DETERMINATION OF THE INFLUENCE OF INTERFACE DELAMINATION ON THE ELASTIC PROPERTIES OF FIBER REINFORCED COMPOSITE MATERIALS

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ABSTRACT

The aim of this study was to investigate the influence of interface delamination on the elastic properties of fiber reinforced composite materials. Transverse Young’s modulus in the presence of different levels of localized and homogeneously distributed interface damage in two structures with 0.3 and 0.6 fiber volume fractions were simulated in a commercial finite element code. To achieve this, a new approach to simulate interface damage was addressed by selective merging of fiber and matrix nodes at the fiber-matrix interface. It was found that elastic properties were decreased by increasing interface delamination for both 0.3 and 0.6 fiber volume fractions. In addition, the 0.6 fiber volume fraction model showed higher elastic properties, but lower when the interface damage was increased to more than 45% due to the higher fraction of damaged fiber. Furthermore, localized damage results in slightly higher stiffness values than homogeneously distributed damage

ABSTRAK

Tujuan kajian ini ialah untuk menyiasat pengaruh pelekangan antara muka pada sifat kekenyalan bahan-bahan komposit yang diteguhkan serat. Modulus Young melintang di pelbagai tahap kehadiran setempat dan keseragaman taburan kerosakan antara muka di dua struktur iaitu 0.3 dan 0.6 pecahan serat isipadu disimulasikan dalam satu elemen komersial kod yang terhad. Untuk mencapai ini, satu pendekatan baru untuk mensimulasikan kerosakan antara muka dikemukakan dengan kaedah percantuman terpilih nodus serat dan matriks di antara muka matriks serat .Di dapati bahawa sifat-sifat kenyal telah turun apabila antara muka bertambah pelekangan untuk kedua-dua 0.3 dan 0.6 pecahan isipadu serat. Dalam pada itu, model pecahan isipadu serat 0.6 menunjukkan sifat-sifat kenyal adalah lebih tinggi, tetapi lebih rendah apabila kerosakan antara muka telah dinaikkan kepada lebih 45% yang disebabkan pecahan serat rosak adalah lebih tinggi . Tambahan pula, kerosakan setempat mengakibatkan nilai ketegaran adalah lebih tinggi sedikit daripada mengedarkan kerosakan seragam.

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LIST OF ABBREVIATIONS

FE	-	Finite element
CFRP	-	Carbon fiber reinforcement polymer
FEM	-	Finite element methods
CTE	-	Coefficient of thermal expansion
OMC	-	Organic-matrix composites
MMC	-	Metal-matrix composites
CMC	-	Ceramic-matrix composites
PMC	-	Polymer-matrix composites
UDC	-	Unidirectional fiber-reinforced composite
CZM	-	Cohesive zone model
DOF	-	Degree of freedom
DCB	-	Double cantilever beam (specimen)
ELS	-	End-loaded split
FRMM	-	Fixed-ratio mixed mode
ENF	-	End notched flexure (specimen)
SLB	-	Single leg bending (specimen)
VCCT	-	Virtual crack closure technique

RVE	-	Representative volume element
MMB	-	Mixed mode bending (specimen)
FRM	-	Fiber reinforced matrix
PDM	-	Progressive damage modeling

LIST OF SYMBOLS

E - Young’s modulus

ν - Poisson’s ratio

ε - Strain in materials

F_r - Reaction force in the deformed plane

A - The area of deformed plane

σ - Stress

f - Fiber volume fraction

A_D - Total damaged area

D - Damage criteria

E_{ct} - Transverse Young’s modulus

CHAPTER 1

INTRODUCTION

1.1 Project Background

Composite materials are multiphase materials obtained through the artificial combination of different materials in order to attain properties that the individual components by themselves cannot attain. They are not multiphase materials in which the different phases are formed naturally by reactions, phase transformations, or other phenomena. An example is carbon fiber reinforced polymer. Composite materials can be tailored for various properties by appropriately choosing their components, their proportions, their distributions, their morphologies, their degrees of crystallinity, their crystallographic textures, as well as the structure and composition of the interface between components. (Campbell, 2010)

The physical behavior of composite materials is quite different from that of most common engineering materials that are homogeneous and isotropic. For instance, metals generally have similar composition regardless of where or in what orientation a sample is taken. In contrast, the makeup and physical properties of composites vary with location and orientation of the principal axes (R. M. Jones, 1999). An example of a composite material is a lightweight structural composite that is obtained by embedding continuous carbon fibers in one or more orientations in a polymer matrix. The fibers provide the strength and stiffness, while the polymer serves as the binder.

Composite materials are finding applications in a growing variety of primary and secondary structural roles in the aircraft, aerospace, and automotive industries due to their advantageous low density (lower than aluminum), high strength (as strong as high-strength steels), high stiffness (stiffer than titanium, yet much lower in density), good fatigue resistance, good creep resistance, low friction coefficient and good wear resistance, toughness and damage tolerance (as enabled by using appropriate fiber orientations), and chemical resistance (chemical resistance controlled by the polymer matrix). However, composite laminates are particularly susceptible to impact damage and dramatic strength reductions can occur even in the presence of barely visible impact damage (Abrate, 1991; R. Jones, Paul, Tay, and Williams, 1988; Richardson and Wisheart, 1996). In particular, the damage caused by high-velocity impact is not a big problem, in terms of detection, because it can easily be observed by visual inspection and then promptly repaired. However, the same is not true for the low-velocity impacts. In this case, small amounts of energy can be absorbed through localized damage mechanisms without extensive plastic deformation. (Jeon, Lee, Kim, and Huh, 1999)

The impact loading can cause extensive delaminations and matrix cracking within the laminates that may not be visible on the surface. For example, impact damage is considered the primary cause of in-service delamination in composites giving reductions in the compressive residual strength up to 60% (Adams and Cawly, 1989). As the result, transverse impact resistance is particularly low due to the lack of through-thickness, reinforcement with interlaminar stresses - shear and tension - often the stresses which cause first failure due to the correspondingly low interlaminar strengths. Delamination is therefore a very important mode of impact damage. (Garg, 1988)

Interlaminar stress in composite structures usually results from the mismatch of engineering properties between plies. These stresses are the underlying cause of delamination initiation and propagation. Hence, delamination is defined as the cracking of the matrix between plies. The aforementioned stresses are out-of-plane and occur at structural discontinuities. In cases where the primary loading is in-plane, stress gradients can produce an out-of-plane load scenario because the local structure may be discontinuous. (Reinhart and Clements, 2001)

During the production of composite materials sub-critical damage may occur due to handling issues, dropped tools etc. This damage can go undetected, and when the structure undergoes the normal loading conditions it is subjected to in the field, the sub-critical damage may develop into interlaminar delamination which will eventually result in catastrophic failure of the structure (Culliton, 2009). Finite element (FE) based analysis is often used to assess whether a given flaw, or delamination, or element debonding, will grow. (Ankersen and Davies, 2009)

1.2 Problem Statement

Although carbon fiber reinforcement polymer (CFRP) composites are used in high performance industries due to their superior mechanical properties, interface delamination occurs at the fiber/matrix interface limits their applications and can result in catastrophic failure. In this study, the effect of interface delamination on the elastic properties of carbon fiber reinforcement epoxy is determined by employing FE methods.

1.3 Objective of the Research

There are three objectives of the study:

- Accurate modeling of fiber and matrix.
- Subjecting validated models to different sizes of interface delamination.

- Determination of elastic modulus in the presence of different sizes of interface delamination.

1.4 Scope of Study

The scopes of the study are as the following:

- Generate models with different interface delamination sizes.
- FEM analysis of 3D models carries out to explore elastic properties of CFRP composites.
- Fiber of carbon and matrix of epoxy apply as representative materials.
- MSC.Marc commercial code and Microsoft Excel 2010 is used.

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