeycomb core as shown in Figure 1.2[2].