Vibration Analysis of Hybrid Composite Laminated Beam with Crack in ANSYS APDL

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Abstract. In this paper, whole work is done for hybrid laminated composite beam which is made of three composite materials boron-epoxy, aramid-epoxy, and s-glass-epoxy. A numerical study, using finite element method is carried out to analyse the free transverse vibration behaviour of composite beam. ANSYS APDL is used as a finite element solver to simulate the free transverse vibrations. A variety of parametric studies is performed to check the effects of various parameters associated with crack geometry and laminate property on the three least natural frequencies. Parameters for the investigation are included as fibre volume fraction, ply angle for (0°/Φ°/0°/Φ°/0°/90°/(90°-Φ)°/0°/(90°-Φ)°/0°) stacking sequence, location of crack geometry relative to the restricted end, depth of crack (a) and support conditions (C-C & C-F configuration) for hybrid laminated composite beam, trend of the least three transverse natural frequencies is also discussed in detail. It is noted that maximum value of natural frequency occur at Φ equals to 90° for both (C-C) and (C-F) and for relative crack depth 0.5 to 0.6, there is sharp decrement in natural frequency for (C-F). Other factors of laminate and crack geometry are also discussed in present analysis, which shows a great scope of this hybrid composite with (0°/Φ°/0°/Φ°/0°/90°/(90°-Φ)°/0°/(90°-Φ)°/0°) stacking sequence in the field of aviation and prosthetics.

Keywords: Hybrid laminated composite, Transverse vibration, Ply angle, Fibre volume fraction, Stacking sequence.

1. Introduction

Composites have two or more than two phases and both the phases should not be soluble in each other and both have different chemical attributes which shows independence on Hume-Rothery rule. In the present scenario, conventional materials like metals and alloys are replaced by smart materials like composites, functionally graded materials (F.G.M.) and fibre metal laminates (F.M.L.) etc. The use of composite material became important due to its high fatigue applications as well as for its low weight to strength ratio which is required for the static and dynamic problems. The past history of various carried studies represents that the main cause of failure of any composite structure is delamination of the laminate [1-2] and especially under the presence of various geometrical discontinuities like crack and notch which cause stress concentration as well as decrement in the value of natural frequency [3]. This decrement in the value of natural frequency becomes very dangerous because it increases the probability of resonance at a lower
frequency in the case of the dynamic behaviour of the structure in different modes and also affects damping coefficient, mode shape, and natural frequency [4]. For eliminating the resonance problem, it is necessary to know the damping factors and natural frequency of the system and different mode shapes for strengthening the structure where as required [5].

2. Techniques of Vibration Analysis
There are two types of methods for investigation, first one is the analytical [6-7] and the second one is the experimental approach. The experimental approach gives an exact solution with various advantages like great exposer, high-level control, and clear-cut results to the researcher. There are some benefits with the analytical approach like less time consumption, no issue regarding machine set up and comparatively cheaper than experimental approach. Practically, it is not easy to get exact solution of all engineering complex problem, for this purpose, there are some methods which give approximate solution like F.E.M.[8] and F.E.M. has many software packages like ANSYS [9], ABAQUS, Solid Works, Fluent, FORTRON, etc.

3. Validation with Krawczuk & Ostachowicz
In the present examination results are first approv ed by model given by Krawczuk and Ostachowicz [10] for graphite-polyamide composite as shown in figure 1 and further examination is expanded for hybrid composite for different parameters of laminate like fibre volume fraction (V), ply angle (\( \Phi \)) and with crack, the crack geometry is also taken as a parameter for present analysis which influences the natural frequencies of freely vibrated cantilever composite beam.

![Figure 1. Comparison between present analysis and Krawczuk & Ostachowicz [10] for fibre volume fraction (V) =0.1](image)

4. Materials and Methodology

4.1 Governing Equation
Governing equation for the free vibration condition of the beam is expressed by [11-12]
In the expression,

\[ [K] - \omega^2 [M] [q] = 0 \] (1)

\[ q = \text{Degree of freedom, } K = \text{Stiffness matrix, } M = \text{Mass matrix} \]

**Table 1.** Properties of boron epoxy, aramid epoxy and s-glass epoxy [13 - 15]

| Mechanical Properties of Fibre (f) & Matrix (m) | Modulus of Elasticity (GPa) | Shear Modulus (GPa) | Poisson's Ratio | Mass Density (kg/m³) |
|-----------------------------------------------|-----------------------------|--------------------|----------------|---------------------|
| Boron Fibre and Epoxy                          | 3.25                        | 393                | 1.25           | 163.75              | 0.3                 | 0.2                 | 1250               | 2700               |
| Aramid Fibre and Epoxy                         | 3.25                        | 131                | 1.25           | 48.51               | 0.3                 | 0.35                | 1250               | 1450               |
| S-Glass Fibre and Epoxy                        | 3.25                        | 86.9               | 1.25           | 35.61               | 0.3                 | 0.22                | 1250               | 2490               |

**4.2 Model of Beam**

In the present model of the beam the said crack is a transverse crack having V shape. The geometrical parameters of composite beam has taken as length (L), width (B) and height (H) are 1.0 m, 0.05 m, and 0.025 m respectively as shown in Figure 2. All the fibres are assumed to be oriented at an angle Φ.

**Figure 2.** Schematic labelled design of laminate & laminated composite beam with transverse surface crack in clamped-free (C-F) configuration

**4.3 Description of used element**

In the present analysis, solid shell 190 (SOLSH 190) element is used as shown in figure 3. SOLSH 190 provides combine properties of the solid and shell elements.

**Figure 3.** Geometry description of solid shell (SOLSH 190) element type

**5. Results and Discussion**

In the present investigation, the effect of various parameters is studied. Fibre volume fraction (V), relative crack depth (a/H), crack location (L1/L), support conditions, and ply angle of fibre (Φ) on transverse natural frequency studied and represented for stacking sequence \((0°/Φ°/0°/Φ°/0°/90°/(90°-Φ°)/0°/(90°- Φ°)/0°).\)
5.1 Influence of Ply angle (Φ) on three least transverse natural frequencies for the cracked hybrid composite beam with relative crack depth (a/H) = 0.6, crack location (L/L) = 0.5 and V=0.5

5.1.1 For (C-F) configuration

![Figure 4. Ply angle (Φ) as a parameter of first natural frequency](image1)

![Figure 5. Ply angle (Φ) as a parameter of second natural frequency](image2)

![Figure 6. Ply angle (Φ) as a parameter of third natural frequency](image3)

5.1.2 For (C-C) configuration

![Figure 7. Ply angle (Φ) as a parameter of first natural frequency](image4)

![Figure 8. Ply angle (Φ) as a parameter of second natural frequency](image5)
Figure 9. Ply angle (Φ) as a parameter of third natural frequency

From figure 4 to 6, it is cleared that minimum natural frequency is observed at 15° ply angle in the presence of transverse crack due to less stiffness of the beam for transverse vibration while the maximum natural frequency at 90° ply angle because of high stiffness of beam in C-F configuration. In C-C configuration the beam became less stiff at 45° and more stiff at 90° for which lowest and highest natural frequencies are observed respectively as shown in figure 7 to 9.

5.2 Influence of relative crack depth (a/H) on three least transverse natural frequencies for the cracked hybrid composite beam with Ply angle (Φ)=90°, crack location (L1/L) = 0.5, and fibre volume fraction (V)=0.5

5.2.1 For (C-F) configuration

Figure 10. Relative crack depth as a function of first natural frequency

Figure 11. Relative crack depth as a function of second natural frequency

Figure 12. Relative crack depth as a function of third natural frequency

5.2.2 For (C-C) configuration
Figure 13. Relative crack depth as a function of first natural frequency

Figure 14. Relative crack depth as a function of second natural frequency

Figure 15. Relative crack depth as a function of third natural frequency

All three natural frequencies are observed minimum and maximum at relative crack depth \((a/H) = 0.9\) and \(0.1\) respectively for both C-F and C-C configuration as shown in figure 10 to 15, because, since the size of crack increases the stiffness value of the beam decreases due to which natural frequency decreases.

5.3 Influence of relative crack location \((L_1/L)\) on three least transverse natural frequencies for the cracked hybrid composite beam with Ply angle \((\Phi) = 90^\circ\), crack depth \((a/H) = 0.5\) and fibre volume fraction \((V) = 0.5\)

5.3.1 For (C-F) configuration

Figure 16. Relative crack location as a function of first natural frequency

Figure 17. Relative crack location as a function of second natural frequency
In C-F configuration least natural frequencies are observed minimum when crack is developed nearer to fixed end as a result of high flexibility of the beam which causes high tendency of vibrations as shown in figures 16 to 18. All three least natural frequencies are observed maximum and minimum on two values of relative crack location because beam became symmetrical in C-C configuration as both ends are fixed so about crack location 0.5, there is a symmetry in trend as shown in figures 19 to 21.

6. Summary and Conclusion
1. It is cleared by the figure 4 to 6, for the cracked beam with the $(0°/Φ°/0°/Φ°/0°/(90-Φ)°/0°/(90°-Φ)°/0°)$ stacking sequence for the crack geometry $(a/H) = 0.6$, $(L_1/L) = 0.5$, all three least transverse natural frequencies are minimum for the value of $Φ$ equals to 15°, maximum at 90° for C-F configuration & by figure 7 to 9, minimum for the value of $Φ$ equals to 45° and maximum at 90° for C-C configuration.

2. It is cleared by the figure 10 to 12, for the cracked beam with the $(0°/Φ°/0°/Φ°/0°/(90°-Φ)°/0°/(90°-Φ)°/0°)$ stacking sequence for the relative crack location $(L_1/L) = 0.5$, fibre volume fraction 0.5 and $Φ$ equals to 90°, all three least transverse natural frequencies are minimum for the value of relative crack depth $(a/H)$ equal to 0.9, maximum at crack depth $(a/H)$ equal to 0.1 in C-F configuration & by figure 13 to 15, minimum for the value of relative crack depth $(a/H)$ equal to 0.9 and maximum at crack depth $(a/H)$ equal to 0.1 but there is sharp decrement is represented between 0.5 to 0.6 value of relative crack depth in the trend of all three natural frequencies in C-C configuration.

3. It is cleared by the figure 16, the lowest value of first natural frequency observed at relative crack location 0.1 and highest at 0.7 and there is a sudden increment in the value of first natural frequency, from 0.2 to 0.3 and again the trend is increasing linearly from 0.3 to 0.7 and again sudden decrement has seen from 0.7 to 0.8 for C-F configuration & by figure 17, lowest value of second natural frequency observed at relative crack location 0.1 and highest at 0.3 in C-F configuration.

4. It is cleared by the figure 18, the lowest value of the third natural frequency observed at relative crack location 0.8 and highest at 0.5 and there is an increment in the value of third natural frequency, from 0.2 to 0.3 and again trend is linearly increasing from 0.3 to 0.5 and linearly decreasing from 0.5 to 0.8 in C-F configuration.

5. It is cleared by the figure 19, the lowest value of first natural frequency observed at relative crack location 0.1 and 0.9 and highest at 0.3 and 0.7 for C-C configuration and trend is making mirror image about 0.5 & by figure 20, lowest value of second natural frequency observed at relative crack location 0.2 and 0.8 and highest at 0.5 for C-C configuration and the trend is making mirror image about 0.5.

6. It is cleared by the figure 21, the lowest value of third natural frequency observed at relative crack location 0.2 and 0.8 and highest at 0.3 and 0.7 for C-C configuration and trend is making mirror image about 0.5.

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