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Tensile fracture characterization of adhesive joints by standard and optical techniques

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ABSTRACT

The use of adhesive joints has increased in recent decades due to its competitive features compared with traditional methods. This work aims to estimate the tensile critical strain energy release rate (G_{IC}) of adhesive joints by the Double-Cantilever Beam (DCB) test. The *J*-integral is used since it enables obtaining the tensile Cohesive Zone Model (CZM) law. An optical measuring method was developed for assessing the crack tip opening (δ_n) and adherends rotation (θ_o). The proposed CZM laws were best approximated by a triangular shape for the brittle adhesive and a trapezoidal shape for the two ductile adhesives.

1. Introduction

The developments in adhesives technology made possible the use of adhesive bonding in many fields of engineering, such as automotive and aeronautical, because of higher peel and shear strengths, and ductility. As a result, bonded joints are replacing fastening or riveting [1]. More uniform stress fields, capability of fluid sealing, high fatigue resistance and the possibility to join different materials are other advantages of this technology. However, stress concentrations exist in bonded joints along the bond length owing to the gradual transfer of load between adherends and also the adherends rotation in the presence of asymmetric loads [2]. A large amount of works addresses the critical factors affecting the integrity of adhesive joints, such as the parent structure thickness, adhesive thickness, bonding length and geometric modifications that reduce stress concentrations [3–5].

A large number of predictive techniques for bonded joints is currently available, ranging from analytical to numerical, using different criteria to infer the onset of material degradation, damage or even complete failure. Initially, stresses were estimated by analytical expressions as those of Volkersen [6], which had a lot of embedded simplifying assumptions, and the current stresses were compared with the allowable material strengths. Many improvements were then introduced, but these analyses usually suffered from the non-consideration of the material ductility. Fracture mechanics-based methods took the fracture toughness of materials as the leading parameter. These methods included more simple energetic or stress-intensity factor techniques that required the existence of an initial flaw in the materials [7,8]. More recent numerical techniques, such as CZM, combine stress criteria to account for damage initiation with energetic, e.g. fracture toughness, data to

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Nomenclature

$\vec{v}_{bottom}$	direction vector of the bottom curve
$\vec{v}_{top}$	direction vector of the top curve
a	crack length
a_0	initial crack length
a_{eq}	equivalent crack length
arccos	inverse cosine function
B	width
C	compliance
C_0, C_1, C_2, C_3	polynomial constants
C_i	experimentally measured initial compliance
d	calibration length for the optical method
E	Young's modulus
E_f	corrected flexural modulus
G	shear modulus
G_C	critical strain energy release rate
G_I	tensile strain energy release rate
G_{IC}	tensile critical strain energy release rate
G_{IIC}	shear critical strain energy release rate
h	adherend thickness
L_T	total length of the specimen
m_{bottom}	slope of the bottom curve
m_{top}	slope of the top curve
P	load
p_i (i = 1, 2, ... 8)	points for the optical method
P_u	load per unit width
q	quadratic approximation function
R	correlation factor
t_A	adhesive thickness
t_A^{CT}	current t_A value at the crack tip
${t_A}^i$	initial value of t_A
t_n	current tensile traction
t_n^0	cohesive strength in tension
t_s^0	cohesive strength in shear
U	strain energy
u	x-coordinate displacement
v	y-coordinate displacement
x_1, x_2, x_3	x coordinates of the points for the fitting procedure
y_1, y_2, y_3	y coordinates of the points for the fitting procedure
$\alpha_1, \alpha_2, \alpha_3$	constants for the cubic equation of a_{eq}
$\beta_1, \beta_2, \beta_3$	fitting polynomial coefficients
Δ	crack length correction
δ	displacement
δ_n	crack tip opening
δ_{nc}	tensile end-opening at failure
ε_f	tensile failure strain
θ_o	crack tip adherends rotation
θ_p	adherends rotation at the specimen's free ends
σ_f	tensile failure strength
σ_y	tensile yield stress
CBBM	Compliance-Based Beam Method
CBT	Corrected Beam Theory
CCD	Charge-Coupled Device
CCM	Compliance Calibration Method
CZM	Cohesive Zone Model
DCB	Double-Cantilever Beam
ENF	End-Notched Flexure
LEFM	Linear Elastic Fracture Mechanics
LVDT	Linear Variable Differential Transducer