Dynamic Response of Nanocomposite Laminates During Low, Medium and High Velocity Impact Loading

G. Balaganesan[*1], R. Velmurugan[2], K. Kanny[2]

[1,2]Department of Aerospace Engineering, Indian Institute of Technology Madras, India

[1,2]Department of Mechanical Engineering, Durban University of Technology, Durban, South Africa

[*1]gbganesh@iitm.ac.in; [2]ramanv@iitm.ac.in; [3]kkanny@dut.ac.za

Abstract

The composite laminates are subjected to impact loading in various conditions with different energy levels. The energy levels are varied by varying mass and speed of the striking mass. The conditions are low velocity of impact with heavy mass, light mass projectile with medium and high velocity of impact. The impact due to bullet is considered as light mass with high velocity of impact. Dynamic response of nanocomposite laminates in drop mass test and projectile impact is studied for low velocity impact. The acceleration and time duration of vibration are found experimentally for the glass/epoxy laminates with and without nano fillers. The values of peak acceleration and period of vibration are compared for the laminates of different thicknesses and percentage of filler dispersion. The damping factor values are predicted for low velocity impact loading by logarithmic decrement method and by FFT spectrum analysis for medium and high velocity impact.

Keywords

Nanocomposites; Impact Loading; Dynamic Response; Acceleration; Vibration; Damping

Introduction

It is essential to design of structures for minimum noise and vibration. The information on damping coefficients of structural materials is also essential for dissipation of energy during vibration of a structure [1]. Experimental and analytical characterization of damping is not easy, even for conventional structural materials, and the anisotropic nature of composite materials makes it even more difficult [2-3]. A structure can be made to vibrate with excessive, sustained, oscillatory motion during the operation of a system. Resonant vibration is caused by an interaction between the inertial and elastic properties of the materials within the structure. Resonant vibration is often the cause of, or at least a contributing factor to many of the vibration related problems that occur in structures and operating machinery. For better understanding of any structural vibration problem the resonances of a structure needs to be identified and quantified [4-5]. Vibration modes are used as a simple and efficient mean of characterizing resonant vibration. A common way of doing this is to define the structure's modal parameters natural frequency and damping factor. The flexural damping capacity of the composite laminates is due to the material properties, the ply orientation and the stacking sequences of the layers [6-8]. In the past, there were several works on analytical models to predict the damping responses of composite laminates for various lay-up specifications [9-10]. Della and Shu [2007] reviewed analytical models and numerical analysis for the free vibration of delaminated composites. The models were classified according to fundamental theoriesand assumptions. They presented and compared the results of some of the models. Also they have discussed the influence of delamination on the natural frequencies and mode shapes of the composite laminates. Andraset.al [2015] have studied on free vibration of laminated composite beams. They have modeled delaminated composite as simply layered beam elements. The coupling between the flexural and longitudinal vibration is considered in the delaminated part by periodic normal forces during the free vibration of the system. Mihai and Constantin [2014] studied different possible cases of the impact between the empennage and an external body with different consistencies: a rigid one and an organic tissue one (e.g. a bird). In order to correctly describe the deformation and rupture of the empennage, due to the high strain rate the Johnson–Cook material model was used in their study. Suleyman at al. [2014] studied on the nonlinear dynamic response of a hybrid laminated composite plate composed of basalt, kevlar/epoxy and glass/epoxy under the blast load and also investigated the damping effects. Tian et al. [2014]

2325-6796/15/02 056-14, © 2015 DEStech Publications, Inc.
doi: 10.12783/fae.2015.0402.03

studied the dynamic performances of high-speed train are analyzed under different wind shear environments. Matadi et al. [2015] discussed the response of composite laminates subjected to low velocity impact.

Avila et al., [2007] carried out vibration analysis of fiber glass/epoxy/nano clay nanocomposites. They have presented the natural frequency, damping factor and mode shape for the laminates with and without clay. Also it was reported that dispersion of nano clay effectively improved the damping coefficient and changed the mode shapes and natural frequencies. Deshmane et al., [2007] worked on the reinforcement of PP and PE with 4 wt. % nano-clay lead to a striking variation in impact toughness behavior under identical processing conditions. Our previous studies, Velmurugan and Balaganesan [2013] and [2014], focused on experiments and analytical model on energy absorption of nanocomposites laminates subjected to impact loading above ballistic limits. It is observed that the presence of clay enhances the energy absorbing capacity of the laminates during perforation. In our earlier study [2011] on modal analysis of pre and post impact on nanocomposite laminates, the effect on dispersion of nanoscale fillers was studied on vibration parameters natural frequency and damping factor. It was observed that dispersion of nanoclay controls delamination and hence increasesthe natural frequency of nanocompositelaminates.Thenanoscale fillers act as secondary fibers in the matrix system and due to their large surface area interaction improves for better energy transfer between filler and matrix. This enhances the damping coefficient of compaoiste laminates when subject to impact. The vibration study focuses to predict vibration parameters natural frequency and damping factors. Impact loading on the composites makes the composite to vibrate after the contact time period of the projectile. The contact period depends on the velocity of the impact. For the below ballistic impact, the point of impact subjected to plastic failure and the remaining area of the laminate subjected to elastic deformation till the period of contact and the energy is disspated by the vibration of the laminate. When the impact is above ballistic limit, the most of project energy is absorbed in various failure modes and vibration. The vibration of plates at different speeds of impact is not seen in the literature. Hence it is proposed to study the dynamic response of nanocomposites for low, medium and high velocity impact loading.

In this work, an attempt wasmade to find the response of the laminates acceleration and period of vibration for different impact loading conditions. The laminates wereprepared from WRM glass fiber/epoxy with 1-5 weight % of nano filler.The effect of nano clay incorporation in the glass/epoxy fiber laminates, with orientation of 0°/90°, wasstudied for low, medium and high velocity impact loading. The damping factors values wereobtained for the laminates subjected to low velocity impact and the effect of nano clay wasstudied.

Experiments

Preparation of Specimens

The nano composite laminates were fabricated in two steps. Clay was mixed with resin using shear mixer at 750 RPM for 2hrs and kept in the vacuum oven to remove the air bubbles at room temperature, for better dispersion. Glass fiber woven roving mat (WRM) of 610 gsm was used for this work. Hardener, TETA of 10% was mixed with the epoxy-clay mixture, by weight. The laminates were prepared by hand lay-up technique and then compressed in compression molding machine. Laminates with 3, 5 and 8 layers of WRM size 300mm x 300mm were prepared for testing.

Fig. 1(a) shows the TEM image of the nano clay dispersed with epoxy matrix. The cross section of the clay is in few nano meters and the length is in micron size. Fig. 1(b) shows the TEM image of bunch of clay layers. The clay has high aspect ratio which acts as secondary fibers when reinforced with matrix. Magnicium and Silica are the major elements in clay.

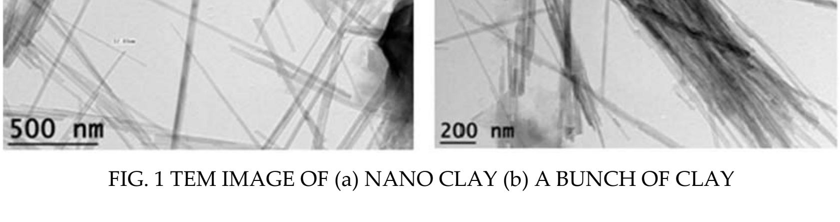

FIG. 1 TEM IMAGE OF (a) NANO CLAY (b) A BUNCH OF CLAY

Drop Mass Test

The impact test is performed using drop mass setup and the spherical nose projectiles are used for the test. The plate is fixed horizontal plane in the fixture which supports all the four sides of the laminate of size 300mm x 300mm. An accelerator is fixed in the bottom side of the plate to measure the time response. The projectile of mass 558 grams is fixed in a circular plate, and the total mass of 2.45kg is dropped from 0.25m and 0.5m heights with maximum velocities at the time of strike as 2.21 m/s and 3.13 m/s by using electro magnet. The corresponding energy released by the drop mass is 6J and 12J respectively. From the time response curve, the damping factor of the laminate for particular impact velocity is calculated using logarithmic decrement method. The formula for finding damping factor (ζ) using logarithmic decrement method is

$$\zeta = \delta^2 / (4\pi^2 + \delta^2)^{0.5} \tag{1}$$

Projectile Impact Test

In projectile impact, the impact velocities are considered below and above the ballistic limit. The projectile of diameter 9.5 mm with spherical nose of mass 7.6g is used for this study. As the velocity of impact is well within ballistic velocity, the strain in the fibers is below the failure strain and within the elastic region. This causes the rebound of the projectile as well as vibration of the laminate. A shock accelerometer of capacity 100kg, PCB make, model No. 350B21, is used to capture the response through the Data Acquisition (DAQ) Card [NI-PXI 4472] and the response is recorded in a personal computer. The accelerometer is fixed at a distance ¼ length of diagonal, from one of its corner which is also a non-nodal line. The projectile is impacted at the center of the laminates. The time response and frequency response of the laminates are obtained. The time response curve is discussed for the acceleration, time period of vibration, effect of clay presence in the matrix and thickness of the laminates. Fig. 2 (A) shows gas gun set up used for projectile impact loading. Laser diode is used to predict velocity of projectile before impact on target and residual velocity is predicted by two aluminium foil circuit method for above ballistic impact. The velocity range is obtained by changing pressure of gas in the chamber. Fig. 2 (B) shows drop mass impact testing facility for conducting low velocity impact.

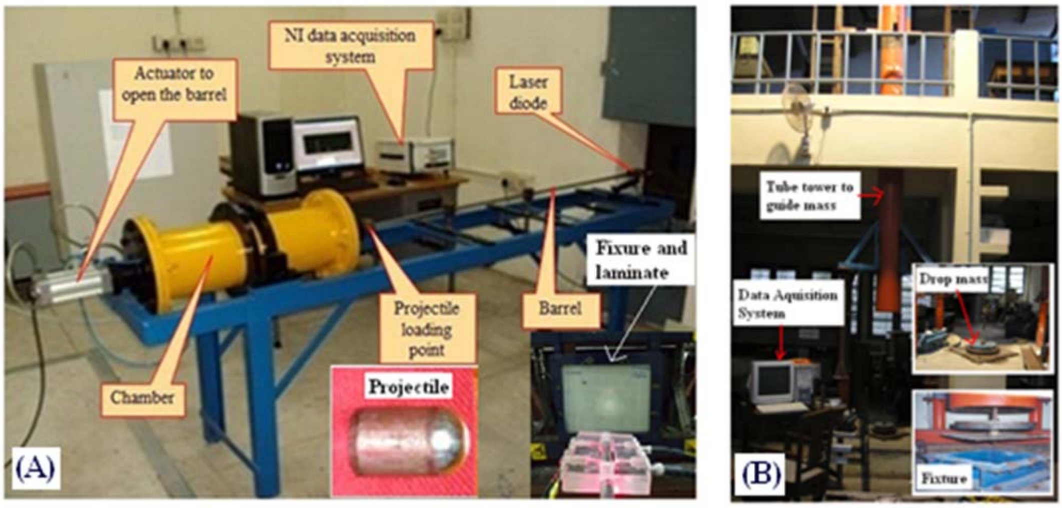

FIG. 2 (A) GAS GUN EXPERIMENTAL SET UP FOR IMPACT TESTING, (B) DROP MASS SET-UP

Results and Discussions

Impact Response during Drop Mass Test

1) Impact Response

Dropmass test were carried out in the three layer laminates with and without clay. The plate is fixed horizontal plane in the fixture which supports all the four sides of the laminate of size 300mm x 300mm. Figs. 3 and 4show time response curve for the impact velocities 2.21 m/s and 3.13 m/s for different fractions of clay additions. The vibration of laminate without clay at velocity 2.21 m/s is nullified in 500 ms, for 5% clay ocillation is nullified within 150 ms.It is also noticed that the number of ocillations reduced for increase in velocity. For 1% clay at velocity 2.21m/s vibration is nullified only after 400 ms, at velocity 3.13 m/s the vibration is nullified after 200 ms. In the lowest velocity of impact the contact time between the specimen and the projectile is more not only due to low velocity but also the drop energy isnot sufficient to penetrate the laminate. Since the contact time is more and most of the energy is converted into vibration, but in high velocities part of the energy dissipates to penetrate the laminate and the remaining energy is used in vibration. When the velocity increases, the contact time between the specimen and projectile decreases and impact damage i.e., penetration level of projectile increases. But it is observed that for the same velocity level increase in clay addition controls the impact damage and also oscillations are very much controlled.

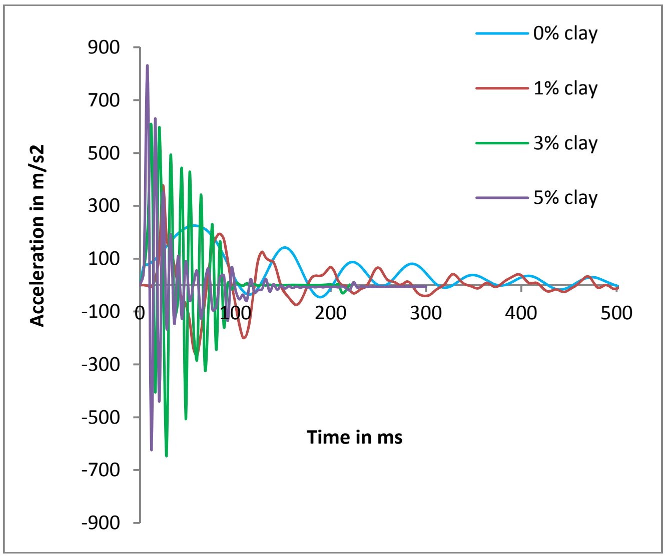

FIG. 3TIME RESPONSE CURVE OF LAMINATES AT THE VELOCITY OF 2.21 M/S

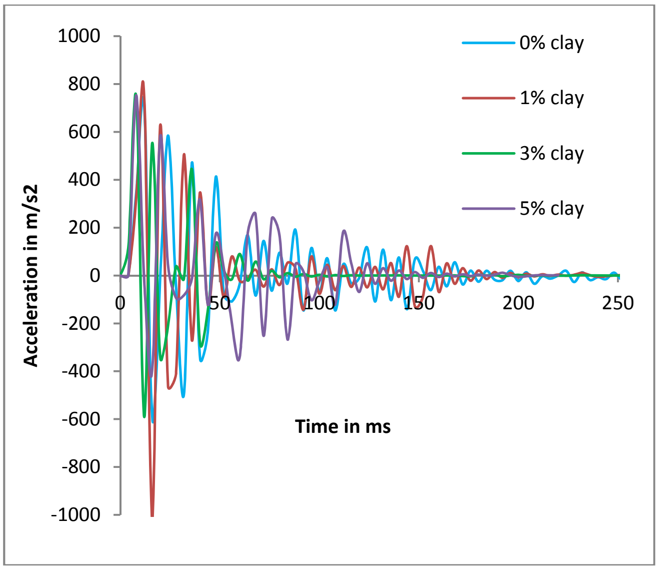

FIG. 4TIME RESPONSE CURVE OF LAMINATES AT THE VELOCITY OF 3.13 M/S

2) Damping Factor

The damping factor values of the laminates are obtained from logarithmic decrement method. The maximum acceleration values in successive oscillations are considered to find logarithmic values and the damping factor values are obtained. Fig. 5 shows the damping factors of the laminates with and without clay subjected to impact velocities 2.21 m/s and 3.13 m/s. The damping factor for the laminate without clay is 0.031 when subjected to impact at 2.21 m/s. The damping factor for the laminate with 1% clay is 0.048 and the increase is about 56% when compared to laminate without clay. The damping factor values for the laminates with 3% and 5% clay are 2 and 2.2 times of damping factor of the laminate without clay. The damping factor for the laminate without clay subjected to impact velocity 3.13 m/s, is 0.036. The increase in damping factor for the laminate with 1% clay is about 40% higher than the laminate without clay. The damping factor values for the laminate with 3% and 5% clay are 1.77 and 2.2 times higher than the laminate without clay. The damping factor for impact velocity 2.21 m/s is less than that at 3.13 m/s. This is due to the higher contact time between the specimen and the projectile at low velocity the vibration developed is high and also as discussed earlier, most of the energy at low velocity is converted into vibration which leads to low damping factors. But it is observed that increase in nano clay percentage appreciably controls the amplitude ofacceleration and increases the damping factor. For higher velocities the damping factor value increases due to low contact time and low vibration energy is dissipated in the laminate. Hence it is clear that addition of clay in the matrix enhances damping capacity of the composite laminates.

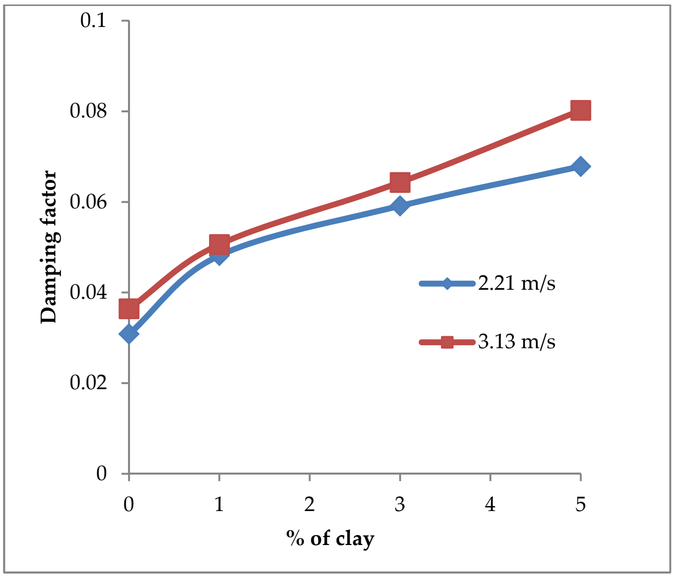

FIG. 5DAMPING FACTOR OF THE LAMINATES SUBJECTED TOIMPACT VELOCITIES 2.21 m/s AND 3.13 m/s

Time Response of the Laminates during Projectile Impact

The laminated composite plates of 3, 5 and 8 layers with and without clay are subjected to impact by projectile velocities below and above the ballistic limit. The tests are carried out to determine the time response during vibration by using a shock accelerometer. When the projectile is impacted on the laminate, the laminate vibrates and then decaysin its acceleration of vibration. Here, the acceleration values are plotted against the time. The changes in amplitude and time period for different velocities of impact, thickness of the laminate and effect of clay dispersion are discussed for various impact velocities of projectile.

1) Time Response of Three Layer Laminates

Figs. 6-9 show time response for acceleration for three layer laminates with and without clay when subjected to 35m/s, 65 m/s, 110 m/s and 135 m/s. In theses velocities, 35 m/s and 65 m/s are below the ballistic limit and 110 m/s and 135 m/s are above the ballistic limit. Fig. 6 shows time response curve for laminates without clay. The maximum acceleration value is about 57000 m/s^2 at 35 m/s and is about 5000 m/s^2 at 135 m/s. The decay of amplitude of acceleration is taken 70 ms for 35 m/s and 17 ms for 135 m/s. When the laminates are subjected to impact below ballistic limit, the laminates dissipates energy in vibration mode. Whereas this energy is less in case, the impact velocity is above the ballistic limit.

Fig. 7 shows time response curve for laminate with 1% clay. The maximum acceleration is about 78000 m/s^2 for the laminate when subjected to 65 m/s. The maximum acceleration values for 110 m/s and 135 m/s are less than 10000 m/s^2. The period is less than 20ms for these velocities.

Fig. 8 shows for the laminates with 3% clay, the maximum acceleration for this laminate is about 50000 m/s^2 at 35 m/s. The maximum acceleration is about 80000 m/s^2 for the laminate subjected to 65 m/s.

Fig. 9 shows time response curve for laminates with 5% clay. The maximum acceleration for the laminate subjected to 65 m/s is about 90000 m/s². The maximum acceleration values for 110 m/s and 135 m/s are less than 10000 m/s² which is similar to other laminates. At higher velocities of impact there are not many changes observed in maximum acceleration and time period.

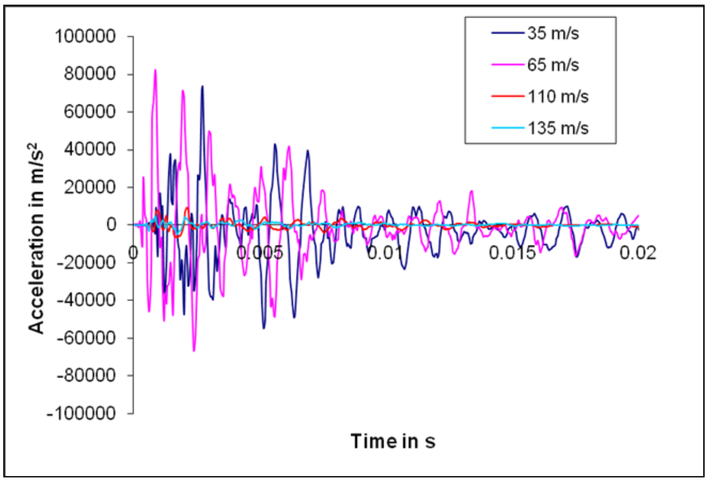

FIG. 6ACCELERATION-TIME RESPONSE FOR THREE LAYER LAMINATE WITHOUT CLAY FOR FOUR DIFFERENT VELOCITIES

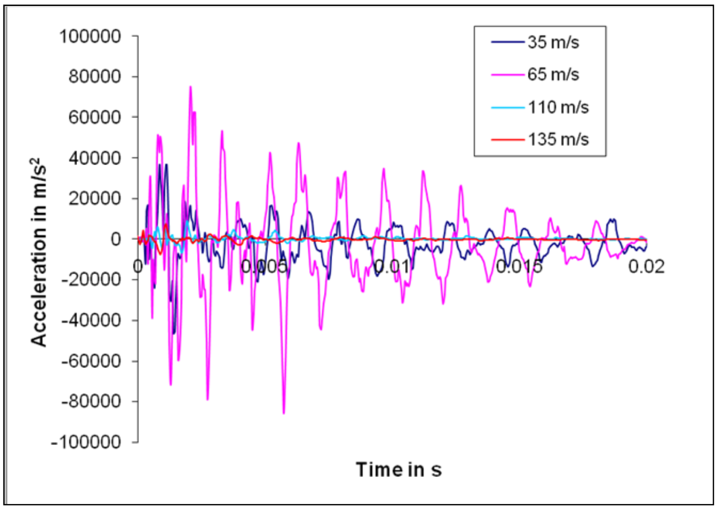

FIG. 7ACCELERATION-TIME RESPONSE FOR THREE LAYERLAMINATE WITH 1% CLAY FOR FOUR DIFFERENT VELOCITIES.

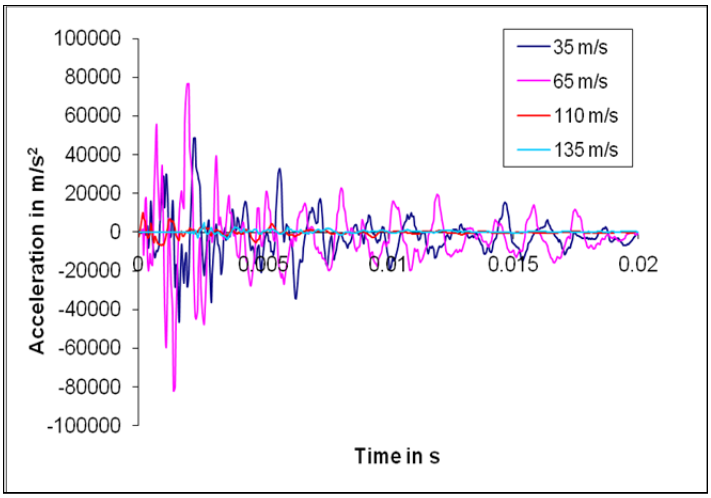

FIG. 8ACCELERATION-TIME RESPONSE FOR THREE LAYERLAMINATE WITH 3% CLAY FOR FOUR DIFFERENTVELOCITIES.

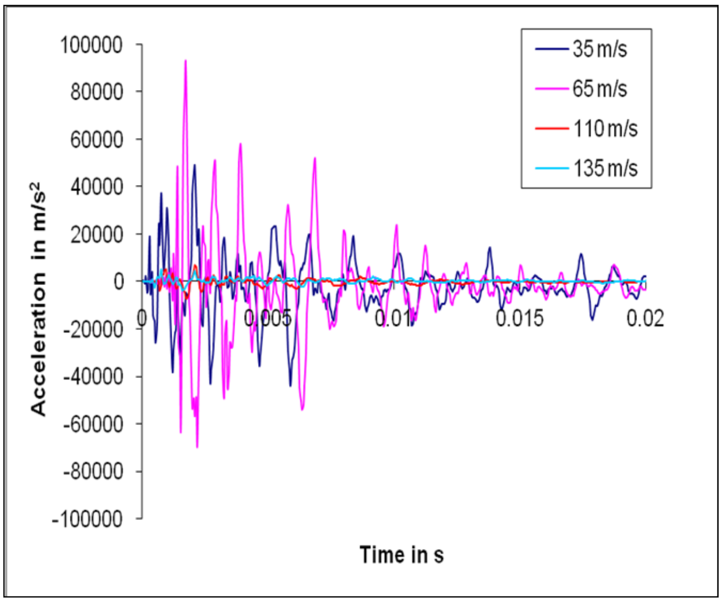

FIG. 9ACCELERATION-TIME RESPONSE FOR THREE LAYERLAMINATE WITH 5% CLAY FOR FOUR DIFFERENT VELOCITIES.

2) Time Response of Five Layer Laminates

Figs. 10 shows the time response of 5 layer laminates without clay subjected to impact velocities below and above ballistic limit. The plot shows the vibration period for 20 ms. The number of oscillations in the 20 ms is about 26 whereas in the 3 layer laminate it is about 13 which is seen in Fig. 6. The maximum amplitude of acceleration for impact velocity of 65 m/s, is about 100000 m/s^2. The maximum acceleration values for the impact velocities 135 m/s and 152 m/s are less than 10000 m/s^2. Fig. 11 shows the corresponding curves for laminate with 1% clay. It is observed that the maximum acceleration is about 125000 m/s^2. The number of oscillations in 20 ms is same as in the laminate without clay.

Figs. 12 and 13 show time response of the laminates with 3% and 5% clay respectively. The maximum acceleration values are about 150000 m/s^2 and 80000 m/s^2 respectively for the laminates with 3% and 5% clay for the velocity of impact at 65 m/s. The decay of acceleration is nullified in 20 ms for the laminate with 5% clay. It is seen that as the clay amount in laminate is increased, the maximum amplitude of acceleration decreases where due to the increase in damping factor of the laminates with high clay content.

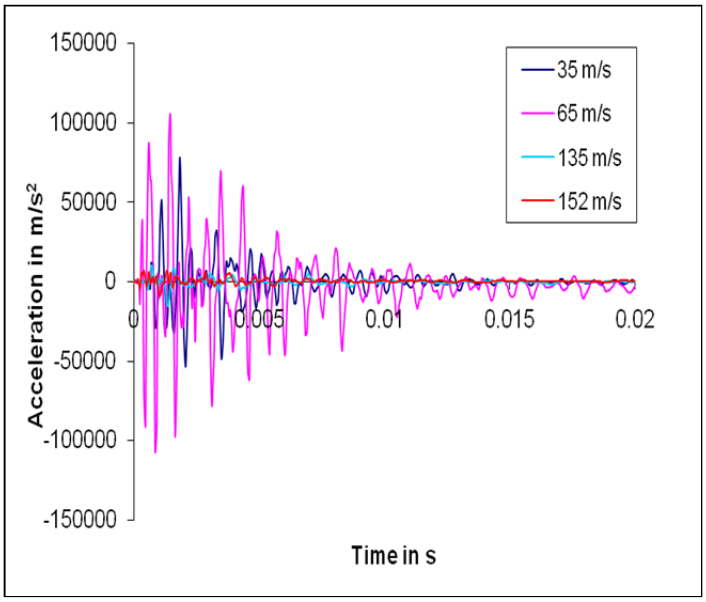

FIG. 10ACCELERATION-TIME RESPONSE FOR FIVE LAYERLAMINATE WITHOUT CLAY FOR FOUR DIFFERENTVELOCITIES

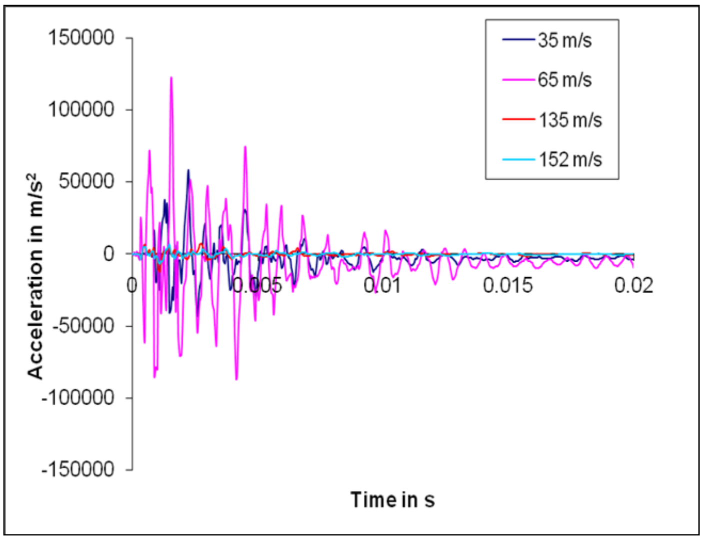

FIG. 11ACCELERATION-TIME RESPONSE FOR FIVE LAYER LAMINATE WITH 1% CLAY FOR FOUR DIFFERENT VELOCITY

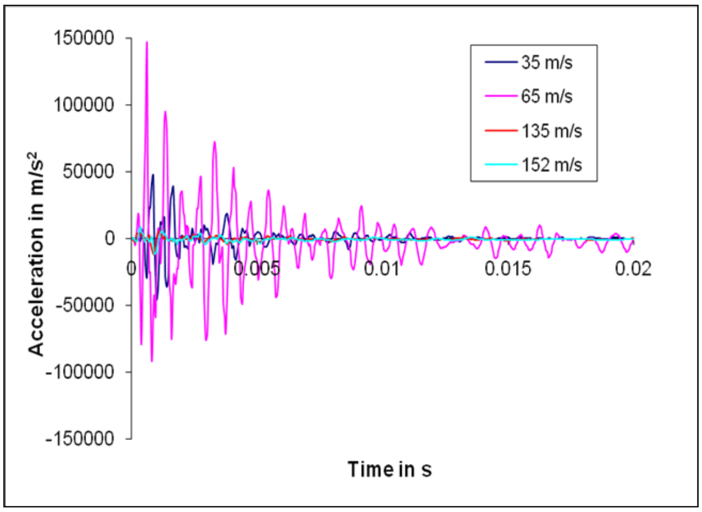

FIG. 12ACCELERATION-TIME RESPONSE FOR FIVE LAYER LAMINATE WITH 3% CLAY FOR FOUR DIFFERENT VELOCITIES

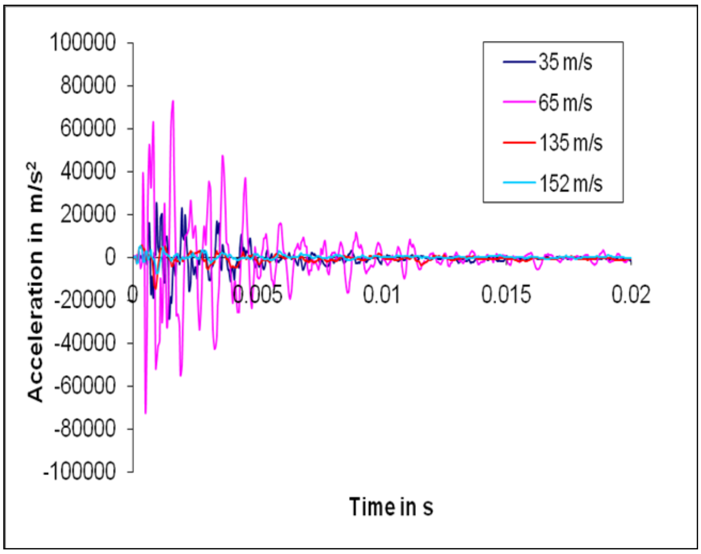

FIG. 13ACCELERATION-TIME RESPONSE FOR FIVE LAYER LAMINATE WITH 5% CLAY FOR FOUR DIFFERENT VELOCITIES

3) Time Response of Eight Layer Laminates

Figs. 14–17 show the time response of 8 layer laminates with and without clay subjected to impact velocities below and above ballistic limit. The plot shows the vibration period for 20 ms. The number of oscillations in the 20 ms is more than 50 which is high compared to 3 and 5 layer laminates. The maximum acceleration is observed for impact velocity of 65 m/s, the value is about 80000 m/s^2. The maximum acceleration value for the impact velocities 135 m/s and 152 m/s are similar to 3 and 5 layer laminates. The complete decay in acceleration of vibration is observed in 20 ms.This is because of the increase in thickness of the laminates. As the thickness of the laminate increases, the stiffness of the laminates also increases which results in increased number of oscillations.

Fig. 15 shows the time response for the laminate with 1% clay. It is observed that the maximum acceleration is about 80000 m/s^2 for 35 m/s and 65 m/s velocities of impact. The maximum acceleration value at 204 m/s is half of the maximum acceleration value at 152 m/s.

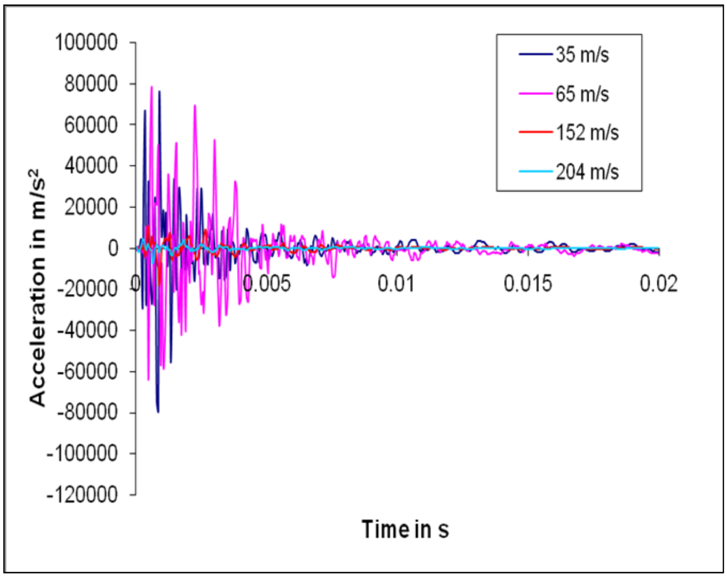

FIG. 14 ACCELERATION-TIME RESPONSE FOR EIGHT LAYER LAMINATE WITHOUT CLAY FOR FOUR DIFFERENT VELOCITIES

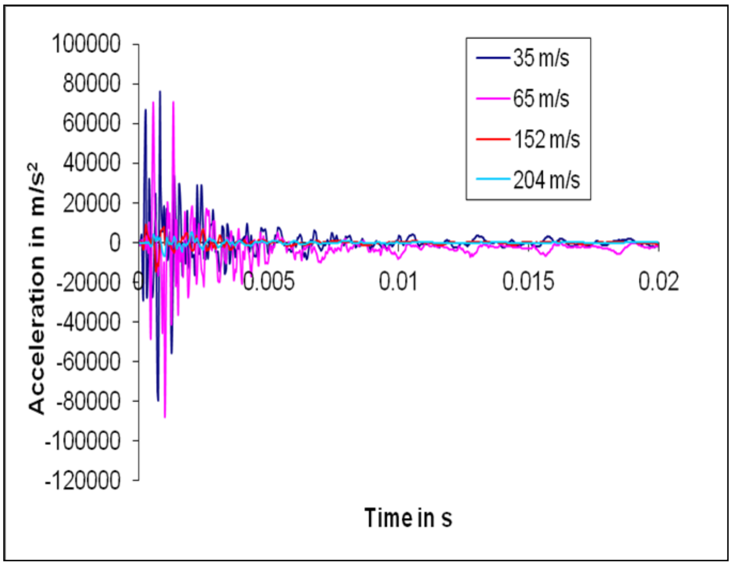

FIG. 15ACCELERATION-TIME RESPONSE FOR EIGHT LAYER LAMINATE WITH 1% CLAY FOR FOUR DIFFERENT VELOCITIES

Figs. 16 and 17 show acceleration-time response of laminates with 3% and 5% clay respectively. The maximum acceleration values are about 100000 m/s^2 for laminates with 3% and 5% clay for the velocity of impact 65 m/s.

The decay of acceleration signal is nullified in 20 ms similar to other 8 layer laminates. In 8 layer laminates, there arenotmany changes in the maximum acceleration values for below ballistic limit. For velocities above ballistic limit, the maximum acceleration values for 204 m/s are less than the maximum acceleration values at 152 m/s.

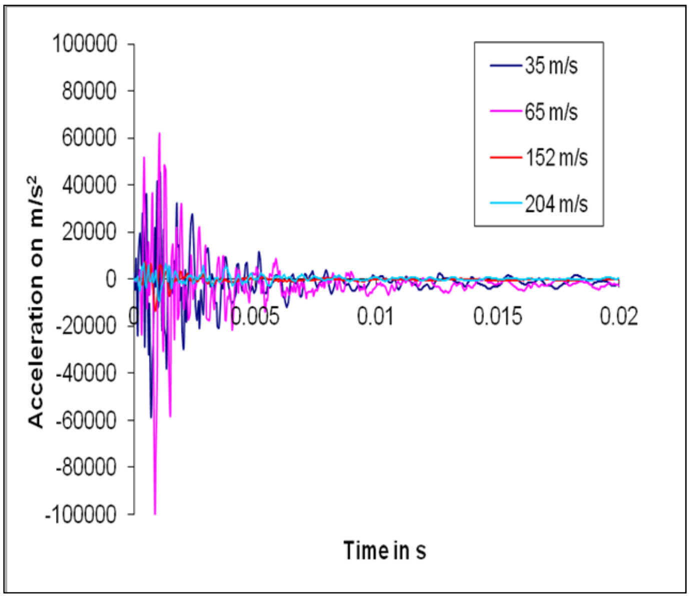

FIG. 16ACCELERATION-TIME RESPONSE FOR EIGHT LAYER LAMINATE WITH 3% CLAY FOR FOUR DIFFERENT VELOCITIES

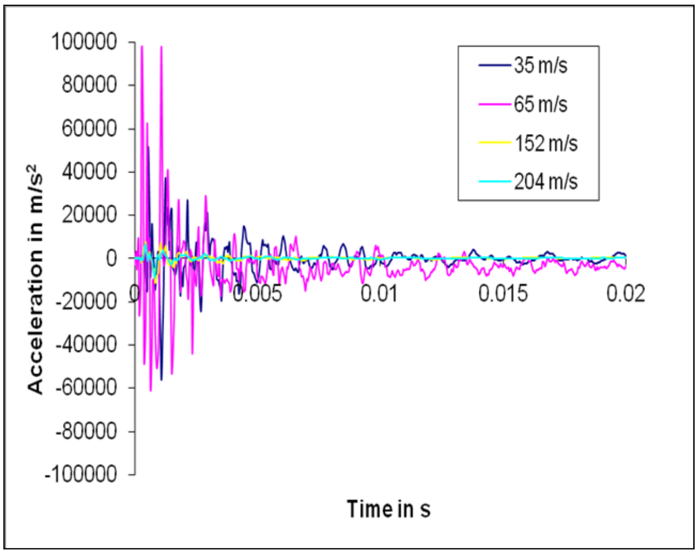

FIG. 17 ACCELERATION-TIME RESPONSE FOR EIGHT LAYER LAMINATES WITH 5% CLAY FOR FOUR DIFFERENT VELOCITIES

Effect of Clay Dispersion in Response

The results for the maximum acceleration and the corresponding period of time are shown in Table 1 for three layered laminates of velocity 35 m/s and 135 m/s respectively. At 35 m/s, the maximum acceleration values of laminates with clay are less than the laminates without clay. The maximum acceleration values are decreasing up to 3% clay and increasing up to 5% clay. The period of time for vibration is 70 ms for laminate without clay and it is decreasing up to 3% clay then remains almost the same. At 135 m/s, the maximum acceleration values are less than 10% of the values at 35 m/s. The maximum acceleration values are decreasing up to 3% clay and increasing for 4% and 5% clay. The time period for vibration is less than 20 ms in all the cases. As the impact velocity increases, the time period of oscillations decreases. This is because at high velocities the vibrational energy is less than the energy absorbed in other modes.

TABLE 1 ACCELERATION AND TIME TAKEN FOR VIBRATION DURING IMPACT FOR 3 LAYER LAMINATE WITHOUT CLAY AT 35 M/S AND 135 M/S

Laminate	Velocity-35 m/s		Velocity-135 m/s	
	Maximum acceleration in m/s^2	Time in ms	Maximum acceleration in m/s^2	Time in ms
Without clay	75325	70	5072	17
1% clay	56522	68	4919	17
2% clay	53436	67	4965	16
3% clay	48522	66	4893	16
4% clay	49127	66	5859	15
5% clay	52928	66	6680	16

Table 2 shows the maximum acceleration and time period for 5 layer laminate at 35 m/s and 152 m/s velocities of impact. The maximum acceleration value of laminate without clay at 35 m/s is 75265 m/s^2, and the value is decreasing up to 5% clay. The time period for vibration is between 26 ms and 35 ms. At 152 m/s, the maximum acceleration values are decreasing for laminates with 5% clay and the time period is between 10 ms and 15 ms.The maximum acceleration in laminates without clay is higher than that in laminates with clay. This shows that the clay layers act as a cushion and absorbs the energy. In other words, it is due to the increase in damping factor of the laminates with clay.

TABLE 2ACCELERATION AND TIME TAKEN FOR VIBRATION DURING IMPACT FOR 5 LAYER LAMINATE WITHOUT CLAY

AT 35 M/S AND 152 M/S **Laminate**	Velocity-35 m/s		Velocity-152 m/s	
	Maximum acceleration in m/s^2	Time in ms	Maximum acceleration in m/s^2	Time in ms
Without clay	75265	35	6872	15
1% clay	55545	32	6286	13
2% clay	51170	30	5694	13
3% clay	50697	30	5590	12
4% clay	45447	29	5548	10
5% clay	35613	26	5515	10

Table 3 shows the maximum acceleration and time period for 8 layer laminates at 35 m/s and 204 m/s velocities of impact. The maximum acceleration value of laminate without clay at 35 m/s is high, and the value is decreasing up to 5% clay. The time period for vibration is between 23 ms and 27 ms. For 204 m/s, the maximum acceleration values are decreasing for laminates with clay up to 5%. Also it is observed that the time period decreases from 10 ms to 8 ms as the clay percentage increases.

Fig. 18 shows the microscopic images of fractured surface of three layer laminates subjected to velocity of 85 m/s. Fig. 18(a) shows the fractured surface of laminate without clay. It shows failure of fibers for about 8 mm width in the impacted zone of the laminate and the velocity of impact is below the ballistic velocity of the laminate. It clearly shows that the energy possessed by projectile is absorbed by the failure of matrix and fiber. Fig. 18(b) shows the fracture surface of laminate with 1% clay subjected to the velocity of 85 m/s. It is observed that the failure zone of fibers is about 3 mm in width and failure of matrix is noticed in the impacted zone. In Fig. 18(c), for laminate with 2% clay, the failure zone of fiber is noticed for about 2 mm width and complete crack of matrix is seen in the impacted and surrounding zone. For laminates with 3% clay, subjected to the same impact velocity, there is no complete failure of fiber noticed in the point of impact, but there is partial crack in a strand. But the failure of matrix of about 8 mm width is seen in the impacted zone, which is shown in Fig. 18(d). Fig. 18(e) shows the failure of impacted zone of laminate with 4% clay. The failure of fiber is completely absent and the crack in the matrix is noticed in concentric form around the point of impact. This is due to the propagation of stress waves towards the boundary from the impact point. Due to the impact, partial separation of matrix is noticed. When the laminate with 5% clay is subjected to impact, after the failure of matrix the fiber is partially failed within the range of about 3 mm in both warp and weft directions. This is shown in Fig. 18(f). Clay dispersion in matrix improves energy absorption due to impact loading and it protects failure of fiber. For 1% and 2% clay dispersion in matrix, partial failure of fiber and matrix is observed. For laminate with 3% and 4% clay, most of the impact energy is absorbed by the matrix and the fibers are protected. But for 5% clay dispersion, crack is observed in the matrix due to brittleness of matrix.

TABLE 3 ACCELERATION AND TIME TAKEN FOR VIBRATION DURING IMPACT FOR 8 LAYER LAMINATE WITHOUT CLAY AT 35 M/S AND 204 M/S

Laminate	Velocity-35 m/s		Velocity-204 m/s	
	Maximum acceleration in m/s²	**Time in ms**	**Maximum acceleration in m/s²**	**Time in ms**
Without clay	82651	27	6433	10
1% clay	80538	27	6146	10
2% clay	57753	26	5841	9
3% clay	62392	26	5872	9
4% clay	51481	24	5677	8
5% clay	50593	23	5411	8

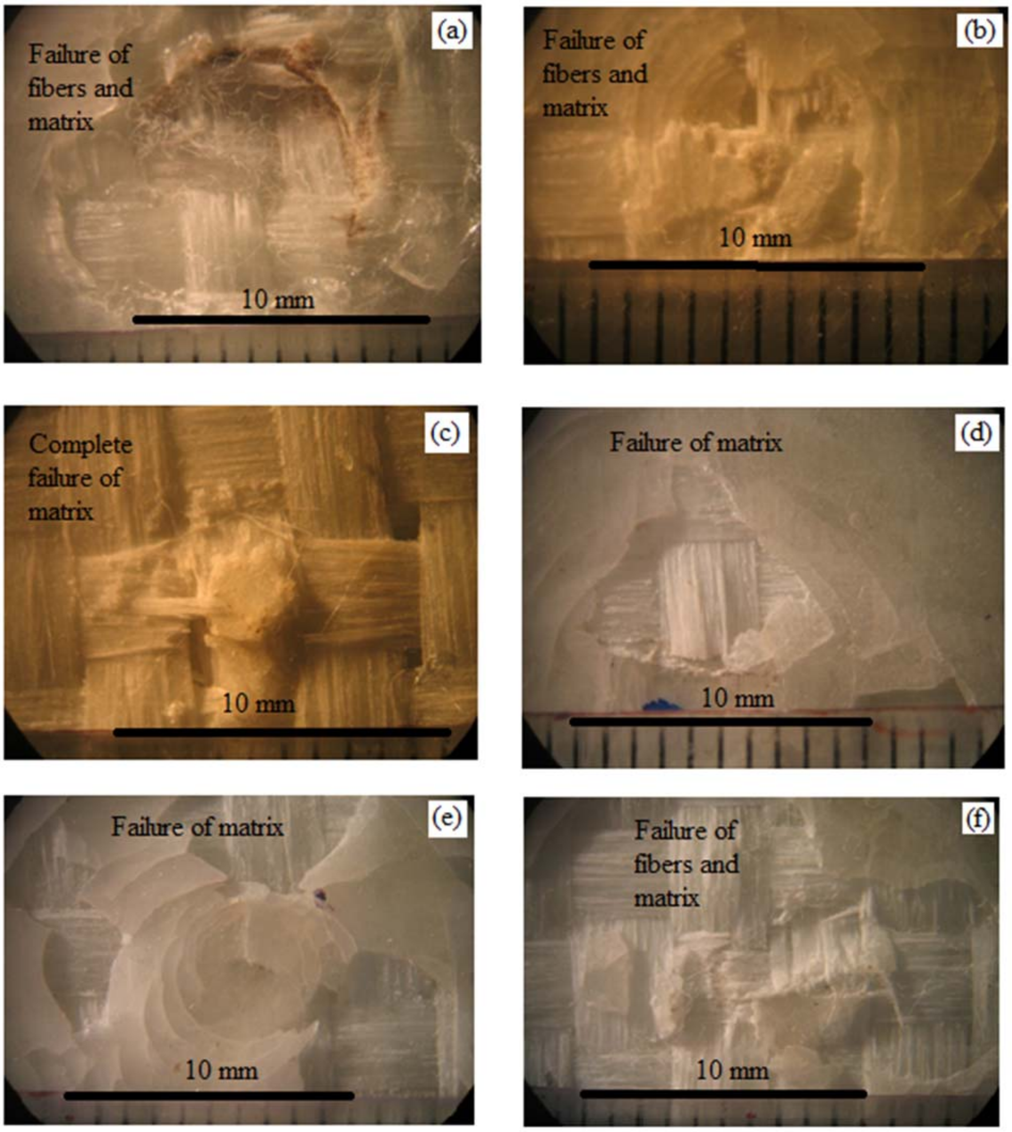

FIG. 18FRACTURED SURFACE OF THREE LAYER LAMINATES SUBJECTED TO IMPACT VELOCITY OF 85 M/S (A) WITHOUT CLAY (B) WITH 1% CLAY (C) WITH 2% CLAY (D) WITH 3% CLAY (E) WITH 4% CLAY (F) WITH 5% CLAY, VELMURUGAN AND BALAGANESAN [2013].

Conclusions

Composite laminates of three, five and eight layers are subjected to impact by drop mass for low velocity impact and projectile impact at velocities below and above the ballistic limit with clamped in all the edges. The shock accelerometer recorded the acceleration response of the laminates during impact of the projectile.

- Nano clay dispersion in matrix enhances damping factor in low velocity impact and reduces the period of vibration.
- In projectile impact, the maximum amplitude of acceleration values for velocities below ballistic limit is higher than that for velocities above ballistic limit.
- The maximum amplitude of acceleration values for the laminates subjected above ballistic limit are less than 10% of maximum amplitude of acceleration values of laminates of velocities below ballistic limit. The maximum amplitude of acceleration values are increasing up to a threshold velocity below ballistic velocity and decreases further in increase of velocity.
- The time period for vibration below ballistic limit is higher than that for velocities above ballistic limit.
- The number of oscillations for three layer laminates are less than five and eight layer laminates in a time period of 20 ms. Number of oscillations increases as the thickness of the laminate increases.

ACKNOWLEDGMENT

The authors gratefully acknowledge the support received from Department of Science and Technology, India through Indo – South African collaboration research project.

REFERENCES

[1] AndrasSzekrenyes, A special case of parametrically excited systems: Free vibration of delaminated composite beams, Eupoian Journal of Mechanics A/Solids, 49(2015), 82-105.

[2] Avila, A., M.I. Soares and A.S. Neto (2007) A study on nano structured laminated plates behavior under low-velocity impact loadings. *International journal of impact engineering*, 24, 28-41.

[3] Balaganesan G, R. Velmurugan, M. Srinivasan, N. K. Gupta and K. Kanny Energy absorption and ballistic limit of nanocomposite laminates subjected to impact loading, International Journal of Impact Engineering 2014; 74: 57-66.

[4] Borvik T, Hopperstad OS, Langseth M, Malo KA. Effect of target thickness in blunt projectile penetration of Weldox 460 E steel plates. IntJImpEng 2003; 28: 413-464.

[5] Della, C.N. and D. Shu (2007) Vibration of Delaminated Composite Laminates: A Review. *Applied Mechanics Reviews*, 60, 1-20.

[6] Deshmane, C., Q. Yuan, R.S. Perkins and R. D. K. Misra (2007) On striking variation in impact toughness of polyethylene–clay and polypropylene–clay nanocomposite systems: the effect of clay–polymer interaction. *Material Science Engineering A,* 458(1–2), 150–157.

[7] Garcia-Castillo SK, Sanchez-Saez S, Lopez-Puente J, Barbero E, Navarro C. Impact behaviour of preloaded glass/polyester woven plates. Compos SciTechnol 2009; 69:711-717.

[8] Lee DG, Lim TS, Cheon SS. Impact energy absorption characteristics of composite structures. *Compos Stru*ct 2000; 50: 381-390.

[9] Leissa, A.W, *Vibration of plates*. Scientific and Technical Information Division of NASA, NASA SP-160, Washington, 1969.

[10] Mahi, A.E.I., M. Assarar *Journal of Adhesion Science Technology,*

[11] Y. Sefrani and J.M. Berthelot (2008) Damping Analysis of orthotropic composite materials and laminates. *Composites: Part B*, 39, 1069-1076

[12] Miyagaw .H and L.T. Drzal (2004) The effect of chemical modification on the fracture toughness of montmorillonite clay/epoxy nanocomposites., 18(13), 1571–1588.

[13] Nieves, F.J., F. Gascon and A. Bayon (2004) Natural frequencies and mode shapes of flexural vibration of plates: laser-interferometry detection and solutions by Ritz's method. *Journal of Sound and Vibration*, 278, 637–655.

[14] Ohta, Y., Y. Narita and K. Nagasaki (2002) On the damping analysis of FRP laminated composite plates. *Composite Structure*, 57,169–175.

[15] Osman, M.A. and A. Atallah (2005) Interparticle and particle–matrix interactions in polyethylene reinforcement and visco elasticity. *Polymer*, 46(22), 9476–9488.

[16] R. MatadiBoumbimba, C. Froustey , P. Viot, P. Gerard, Low velocity impact response and damage of laminate composite glass fibre/epoxy based tri-block copolymer, *Composites Part B*, 76(2015), 332-342

[17] Roland, L. Woodcock, R.B. Bhat and I.G. (2008) Stiharu Effect of ply orientation on the in-plane vibration of single –layer composite plates. *Journal of sound and vibrations*, 312, 94-108.

[18] SüleymanBaştür, k HaydarUyanık, ZaferKazanc. Nonlinear damped vibrations of a hybrid laminated composite plate subjected to blast load, Procedia Engineering, 88(2014), 18-25.

[19] Sun L, Ronald F. Gibson, Gordaninejad F, Suhr J. Energy absorption capability of nano composites: A review. Compos SciTechnol 2009; 69: 2392-2409.

[20] Velmurugan R, Balaganesan G. Energy absorption capability of glass/epoxy nano composite laminates. Int J Crash 2013; 18: 82-92.

[21] Velmurugan. R and Balaganesan. G (2011) Modal analysis of pre and post impacted nano composite laminate, Latin American Journal of Solids and Structures, 8, 9-26.

[22] Viana, J. C (2006) Polymeric materials for impact and energy dissipation. Plast Rubber. *Composites*, 35(6–7), 260–267.

[23] Mihai Ivanica, Constantin Rotaru. Numerical Investigation of an Impact Between an External Body and an Aerodynamic Surface. *Frontiers in Aerospace Engineering*, 2014, 3(2), 56-63. doi: 10.14355/fae.2014.0302.04

[24] Tian Li, Jiye Zhang, Yisheng Zou, Weihua Zhang. Dynamic Performances of High-speed Train in Wind Shear. *Frontiers in Aerospace Engineering*, 2014, 3(1), 17-22. doi: 10.14355/fae.2014.0301.03.

G. Balaganesan Chennai, Tamilnadu, India. 02.09.1970

Ph. D in Aerospace Engineering, Indian Institute of Technology Madras, Chennai – 600036, Tamilnadu, India. His research area is impact studies on composites and repair of pipes and composites.

He is in-charge of the institute students training facilities that has as many as power tools for wood working, metal working, foundry, smithy, welding, composites, plastics, modern machine shops and laboratories of basic electrical, electronics, pneumatics and hydraulics for imparting hands-on training to the students, He has been involved in teaching-learning in this environment for the past 15 years or so with a constant interaction with the students.