Influence of edge crack parameters and type of laods on the Buckling behavior of Composite Laminated Plates

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Abstract— The present study focused mainly on the buckling behavior of cracked composite laminated plates (edge cracks) subjected to mechanical loads. The critical buckling load was studied for cracked composite laminated plates and it subjected for two types of compression loads (uniaxial or biaxial). This study included effect of crack parameters (length and position) for two boundary conditions. The problem was solved numerically and employing the finite element method by using ANSYS program to estimate of critical buckling load. The main conclusion from this work was confirmation that the buckling behavior of cracked laminated plate for SSSS boundary condition vary inversely for SFSF.

Keywords— Cracked laminated plates, buckling behavior, normalized critical buckling load, crack parameters.

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1 INTRODUCTION

Plates can be classified as being thin or thick. Thin plates structural components such as plates and shells are commonly used in practical applications such as aerospace, naval, nuclear power plant, pressure vessels, mechanical and civil engineering structures and so on and the safety assessment of such structures must carefully consider all the phenomena which can decrease the bearing capacity of such elements, such as buckling phenomenon**.**

The transition of the plate from the stable state of equilibrium to the unstable one is referred to as buckling or structural instability. The smallest value of the load producing buckling is called the critical or buckling load. It is important to note that a plate leading from the stable to unstable configuration of equilibrium always passes through the neutral state of equilibrium, which thus can be considered as a bordering state between the stable and unstable configurations. In the mathematical formulation of elastic stability problems, neutral equilibrium is associated with the existence of bifurcation of the deformations. According to this formulation, the critical load is the smallest load at which both the flat equilibrium configuration of the plate and slightly deflected configuration are possible **[1].**

Composite materials are materials that combine two or more materials (a selected filler or reinforcing elements and compatible matrix binder) that have quite different properties that when combine offer properties which are more desirable than the properties of the individual materials.

Because composite materials have superior mechanical properties compared to single phase materials, such as high stiffness and strength to weight ratios, they are extensively used in aerospace, automobile and naval engineering that have stringent stiffness and strength requirements **[2].**

Buckling phenomena of cracked plates under different situations has been gained extensive attention by researchers.

[Vafai and Estekanchi 1999] presented study on the behavior of plates with central and edge cracks under tension, compression and periodic compressive. They showed the effects of various parameters such as crack length, boundary condition and Poisson's ratio on the buckling behavior of plates **[3]. [Kumar Y.V. S. and Paik J.K. 2004]** studied the estimation of buckling loads of simply supported square steel plates with cracking damages. The hierarchical trigonometric functions are used to define the displacement function of the cracked plate. The buckling loads of plates with various types of cracks, such as edge crack and central crack, are estimated under uniaxial compressive load, biaxial compressive load and in-plane shear load **[4]. [Khedmati et al. 2009]** addressed a finite element study on the buckling strength of a cracked plate with simpley supports subjected to an axial compressive edge load. The effects of crack location, crack orientation, crack length and plate aspect ratio are analyzed **[5]. [Brighenti Roberto . 2010]** investigated the effects of a central straight crack on the buckling collapse of rectangular elastic thin plates characterized by different boundary conditions, crack length and orientation under compression, tension or shear loading are analyzed. Accurate FE numerical parametric analyses have been performed to get the critical load multipliers in such loading cases **[6]. [Saleh N.A. 2011]** conducted a study on the buckling phenomenon of various cracked plates under compression load to determine the normalized critical buckling load by considering the effects of crack length and crack location as well as loading direction parallel or perpendicular with respect to crack faces. Several FE numerical parametric analyses results were presented **[7]. [Saleh N.A. and Khalsan S.. 2012]** studied the buckling behavior for edge cracked plates

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under compression loading by considering the influence of crack parameters, plate aspect ratio and plate boundary conditions. The problem was solved numerically based on finite element method using ANSYS software version11 **[8]**. **[Kawther Khalid Younus 2012]** investigated the buckling behavior of damaged and undamaged laminate plate with different load types and boundary conditions. Mechanical loads are analyzed by analytical and experimental analysis for undamaged plates, and numerical and experimental analysis for damaged laminates **[9].**

From above review it can be concluded that most of these studies were performed on the plates, cylinder shells and panels with either central or edge crack with varying crack parameters (length or position or orientation) under uniaxial load, and effect of these parameters on the buckling behavior based by finite element method or experimental method. As well as, all researches used isotropic material except research **[9]**, where she used orthotropic material with dameges. This present work inclouded the cracked laminate plate which focused on the edge crack, where buckling solution was numerical method (FE) used to analyze such cracked laminates**.**

2 NUMERICAL ANALYSIS

2.1 Finite Element Method

The numerical techniques, such as finite element method, boundary element method, large number of FEM software packages such as ANSYS program, etc. are widely used in solving the buckling problems. In the finite element method, each member of the structure is subdivided into a series of fairly short elements, each connected to each other at the nodal points. The choice of elements depends on the physical makeup of the body under actual loading conditions and on how close to the actual behavior the analyst wants the results to be. The linear buckling problem is formulated as a standard eigenvalue problem, in order to obtain directly critical loads and buckling modes as part of the solution for cracked plate.

The non-dimensional buckling load obtains from equation below **[10].**

$$\lambda = N_{cr}\, b^2/(E_2\, h^3) \qquad (1)$$

Where:

λ: Non-dimensional buckling load.

N_{cr}: Critical buckling load.

E_2: Transverse modules of elasticity.

b and h: width and thickness of plate respectively.

The non-dimensional critical buckling load of cracked plate to non-dimensional critical buckling load of the uncracked plate with similar geometry and material properties subject to uniform load for first buckling mode is called normalized buckling load and it obtains from equation below **[7]**.

$$\lambda^* = \lambda_{cracked} / \lambda_{uncracked} \qquad (2)$$

Where

λ^*: normalized buckling load.

$\lambda_{cracked}$: non-dimensional critical buckling load of cracked plate.

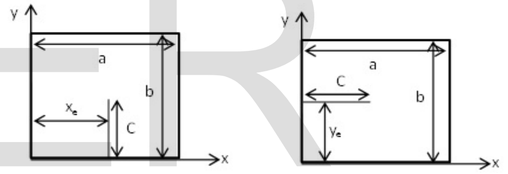
$\lambda_{uncracked}$: non-dimensional critical buckling load of uncracked plate.

2.2 Element Selection

ANSYS provides a variety of element types ranging from one dimensional element to three dimensional elements. For the purpose of the present work, an element called ***shell 281*** is selected which is suitable for analyzing thin to moderately thick shell structures. The element has eight nodes with six degrees of freedom at each node: translations in the x, y, and z axes, and rotations about the x, y, and z axes. It may be used for layered applications for modeling composite shells. It is include the effects of transverse shear deformation.

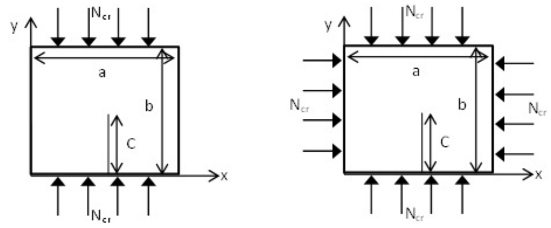
3 MODEL DESCRIPTION OF CRACKED PLATES

The geometry of cracked laminated plates are (length a=100mm, width b=100mm and thickness h=4mm) with variable crack length (C) and crack position (x_e and y_e), shown in figure 1. The No. of layares (N=4) with symitric cross ply $0^o/90^o/90^o/0^o$ subjected to two types of loading uniaxial and biaxial, shown in figure 2. The effect of boundary conditions studied with two types simply supported for all edges SSSS and simply supported for two opposite edges and free other edges SFSF, shown in figure 3



a: Vertical edge crack b: Horizontal edge crack

Fig. 1. Dimension of cracked laminated plates.

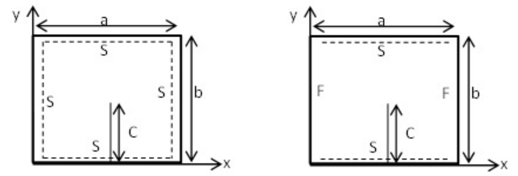


a: Uniaxial load b: Biaxial load

Fig. 2. Types of loading.

4 EXPERIMENTAL WORK

The experimental work includes the experimental tensile test of specimens which were manufactured in the laboratory. The tensile test can be done to calculate the mechanical properties of composite material (fiber-glass/polyster), where the elastic modulus (E_1=22.52 GPa, E_2=5.21 GPa), shear modulus (G_{12}=1.82 GPa) and poison's ratio (ν_{12}=0.335).



a: Simply supported SSSS b: Simply supported-free SFSF

Fig. 3. Types of boundary conditions.

5 VERIFICATION OF PRESENT PROGRAM

According to the results shown in table 1 the maximum error percentage between the results of reference [4] and present reaches to (0.87%) for square cracked plate by using finite element method (ANSYS program).

Table 1: Verification of present program for cracked plate

2C/b	Non-dimensional (λ) of reference [4]	Non-dimensional (λ) of present	Error (%)
0.1	4.01	4.01	0
0.2	4	3.99	0.25
0.3	3.94	3.92	0.51
0.4	3.74	3.72	0.54
0.5	3.44	3.41	0.87

a/b=1, b/h=100,
E=205.8 GPa,
ν= 0.3

Figure 4 shows the verification of finite element method (ANSYS program) for cracked plate with reference [8]. The results of this reference are extracted by using digitizer program. From this figure it is clearly observed that there is a good agreement between the results of the present study and this reference.

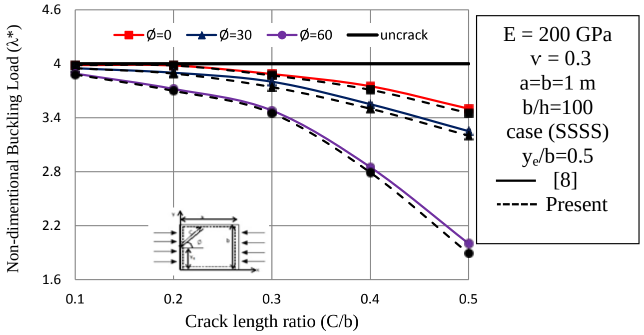


Fig. 4 Verification between present ANSYS program and [8] for edge cracked plate

6 RESLTS AND DISCUSSIONS

The present study focused mainly on the buckling behavior of composite laminated plates subjected to mechanical load. The results are divided to two cases. Case 1, the cracked laminated plates subjected to uniaxial load and case 2 it subjected to biaxial load. The figures from 5 to 9, y-axis is normalized buckling load (λ*) and x-axis is crack length ratio (C/b). But figure 10, the x-axis is crack position ratio (x_e/b)

6.1 Case 1

Figure 5 shows the effect of crack position ratio (xe/b) on the normalized buckling load (λ*) for SSSS boundary condition when crack is parallel to load direction. From this figure as can be seen, the normalized buckling load decreases insignificantly when crack length ratio (C/b) various from (0.125 to 0. 25). While, it is decreasing significantly when crack length ratio (C/b) various from (0.25 to 0.5), where maximum decreasing reaches to (22.79%, 24.6%, 20.57% and 19.56%) for (x_e/b =0.125, 0.25, 0.375 and 0.5) respectively at (C/b=0.5). In other words, it is clear that, whenever the crack position keeps away from the middle of cracked edge, the normalized buckling load is decreased, this similar to reference [8].

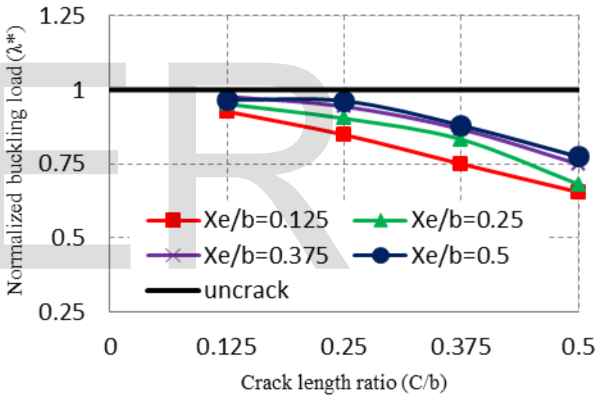


Fig. 5. Effect of crack position ratio (x_e/b) on the normalized buckling load (λ*) for SSSS.

Figure 6 shows the effect of crack position ratio (xe/b) on the normalized buckling load (λ*) for SFSF boundary condition when crack is parallel to load direction. From this figure as can be seen, the normalized buckling load decreases insignificantly with increasing crack length ratio for crack position ratio (x_e/b =0.125 and 0.25). While, it is decreasing significantly for (xe/b =0.375 and 0.5) when crack length ratio (C/b) various from (0.125 to 0. 5), where maximum decreasing reach to (4.32% and 4.33%) for (x_e/b =0.375 and 0.5) respectively at (C/b=0.5) with respect to (C/b=0.125). In general, it can be deduced that, whenever the crack position is neared to the middle of cracked edge the normalized buckling load (λ*) is decreased because the laminated plate will split into two parts by effect of free edge.

Figure 7 shows effect of crack face on the normalized buckling load (λ*) for SSSS boundary condition when crack position is at the middle of edge. From this figure it is clear that, the normalized buckling load (λ*) decreases with increasing of crack length ratio (C/b) for crack face parallel to the load direction case, because the crack is opening. While for perpendicular case, it is increased because the crack is closing. The maximum decreasing and increasing is reach to (10.5% and 20.1%) for parallel and perpendicular cases respectively at (C/b=0.5) respect to (C/b=0.125). In other words, when the crack face parallel to the load direction is more importance than the perpendicular to the load direction because it does on decreasing of the buckling load, this similar to reference [4].

Figure 8 shows effect of crack face on the normalized buckling load (λ*) for SFSF boundary condition when crack position is at middle of edge. It is clear that, the perpendicular crack face perpendicular to load direction is more effect than that parallel with maximum percentage (38.19%) at (C/b=0.5), because the crack position of perpendicular case is on the free edge. In both cases, the normalized buckling load (λ*) decreases with increasing of crack length ratio.

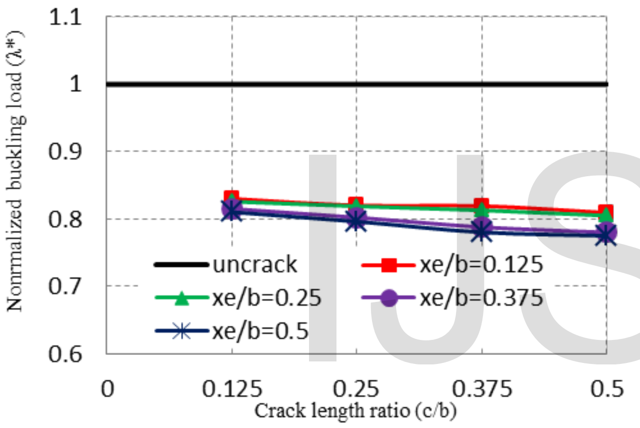


Fig.6. Effect of crack position ratio (x_e/b) on the normalized buckling load (λ*) for SFSF.

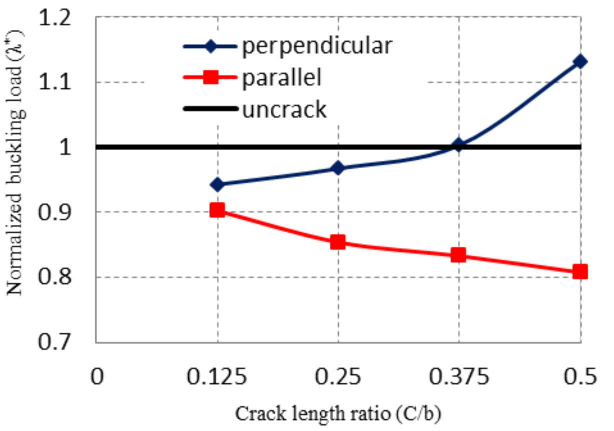


Fig.7. Effect of crack face direction on the normalized buckling load (λ*) for SSSS.

6.2 Case 2

Figure 9 shows effect of crack length ratio (C/b) on the normalized buckling load (λ*) for different boundary condition SFSF and SSSS when crack position ratio (x_e/b=0.5). From this figure as can be seen for (SFSF) case, the normalized buckling load decreases insignificantly when crack length ratio (C/b) various from (0.125 to 0. 25). While, it is decreasing significantly when crack length ratio (C/b) various from (0.25 to 0.5), where maximum decreasing reaches to (32.45%). For SSSS case it is notice that, the normalized buckling load increases insignificantly when crack length ratio (C/b) various from (0.125 to 0.5), where maximum increasing reaches to (2.6%). In other words, the boundary condition SFSF case is affected more than the boundary condition SSSS case, because the free

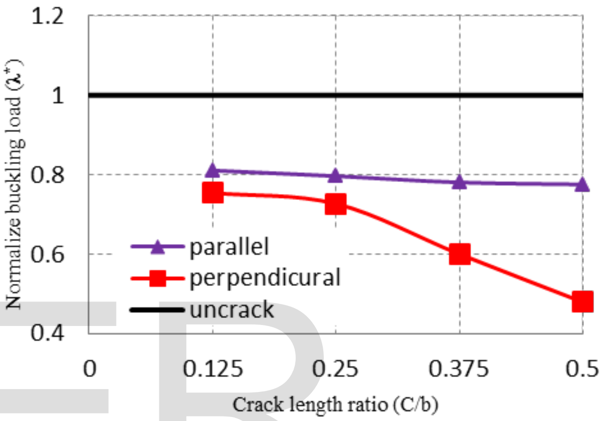


Fig. 8. Effect of crack face direction on the normalized buckling load (λ*) with SFSF.

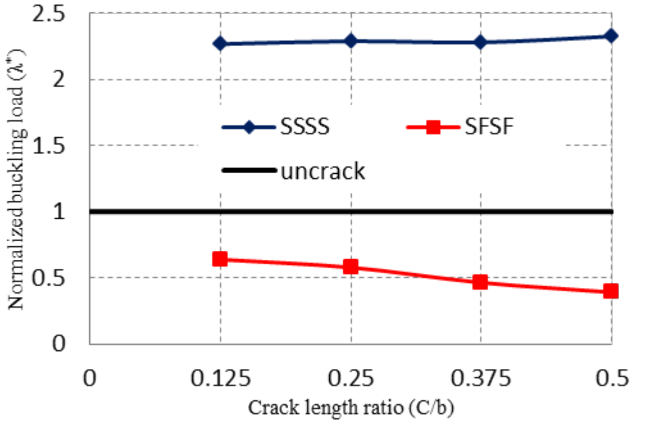


Fig. 9. Effect of crack length ratio (C/b) on the normalized buckling load (λ*).

The relation between the normalized buckling load (λ*) and crack position ratio (x_e/b) for two boundry conditions SFSF and SSSS when crack length ratio (C/b=0.5) is shown in figure 10. From this figure it is notice that, the normalized buckling load decreases insignificantly when crack position ratio (x_e/b) various from (0.125 to 0. 25), while it is decreased noticeable when crack position ratio (x_e/b) various from (0.25 to 0.5) for SFSF, where maximum decreasing reaches to (13.6%). For SSSS case it is notice that, the normalized buckling load increases clearly when crack position ratio (x_e/b) various from (0.125 to 0.5), where maximum increasing reaches to (31.2%). In other hand, it can be deduced that as just as in section (5.1).

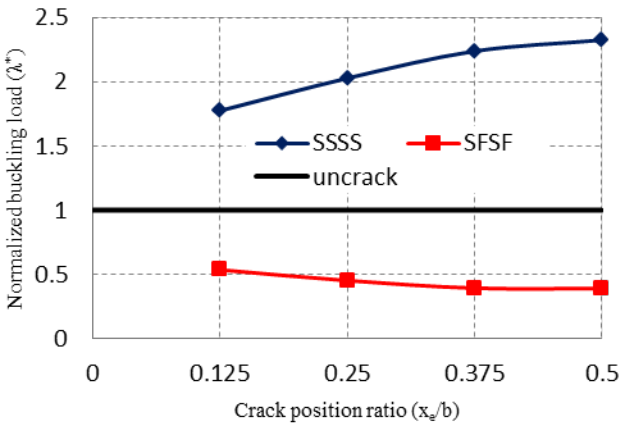


Fig. 10. Effect of crack position ratio (x_e/b) on the normalized buckling load (λ*).

7 CONCLUSIONS

The following conclusions may be drawn out from the present study:

1. Small cracks produce a less influence on the normalized critical buckling and this influence increases as the crack gets bigger.
2. It was noted that when the crack face perpendicular to the loading direction, the normalized critical buckling load was higher than parallel for (SSSS) but it is less than for (SFSF).
3. In general, the normalized critical buckling load increases as the crack approaching to plate center for SSSS, while it was vary inversely for SFSF.
4. In general from results of present, the normalized critical buckling load for SFSF at edge crack was less reduction than SSSS.

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