Non-Linear Structural Response Of Multiscale Composite Panels

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Abstract

Composite hull panels in the form of flat and curved panels find wide applications ranging from aircraft, spacecraft, surface ships and underwater vehicles. In all these applications the laminated composite panels are being subjected to different loading conditions, among them air blast load is of significant importance. In this study, non-linear structural response of carbon nanotube (CNT) reinforced multiscale composite (Glass Fiber/CNT/Epoxy) panels subjected to air blast loading is studied using commercially available finite element analysis software ANSYS. Three types of panels which are considered for the study are flat, concave and convex. Numerical homogenization is employed to evaluate the effective elastic properties of randomly distributed CNT based multiscale composites. The dynamic response of multiscale composites is compared with the conventional composite materials under clamped and simply supported boundary conditions.

Keywords:- CNT Reinforced Composite Panels; Effective Elastic Properties; Finite Element Method; Air blast loading;

1. Introduction

Carbon nanotubes (CNTs) discovered by Iijima in 1991 [1], have attracted researcher's great attention due to their outstanding mechanical properties such as high strength, stiffness and resilience, as well as superior electrical and thermal properties. Computational approach can play a significant role in the development of the CNT reinforced composites. Although CNTs embedded in a matrix have modeled and analyzed successfully using molecular dynamics [2, 3] and continuum mechanics models [4-8], there have been very few reported studies in modeling Multiscale Composites.

Composite hull panels in the form of flat and curved panels find wide applications ranging from aircraft, spacecraft, surface ships and underwater vehicles. In all these applications the laminated composite panels are being subjected to different loading conditions, among them air blast load is of significant importance.

Under, time-dependent pressure loading such as air blast load, the structural components undergo large deflections over a very short time span, requiring geometrically non-linear dynamic analysis for investigation of their response. Geometric nonlinearity is the change in the elastic deformation characteristics of the structure caused by the change in the structural shape due to large deformations.

The dynamic response of conventional composite panels subjected to explosive loading has been studied by different authors. Ramajeyathilagam [9] has presented theoretical and experimental non-linear transient dynamic response of isotropic ship hull panels subjected to under water shock loading. An attempt has been made by the same author to predict the response and failure modes of three types of isotropic hull panels (flat, concave and convex).

Turkmen and Mecitoglu [10] presented the geometrically non-linear response of laminated composite plates subjected to air blast loading. Hunpark and Lee [11] developed a methodology for determination of dynamic response of composite structures under high explosive blast wave loading taking into effect of progressive material damage and failure.

In this study, non-linear structural response is presented for three types of multiscale composite panels subjected to air blast loading under two different types of boundary conditions. The analysis is performed using finite element method. The elastic properties for non-linear structural analysis are evaluated using numerical homogenization.

2. Air Blast Loading

The shock or blast wave is generated when the atmosphere surrounding the explosion is forcibly pushed back by the hot gases produced from the explosion source. The front of the wave called the shock front, is like a wall of highly compressed air and has an overpressure much greater than that in the region behind it. This peak overpressure decreases rapidly as the shock is propagated outward. After a short time the pressure behind the front may drop below the ambient pressure, as shown in Fig. 1. During such a negative phase, a partial vacuum is created and air is sucked in. The air blast pressure on an exposed surface is a function of the air blast pressure magnitude, the orientation, geometry and size of the surface which the shock wave encounters. The pressure that arrives at a certain distance from the explosive depends on the distance and size of the explosive.

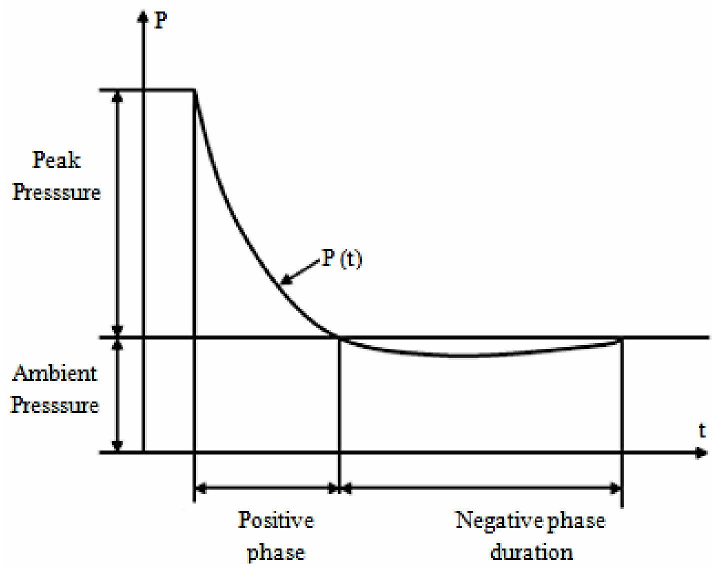

Fig. 1 Pressure - time curve for air blast wave

An approximation to the time variation of the blast pressure is given by the Friedlander decay function as

$$P(t) = P_m\left(1 - \frac{t}{t_p}\right)e^{-\frac{\alpha t}{t_p}} \qquad (1)$$

Where P(t) is the pressure at any instant of time t, P_m is the peak pressure, t_p is the pulse duration and α is the wave parameter.

3. Validation of Finite Element Model

To verify the applicability of software for the blast analysis, simulation results are compared with the experimental results of reference problem [10]. The square composite plate is with a side of 0.22 m consisting of seven plies with 0.00196 m thickness. The properties of the material are listed in Table 1.

Table 1 Material properties for validation of finite element model for blast loading [10]

E_L (GPa)	E_T (GPa)	G_{LT} (GPa)	ν_{LT}	ρ (kg/m^3)
24.014	24.014	3.79	0.11	1800

The layer stacking sequence of the plate is [90/0/90/0/90/0/90] and and stacking sequence of composite plate is shown in Fig. 2.

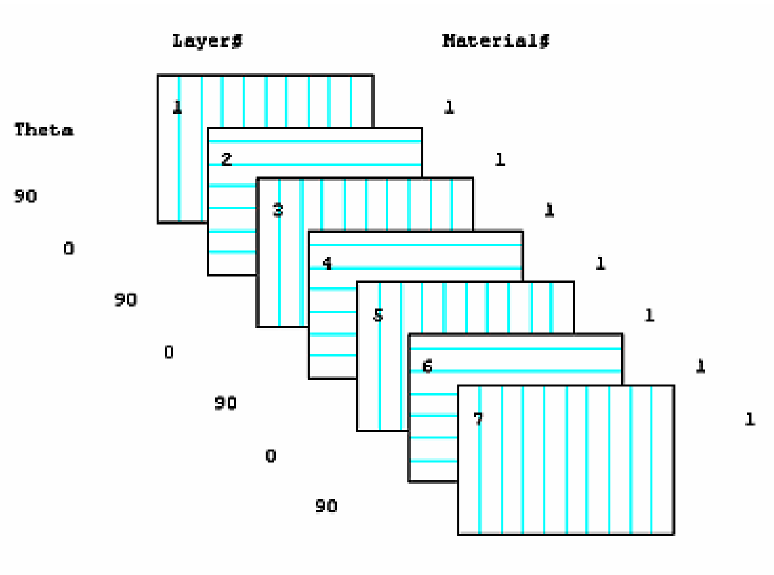

Fig. 2 Stacking sequence of composite plate for blast analysis

The plate is clamped at all edges as shown in Fig. 3 For the present problem, a peak pressure of 28906 N/m^2, pulse duration of 0.0018 sec and wave parameter of 0.35 are used.

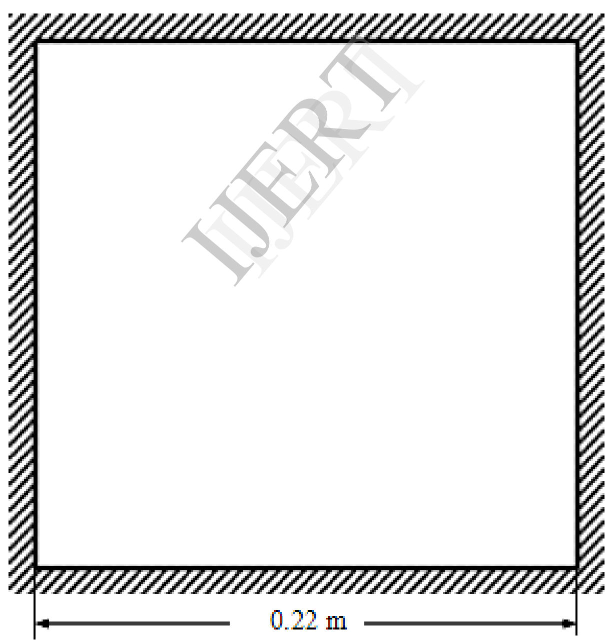

Fig. 3 Square composite plate clamped at all edges

In this study, the ANSYS 11.0 finite element analysis software is used in the modeling and analysis of the plate. The finite element model for the plate consists of two dimensional shell elements with seven layers in the transverse direction. In the finite element model no slippage is assumed between the element layers. Shear deflections are included in the element, however, normal to the center plane before deformation is assumed to remain straight after deformation. The plate is discretized by the use of eight noded laminated shell elements such as SHELL99. The finite element models of the square composite plate using different mesh densities have been developed and the results have been studied to obtain a mesh that is fine enough to obtain converged FEM results. The final optimum mesh that produces converging results is shown in Fig. 4. The pressure load is applied on the whole surface of the plate as a function of time.

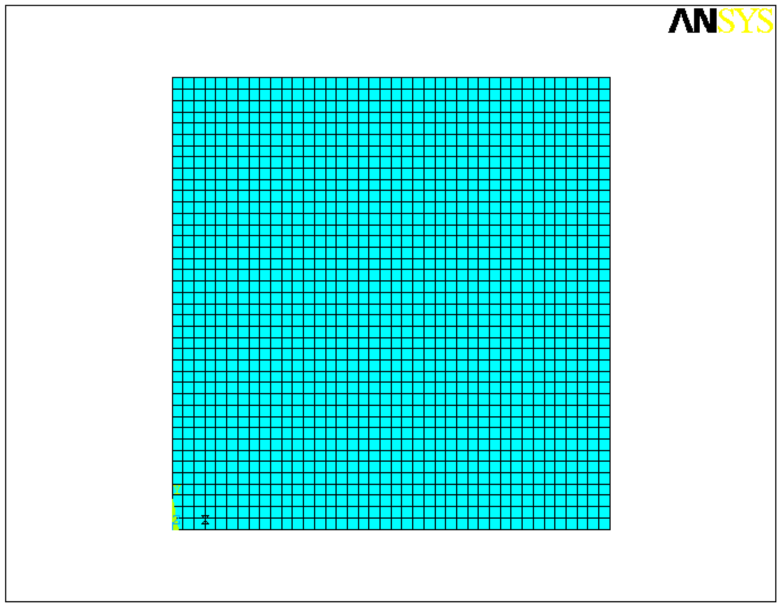

Fig. 4 Finite Element model of Square Plate

A total of 50 time function points is used in describing the exponentially decaying blast load for the analysis. The Newton-Raphson technique is used for the nonlinear transient analysis. Time increment is taken to be 0.1 ms for this analysis. The analysis is performed assuming that the pressure is uniformly distributed on the plate. In this approach, the load is subdivided into a series of load increments. The load increments can be applied over several load steps. The dynamic response of square plate for blast loading is evaluated using finite element method, after applying required clamped boundary conditions.

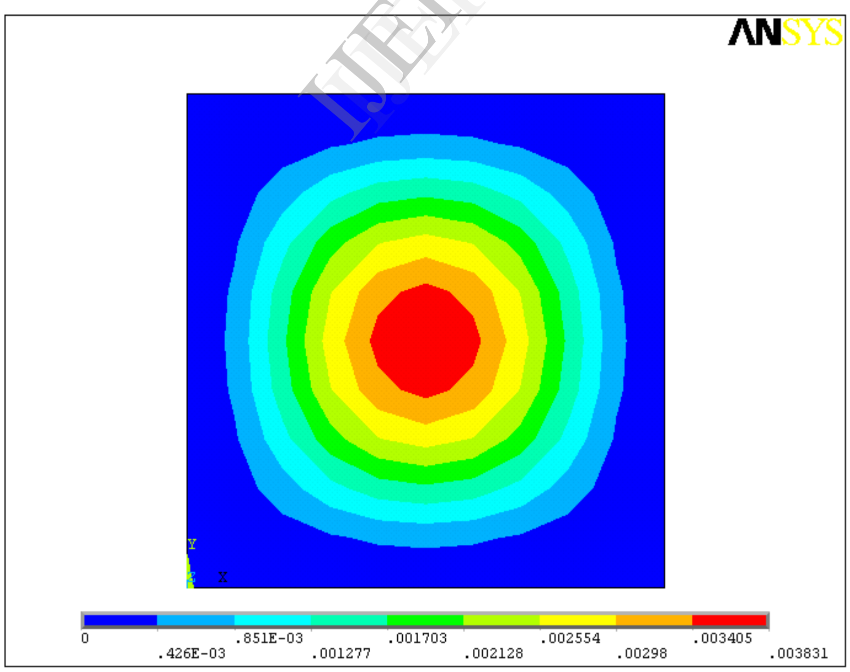

Fig. 5 A typical displacement contour of square plate subjected to blast loading

A typical displacement contour is shown in Fig. 5 and the displacement results predicted by finite element simulation are presented in Fig. 6.

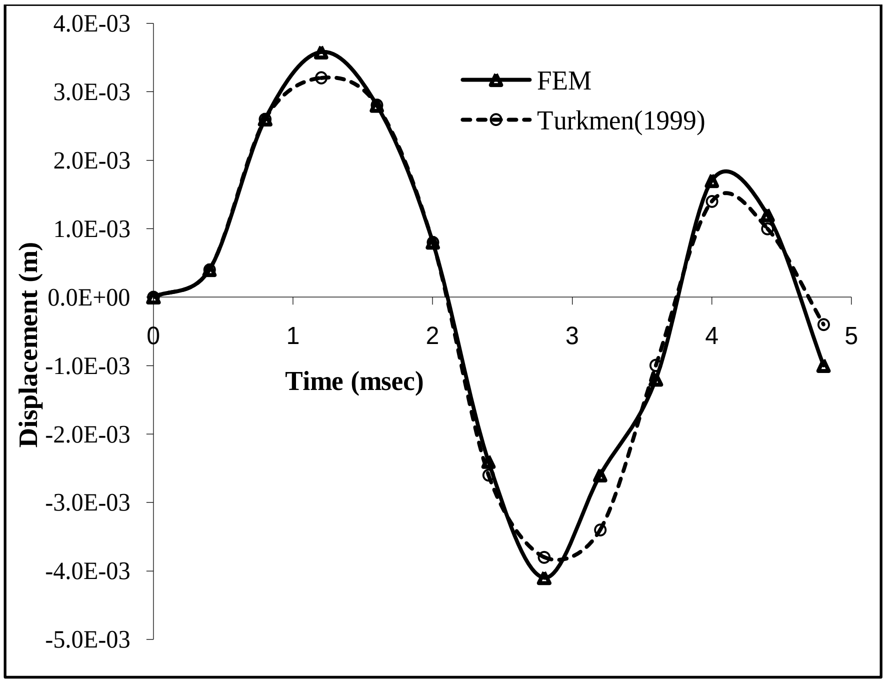

Fig. 6 Displacement-time history plots of square plate for air blast loading

From the results it is observed that, there is a good agreement between the predictions and experimental values available in the literature. The maximum displacement obtained by finite element method is 0.0036 m compared to the experimental value is 0.0034 m.

4. Response of Multiscale Composite Panels for Blast Loading

To study the response of multiscale composites subjected to blast loading, three types of hull panels (flat, concave and convex) are considered. To understand the dynamic response of structures subjected to blast loading, a hull panel of size 1.5 m x 0.6 m x 0.02 m is used. The panel is assumed to have 40 layers of 0.005 m thick. Lamination sequence of $[0/90]_s$ is assumed for the panel. In case of concave and convex hull panels, shell rise ratio 0.05 with projected dimensions 1.5 m x 0.6 m x 0.02 m is used. The properties of the material are calculated by using numerical homogenization [12] and are listed in Table 2.

Table 2 Effective elastic properties of orthotropic plate for blast analysis [12]

Material	Effective Elastic properties (At V_{cnt} = 5% & V_f = 60%)				
	E_L (GPa)	E_T (GPa)	G_{LT} (GPa)	υ_{LT}	Density (kg/m^3)
Conventional Composite (Glass/Epoxy)	43.4	14.79	4.373	0.24	1980
Multiscale Composite (Glass/CNT/Epoxy)	44.0	19.55	5.902	0.264	1984

Two types of plates with different boundary conditions are considered for study. For plate shown in Fig. 7 (a) all edges are fixed (CC), for plate shown in Fig. 7 (b) all edges are simply supported (SS) boundary conditions are imposed.

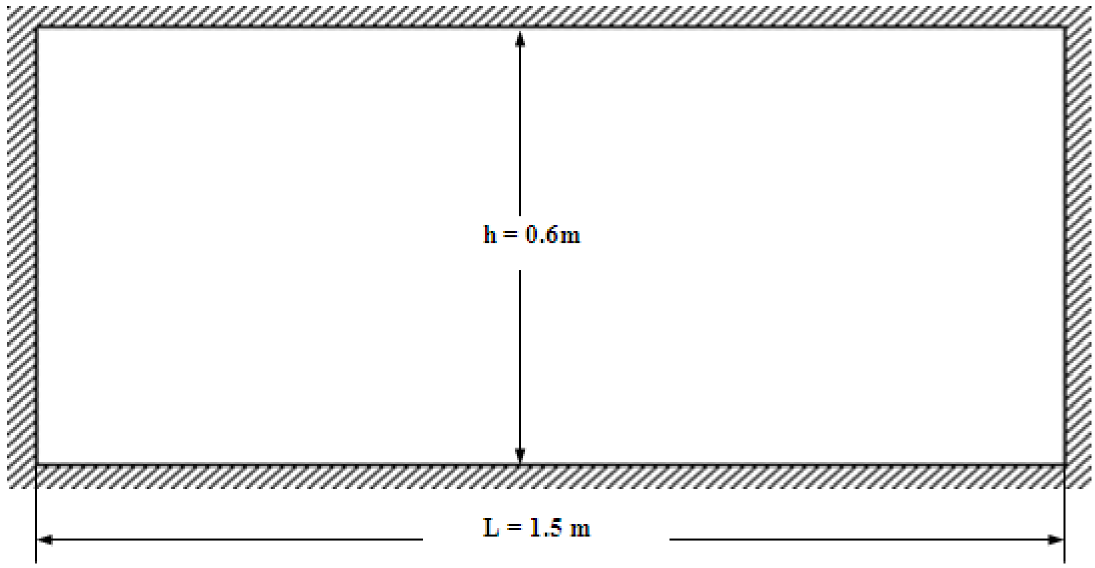

Fig. 7 (a) Plate with clamped boundary conditions

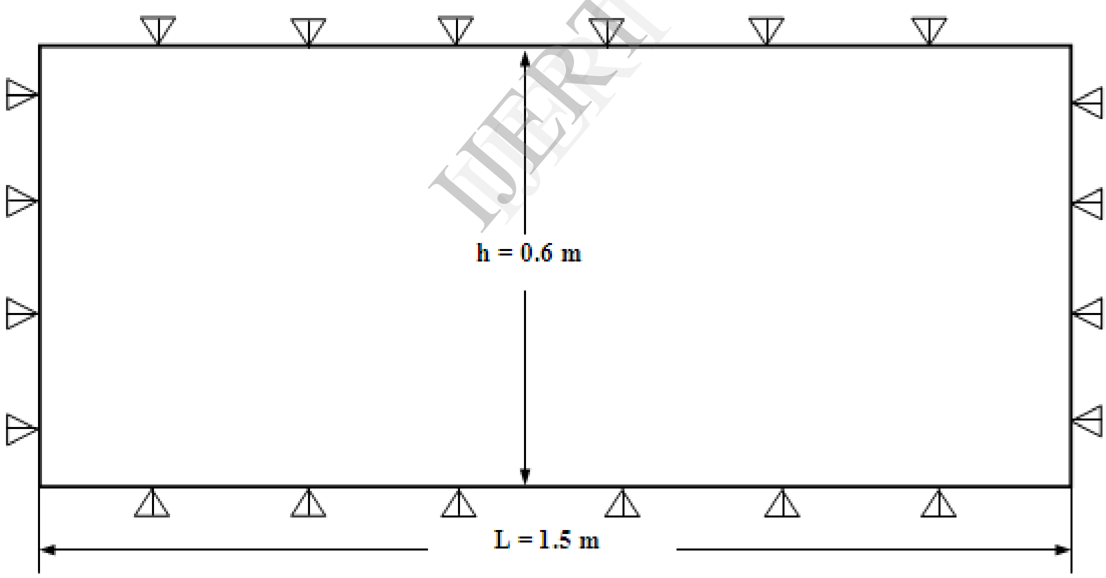

Fig. 7 (b) Plate with simply supported boundary conditions

5. Results and Discussion

Numerical results of the displacement-time histories for both conventional and multiscale composite panels, subjected to blast loading under clamped and simply supported boundary conditions are presented in Figs. 8-13.

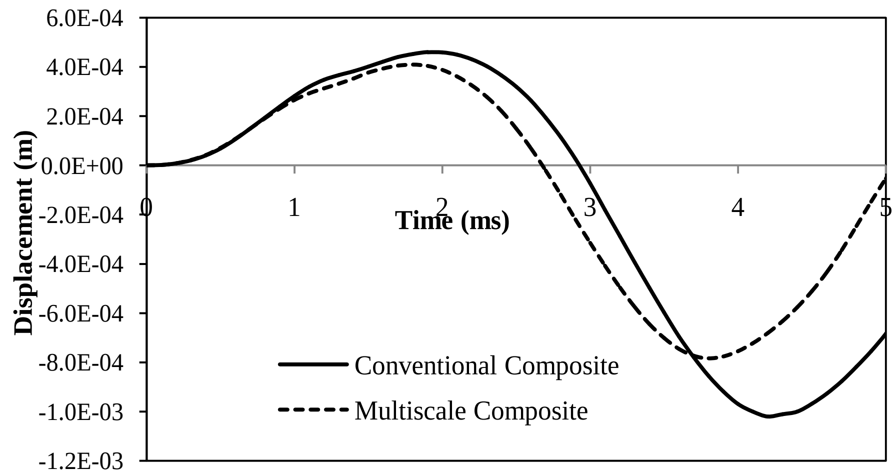

Fig. 8 Displacement - time history of flat panel under clamped boundary conditions

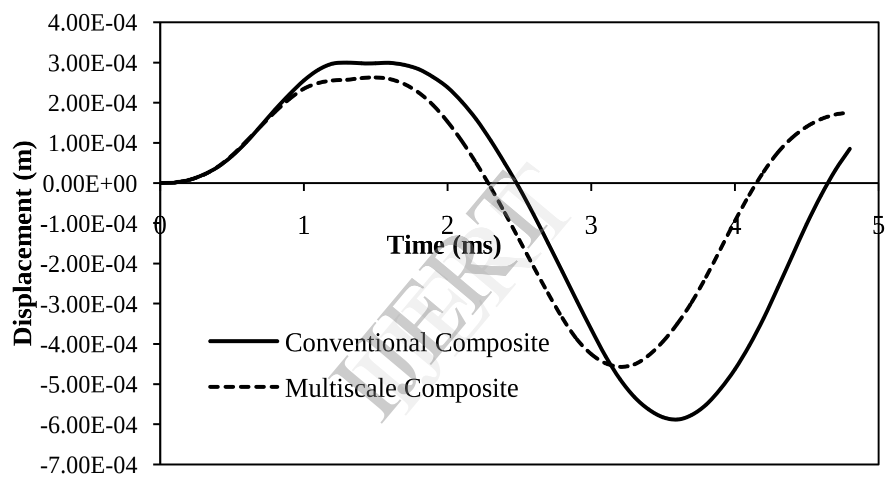

Fig. 9 Displacement - time history of concave panel under clamped boundary conditions

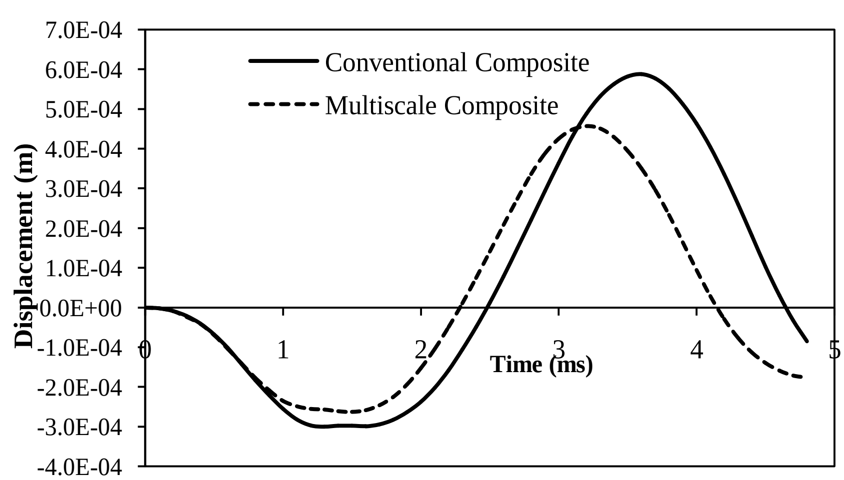

Fig. 10 Displacement - time history of convex panel under clamped boundary conditions

Figs. 8-10 show the comparison of displacement time history results of the conventional and multiscale composite panels under clamped boundary conditions subjected to blast loading. From the results in Fig. 8, it can be noted that adding CNTs to glass fiber flat composite panels reduces peak displacement by 22% compared to conventional composite flat panels. Fig. 9 presents comparison of displacement time history results of conventional and multiscale composite concave panels. The results show that the peak displacement of multiscale composite concave panels reduces by 28% compared to conventional composite panels. The displacement time history results of the multiscale and conventional composite convex panels are compared in Fig. 10. From the results it is observed that the peak displacement of multiscale composites reduces by 28% compared to conventional convex panels.

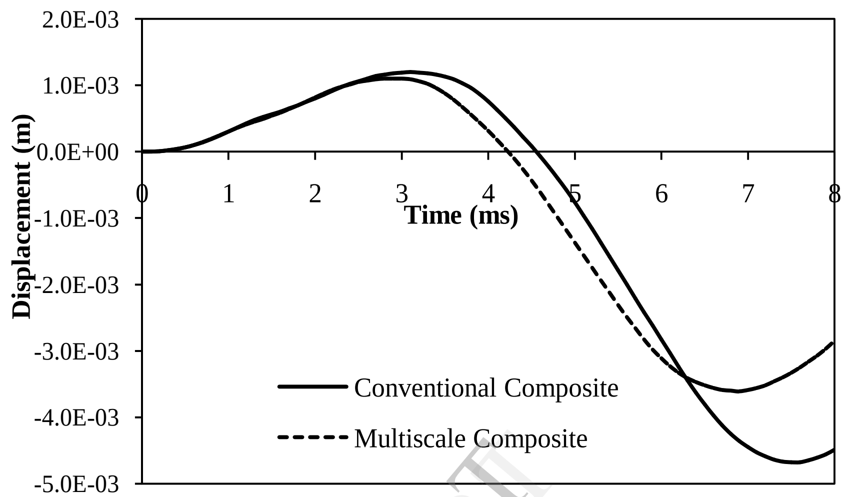

Fig. 11 Displacement - time history of flat panel under simply supported boundary conditions

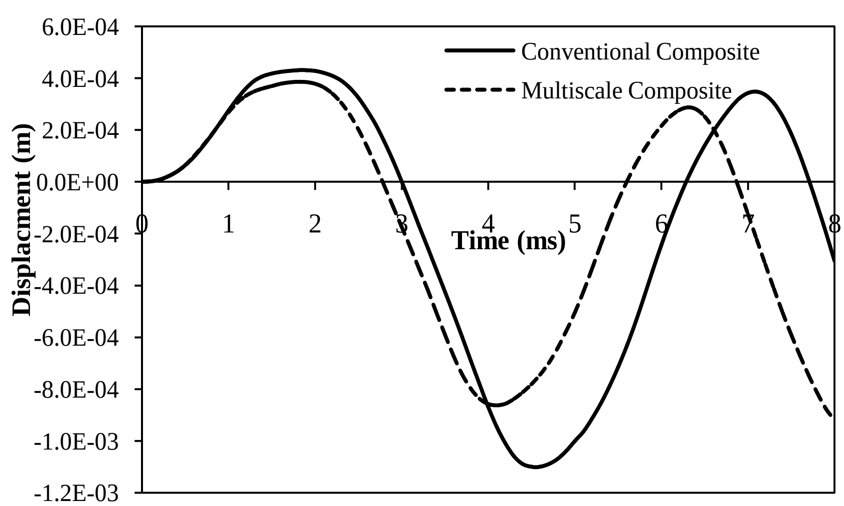

Fig. 12 Displacement - time history of concave panel under simply supported boundary conditions

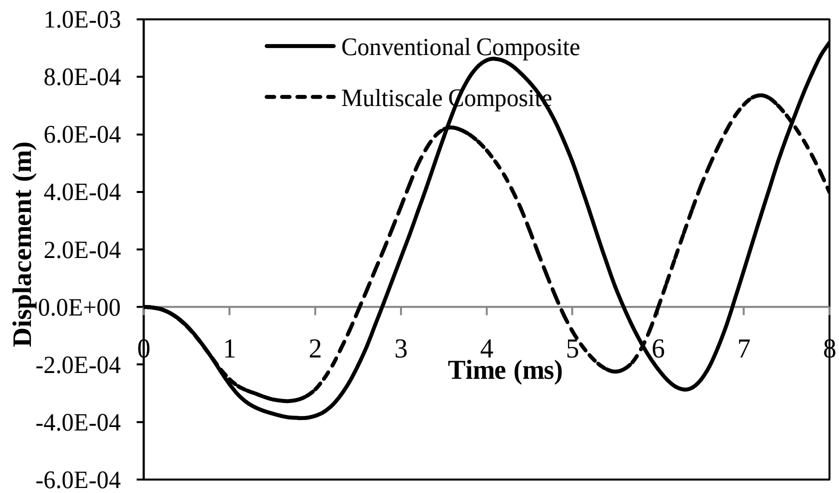

Fig. 13 Displacement **-** time history of convex panel under simply supported boundary conditions

The displacement time history results of the conventional and multiscale composite panels subjected to blast loading under simply supported boundary conditions are compared in Figs. 11 - 13. From the results in Fig. 11, it is observed that the peak displacement at the centre of multiscale composite flat panel reduces by 29% than conventional composite flat panel. Comparison of displacement time history results of conventional and multiscale composite concave panels are shown in Fig. 12. The results show that by the addition of CNTs into the glass fiber composite the peak displacement reduces by about 38% compared to conventional composite concave panels. Fig. 13 show that the reduction in peak displacement of multiscale composite convex panels is about 38% compared to conventional composite convex panels.

6. Conclusions

Non-linear structural response is presented for three types of multiscale composite panels subjected to blast loading under clamped and simply supported boundary conditions. The response of the plate is very much satisfactory and it is observed the reduction in peak displacement of multiscale composite flat panels is about 22% compared to conventional composite flat panels and in case of concave and convex panels the reduction is about 28% under clamped boundary conditions. It is found that the reduction in peak displacement of multiscale composite panels is about 29% for flat panels and 38% in case of concave and convex panels under simply supported boundary condtions. In depth study reveals that the reduction in peak displacement is due to increase in stiffness and inter laminar resistance of multiscale composites due to CNTs reinforcement. From the results it can also be noted that the concave and convex panels suffer lesser deformation than the flat panel because of membrane resistance offered by the initial curvature of concave panel. So, it can be noted that the concave and convex panels offer better resistance for blast loading under clamped boundary conditions.

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