Investigating the effect of delamination size and shape on laminated FRP composites under vibration loading

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Abstract

Fiber Reinforced Polymer (FRP) laminated composites have extensive application in the field of aerospace, marine, sports, bio-medical and lot more. FRP is mostly utilised for its high strength to weight ratio. Since, its failure is catastrophic in nature. There is need to study its failure mechanism. From the previous studies it is found that the most critical defect to the laminate composite is delamination. This delamination degrades its strength and stiffness to much greater extent and leads to catastrophic failure. In this investigation the effect of delamination size and shape on natural frequency of composite laminate using COMSOL Multiphysics. The investigation reveals the reduction in natural frequency with the increment in size of delamination. The study also suggests, the shape of delamination contribute its significant effect on natural frequency.

Keywords

Laminate composite, delamination defect, natural frequency, COMSOL Multiphysics.

Introduction

Laminated composite are very susceptible to out of plane impact loading. Out of plane low velocity impact loading creates defects, barely visible impact damage (BVID), in laminated composites which brings stability reduction and structural degradation. As the name suggest it barely visible to naked eyes but very critical to composite structures, these type of defects are detected by non-destructive testing. Structural integrity of the engineering component from fiber reinforced laminate composite is highly influenced by interlaminar embedded defect. Degree of degradation of mechanical properties greatly depends on the size of delamination defects hiding in between the two lamina. Shape of the delamination decides, how the delamination is going to propagated and leads to catastrophic failure of laminated structures. Therefore, effect of shape of natural frequency also need to be included in the study. In this investigation, size and shape of delamination defect is broadly taken under consideration since these two parameter influence the structural performance of laminate composite.

Numerous analysis has been reported the impact of delamination on performance of laminated composite under different loading condition. It is also reported that the location of delamination, ply sequence and orientation of lamina play significant role. Gadelrab done a numerical analysis on the effect of delamination on the natural frequency of laminated beam with different boundary condition. Study suggested that delamination introduces a local flexibility which decreases the natural frequency of the beam [1]. Engblom et al. numerical study on delamination at different location and sizes reveals that the along with the size of delamination, location of defect also contribute to the natural frequency of the laminate composite [2]. Udupa et al. investigated the effect of delamination location and size in laminated beam with different boundary condition under vibration and concludes that the natural frequency decreased with the reduction in effective longitudinal Young’s modulus of composite laminate. Study also reported that the natural frequency in simply supported condition is higher than the cantilever beam. As stiffness of beam is higher for simply supported condition hence contribute its effect to natural frequency [3]. Shu at al. investigated the effect of delamination in exponentially functionally graded beam. Study supports the effect of size of delamination as reported by other researchers. Adding to the fact that as the ration of young modulus increases natural frequency increases, but this increase become insignificant if longer delamination [4]. Study of axially compressed laminated composite beam-columns with multiple delamination under free vibration by Voyiadjis et al. His study agrees with the size and location of the delamination impact on stiffness and natural frequency. In addition to it, multiple delamination is also studied, results affirm that the multiple delamination is more significant to elastic buckling than the normalized natural frequency for each longitudinal, lateral and moving cases. The amount of degradation of frequency and buckling load is more pronounced for lateral multiple delamination than longitudinal multiple delamination [5].

This study is divided in to two parts, first is comprised of the effect of size of delamination on the different types of material laminate and other part of the study is to investigate the effect of shape of delamination on the natural frequency of different material laminates.

Theory for laminate composite with delamination defect

Market is dominated by laminated composite, as it provides high strength with lesser weight as compared to its conventional material counterpart. This leads to the devolvement of the refined plate theory to eliminate the shortcomings of the classical laminate plate theory (CPLT). Improved global maximum deflection, natural frequency and critical buckling load have been calculated using first order and higher order shear deformation theories [6,7]. But, conventional theories based on single continuous and smooth displacement field yield poor estimation of through thickness interlaminar stresses. Since failure mode are related to interlaminar stresses, these refined plate theories to model the local behaviour of plate accurately are needed. The layer-wise plate theory predicts accurate local response like interlaminar stresses, in-plane stresses and displacement, etc[8,9].

Simulation is done with the help of COMSOL Multiphysics. Here, layerwise (LW) theory has been used to model interface where different load and constraints can be applied, which later is used to evaluate stresses and other variables in each layer of shell. To model a laminate composite shell a 2D surface geometry is required as a base surface and to add layers to it layered material node is used, layered material functionality to model several stacked on the top of each other having different thickness, material properties, and fiber orientations. Mesh size and material of the interface can also be changed as required.

For the simulation of delamination of laminate composite under vibration solid mechanics module is used. To model a laminate a base surface of 250 mm x 250 mm was formed first, to facilitate stacking for laminate. The laminate composite constitutes of three laminas of 0.5 mm orientation of 90^o, 45^o and 0^o from bottom to top, material (graphite-epoxy) has been assigned to each layer. Laminas are bonded to each other with the help of epoxy. The delamination in laminated composite is induced between layer second and third with the help of Thin elastic layer, Interface feature available in the layered shell interface. Boundary condition is given to the laminate as of cantilever. The 2D triangular elements are used to simulate laminate composite. Approximately 4000 elements are used to simulate laminate composite. Study comprised of two parts. One is effect of delamination size and other is the effect of delamination shape. First study is conducted for delamination size, for this four square size delamination of 50mm x 50 mm, 100mm x 100mm, 125mm x 125mm and 150mm x 150 mm. Second study is conducted for different shape, for this delamination of square shape 120mm x120mm, rectangular shape of 72mm x 200mm and 200mm x 72mm by keeping the area of delamination same for comparison. The position of delamination is kept at the centre of laminate. Left side of the laminate is fixed. The properties of graphite-epoxy is listed below in the table no 1 that is used in the simulation of laminated composite [10].

Table no. 1 Properties of Graphite-Epoxy(FRP)

Elastic properties	Graphite-Epoxy
E_x (GPa)	181.00
$E_y = E_z$ (GPa)	10.30
$G_{xy} = G_{xz}$ (GPa)	7.17
G_{yz} (GPa)	4.00
$m_{xy} = m_{xz}$	0.28
m_{yz}	0.30

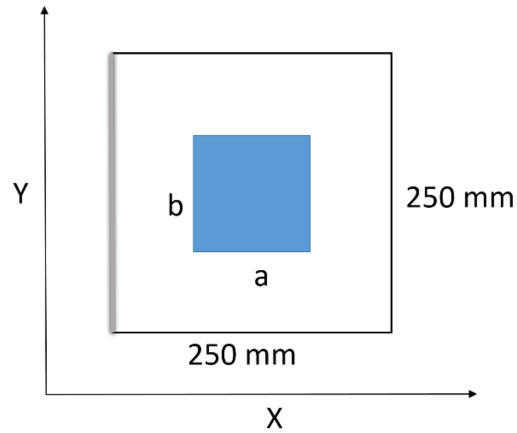

Figure 1. Layout of the delamination in graphite epoxy laminate composite

Results and Discussion

Results shows that delamination size has an impact on the natural frequency of graphite laminated composite. As the delamination size increase it is observed that the natural frequency decreases simultaneously. Systematic study has been conducted to notice the behaviour of delamination size on natural frequency. From figure 2 it is observed that the mode shape of the square laminate with square delamination is different for the different delamination size at 10th mode. Different behaviour of the mode shapes where observed for different delamination size of the graphite-epoxy laminated composite. This is the fact that as the delamination size increases it degrade the global stiffness of the laminate composite which is the main cause behind the reduction in natural frequency of the laminated composites.

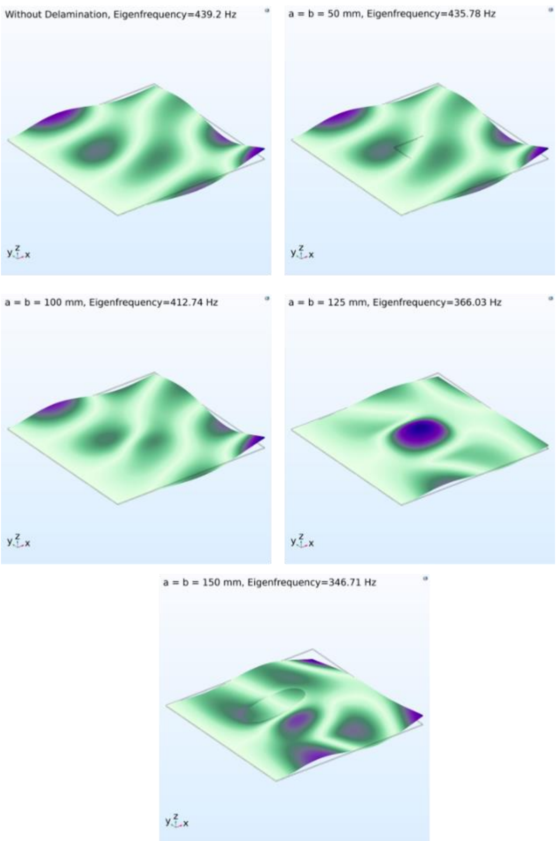

Figure 2. The mode shape of laminate at 10th mode for square delamination of different size.

The variation of natural frequency with respect to delamination size is plotted in figure 3.

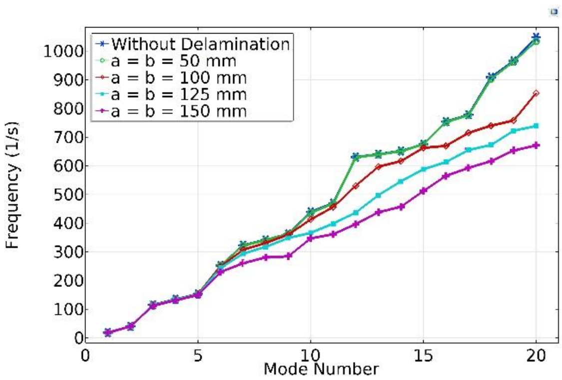

Figure 3. variation of natural frequency with respect to mode no. of different square size delamination

The decrement in natural frequency with respect to increment in delamination size is due the effect to loss in local stiffness in laminate composite. This loss in local stiffness in laminate contribute to global stiffness of laminate which leads to the decrement of natural frequency of the laminate composite.

Table no. 2 represents data from the simulation of square delamination with different size. (Here WD represents without delamination intact laminated composite)

Table no. 2 Natural frequency data for square delamination with increasing delamination size with respect to mode.

Mode no.	WD	a,b= 50 (mm)	a,b= 100 (mm)	a,b= 125 (mm)	a,b= 150 (mm)
1	18.4	18.4	18.3	18.2	18.1
2	39.8	39.8	39.8	39.7	39.7
3	115.2	115.2	114.8	113.9	111.7
4	134.4	134.4	133.9	132.9	130.9
5	153.1	153.1	152.2	151	148.8
6	252	251.9	249.2	243.7	229.4
7	323	321.5	306.7	293.7	260.1
8	341.3	340.4	330.8	317.2	280.4
9	362.1	362	359.4	347.9	284
10	439.2	435.8	412.7	366	346.7
11	469.7	468.1	456	398.4	361.2
12	630	629.4	530.2	436.6	396.8
13	640.1	639	596.6	497.4	437.8
14	651.6	650.6	616.2	545.5	456.9
15	674.8	674.5	662.4	587.7	511.7
16	753.9	752.2	669.2	612.8	564.8
17	777.7	776.2	714.5	654.8	592.5
18	908.7	902.6	739.8	672.3	615.9
19	965.6	962.8	757.7	722	653.1
20	1047.7	1034.2	853.1	738.3	670.7

Second part of the study is to evaluate the effect of shape on natural frequency of laminate. Shape of the delamination contribute its effect on natural frequency of laminate. To study its effect three shape are used one is square of 120mm x 120mm and others are rectangle with different orientation (72mm x 200mm and 200mm x 72mm). Effect of shapes on natural frequency is shown with the help of plot shown in figure 4.

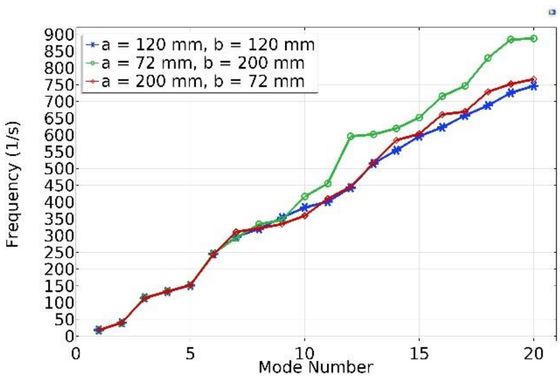

Figure 4. variation of natural frequency with respect to mode no. of different delamination shapes

From figure 4. This is clear that the change in natural frequency with respect to shape of delamination is not dominant when mode no. is less. But it can be deduced from the figure that as the mode no. increases the effect of shape on natural frequency becomes dominant.

Table no. 3 represents the data from the simulation results of effect of shape of delamination on natural frequency of the laminated composite. From the data its self it is evident that at lower mode the variation is very little but variation is significant at higher mode no.

Table no. 3 Natural frequency data for different shape of delamination with respect to mode

Mode	120mm x120mm	72mm x200mm	200mm x72mm
1	18.2	18.3	18.3
2	39.7	39.7	39.7
3	114.1	114.9	113.1
4	133.1	133.5	133.3
5	151.2	151.9	152.2
6	245	245.9	243
7	296.2	293.6	311.2
8	320.3	333.7	321.5
9	353.6	347	334.4
10	383.9	416.6	359.3
11	401.1	455.3	410
12	442.6	596	445.6
13	515.1	601.8	517
14	554.5	619.6	584.4
15	596.4	651.9	603.3
16	622.8	715.7	661
17	658.2	746.5	669.6
18	688	829.8	728.7
19	725.8	884.9	752.1
20	746.4	887.7	766.4

Conclusion

From the present study it can be conclude that as the size of the delamination increases the natural frequency of the laminate decreases. This study also conclude that the shape also has great impact on the natural frequency of the laminate. This study established the fact that shape must also considered while analysing natural frequency of the laminate composite.

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