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Buckling Behavior and Compressive Failure of Composite Laminates Containing Multiple Large Delaminations Growth with Cohesive Element Method

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Abstract

The effects of delamination and delamination growth on buckling load on compressive loading for E-glass/epoxy composite laminates using multiple large delaminations with cohesive elements have been studied. A numerical study is carried out to determine the buckling load of rectangular composite plates. For the numerical (0/90/0/90)s oriented cross-ply laminated plates with multiple large delaminations are produced by using hand lay-up technique. The results of the delamination growth of structure of plates are found by clamping from the two edges by using FEM software and then these results are compared with the results obtained by experimental results. In addition, the compressive failure loads of composite laminates containing multiple large delaminations are found by compression test fixture. It is found that the longest and near-surface delamination size influences the buckling load and compressive failure load of composite laminates.

Keywords: Buckling, delamination growth, cohesive, finite element method

Introduction

Delamination is one of the most common and dangerous failure modes in laminated composites. Some of the causes of delaminations are manufacturing defects, impact load, and edge effects. Delaminations can bring about significant reduction in the strength, stiffness and load carrying capacity of laminated composites under compressive loads. Numerous computational have been carried out to determine the effect of delamination on the buckling behavior of laminated composites. [Whitcomb and Shivakumar] studied effects of delamination on the buckling and post buckling behavior of laminated composite suffering from rectangular embedded delaminations.

Helpful Hints

Manufacturing of the composite plates

The laminated composite plates with delamination and without delamination with (0 /90 /0 /90) s fiber orientation are manufactured from the unidirectional E-Glass fiber and epoxy resin. The mechanical properties of the laminated composite plate are obtained by the standard tests. The composite laminated plates is produced by hand lay-up technique for determination of the mechanical properties. Average mechanical properties of the composite materials obtained from the experimental results are listed in Table 1.

Table 1. Mechanical properties of E-Glass/epoxy composites [Aslan and Sahin].

Fiber volume ratio	V_f	65	%
Density	ρ	1.27	g/cm^3
Longitudinal modulus	E_1	41250	MPa
Transverse modulus	E_2	9240	MPa
In-plane shear modulus	G_{12}	3380	MPa
Major Poisson's ratio	υ_{12}	0.26	-

Also mechanical properties of the cohesive elements taken in Table 2.

Table 2: mechanical properties of the cohesive elements [Wang et al].

Longitudinal Young's modulus	E_{11}	115	GPa
Transverse Young's modulus	$E_{22}= E_{33}$	8.5	GPa
Shear modulus	$G_{12}= G_{23}$	4.5	GPa
Shear modulus	G_{13}	3.3	GPa
Poisson's ratio	$\upsilon_{12}= \upsilon_{13}$	0.29	-
Poisson's ratio	υ_{23}	0.3	-
Penalty stiffness	K_P	850	MPa
Interlaminar tensile strength	T	3.3	MPa
Interlaminar shear strength	S	7	MPa
Fracture toughness	G_{IC}	0.33	N/mm
Fracture toughness	$G_{IIC}= G_{IIIC}$	0.8	N/mm

Modeling

The delaminations are assumed to be through the width. The gauge length of the specimen, L, is selected as 100 mm, the width w 30 mm, and the thickness t 2.4 mm. All multiple-delamination specimens have three delaminations distributing in the middle interface. Geometry of composite plate with three delaminations is illustrated in Fig. 1.

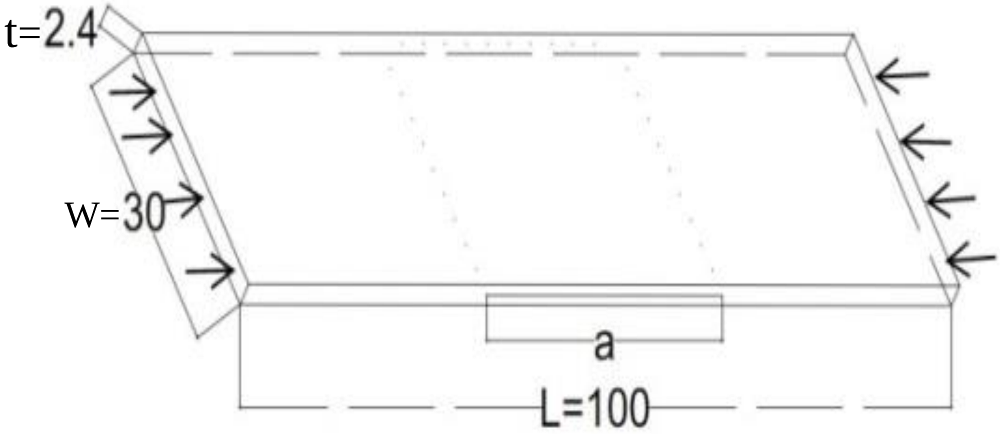

Fig. 1: Geometric Of Composite Plate.

Finite element mode

Under pure Mode I, II or III loading, the onset of damage at the interface can be determined simply by comparing the stress components with their respective tolerance. However, under mixed mode loading, damage onset may occur before any of the stress components involved reaches their respective tolerance. Therefore, it is assumed that delamination initiation can be predicted using the quadratic failure criterion [3].

$$\sqrt{\left(\frac{\sigma_z}{T}\right)^2+\left(\frac{\tau_{xz}}{S}\right)^2+\left(\frac{\tau_{yz}}{S}\right)^2}=1 \qquad (1)$$

Under mixed-mode loading, the damage growth can be predicted using the quadratic interaction between the energy release rates in the same way as the delamination initiation can be predicted using the quadratic failure criterion [3].

$$\sqrt{\left(\frac{G_I}{G_{IC}}\right)^2+\left(\frac{G_{II}}{G_{IIC}}\right)^2+\left(\frac{G_{III}}{G_{IIIC}}\right)^2}=1 \qquad (2)$$

Numerical study

The length of the delamination is a. The ratios of the delaminations length to specimen gauge length, a/L, are selected as 0.3, 0.5 and 0.8 in this numerical study. The buckling numerical are done under uniaxial compressive loading. The buckling numerical are carried out under displacement control and load–displacement plots are obtained.

Results and discussion

In the first part of this study, the critical buckling load results are obtained numerically for (0/90/0/90) s fiber orientation. The numerical critical buckling loads for different a values for delamination and delamination growth are given in Fig. 2, 3.

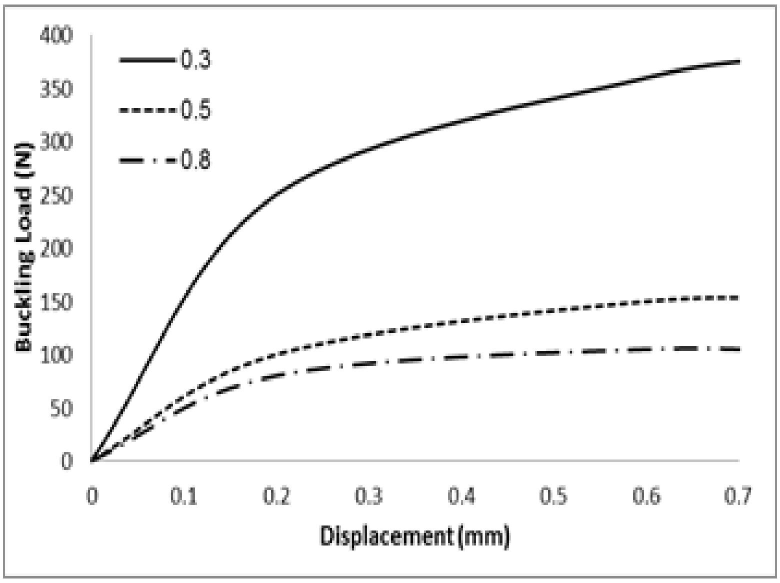

Fig. 2: buckling loads for different for delamination.

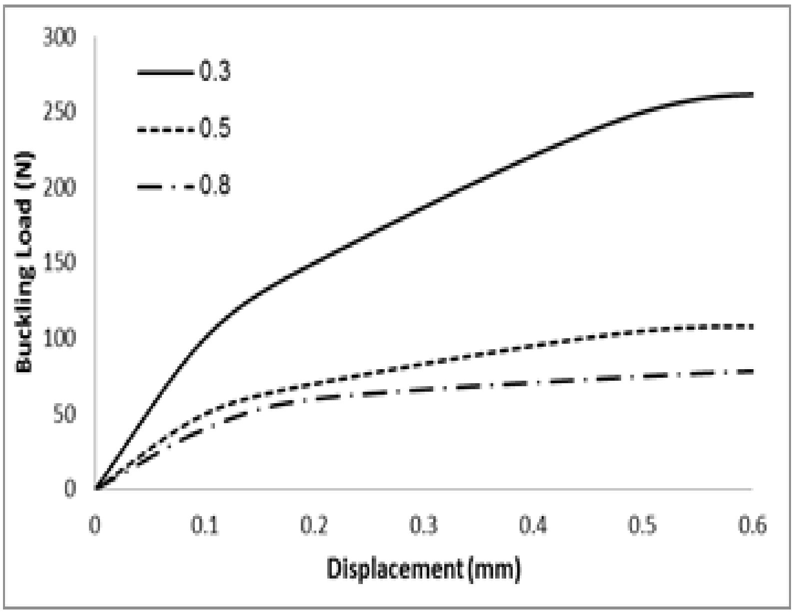

Fig. 3: buckling loads for different for delamination growth.

To illustrate the influence of the delamination length on the compression strength, the compression strength of plates was normalized with the corresponding strength without a delamination. The results, shown in Fig. 4, 5. Indicate that the compression strength is considerably reduced by the presence of a/L delamination, and that the reduction is more severe for longer delamination.

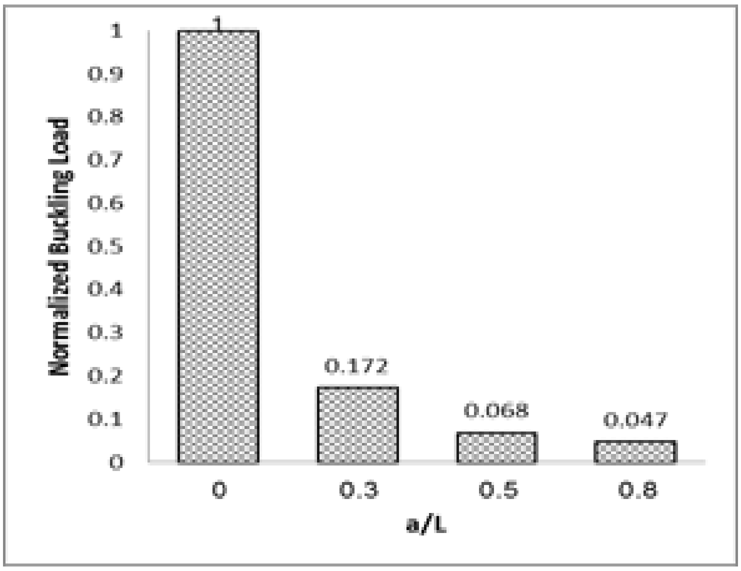

Fig. 4: Influence delamination on Buckling Load.

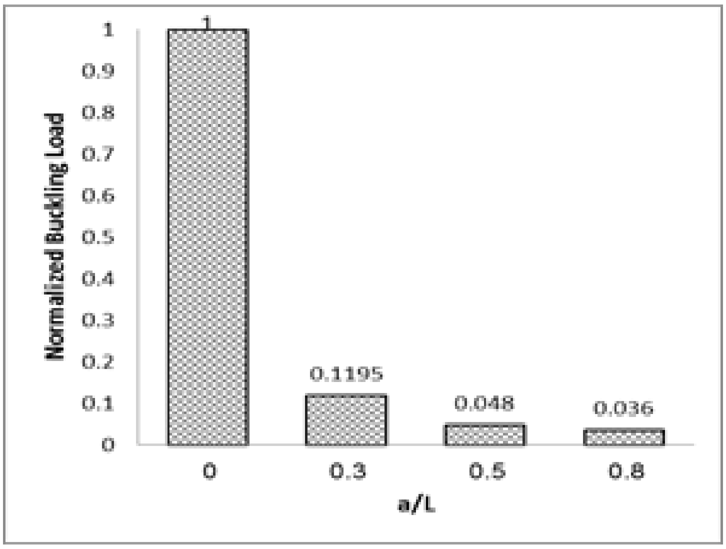

Fig. 5: Influence delamination Growth on Buckling Load.

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