

Numerical and Experimental Investigations on Vibration of Delaminated Composite Shell

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ABSTRACT

The laminated composite shell structures are acting as most desired structure in various field of modern engineering. These are frequently used in various industries such as aerospace, construction, nuclear field, automotive, petrochemical industries, ship & rocket building due to high specific strength and stiffness of composite materials. Because of their ability to meet the design requirements of strength & stiffness, composite materials have greater importance in recent years. But during the manufacturing and service life, there will be delamination damage in composite laminate which is not visible due to embedded within the composite structures. However it reduces the strength and stiffness of the laminated structures and also effects on the vibration characteristics of the structures. The present work deals with the numerical and experimental investigation on free vibration characteristics of delaminated composite cylindrical shell. Experimental setup and procedure of the modal testing were described. Fabrication procedure of the shell was also described. Natural frequencies were determined using a computer programme in MATLAB environment based on finite element method (FEM). The results using the present formulation were compared with other existing literature. Also comparison was made between the experimental values and numerical predictions using FEM. The effects of percentage delamination on natural frequency of the composite shell were studied. The influence of various parameters i.e. curvature, delamination area, ply lay-up and aspect ratio on vibration response were discussed for different boundary conditions.

INTRODUCTION

Composite materials are frequently used in various applications such as aerospace field, construction of dome roof structures in airport, nuclear field, automotive industries, petrochemical industries, ship & rocket building due to high specific strength and stiffness, thermal characteristics etc.

Shell panels have more priority in modern engineering applications because of their ability to meet the design criteria of strength, stiffness and aesthetic requirements. Due to distinct structural advantages, laminated curved panels have been extensively used in aerospace industries such as fuselage, aircraft wings etc. where structures are mostly. Shell members have often been used in modern structural design applications. Comprehensive understanding of the mechanical behaviour of composite shell is important to assure the unification of these structures during service life.

But there will be delamination in composite laminate during manufacturing (e.g. incomplete wetting, air entrapment) or during service life (e.g. low velocity impact, bird strikes). They may not be visible or barely visible on the surface, since they are embedded within the composite structures.

However the presence of delamination may significantly reduce the strength and stiffness of the structures and also may affect some design parameters such as the vibration characteristics of the structure (e.g. natural frequency and mode shapes).

This is because the desired performance can be achieved by controlling the ply orientation and the stacking sequence can alter their structural properties leading to an optimal design. Since the safety and durability of the structures are greatly affected by the delamination presence in laminated curved panel, a comprehensive understanding of the delamination behaviour is more vital in the assessment of structural performance of laminated composites.

Shell members with delamination may result in significant changes to their dynamic characteristics. So it plays a critical role in the structural element from the point of design aspect. Therefore it is essential to study the effects of delamination on the composite shell.

REVIEW OF LITERATURE

Introduction

The strength and stiffness of the structures are greatly affected due to the delamination present in the composite specimens and subsequently it influence on the vibration characteristics of the composite structures. Therefore this delamination behaviour is an importance aspect during the structural design of laminated composite structures. There are so many researcher investigated on laminated composite shell for free vibration analysis. But the available literature on free vibration of the delaminated composite shell is very limited. The studies in this chapter are grouped into two parts as follows.

- Review on laminated composite shells.
- Review on composite shells with delamination.

Reviews of Laminated Shells

Plenty of studies are available on the vibration analysis of laminated composite shells. The earlier investigations on dynamics analysis of composite shells is reviewed by Qatu, Sullivan and Wang (2010). In an earlier study, free vibration analysis of laminated cylindrical shells based on Sander's first approximation theory was studied by Bert and Kumar (1982). The theoretical formulation on free vibration analysis of cross ply laminated cylindrical panels was developed by Soldatos (1984). He also compared the numerical results of vibration with most of thin shell theories. Librescu *et al.* (1989) deals with the evidence of a shear deformable theory of cross-ply laminated composite shallow shells and also investigated the vibration analysis and static buckling problems of doubly curved shallow panels for a variety of boundary conditions. Narita and Ohta (1993) studied the free vibration analysis of laminated cylindrical shell using finite element approach. He investigated the vibration characteristics by varying the composite material constants and cross ply stacking sequences with typical edge conditions. Lam and Loy (1995) presented the analysis on natural frequencies of the forward and backward modes of thin rotating laminated cylindrical shells.

A similar layer wise laminated shell theory was developed for doubly curved thick composite panels subjected to different combination of three dimension boundary conditions. Piece-wise continuous, quadratic interpolation functions through the thickness, were combined with beam function expansions in the two in plane directions of the laminate, to model the dynamic behaviour of laminated spherical panels. Singh (1999) studied the free vibration analysis of doubly curved deep sandwich panels. Natural frequencies are obtained by using Rayleigh-Ritz method. The formulation was developed for the analysis of open panels circumscribed by four curvilinear edges. Numerical results were obtained for circular, cylindrical and spherical sandwich panels with one edge clamped and other remaining free and also two opposite edges clamped and two others free.

Lam and Qian (2000) analysed the free vibration of thick symmetric angle ply laminated composite cylindrical shells using first order shear deformation theory. The frequency characteristics for thick symmetric angle ply laminated composite cylindrical shells with different h/R ratio and L/R ratios are studied in comparison with those of symmetric cross ply laminates. Also the author investigated the influence of lamination angle and number of lamination layers on frequency with simply supported boundary condition. Sahu and Datta (2001) studied the vibration and parametric resonance characteristics of laminated composite doubly curved shells subjected to various in-plane static and periodic loadings using finite element analysis based on first order shear deformation theory. The effects of number of layers, static load factor, side to thickness ratio, shallowness ratio, boundary conditions, degree of orthotropic, ply orientations and various load parameters on the principal instability regions of doubly curved panels were studied in this paper.

Bhattacharya *et al.* (2002) developed a shear deformable shell element based on Reissner's hypothesis for the analysis of smart laminated composite shells. The electric field was defined in the curvilinear co-ordinate system. Lame's parameters and the radii of curvature are generated within the model. He studied the active vibration control of laminated spherical shells by considering radius of curvature and different ply lay-up.. Sahu and Datta (2002) studied the frequencies of vibration and instability behaviour of curved panels with cut outs subjected to in-plane static and periodic compressive edge loadings using finite element method. Sairam and Sreedharbabu (2002) investigated on natural frequency of composite spherical shell cap with and without a cut-out using the finite element method based on a higher-order shear deformation theory. The author observed that, the fundamental frequency of composite spherical panels generally increases with the increase in cut-out size except in the case of simply supported orthotropic spherical shell cap with fibres along meridional direction in which the fundamental frequency decreases. The dynamic analysis of laminated cross-ply composite non-circular thick cylindrical shells subjected to thermal/ mechanical load is carried out based on higher-order theory was studied by Ganapathi *et al.* (2002).

Zhao *et al* (2004) analysed the free vibration of laminated two side simply supported cylindrical panels by the mesh free kp-Ritz method. This study also examined the effects of different curved edge boundary conditions on the frequency characteristics of cylindrical panels. Latifa and Sinha (2005) improved the finite element analysis of multi-layered, doubly curved composite shells by using Koiter's shell theory and Mindlin's hypotheses. He presented the free

vibration analysis of doubly curved, laminated composite shells. The nonlinear free vibration behaviour of laminated composite shells subjected to hygro thermal environments using the finite element method based on first-order shear deformation theory is investigated by Swamy and Sinha (2007). The analysis is carried out by varying the curvature ratios and side to thickness ratios of composite cylindrical shell, spherical shell and hyperbolic paraboloid shell panels with simply supported boundary conditions. Nguyen-van *et al.* (2008) analysed laminated plate/shell structures based on FSDT with a quadrilateral element. The author presented free vibration analysis of laminated composite plate/shell structures of various shapes, span to thickness ratio, boundary conditions and lay-up sequences. Oktem and Chaudhuri (2009) used higher order theory for the vibration behaviour of cross ply doubly curved panels. The author determined the natural frequency by considering the influence of curvature, lamination, material properties, thickness as well as their interactions. He used all the edges simply supported boundary conditions. Kurpa *et al* (2010) studied on the vibration behavior of laminated composite shells by using R-function theory and variational methods based on first order shear deformation theory. They investigated on the dynamic behavior of the shallow shell by considering the influence of different parameters such as curvature, geometry, ply orientation and boundary conditions. Alijani *et al* (2011) investigated on the nonlinear vibration analysis of doubly curved shell due to thermal effects. Nonlinear HSDT was considered for the geometric nonlinear analysis of functionally graded shells. They discussed the effects of FGM law index, thickness ratio and temperature variations on the frequency amplitude nonlinear response. Mochida *et al* (2012) studied the dynamic behavior of the double curved shallow shell by using Superposition-Galerk in Method (SGM). Also studied the natural frequency of thin shells by considering the different curvature ratio, aspect ratio and boundary conditions. The free vibration analysis of laminated conical shells was investigated by Civalek (2013) through discrete singular convolution method based on the shear deformation theory. Also examined the influence of geometry and material properties on the dynamic behavior of conical shell. Kouchakzadeh and Shakouri (2014) determined the dynamic characteristics of two joined cross ply laminated conical shells using Donnell's shallow shell theory. Also studied the influence of semi-vertex angle, meridional lengths and shell thicknesses on the natural frequencies of conical shells.

Reviews of Shells Withd Elamination

The literatures containing vibrations of composite shells with delamination are scarce in literature. The free vibration and transient response of multiple delaminated doubly curved composite panels subjected to hygro thermal environment was analyzed by Parhi *et al.* (2001) using finite element formulation based on first order shear deformation theory. The author observed that the frequency decreases with increase in moisture content and temperature for any delamination area. It also observed that, the vibration characteristic of shells are more influenced by curvature. Liu and Yu (2003) studied the finite element modelling of delamination by layer wise shell element allowing for inter laminar displacements. In his paper, he gave a brief review of the layer wise shell element. He considered geometrically non-linear analysis involving finite rotation and finite strain. According to his results he suggested that central delamination is more damaging than the edge and corner delamination for it causes a greater reduction in the strength and integrity of the plate, in particular in the early stage of shear mode delamination. Kim and Cho (2003) derived an higher order shell theory for composite shell with several delamination. It studied the effects of number, shape, size and locations of the delamination. Yang and Fu (2006) studied the composite curved panel for delamination growth. They also developed a equation for buckling analysis of single curved laminated panel based on the vibrational principle of moving boundary. The author analysed on growth of delamination by considering the effects of delamination size, stacking sequence, material properties and boundary conditions. Jinhua and Yiming (2007) analysed the dynamic stability for composite single curved panel with delamination.

Park and Lee (2009) investigated on delaminated spherical shell by considering in-plane pulsating forces for dynamic stability analysis. In this study, a finite element formulation was developed based on higher order shell theory. They presented the dynamic analysis dueto the effects of the radius to length ratio, size and location of delamination, fiber lay-up etc. It also investigated the effects of the amount of the periodic in-plane load on the instability region. Lee and Chung (2010) developed a formulation for vibration analysis of curved panels with delamination around a central cut-out using finite element analysis. In this literature, it mainly shows that the effect of the curvature to length ratio, delamination and cut out size, the number of layer and the location of delamination in the layer direction. Nanda and Sahu (2012) studied the vibration behaviour of the delaminated composite shell with delamination by using finite element method based on first order shear deformation theory. In this paper, the author determined the natural frequencies of the delaminated cylindrical, spherical and hyperbolic paraboloid shells due to the effect of delamination size and number of layers.

Objective And Scope Of Present Investigation

Various analytical and numerical methods have been used in studying the dynamic behaviour of delaminated composite shells. Experimental studies on vibration of delaminated shells are not available in open literature. The present work deals with an experimental investigations on free vibration analysis of composite cylindrical shell by considering the effects of curvature, percentage of delamination area, aspect ratio, number of layer and different boundary condition. The experimental results are compared with prediction based on finite element methods.

MATHEMATICAL FORMULATION

In this chapter the finite element mathematical formulation for vibration of the shell structures of various geometries with delamination is carried out. For analysis, here a double curved panel of composite laminate is considered. The boundary conditions are incorporated in the most general manner.

Finite Element Analysis

A composite doubly curved panel as shown in Fig: 1 consists of „n“ number of laminate is considered for analysis.. The sides of panel in x and y directions are represented as a and b respectively.

Governing Equation For Free Vibration Analysis

The finite element formulation is developed for the dynamic analysis of laminated composite shells with delamination using the first order shear deformation theory. An eight-nodded continuous isoparametric shell element is employed in the present analysis with five degrees

Of freedom viz. u, v, w, θ_x , and θ_y at each node.

The eigen value equation for the free vibration analysis of delaminated composite shell can be expressed as

$$([K] - \omega^2[M])\{\Phi\} = \{0\} \quad (19)$$

Where [K] and [M] are the global stiffness and global mass matrices, ω is the natural frequency and Φ is the corresponding eigenvectors i.e. mode shape.

Computer Programme

A computer programme is developed by using MATLAB environment to perform all the necessary computations. The element stiffness matrix and element mass matrix are derived using above formulation. Numerical integration technique by Gaussian quadrature is adopted for element matrices. The global matrices are obtained by assembling the corresponding element matrices. The boundary conditions are imposed restraining the generalised displacements in different nodes of the discretized structures. Different delamination such as 6.25%, 25% and 56.25% of area of shell are considered for the vibration analysis of composite cylindrical shell as shown in Appendix.

EXPERIMENTAL PROGRAMME

Introduction

In this chapter, the details of the experimental works are conducted on the vibration analysis of woven roving composite cylindrical shells with delamination. Therefore composite shells are fabricated for the aforementioned experimental work and the material properties are found out by tensile test as per ASTM D3039/D3039M (2008) guidelines to characterise the delaminated composite shells. The experimental results are compared with the analytical or numerical predictions.

Materials

For fabrication of laminated composite specimens which are required for tensile as well as free vibration testing, following materials were used as

- ❖ Woven roving glass fiber
- ❖ Epoxy
- ❖ Hardener
- ❖ Polyvinyl alcohol spray
- ❖ Teflon film for artificial delamination

Fabrication of Specimens For Tensile Testing

In the present investigation, the glass: epoxy laminate was fabricated in a proportion of 50:50 by weight fractions of fibre: matrix. Lapox L12 is a liquid, unmodified epoxy resin of medium viscosity and hardener K6 with low viscosity were used with woven roving glass fiber to fabricate the laminated composite specimen. Woven roving glass fibers were cut into required shape and size for fabrication. Epoxy resin matrix was prepared by using 8% hardeners. A flat rigid platform was selected as a contact mould in order to get the flat samples for tensile testing. Hand lay-up method was used for combine the glass fiber with epoxy resin of required sequence. The mould releasing sheet was held on the flat plywood and a polyvinyl alcohol spray was used as releasing agent on plastic sheet. A gel coat was applied over the plastic sheet by brush to get the smooth surface and also protect the fiber from direct contact of environment.

A releasing sheet with polyvinyl alcohol thin film was placed over the lay-up and mould to prevent the bonding between layup and mould surface. Then the prepared specimens were cured under normal temperature for 48hrs. The releasing sheets were removed from the mould after the proper curing of specimen. From the laminates, the specimens were cut into 250 x 25mm (Length x Breadth) size as per ASTM D2344/ D2344 specification by diamond cutter and the thickness was taken as per the actual measurement. The average thickness of specimens for tensile test is found 2.62mm.

Detemination Of Material Constants

Laminated composite plates behave like ortho tropic lamina, the characteristics of which can Be defined by material constants i.e. E_1, E_2, G_{12} and ν_{12} . Laminate having eight layers was casted to estimate its properties. An instrument INSTRON 1195 UTM was used to perform the tensile test on samples cut along longitudinal, transverse and 45° to the longitudinal direction as described in ASTM standard D3039/D3039M (2008). The tensile test specimens are having a constant rectangular cross section in all the cases. The dimensions of the specimen are mentioned below in Table 1.

Table1: Size of the specimen for tensile testing

Length(mm)	Width(mm)	Thickness(mm)
250	25	2.62

The samples were cut from the casted plate as per requirement by tile cutter or diamond cutter. In this study, six specimens were tested as shown in Fig 5 for mean values of material constants.

For measuring the Young's modulus, the specimen was loaded in INSTRON 1195 UTM (as shown in Figure) with a rate of loading of 0.2 mm/minute. Specimens were fixed in the upper jaw first and then gripped in the movable jaw (lower jaw). Gripping of the specimen should be as much as possible to prevent the slippage. Here, it was taken as 50mm in each side for gripping. Initially strain was kept at zero. The load, as well as the extension, was recorded digitally with the help of a load cell and an extensometer respectively. Crack pattern of specimen during testing is shown in Figure 7. From these data obtained, stress vs strain curve was plotted and the initial slope of this curve gives the young's modulus of the materials.

Fabrication of Specimens For Free Vibration Testing

The fabrication procedure for preparation of the shell sample in case of vibration study was same as that of plate only difference is that instead of flat ply, fabricated moulds (as shown in Fig.8) of different curvature were selected for preparing the specimen. Hand lay-up method was used for combine the glass fiber with epoxy resin of eight layers of 0-90° oriented. A Teflon tape was introduced at mid plane 6.25%, 25%, 56.25% central delamination of specimen during casting. After completion of all eight layers of fiber lay-up with resin matrix, again a releasing sheet with polyvinyl alcohol agent were placed over the lay-up and mould to prevent the bonding of epoxy from ply and mould surface. One cover mould of specified curvature with filled sand was kept over the casted mould and left for a 48hrs for curing purpose under normal temperature. Then samples are being transported and cut into required size for vibration testing. A size of 235mm x 235mm shell samples are prepared for conducting the vibration test.

The process of casting for laminated composite cylindrical shells. Fig. shows the introduction of artificial delamination during casting of composite cylindrical shells.



Fig. 1



Fig. 2

Use of gel coat on plastic sheet, Fig Placing of woven roving glass fibre on gel coat & removal of air entrapment using steel roller

The geometrical dimensions (i.e. length, breadth, and thickness), ply orientations and percentage of delamination of the fabricated shells are shown in Table 2. All the specimens described in Table 3 were tested for its vibration characteristics. To examine the influence of boundary condition on the natural frequency of delaminated shells, the samples were tested for three different boundary conditions (B.C) i.e. for four sides free, two opposite sides simply supported and four sides clamped. For different boundary conditions, one iron frame was used. Some of the test specimens with different boundary conditions i.e. F-F-F-F, S-F- S-F and C-C-C-C.

Equipment for Vibration Test

The apparatus which are used in free vibration test are

- Modal hammer (type2302-5)
- Accelerometer(type4507)
- FFT Analyzer(Bruel & Kajer FFT analyzer type-3560)
- PULSE software.

Procedure for Free Vibration Test

The set up and the procedure for the free vibration test are described sequentially as given below. An iron frame was kept for creating the different boundary condition. For all sides free boundary condition, the test specimens were fitted with the string attached to the iron frame as shown in Fig 15. Similarly for C-C-C-C and S-F-S-F boundary conditions, special arrangements have been made by cast iron frame/plate attached to the main iron frame as shown in Fig 16 and Fig17 respectively. The connection of FFT analyser, laptop, transducer, modal hammer and accelerometer with laptop were done. The pulse lab shop version-10.0 software key was inserted to the laptop port. Accelerometer (B&K, 4507) was attached to the sample by means of bee wax and then fitted to the specified frame for different boundary condition. Now with modal hammer (2302-5), a specimen was excited by means of small impact on particular points with 5 times and care should be taken the impact should be perpendicular to the point of contact on the specimen surface. The input signals were captured by the force transducer fixed on the modal hammer. Then the accelerometer sensed the resulting vibration. Both input and output signals are investigated by spectrum analyser and resulting FRF are transmitted to the system. By using pulse software, the output from the analyser was displayed on the analyser screen. Then the natural frequencies of the fitted specimens are measured by moving the cursor to peak of the FRF graph.

RESULTS AND DISCUSSION

INTRODUCTION

The free vibration results i.e. natural frequency of composite shell structures with delamination are numerically studied by using the above FEM formulation in this chapter. The effect of different constraints i.e. curvature radius to side ratio, area delamination, numbers of layers, aspect ratio on different boundary conditions on the vibration of delaminated composite shells are presented using numerical method. The experimental results on free vibration of composite shells are also used to support the numerical predictions. The study is made for vibration analysis as following objectives.

- i. Comparison with previous studies.
- ii. Numerical and experimental results.

Vibration Analysis

The dynamic behaviours of the composite structures are greatly affected by the delamination. Therefore in the present investigation, natural frequencies of delaminated composite cylindrical shells were determined both finite element analysis and experimental programme. The effects of different constraints like delamination area, curvature to side ratio, boundary condition, aspect ratio, and number of layers were studied critically. For free vibration analysis, numerical results are compared with other existing literature. Experimental results are also presented on natural frequency of composite cylindrical shells with delamination.

Comparison with Previous Studies

In order to compute the vibration analysis of composite shell numerically, MATLAB programs are developed based on finite element formulation and delamination modelling mentioned in earlier chapter. For free vibration of laminated composite plate with different boundary conditions, comparison was made between the present numerical results with the other existing literature by Ju *et al.* (1995) using FEM to validate the program.

Effects of Curvature:

To study the effects of curvature on vibration characteristics of laminated composite shell, three different types of specimens are casted whose radius of curvature are $R_1=0.91\text{m}$, $R_2=1.2625\text{m}$ and $R_3=2.09\text{m}$. The geometry and

material properties are same as given in earlier. Both the numerical and experimental natural frequency of laminated composite plate at F-F-F-F boundary condition is shown in Fig 23. Similarly, the natural frequencies for shells having three different radius of curvatures i.e. 0.91m, 1.2625m and 2.09m respectively.

From graph, it is observed that there is a good agreement between numerical and experimental results for fundamental natural frequency. The natural frequency on laminated plate and shells for different curvature radius to side ratio (R/b) are given in Table 6. It represents that at higher modes, there is significant decrease in natural frequency with increase in curvature to side ratio.

Effects of Delamination Area:

The effects of percentage delamination on vibration characteristics of an eight layered composite shell were studied by introducing central mid-plane delamination at 6.25%, 25% and 56.25% of specimen area. The least natural frequency of the delaminated cross ply composite shells with four sides free boundary condition is illustrated in Figure: 27 as a function of delamination area. The experimental fundamental frequencies of 6.25%, 25% and 56.25% delaminated shells are found to decrease by 5%, 10% and 15 % respectively as compared to the laminated shell. This may due to the reduction in stiffness of the laminates.

The same investigation was extended to the composite shells with S-F-S-F (two opposite sides simple supported and others free), C-C-C-C boundary conditions.

From this investigation, it is observed that at 6.25% delamination area, the frequency of specimen is least affected at C-C-C-C boundary condition as compared to other two boundary conditions and also shows that the fundamental natural frequencies are considerable affects due to large delamination area at all three boundary conditions. It is also concluded from this investigation, the natural frequency decreases due to the increase in delamination area.

Effects of Number of Layers of Laminate:

To study the influence of number of layers on vibration behaviour of cross ply composite cylindrical shell with 25% are delamination, samples are prepared having 4, 8, and 12 plies. The specimen densities are calculated as 1650 kg/m³ and 1627 kg/m³ for 4 layers and 12 layers respectively. Both the numerical and experimental values of natural frequency with number of layers are depicted in Figure: 30. From this graph, it shows that due to increase in number of layer, the frequency of shell also increases. And also observe that the fundamental frequency of composite shell of 25% delaminated shell for 8 layers and 12 layers is increased by 2 times and 2.8 times respectively with respect to 4 layered laminates. This result indicates that relatively more number of layers have considerable positive effect on the stiffness of delaminated composite shell.

Effects of Aspect Ratio:

Three different aspect ratios such as $a/b=1$, $a/b=1.5$, and $a/b=2$ are taken in this present work to examine the influence of aspect ratio on vibration characteristics of 25% delaminated composite cylindrical shells. For different aspect ratios, the shell dimension varied. For aspect ratio i.e. $a/b=1$, both length and width are considered as 235mm. For $a/b=1.5$, length and width are taken as 237mm and 158mm respectively. Similarly for $a/b=2$, length and width are considered as 236mm and 118mm respectively. The variations of fundamental frequency with aspect ratios for both numerically and experimentally are depicted in Fig 31. It is found that the experimental fundamental natural frequency of 25% delaminated composite shell with F-F-F-F boundary condition for 1.5 & 2.0 aspect ratio increases by 40% and 85% respectively as compared to 1.0 aspect ratio. Also it indicates that with increase in aspect ratio, the fundamental natural frequency of a delaminated composite shell increases.

Effects of Boundary Condition:

In order to carry out the influence of boundary conditions on natural frequencies of delaminated shells, three types of boundary conditions are considered in this investigation, i.e. F-F-F-F (four edges free end), F-S-F-S (two opposite edges free and other two edges simply supported), and C-C-C-C (four edges clamped). Here specimen of eight layered cross ply composite shell having 25% delamination was taken for the study of influence of boundary conditions.

Both numerical and experimental natural frequencies of composite cylindrical shell with 25% are a delamination at different boundary conditions are presented From this Table, It is found that the first, second and third mode frequencies were least for S-F-S-F (two opposite edges simply supported and other two edges free) boundary condition and the maximum for C-C-C-C boundary condition. The fundamental frequency for 25% delaminated shell at F-F-F-F and S-F-S-F boundary conditions are decreased by 77.52% and 86.39% respectively with respect to C-C-C-C boundary condition. This experimental result represents that the natural frequency of delaminated shells are significantly dependent on the boundary conditions.

Pulse Report:

The Natural frequencies of the free vibration analysis are found out experimentally by using pulse software. Typical pulse reports for the laminated composite shell (for a/b ratio 1.0, and 25% of delamination) are shown in Fig: 32 and

Fig: 33. The peaks of the FRF shown in Fig: 29 give the different natural frequencies of vibration. The coherence shown in Fig: 33 gives indication of the accuracy of measurement.

CONCLUSION

The present investigation deals with the study of the free vibration characteristics of delaminated composite shells. The formulation has been developed by using finite element approach for studying the instability region of mid plane delaminated composite shell. Both numerical and experimental results are obtained for the free vibration characteristics of delaminated composite shells with the effects of different parameters like delamination size, curvature to side ratio, aspect ratio, ply orientation, number of layers of lamina, fiber orientations, boundary conditions etc. From this investigation, we found the following concluding remarks during the analysis of natural frequency of delaminated composite cylindrical shells.

- A detailed formulation is presented and a program is developed in MATLAB environment for the free vibration of delaminated composite shell
- Both numerical predictions and experimental results on vibration of shell panels agrees well.
- The natural frequency of shells increases as compared to plates due to curvature of panel.
- Due to decrease in radius of curvature to side ratio, the frequency of vibration of composite shell increases further.
- There is a decrease in natural frequency of composite shell with increase in percentage of delamination irrespective of all the boundary conditions in woven fiber composite specimens due to reduction in stiffness.
- The fundamental frequency of cylindrical shell with fixed delamination increases due to increase in number of layers due to bending stretching coupling.
- It is observed that there is an increase in vibration characteristic of composite shell with increase in aspect ratio.

The natural frequencies of delaminated shells also vary with different boundary condition. It is observed that the fundamental frequency for C-C-C boundary condition is maximum due to restraint at the edges. However, the S-F-S-F supported delaminated shells shows least frequency among the three conditions tested.

From the above discussion, the vibration behaviour of delaminated shells is influenced by the geometry, material, boundary conditions, the size and position of the delamination. The presence of delamination weakens the structure from the point of view of vibration behavior and causes resonance due to reduction in natural frequency. So delaminations play a critical role on the vibration behavior of the structures. So the designer has to be careful while dealing with structures subjected to delamination. This can be used to the advantage of tailoring during design of delaminated composite structure. The vibration results of the delaminated composite panels can be used as a tool for structural health monitoring, identification of delamination location and extend of damage in composites and also helps in assessment of structural integrity of composite structures.

Future Scope of Research

In the present investigation, the natural frequency of delaminated composite shell was determined numerically and experimentally. The effects of various parameters like delamination area, ply lay-up, aspect ratio, different curvature to side ratio, boundary condition was studied. The further scope of the present study can be extending as follows.

- The present study deals with the square size delamination. This may be extended for different shape of delamination.
- For single delaminated shell, the delamination is considered here is mid plane. So arbitrary location may be taken into account for further extension.
- Free vibration of multiple delaminated shells may be extended.
- The present study is based on linear range of analysis. It can also be extended for nonlinear analysis.
- The effects of damping on instability regions of delaminated composite shells can be extended.
- Free vibration of composite shells with delamination due to hygro thermal effects can be studied.
- Buckling analysis and dynamic stability of delaminated composite shells can be studied.

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