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Study the internal cracks effect on vibration of laminated composite square plates

M.S. Hassan, Z.H. Rashid *, R.A. Sarhan
Mechanical Techniques Department, Technical Institute of Al Musayab,
Al-Furat Al-Awsat Technical University, Babylon, Iraq
* Corresponding e-mail address: zhr.1986@atu.edu.iq
ORCID identifier: https://orcid.org/0000-0002-5017-2404 (M.S.H.);
https://orcid.org/0000-0002-9800-4354 (Z.H.R.); https://orcid.org/0000-0001-7095-684X (R.A.S.)

ABSTRACT

Purpose: The study of cracks behaviour in a composite plate is of significant importance in the dynamics of the Mechanical parts in order to avoid design failures due to resonance or high amplitude vibrations.

Design/methodology/approach: In this paper, a square glass-epoxy composite plate is adopted. The plate has four layers with symmetric and asymmetric lamination. Assuming the cracks are profound as defects. The results were obtained by using a numerical solution of mechanical APDL from ANSYS.

Findings: It has been found for different boundary conditions that the rank of natural frequencies is decreased by increasing the crack ratio due to the reduction of the plate's stiffness, whereas the crack direction has no mentioned effect for a small angle of rotation.

Research limitations/implications: The accuracy of results is verified by comparing a single case of the current work with other previous investigations.

Originality/value: Evaluate the influence of the crack length ratio, angle of the crack rotation, boundary conditions and lamination angles on the natural frequencies of the square composite plate with glass-epoxy materials.

Keywords: Laminate plate, Natural frequency, Boundary condition, Cracked plate, Finite element, ANSYS

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METHODOLOGY OF RESEARCH, ANALYSIS AND MODELLING

1. Introduction

The plates are the essential structural components, and they can be used in various applications such as in the manufacture of automobile chassis, marine vehicles and aerospace, and the reason for the frequent use of composite materials in many engineering departments is due to their high strength, low weight, corrosion resistance and impact resistance. The presence of cracks in the structure can be unsafe due to loading; thus, crack detection plays an

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important role in the integrity of structural parts. Hence, there is a need to carefully study the vibration behaviour of cracked laminated composite panels. A number of researchers have studied the vibration of cracked composite square plates. Some of the selected studies are discussed in the following lines. Bachene et al. [1] used the finite element method (FEM) to find natural frequencies of vibrations on cracked composite panels. The results induced the vibration frequency decreases with an increase in length. Without considering the other crack parameters. C. Huang et al. [2] used Ritz method to analyse the free vibrations of rectangular plates with Internal cracks to get exact mode shapes and natural frequencies for (simply and free) boundary square plates. M. Jweeg et al. [3] studied the effect of crack orientation on the vibration of different composite plates, and the result was validated with ANSYS software. They also observed that frequency differs with dimensions and stiffness of the plate. R. Mohanty [4] determined the vibration response of composite plate at the various parameters of crack have been experimentally and used ANSYS to validate the results. P. Srinivasa and D. Mohan [5] investigated the free vibration response of cracked plates and panels analytically and numerically. F.T. Al-Maliky and D.K. Alshakarchi [6]. Presented free vibration analysed on a central crack plate by using FEM in ANSYS workbench; the plate was cracked on the central as a percentage of its length (10-40%), The results showed that the natural frequencies as a function of crack. Z. Xu and W. Chen [7] used the differential quadrature Finite Element Method to study the vibration analysis of plate with irregular cracks and compare the result with ANSYS. It was concluded that the good agreement between the results is verified by the accuracy and method efficiency. M. Imran et al. [8] reviewed the literature on the effect of vibration on delaminated composite structures subjected to different boundary conditions; the studies have shown that the location and size of delamination in composite structures significantly impacted the natural frequencies and mode shapes. K. Brethee [9] studied the effect of a crack on free vibration of composite plates with clamp boundary conditions by ANSYS. M. Ansari and V. Tiwari [10] used the FEA simulation package of Ansys to find the effect of crack propagation on the natural frequency response of the cantilever, where the crack depth or crack height has significant effect on vibration characteristics.

The purpose of this study is to comprehend the influence of the crack length ratio, angle of the crack rotation, boundary conditions and lamination angles on the natural frequencies of the square composite plate with glass-epoxy materials. The numerical analysis will be performed with the ANSYS (APDL) via the modal analysis to investigate cracked laminate composite plate.

2. Materials and methods

A square composite plate with an internal crack with the plane dimensions of a×b×h with a crack at the centre is considered, as shown in Figure 1. The plate contains four layers with orientation angles (0,90,0,90) and (0,90,90,0) in degrees. The material of glass-epoxy is assumed to be an orthotropic composite.

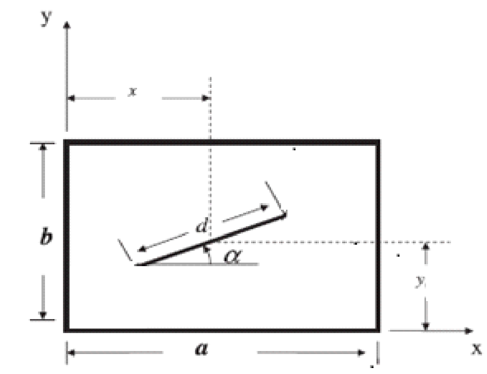

Fig. 1. Illustrates the plate model dimensions

3. Finite Element Modelling

The analysis of the cracked composite plate has been done using the ANSYS software package. The element (SHELL 281) was used to modal the laminated composite plate [11]. This element type has eight nodes and six degrees of freedom at each node, translation and rotation in the axis x, y and z direction as shown in Figure 2. Figure 3 shows the refined mesh of the composite plate.

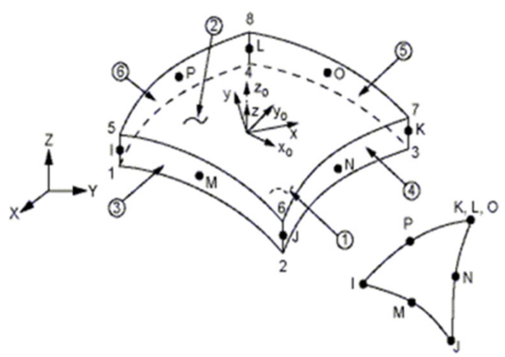

Fig. 2. Illustrates the sheet element type of 281 [11]

Table 1.
Mechanical properties of the glass-epoxy composite plate [12]

E_x, GPa	E_y, GPa	E_z, GPa	PR_{XY}	PR_{YX}	PR_{ZX}	G_x, GPa	G_y, GPa	G_z, GPa	ρ, Kg/m^3
46	10	10	0.3	0.13	0.13	4.70	4.70	4.00	1850

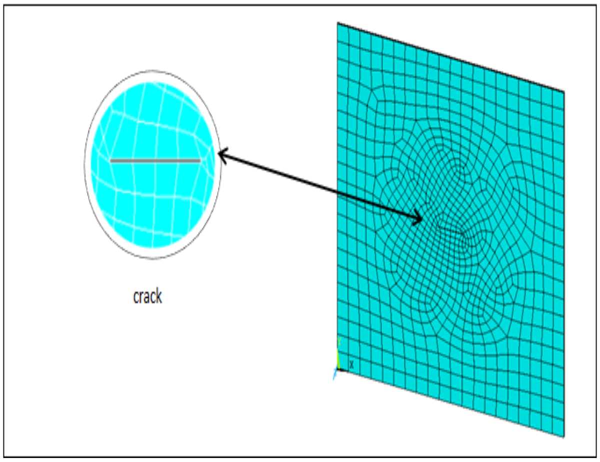

Fig. 3. Illustrates the meshed model

The proposed model consists of four unidirectional equal sheets of symmetric lamination, as shown in Figure 4 and for asymmetric lamination, as shown in Figure 5.

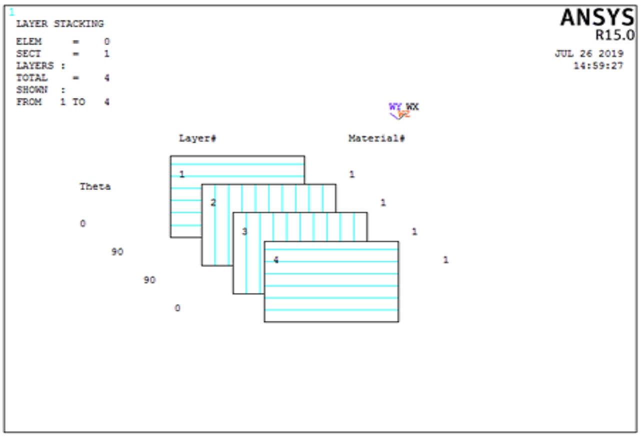

Fig. 4. Illustrates the symmetric lamination of composite plate

The material properties of glass-epoxy composite material are listed in Table 1. With the centre of plate in position, a crack of a/2 and b/2 eight models are organized for each boundary condition, with four inclinations angle of crack for both symmetric and asymmetric lamination. The modal analysis is carried out by the Block Lanczos for the definition of the natural frequencies.

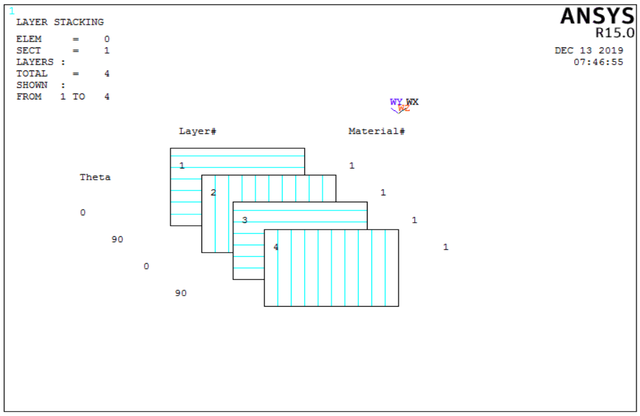

Fig. 5. Illustrates the asymmetric lamination of the composite plate

Simply support (SSSS), full Clamped (CCCC), Clamped Free (CFCF) and (CFFF) simply clamped (cantilever-like) boundary conditions are applied by constraining the nodal displacement in both x and y directions. The plate specifications can be defined as follows: 600 mm x 600 mm in size, thickness ratio (b/h) of 200, crack length ratio (d/a) of (0.1-0.5) and crack depth of 0.5 mm.

4. Convergence and validation study

The rapprochement study is done for frequencies of free vibration of SSSS square 4-layer asymmetric cross-ply laminated composite plates for varied mesh divisions, as shown in Figure 6. The convergence studies showed that meshed size of 20 x 20 is satisfying enough to get a reliable order of accuracy for each model.

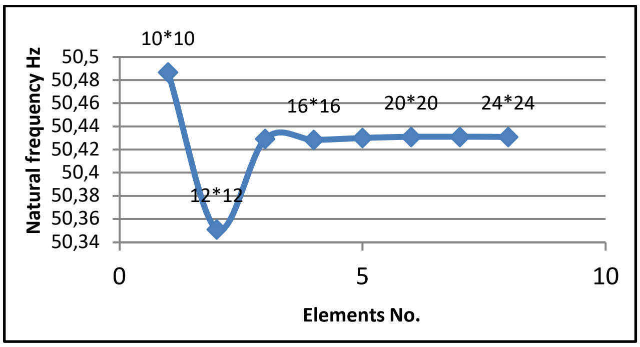

Fig. 6. Illustrates the convergence results for various mesh divisions

5. Methodology validation

A comparison was made for an analysis of a laminated composite square plate with the internal crack of an (SSSS) plate with a flat crack from Ref. [13] for some cases, as listed in Table 2 below, to ensure an accurate solution.

Table 2.
Comparison of natural frequencies in (Hz) with cut-out

d/a	Ref. [13]	Present
0.2	19.3	19.43
0.4	18.2	18.42
0.5	17.7	17.83

6. Results and discussion

For simple support boundary conditions, all sides of the plate were set to zero deformation on the z-axis. Figures 7 and 8 show the variation of the frequency ratio (ωc/ω) with the variable crack length ratio for various crack angles for both symmetric and asymmetric plates.

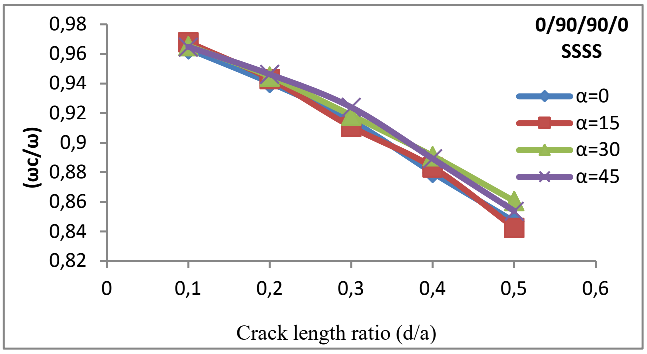

Fig. 7. Illustrates the natural frequency ratio with crack length ratio for symmetric (SSSS)

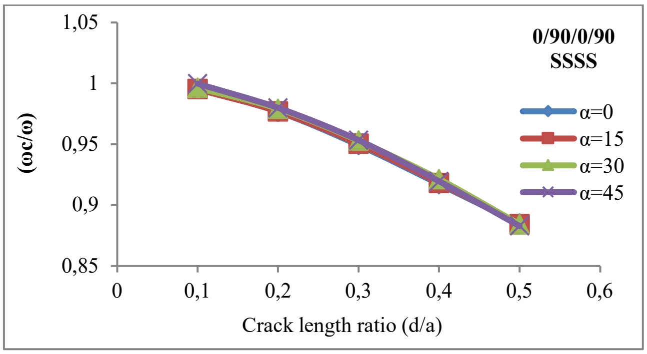

Fig. 8. Illustrates the natural frequency ratio with crack length ratio for asymmetric (SSSS)

Also, Figures 9 and 10 show the frequency ratio variation of (CCCC) boundary condition, whereas Figures 11 and 12 are for (CFCF) boundary condition. Finally, for simply clamped (CFFF) boundary condition, the frequency ratio variation is shown in Figures 13 and 14.

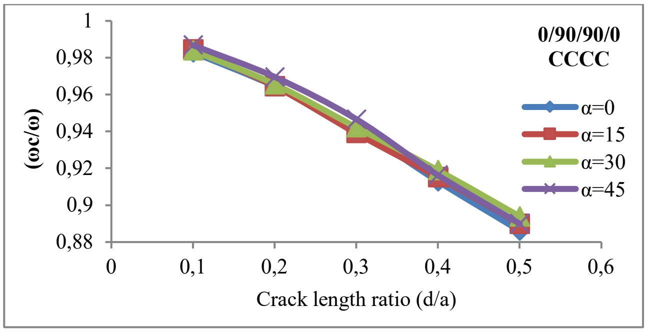

Fig. 9. Illustrates the natural frequency ratio with crack length ratio for symmetric (CCCC)

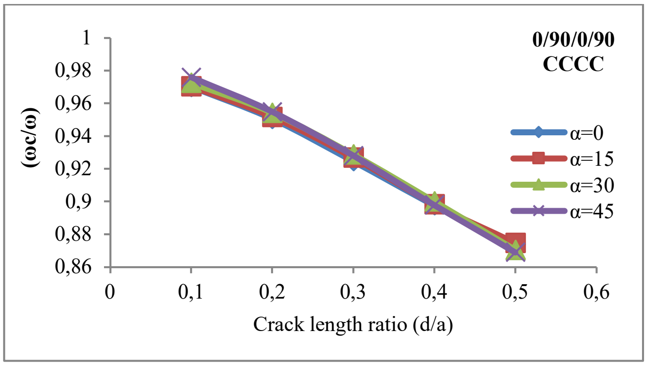

Fig. 10. Illustrates the natural frequency ratio with crack length ratio for asymmetric (CCCC)

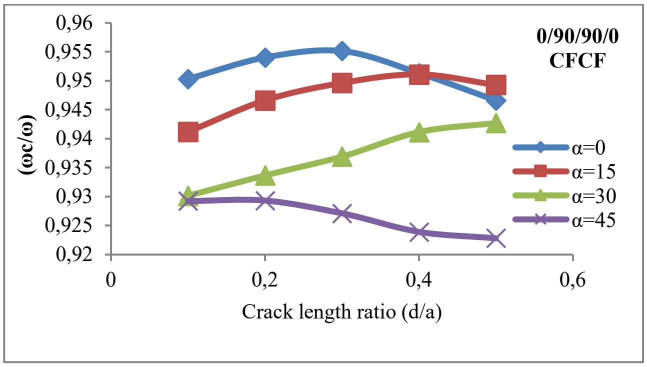

Fig. 11. Illustrates the natural frequency ratio with crack length ratio for symmetric (CFCF)

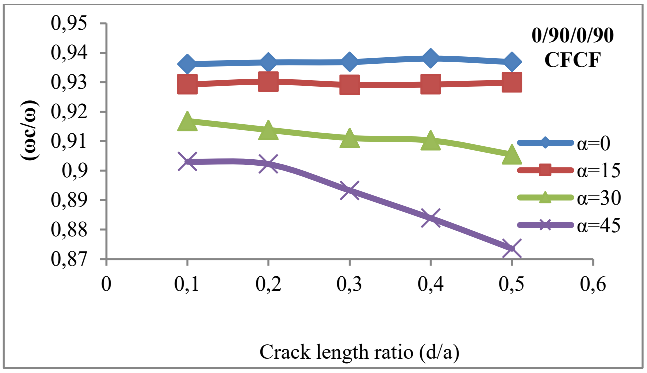

Fig. 12. Illustrates the natural frequency ratio with crack length ratio for asymmetric (CFCF)

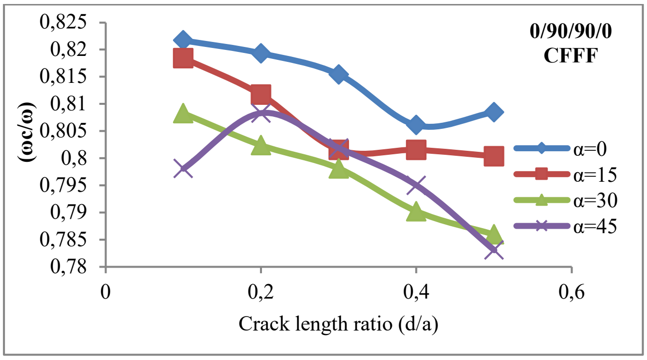

Fig. 13. Illustrates the natural frequency ratio with crack length ratio for symmetric (CFFF)

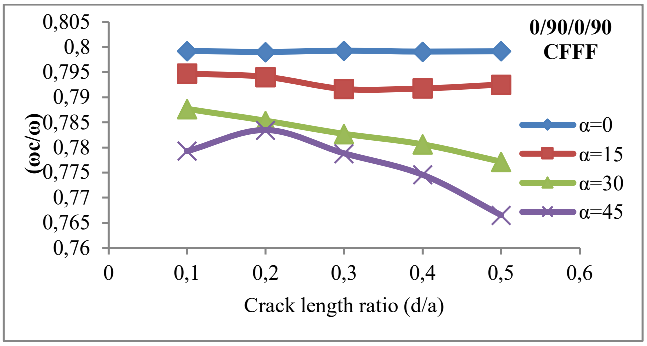

Fig. 14. Illustrates the natural frequency ratio with crack length ratio for asymmetric (CFFF)

The results indicate that the natural frequency decreases with an increasing crack length ratio. Also, it is noticed that the natural frequency ratios variation with the orientation of crack in asymmetric plates is greater than in symmetric plates; it is maximally at 45 degree. It was observed that changing the crack angle clearly affects the frequencies when the boundary conditions are of the CFFF and CFCF. In Descending Order, the increase of crack length ratio effect were in CCCC, SSSS, CFCF and CFFF boundary led to a decrease in the frequency ratio.

7. Conclusions

The results showed that the frequency ratio changes significantly due to the occurrence of crack depending upon orientation angle pay, boundary condition and rotation angle of the crack. It has been observed that for the same lamination angle and boundary condition, the natural frequency ratio of a cracked plate is in reverse relation to the crack length ratio. In general, it has been found for most cases that the rank of natural frequencies is decreased by increasing the crack ratio due to the reduction of plate stiffness, whereas the crack angle has no mentioned effect for a small angle of rotation.

Definitions

b/h – Ratio of the side length of the plate to the thickness
d/a – Ratio of crack length to side length of plate
ωc/ω – Natural frequency ratio (ratio of frequency of cracked plate to uncracked plate)

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