Cairo University

EXPERIMENTAL AND NUMERICAL STUDY ON THE FRACTURE OF HYBRID COMPOSITE MATERIALS

BY

BASSEM SAMEER MOSTAFA ABDEL RAHMAN

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
Mechanical Design and Production Engineering

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Title of Thesis:

Experimental and Numerical Study on the Fracture of Hybrid Composite Materials

Key Words:

Tensile; Bending; Double Cantilever Beam; Glass Fiber Reinforced Polymer.

Summary:

Fiber Metal Laminates (FMLs) are hybrid composite materials that consist of metallic layers bonded together with composite fibers. The current research investigates the behavior of a woven glass fiber reinforced polyester aluminium based (Glare) fiber metal laminate subjected to three types of loadings. The tests are: tensile test, bending test, and double cantilever beam test (DCB). The results of the three tests were compared with monolithic woven glass fiber reinforced polyester (GFRP) laminate subjected to the same types of loads. The effect of the replacement of cross-ply (0/90°) glass fiber reinforced epoxy laminas with woven glass fiber reinforced polyester laminas in GLARE was also investigated.

Disclaimer

I hereby declare that this thesis is my own original work and that no part of it has been submitted for a degree qualification at any other university or institute.

I further declare that I have appropriately acknowledged all sources used and have cited them in the references section.

Name: Bassem Sameer Mostafa Abdel Rahman Date: / / 2020

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Dedication

This thesis is dedicated with love and affection to my parents.

Acknowledgments

I thank all who in one way or another contributed in the completion of this thesis. First, I give thanks to God for protection and ability to do work.

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May the Almighty God richly bless all of you.

Table of Contents

Nomenclature and List of Abbreviations

Nomenclature

a	Initial Crack Length
B	Specimen Width
E	Elastic Modulus
G	Modulus of Rigidity
P	Applied Load
V_f	Fiber Volume
V_m	Matrix Volume
V_c	Composite Volume
v_f	Fiber Volume Fraction
v_m	Matrix Volume Fraction
v_v	Void Volume Fraction
W_f	Fiber Weight
W_m	Matrix Weight
W_c	Composite Weight
w_f	Fiber Weight Fraction
w_m	Matrix Weight Fraction
X^t	Tensile strength in fiber direction
X^C	Compressive strength in fiber direction
Y^t	Tensile strength in matrix direction
Y^t	Compressive strength in matrix direction
S^L	Longitudinal shear strength
S^T	Transverse shear strength
ρ_{ct}	Composite Density
ρ_m	Matrix Density
ρ_f	Fiber Density
υ	Poisson Ratio
γ	Shear Strain
κ	Curvature
ε	Strain
σ	Stress
δ	Deflection
F_f^t	Fiber Failure in Axial Direction
F_m^t	Matrix Failure in Axial Direction
F_f^c	Fiber Failure in Transverse Direction
F_m^c	Matrix Failure in Transverse Direction

Abbreviation

CLT	Classical Laminate Theory
CP	Composite
DCB	Double Cantilever Beam
FML	Fiber Metal Laminate
ILSS	Interlaminar Shear Strength
SERR	Strain Energy Release Rate
UD	Unidirectional
WF	Woven Fiber

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Abstract

Fiber Metal Laminates (FMLs) are special kind of composite structures that are composed of metallic sheets bonded together with composite plies. In the present study, the tensile, bending, and fracture toughness of FMLs are investigated. FMLs in this study consist of aluminium layers having thickness of 0.4 mm each, and woven polyester reinforced fiber glass plies of thickness 0.45 mm each commercially named as Glare. The laminate stacking was set as the [3/2] stacking sequence, in the form of [Al/G/G/Al/G/G/Al], to compose a laminate of seven plies having a total thickness of 3 mm. In order to get deeper understanding of the laminate damage sequence due to different loading conditions, a computationally efficient and reliable finite element model was developed using the commercial software ABAQUS®. Dynamic/Explicit solver was used for the simulation of the three types of tests to capture the damage initiation and evolution process accurately. The ductile damage was used to capture the aluminium layers failure, while the Hashin failure criterion was used to model the failure of composite layers exhibited in the laminate, and the cohesive surface interaction technique to capture delamination between layers. The results obtained from experiments and predicted by Finite Element Analysis (FEA) were then compared and found to be in good agreement. The tensile strength was about 321 MPa at a strain of 2.85% of the gauge length. The interlaminar shear strength (ILSS), flexural strength and corresponding strain were obtained from bending test. The interlaminar shear strength was about 10.4 MPa, and flexural strength had a value of 554 MPa at a strain of 2%. The strain energy release rate was the aimed output from the Double Cantilever Beam (DCB) test, two different initial crack lengths (a) having values of 24 mm and 29 mm respectively were investigated experimentally and numerically. While an initial crack of 40 mm was investigated numerically. The effect of the initial crack length on the Mode-I fracture energy was found to be directly proportional, while the existence of the metal constituent in the laminate led to an increase in the fracture energy due to the effect of the metal plasticity. The Mode I fracture energy was found to be 3 kJ/m^2. The captured damaged simulated models from ABAQUS® were extracted and compared to the final damaged models obtained experimentally and were in good agreement.

The effect of the replacement of cross-ply ($0/90^{\circ}$) glass fiber reinforced epoxy laminas with woven glass fiber reinforced polyester laminas in GLARE laminates on the tensile, bending and interlaminar fracture toughness of the laminate was investigated. Tests results showed that the existence of woven glass fiber laminas increased the tensile strength with decrease in corresponding strain, the flexure strength decreased significantly due to the existence of polyester instead of epoxy resin, and the Mode I interlaminar fracture toughness increased.

In order to visualize Glare strength with respect to their relevant pure composite structures, a detailed finite element model was developed for a composite laminate available in the literature. The investigated composite laminate consists of 26 plies of woven polyester reinforced fiber glass. The tensile strength was about 303 MPa at a strain of 1.73% of the gauge length, while ILSS was about 5.85 MPa, and the flexural strength had a value of 445 MPa at a strain of 1.585% of the gauge length, and the Mode I fracture energy was found to be 1.63 kJ/m^2.