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Energy Dissipation of Nanocomposite Laminates During Impact Loading

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ABSTRACT

Laminates are made of glass woven roving mats of 610 gsm, epoxy resin and nano clay which are subjected to medium velocity impact. Clay dispersion is varied from 1% to 5%. A piston type gas gun set up is employed to impact the composite laminates with spherical nose cylindrical projectile of diameter 9.5 mm and mass 7.6 g. The vibration frequency and damping factor are obtained and the effect of nano clay on these parameters is studied. The energy absorbed by the laminates when subjected to impact loading is studied. The effect of nano clay on energy absorption in static deflection and dynamic loading is studied for different weight % of nano clay and for different thickness values of the laminates. The results show considerable improvement in energy absorption, natural frequency and damping factor due to the presence of nano clay.

Keywords: **N**anocomposites, frquency, damping, delamination area.

1 INTRODUCTION

Energy absorption due to impact loading has received much attention recently. Application of such materials can be found both in automobile and in military structures. These materials are used increasingly due to their superior strength, light weight and adaptable design. Traditionally, metals have been the most commonly used materials for crashworthy structural applications and impact related problems mainly due to their plastic deformation characteristics that enable them to absorb impact energy in a controlled manner. Unlike metals, polymer composite materials do not typically exhibit plastic deformation, although their stress-strain relationships may show sign of nonlinearities, but they are superior to metals for specific energy absorption [9, 10, 24]. Lee et al., [14] proposed a progressive impact fracture model to estimate impact energy absorption characteristics of fiber composite materials. Abrate [1] presented spring-mass models, energy-balance models and impact on infinite plate model for impact studies. The models predict the contact force history and the overall deformation of the plate. Experimental investigation on dynamic behavior was carried out by Pintado et al., [19] for a wide range of impact velocities. Chandra et al. [5] reviewed the damping of fiber reinforced composites.

It has been established in recent years that polymer based composites reinforced with small percentage of nano scale fillers can significantly improve mechanical, thermal and barrier properties of pure polymer matrix [12, 13, 22]. Further the addition of nano phase particles in fiber reinforced plastics have also yielded improvement in impact and other mechanical properties of laminates [21, 23]. Moreover these improvements are achieved through conventional processing techniques without any detrimental effect on processing, appearance, density and ageing performance of matrix. Therefore these composites are now considered for different applications in automotive and aerospace industry. When the dimensions of the reinforcement fibers or particles approach the nanometer scale, numbers of parameters causing the properties of the corresponding composites are different from those of composites reinforced with macro-scale particles. The main factors affecting the properties of nano composites include nano filler dispersion, dimensions, weight fraction, the nature of the matrix material, the interfacial characteristics between nano filler and matrix and the manufacturing process. Mohan et al. [15] observed maximum increase in tensile strength, for 2-3 weight % of nano clay composites when compared to composites without clay. In another study [16], nano size organo clay (OC) is compared with unmodified clay (UC), for dynamic mechanical analysis (DMA) and thermo gravimetric analysis (TGA). Results show that the addition of OC increases the thermal properties of epoxy/glass fiber more than that of UC filled composites. Also it is observed that dispersion of nano clay effectively improves the internal damping of the composites [7]. Della and Shu [8] reviewed free vibration of composites with delamination. Nano particles provide better inter phase strength which affects the damping characteristics of composites [2, 11, 15, 17, 18]. In another work, Avila et al. [3] has proved that the addition of nano clay and graphene nano sheets to fiberglass/epoxy laminates has not only increased the high velocity impact resistance of these composites, but it also has a major influence on their failure mechanism. There are limited studies on impact energy absorption of nano composites due to impact loading. When subjected to impact loading which may not completely damage the structure, most of the energy is absorbed in vibration in addition to some micro cracks. In this work an attempt is made to find the energy absorption of the laminate in vibration mode when the structure behaves elastically without much permanent deformations.

The effect of nano clay incorporation in the glass/epoxy fiber laminates, with orientation of 0°/90°, is studied for velocities ranging from 35 m/s to 82 m/s. The different natural frequencies and damping factors are obtained for the laminates and the effect of nano clay is studied. Quasi static punch test is carried out to find energy absorption of the laminate. The effect of nano clay on energy dissipation in delamination and matrix crack is also studied for laminates of different thickness values and for different impact velocities.

2 EXPERIMENTS

2.1 Preparation of Nano Composites

Dispersion of nano inclusions in the matrix is a very important factor in the mechanical behavior of nanocomposites. For example, when clay nano platelets are dispersed into a polymer matrix, three kinds of possible nanocomposites will result in, depending on the degree of separation of the clay nano platelets: agglomerated, exfoliated and intercalated [4]. If the polymer enters the galleries causing an increase in distance between two layers but the clay layers remain stacked, the composite is ‘intercalated’. If the clay layers are pushed completely apart to create a disordered array, the composite is ‘exfoliated’ [5]. If the polymer cannot enter into several continuous clay layers, the composite is ‘agglomerated’. The exfoliated type has the more contact area which benefits an efficient stress transfer between the nano inclusions and the matrix and results in improved stiffness, strength and failure strain. Hence, it could be an ideal type structural element for energy absorption.

The nano composite laminates are fabricated in two steps. Clay was mixed with resin using shear mixer at 750 RPM for 2 hrs and kept in the vacuum oven to remove the air bubbles at room temperature, for better dispersion. Hardener Tri Ethylene Tetra Amine (TETA) of 10% was mixed with the epoxy-clay mixture, by weight. The laminates were prepared by hand layup technique and then compressed in compression molding machine. Laminates of 300 mm x 300 mm were used for testing.

2.2 Quasi static punch test

Quasi static punch test is performed on the laminates with the projectile that is used to perforate the target in impact loading. This test is performed in an UTM by the application of point load transversely, to the target through the projectile. The fixture used in impact testing is used in this punch test to maintain the same loading and boundary conditions. Figure 1 shows the experimental setup used for quasi static punch test. The projectile is fixed to the movable head of the UTM. Load is applied until the projectile's shank portion enters into the target completely. The load, corresponding to the depth of penetration by the projectile and the maximum deflection, are recorded and plotted. This is repeated for laminates with various percentage of clay contents.

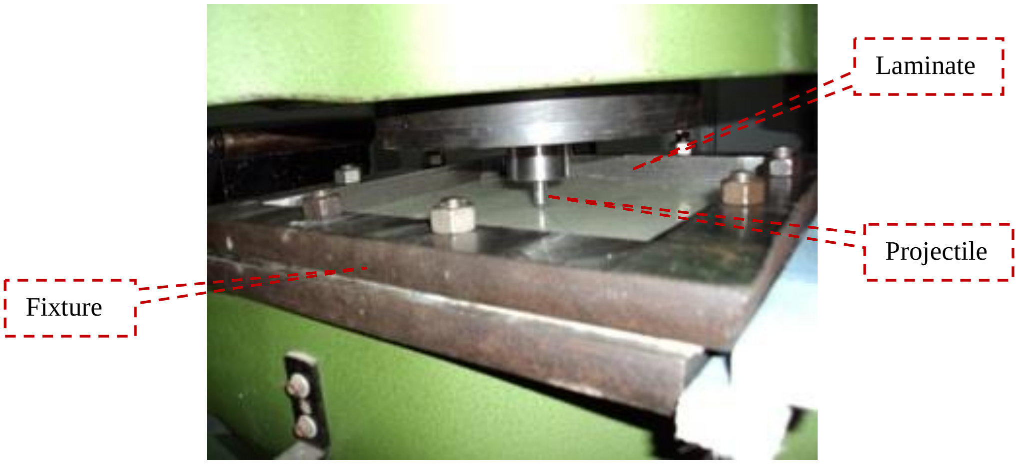

Figure 1: Experimental setup for quasi static punch test

2.3 Impact test

Experiments are performed using the gas gun test setup, which is shown in Figure 2. Plates of required size are clamped at the edges and are subjected to impact load by cylindrical projectile. Incident velocity is measured by laser diode. Air pressure in the chamber is varied to get different velocities in the range of 35 to 82 m/s. Chamber air pressure is maintained by using pressure regulator for getting consistent velocity for experimenting laminates of 2 mm, 3 mm and 5 mm thickness values. These values are obtained by having 3, 5 and 8 number of layers in the laminates, respectively. Shock accelerometer of capacity 100k g PCB make, model No. 350B21, is used to measure the response through the Data Acquisition (DAQ) Card [NI-PXI 4472] and the response is recorded on the computer. The accelerometer is fixed at a distance of ¼th length of diagonal, from one of its corner which is a non-nodal line. The projectile is impacted at the centre of the laminates.

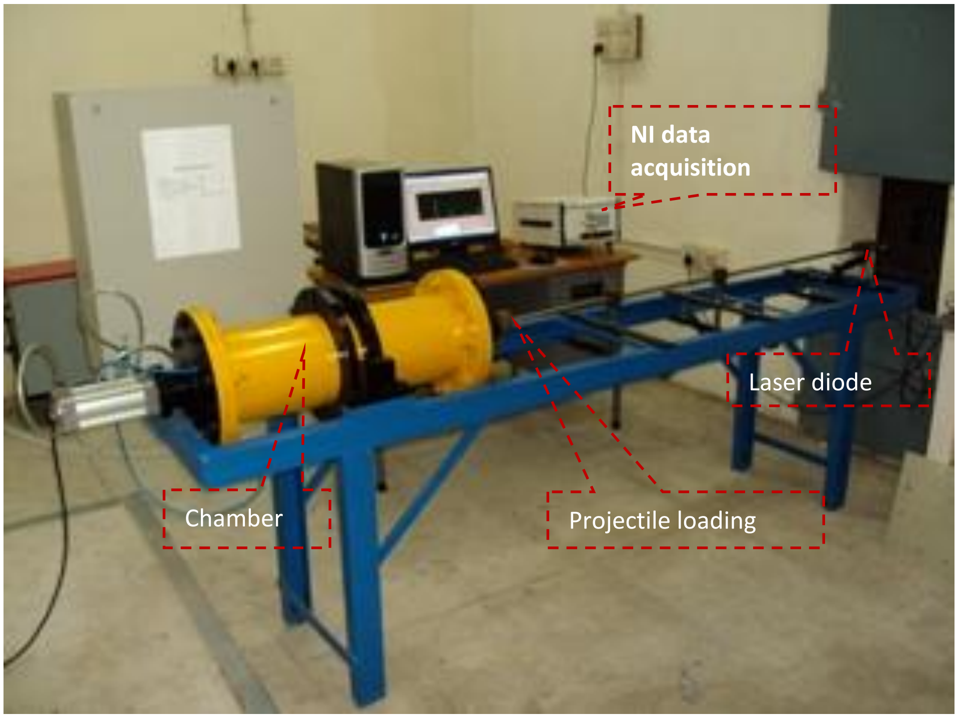

Figure 2: Gas gun setup used for Impact loading [20]

The vibration waveform is composed of a combination of frequency components of different magnitudes. In order to extract data that can be analyzed, the time-dependent vibration signal has to be subjected to a spectral analysis, which processes it and separates it into frequency components. The data for these tests is analyzed by performing a Fast Fourier Transform (FFT) on the recorded accelerometer signal. FFT is a discrete digital signal processing technique for converting a time-dependent signal into a frequency spectrum. The spectrum graphs are two-dimensional plots of the spectrum with frequency (Hz) on the horizontal axis and the amplitude of each discrete frequency component on the vertical axis. The amplitude is a peak hold, displaying the maximum amplitude for that particular frequency in the processed time frame, unless otherwise stated.

The damping factor for the materials is obtained by using the half power band width method, (see Figure 3).

The following expression is used to find the damping factor ξ.

$$\xi = \frac{(f_2 - f_1)}{2f_n} \quad (1)$$

Where f_2 and $f_1$are the frequencies and f_n is the resonance frequency.

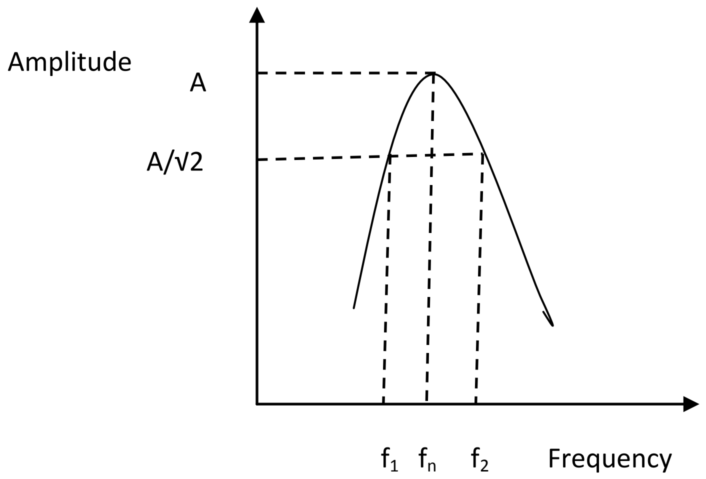

Figure 3: FRF plot for finding damping factor

3 ENERGY DISSIPATION

The energy dissipated by the laminates subjected to impact loading, for velocities, below ballistic limit, is in the form of vibration, failure of matrix in the delaminated area and delamination. During impact a localized deformation around the impact region and global deflection away from the point of impact resulting in-plane compression in the front face and tension in the rear face of the laminate, are produced. The deflection of the laminate in the loading direction causes strain in the fibers and matrix. 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 and vibrates the laminate. The stress waves propagate in radial direction. When these stress values exceed the inter laminar shear stress, there is possibility for failure in the matrix and in the lamina interfaces. The first possible failure that occurs in a target is matrix cracking. Matrix cracking leads to decrease in inter laminar strength of the composite, as a result further loading causes delamination. The energy dissipated in vibration, delamination and in matrix crack, is discussed in the following sections.

3.1 Energy Dissipation in vibration

The energy absorbed by the laminates during vibration is calculated based on its total potential energy when subjected to impact loading.

The total potential energy at the initial of vibration is given by the expression,

$$E_v = \frac{1}{2}kx^2 \tag{2}$$

Where, k is stiffness of laminates obtained from static penetration test and x is peak amplitude of vibration or deflection at the centre of the laminate which is also the point of impact. The amplitude at the centre is obtained from the correlation between the amplitude at the location of accelerometer and impact point and the expressions are given in Eqns. (2) to (4).

For 2 mm thickness laminates,

$$x_{c2} = 3.789A_{accln} + 0.220 \tag{2}$$

For 3 mm thickness laminates,

$$x_{c3} = 4.801A_{accln} - 0.233 \tag{3}$$

For 5 mm thickness laminates,

$$x_{c5} = 3.848A_{accln} - 0.006 \tag{4}$$

In equation (3), x_{c2} is the amplitude or deflection at the centre and x_{accln} is amplitude at the location of accelerometer. Similarly the expressions for 3 mm and 5 mm thickness laminates are given in Eqns. (4) and (5), respectively.

The maximum amplitude at the location of the accelerometer is calculated from the following expression,

$$Acc = A_{accln}\omega^2 \tag{6}$$

In the above Eqn. the maximum amplitude (A_{accln}) and angular velocity(ω) are obtained from the accelerometer signal and Acc is the magnitude of maximum acceleration.

The total energy of the projectile is given by

$$E_T = \frac{1}{2}mv^2 \tag{7}$$

Where m is mass of the projectile and v is velocity of the projectile

3.2 Energy absorbed in delamination

The area of delamination in the laminate (A_{delam}) is measured from the impacted laminates. The energy due to delamination is given by,

$$E_{delam} = A_{delam}G_{IIc} \tag{8}$$

Where G_{IIc} is critical strain energy release rate in mode II which is obtained from three point bending of end notched flexural specimen [17].

3.3 Energy absorbed in Matrix crack

The area undergoing matrix crack is same as delamination area and hence energy due to matrix crack is given by,

$$E_{matcrack} = A_{delam}E_{mt}hV_m \tag{9}$$

Where, E_{mt} is energy absorbed by matrix cracking per unit volume calculated from load-displacement curves of tensile test results of neat epoxy and clay dispersed epoxy specimens, h is thickness of the laminate and V_m is the volume fraction of the matrix.

4 RESULTS AND DISCUSSION

4.1 Stiffness and Energy absorption in quasi static test

Quasi static punch test is performed to find the energy absorbed by the laminates with and without clay. The geometry of the projectile is same as that used in dynamic test. This test is performed on an UTM by the application of transverse load to the specimen through the projectile. The load-displacement values are taken till the projectile punches the test specimen. Stiffness of the laminates is calculated from load-displacement plot. It is observed that there is increase in stiffness values for laminates with clay up to 3%, in laminates of 2 mm, 3 mm and 5 mm thickness values. This is due to exfoliation of nano particles in the composites. When the nano material is increased above 3%, the clay forms intercalation or agglomeration. The area under load-displacement diagram gives the energy absorbed by laminate. The energy absorbed due to static deflection is calculated and it is observed that the laminates with clay absorb more energy in failure than the laminates without clay. This is due to improvement in interlayer shear strength of the laminates with clay. Table 1 shows the values of stiffness and energy absorbed by the laminates with and without clay.

Table 1 Static deflection test results for different laminates

Thickness in mm	Item	Percentage of nano clay					
		Without clay	1%	2%	3%	4%	5%
2	Stiffness(k) (N/mm)	202.53	211.49	216.67	235.89	219.15	221.18
	Energy (J)	8.26	8.61	9.32	9.74	11.562	13.32
3	Stiffness(k) (N/mm)	297.10	336.08	352.47	356.42	328.3	299.74
	Energy (J)	17.14	17.85	19.99	20.01	20.56	24.32
5	Stiffness(k) (N/mm)	505.1	506.6	519.3	579.2	523.1	521.5
	Energy (J)	46.20	48.52	49.33	50.83	52.72	54.21

4.2 Impact response

Experiments are performed using a gas gun to impact the laminates in clamped condition. Chamber pressure is varied to get different impact velocities of projectile. Tests are conducted for the velocities ranging between 35 m/s and 82 m/s. Accelerometer is used to capture time response signal and processed with FFT to get frequency spectrum. The results for laminates of 2 mm, 3 mm and 5mm thickness are discussed. From FFT spectrum, it is understood that the projectile impact induces the laminate to vibrate in different modal frequencies. Figure 4 shows the amplitude response and corresponding frequency response plots for 2 mm thickness laminate with 3% clay when subjected to 35 m/s. The peak mode frequency is 655 Hz for which the amplitude ratio is 1. The maximum energy is dissipated in this frequency. From our previous study on modal analysis [20], it is observed that this range of frequency is its fifth mode of vibration. Also it is observed that 2 mm thickness laminates vibrate in various modes up to 2000 Hz and dissipate the energy received from the projectile. The natural frequency of the laminates is shown in Table 2 for velocities from 35 m/s to 82m/s.

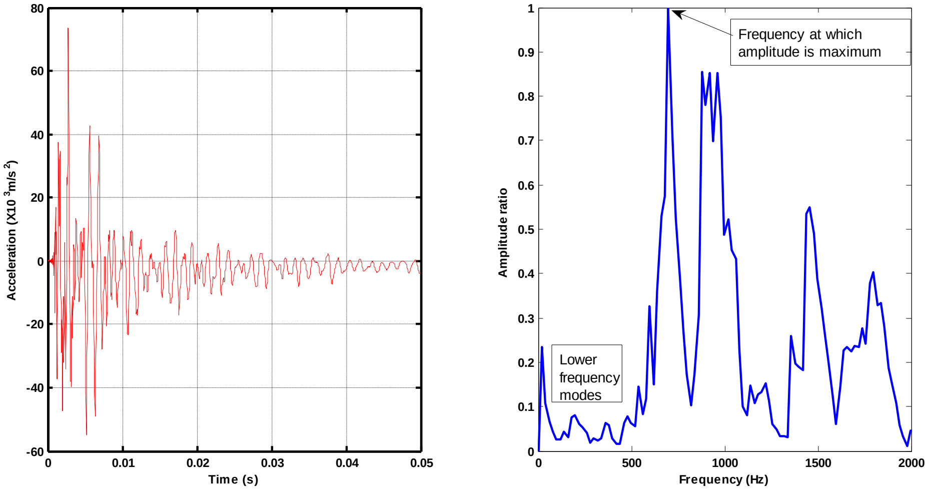

Figure 4: Time response and FFT spectrum for 2 mm thickness laminate with 3% clay subjected to 35 m/s

Table 2 Modal frequency for 2 mm thickness laminates at different velocities

Clay %	Velocity of impact in m/s	Frequency of vibration (Hz)			
		Mode V	Mode VI	Mode VII	Mode VIII
Without clay	Impulse hammer	645	872	998	1181
	35 m/s	604	860	967	1157
	50 m/s	589	819	959	1138
	65 m/s	573	778	951	1129
	82 m/s	523	759	916	1108
1% clay	Impulse hammer	665	908	1172	1233
	35 m/s	613	897	1148	1340
	50 m/s	588	875	1056	1234
	65 m/s	582	856	1035	1221
	82 m/s	578	792	1017	1155
3% clay	Impulse hammer	711	937	1291	1544
	35 m/s	655	897	1259	1540
	50 m/s	650	836	1127	1365
	65 m/s	642	828	1096	1334
	82 m/s	640	820	1059	1336
5% clay	Impulse hammer	727	943	1378	1599
	35 m/s	668	899	1272	1548
	50 m/s	665	845	1138	1376
	65 m/s	661	834	1112	1348
	82 m/s	652	823	1067	1337

Table 3 shows the frequencies for 3 mm thickness laminates with and without clay when subjected to impact loading. These values are compared with frequency values for the modes IV to VII obtained from impulse hammer technique. The laminates with clay show considerable increase in frequency values up to 3% clay and then marginal increase up to 5% clay. But these values are higher than the values of laminates without clay. The possible reason for measured increase in 5% clay, could be due to the agglomeration of clay particles at higher % level. In mode IV, the frequency of the laminate without clay, when subjected to impact of 35 m/s, is 767 Hz and it is 13.6% less compared to impulse hammer method. For the impact velocities of 50 m/s, 65 m/s and 82 m/s, the decrease in frequency values are 17.4%, 20.7% and 22.1% respectively. It is seen that as the impact velocity increases there is decrease in frequency values. This is due to damage of laminates in impact loading. For the laminates with 1%, 3% and 5% clay at 35 m/s, the decrease in frequency values in mode IV are 4.4%, 4.2% and 3.4% respectively when compared to pre impact frequency values. At 82 m/s, the laminates with 1%, 3% and 5% clay, the decrease in frequency values in mode IV are 15.6%, 13.8% and 12.8% respectively when compared to pre impact frequency values. The decrease in frequency values are less in nano clay dispersed laminates when compared to laminates without clay. Also the decrease in percentage is less up to 5% clay, this is due to reduction in damage area of the laminates.

Table 3 Modal frequency of 3 mm thickness laminates for different velocities

Clay %	Velocity of impact in m/s	Frequency of vibration (Hz)			
		Mode IV	Mode V	Mode VI	Mode VII
Without clay	Impulse hammer	878	1208	1613	2124
	35 m/s	767	1172	1586	2098
	50 m/s	725	1114	1551	2071
	65 m/s	696	1086	1492	2049
	82 m/s	684	1020	1373	1976
1% clay	Impulse hammer	887	1242	1656	2177
	35 m/s	848	1215	1619	2138
	50 m/s	832	1164	1587	2102
	65 m/s	815	1136	1538	2098
	82 m/s	749	1043	1419	2057
3% clay	Impulse hammer	986	1331	1723	2272
	35 m/s	944	1280	1637	2226
	50 m/s	893	1259	1614	2157
	65 m/s	867	1185	1590	2118
	82 m/s	850	1147	1536	2104
5% clay	Impulse hammer	991	1362	1775	2284
	35 m/s	957	1295	1739	2238
	50 m/s	908	1268	1728	2159
	65 m/s	889	1226	1679	2127
	82 m/s	864	1202	1614	2117

Table 4 shows the frequencies for the mode I to IV for 5 mm thickness laminates with and without clay. The mode I frequency of the laminates with 1% and 3% clay and without for 35 m/s, 50m/s and 65 m/s velocity of impact is marginally less than that in pre impact frequency values. But in laminate with 5% clay, the frequency values at 35 m/s and 50 m/s are same as in pre impact values. This is due to negligible damage in the laminates. In mode IV for the laminate without clay, the frequency values at 35 m/s, 50 m/s, 65 m/s and 82 m/s are 7.5%, 7.9%, 8.8% and 12.9% less than the frequency values obtained from impulse hammer technique. The corresponding decrease in percentage values for the laminates with 1% clay are 5.9%, 6.4%, 7.7% and 8.1% respectively. For the laminate with 5% clay, the values are less by 3.2%, 3.3%, 4.1% and 4.4% respectively. The laminate with 5% clay shows less percentage of decrease in frequency values when compared to pre impact values. This is due to dispersion of clay in the 5 mm thickness laminates controls the damage due to delamination. In general it is understood that the addition of clay in the matrix increases the natural frequency of vibration due to increase in modulus [12] of nanocomposites.

Table 4 Modal frequency of 5 mm thickness laminates for different velocities

Clay %	Velocity of impact in m/s	Frequency of vibration (Hz)			
		Mode I	Mode II	Mode III	Mode IV
Without clay	Impulse hammer	329	661	990	1201
	35 m/s	328	660	946	1111
	50 m/s	327	659	945	1106
	65 m/s	326	655	935	1095
	82 m/s	311	626	890	1046
1% clay	Impulse hammer	336	675	1012	1230
	35 m/s	334	672	963	1157
	50 m/s	332	668	1291	1151
	65 m/s	330	663	1280	1135
	82 m/s	329	662	942	1130
3% clay	Impulse hammer	357	718	1075	1307
	35 m/s	355	713	1022	1228
	50 m/s	354	712	1016	1225
	65 m/s	351	707	1006	1227
	82 m/s	350	703	1001	1220
5% clay	Impulse hammer	362	728	1091	1327
	35 m/s	362	727	1068	1285
	50 m/s	362	727	1064	1282
	65 m/s	361	727	1063	1273
	82 m/s	359	721	1052	1268

4.3 Damping Factor

The damping factors of the impacted specimens are obtained by half power band width technique from FRF plots. The damping factor is obtained for the frequency mode at which maximum energy is dissipated. Figures 5 to 7 correspond to impact damping factor values for laminates of 2 mm, 3 mm and 5 mm thickness values with and without clay, respectively. From these figures, it is clear that as the clay content is increased, there is increase in damping factor which is due to the presence of the additional medium (clay) in the laminate. It is also seen in laminates without clay that as the input velocity increases damping factor increases. This is due to the fact that as the velocity increases the delamination area increases. Laminates of 2 mm thickness dissipates maximum energy for the frequency in the range of 600 Hz to 700 Hz for the velocities from 35 m/s to 82 m/s depending upon clay content. From FFT, it is observed that this range of frequency corresponds to its fifth mode of vibration and the damping factor is obtained for this mode. This is seen in Fig. 4. When laminates of 3 mm thickness are subjected to the same range of impact velocities, the peak amplitude is observed in its fourth mode of vibration. This is in the range of 900 Hz to 1000 Hz and the maximum energy is dissipated in this mode. When 5 mm thickness laminates are subjected to impact, the peak amplitude occurs in its third mode of vibration for 35 m/s velocity. For velocities 50 m/s, 65m/s and 82 m/s the peak amplitude occurs in its fourth mode of vibration. Hence it is clear that as the input energy is high the peak amplitude of vibration occurs at higher modes of vibration.

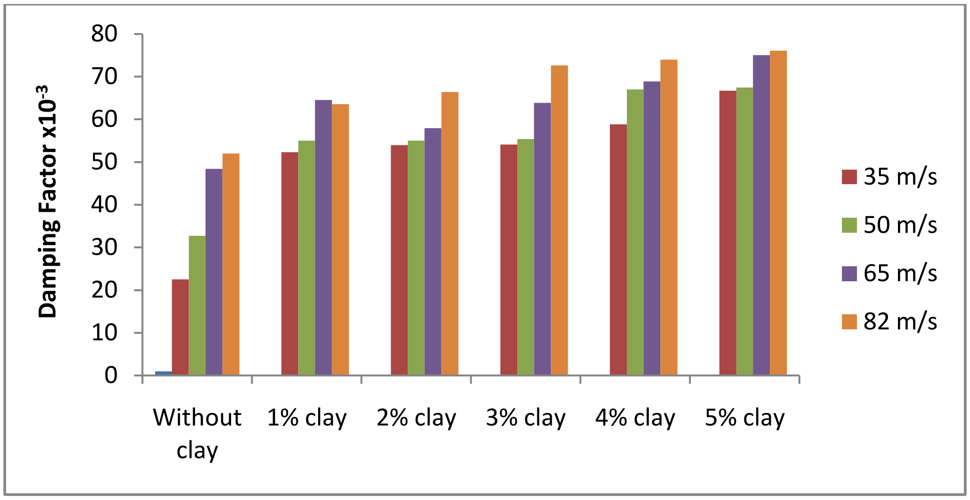

Figure 5: Damping factor for 2 mm thickness laminates subjected to impact loading

The damping factor values are between 0.02 to 0.08 for all laminates with and without clay and for different modes of vibration. Since most of energy is dissipated in the peak amplitude, this value is considered for reference and this value is 1 in FFT, the damping factor corresponding to this mode is considered and compared. Figure 5 shows damping factor for the 2 mm thickness laminates subjected to impact loading. At impact velocity 35 m/s the damping factor for laminate without clay is 0.0225 and for the laminate with 5% clay the damping factor is 0.0667. The damping factor is increased by three times. When the laminates without clay is subjected to velocities 50 m/s, 65 m/s and 82 m/s the corresponding damping factor values are 0.032, 0.048. and 0.051 respectively. When the lamintes with 5% clay is subjected to the same velocities the improvement in damping factor is about two times. The increase in damping factor is observed in the laminates with clay up to 5%. Rate of increase in damping factor is high in laminates with clay up to 2% dispersion.

Figures 6 and 7 correspond to peak amplitude mode damping factor values for 3 mm and 5 mm thickness laminates, respectively. It is seen that there is improvement in damping factor for laminates when clay is added. When the 3 mm thickness laminate without clay is subjected to 35 m/s, the damping factor is 0.0272 and for the laminate with 4% clay the damping factor is 0.0425, the improvement in damping factor is 56%. When the laminates without clay are subjected to 50 m/s, 65 m/s and 82 m/s the damping factor values are 0.032, 0.033 and 0.041 respectively. The lamintes with 3% clay are subjected to the same velocities the improvement in the damping factor values are 28%, 26% and 13.5% respectively. The decrease in percentage increase of damping factor at higher velocity of impact is due to higher damage area in laminates without clay. The increase in delamination area makes an increase in damping factor.

When 5 mm thickness laminate is subjected to 35 m/s the damping factor for laminate with 3% clay shows an improvement of 75% when compared to laminate without clay. The improvent of damping factor is between 67% to 100% when these laminates with 3% clay are subjected to the velocities ranging from 35 m/s to 82 m/s.

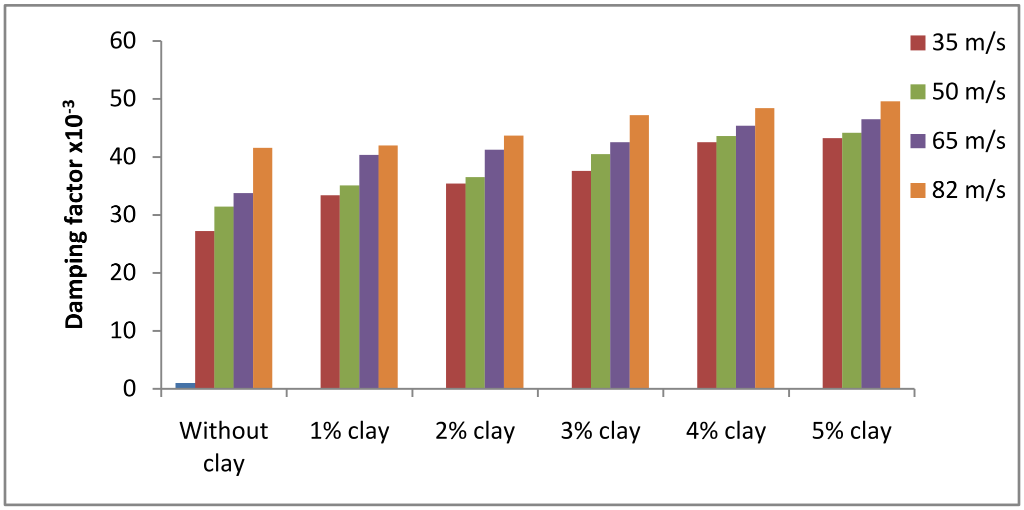

Figure 6: Damping factor for 3 mm thickness laminates subjected to impact loading

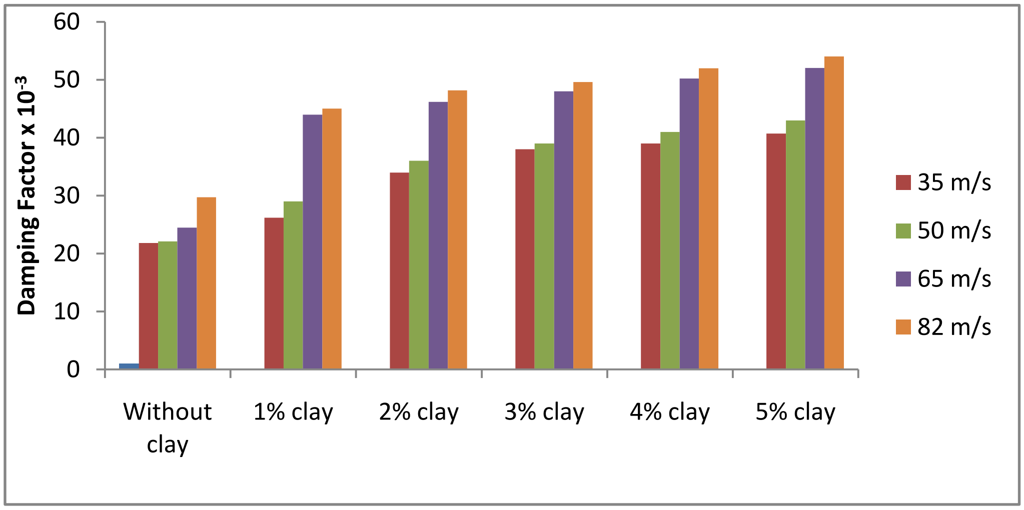

Figure 7: Damping factor for 5 mm thickness laminates subjected to impact loading

Among the 2 mm, 3 mm and 5 mm thickness laminates, 2 mm thickness laminates show high improvement in damping factor due to the presence of clay. There is an improvement in damping factor in laminates of thickness values 3 mm and 5 mm as the impact velocity increases. Energy dissipation occurs when interfacial slip of nano scale fillers is activated in host matrix material, which leads to improvement in damping factor. For rigid nano-particles, the high stress area around the particles will lead to initial microcracks and inelastic deformation in the matrix. The interfacial shear strength between nano-filler and matrix is higher than that in conventional composites which is due to the formation of cross-links or shield of the nano-fillers and form thicker interphases. The nano scale filler in the matrix acts as secondary fiber which enhances the energy absorption of the laminates when subjected to impact loading.

4.4 Energy dissipated in vibration, delamination and matrix crack

The vibration energy is calculated based on initial deflection and stiffness values of the laminates as given in Eqn. (2). The initial energy varies from 4.65 J to 25.55 J where the impact velocity is varied from of 35 m/s to 82 m/s. The impact tests are performed below the ballistic limit of the laminates. The rebound of the projectile is observed in all tests and the part of projectile energy is carried for this. The laminates of 2mm, 3mm and 5 mm are considered for this study. Fig. 8 corresponds to 2 mm thickness laminates subjected to impact velocity of 50 m/s which is below ballistic limit. The vibration energy of laminate without clay when subjected to 9.5 J energy of impact is 2.99 J and for the same energy input, the value for the laminate with 3% clay, is 3.62 which is 21% higher than the laminate without clay. The energy absorption in vibration is decreasing when the clay value is above 3% in the matrix. But still the values are higher than the laminates with clay. Figure 8 shows the delamination and matrix crack energies absorbed by the 2 mm thickness laminates with and without clay. When the laminates without clay are subjected impact loading the energy absorption in delamination is higher than the energy absorption in vibration. This value is higher than that in laminates with clay. But in nano composites, delamination and matrix crack energies are decreasing up to 5% clay. This is because the dispersion of clay controls delamination area in impact. For the velocity of 50 m/s, the input projectile energy is 9.5 J, and the total energy absorption of glass/epoxy laminate is 8.42 J, in which the vibration energy is 2.99 J, delamination energy is 3.66 J and matrix crack energy is 1.77. For the same velocity, nano composite with 3% clay absorbs 4.72 J, in which the energy dissipation in vibration, delamination and matrix crack are 3.62 J, 0.69 J and 0.41 J respectively. Energy dissipation in vibration is higher in nanocomposites which are due to the increase in surface area between matrix and nano filler interface. Also the presence of clay controls the damage of the laminates in impact loading. As the velocity of impact increases to 82 m/s, the projectile energy is 25.55 J and the energy absorption in laminate without clay due to vibration is 6.46 J. The increase in energy absorption in vibration is observed in all the cases. The laminate with 3% clay absorbs 9.61 J of energy in vibration which is 50% higher than the laminate without clay. This can be seen in Figure 9. The delamination and matrix crack energies are less than the energy absorbed in vibration for the laminates with and without clay. The energy absorbed by delamination and matrix crack for the nano composites is less than that of laminate without clay. The delamination energy of laminate with 3% clay is less by 50% of the laminate without clay. The matrix crack energy for laminate with 3% is about 50% less than that in laminate without clay.

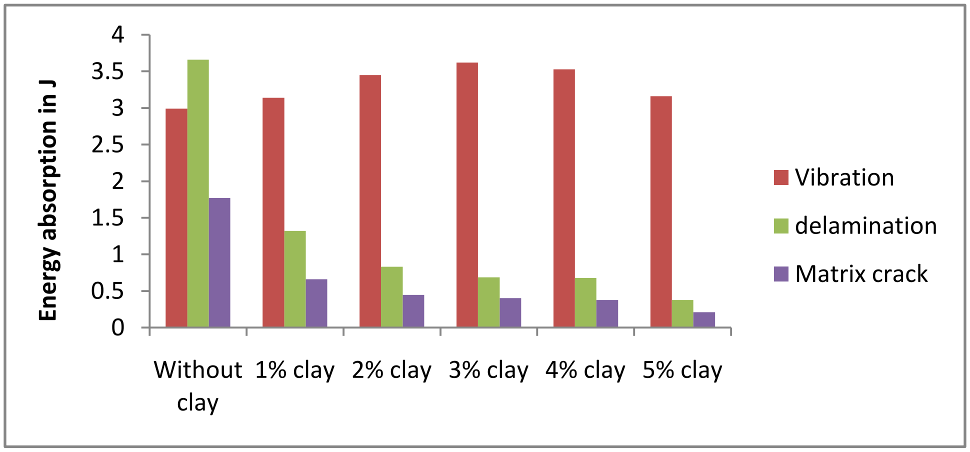

Figure 8: Showing the energy absorbed by the 2 mm thickness laminate when subjected to impact velocity 50 m/s

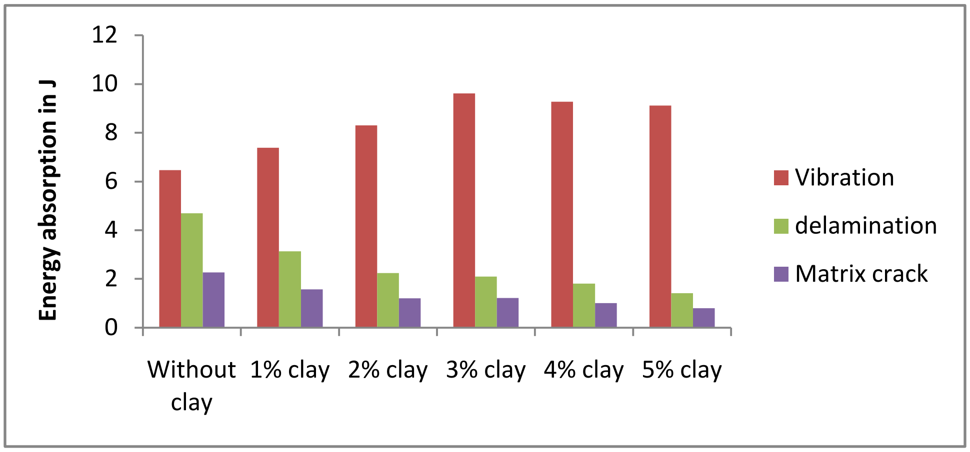

Figure 9: Showing the energy absorbed by the 2 mm thickness laminate when subjected to impact velocity 82 m/s

Figures 10 and 11 show the energy absorbed by the 3 mm thickness laminates by vibration, delamination and matrix crack for the input projectile energy of 9.5 J and 25.5 J respectively. The vibration energy increases as the % of clay dispersion increases up to 3% and decreases on further increase of clay. This is similar to 2 mm thickness laminates. The maximum energy dissipation in vibration is about 50% higher than the laminate without clay. As the input energy of the laminate increases the energy absorbing capacity of the laminate in vibration also increases. Due to increase in thickness of the laminates, the damage area in delamination is less and, hence the energy absorbed in delamination and matrix crack is less when compared to 2 mm thickness laminates. The energy absorbed in delamination and matrix crack is 1 J for the laminates without clay for input energy of 9.5 J and it is about 2 J for input energy of 25.55 J. But in the laminates with clay, the energy due to damage is less by 50% compared to laminate without clay. This can be seen Figure 10. In nano composite laminates, the delamination and matrix crack energies are reduced, further the damage area for 4% and 5% clay dispersion is less. It is clear that for the input energy at 9.5 J, there is no damage in the laminate with 5% clay and hence most of the energy is absorbed in vibration mode.

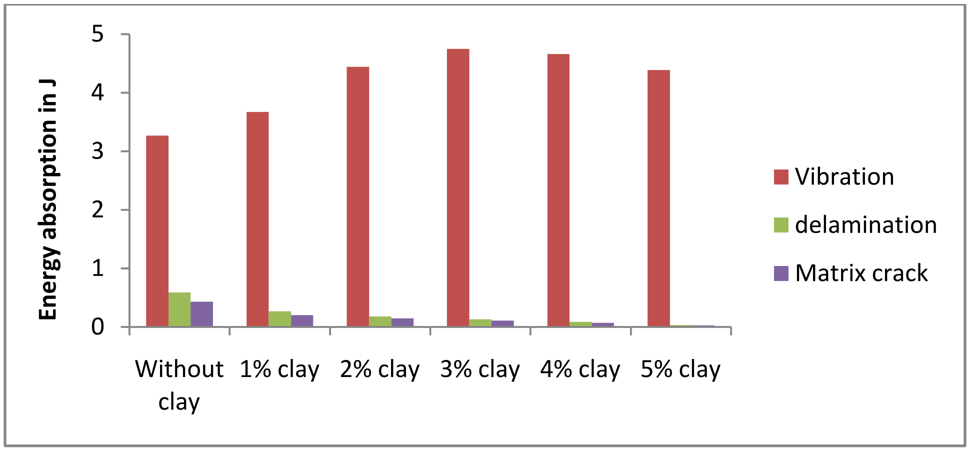

Figure 10: Showing the energy absorbed by the 3 mm thickness laminate when subjected to impact velocity 50 m/s

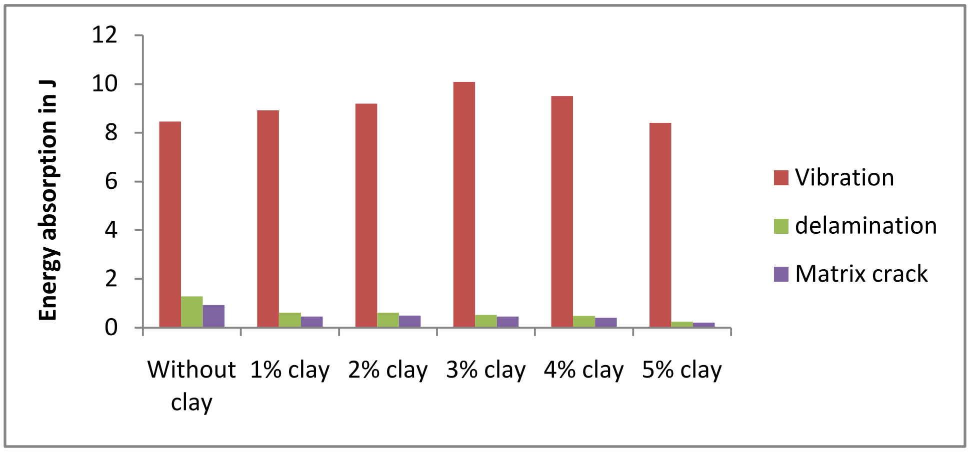

Figure 11: Showing the energy absorbed by the 3 mm thickness laminate when subjected to impact velocity 82 m/s

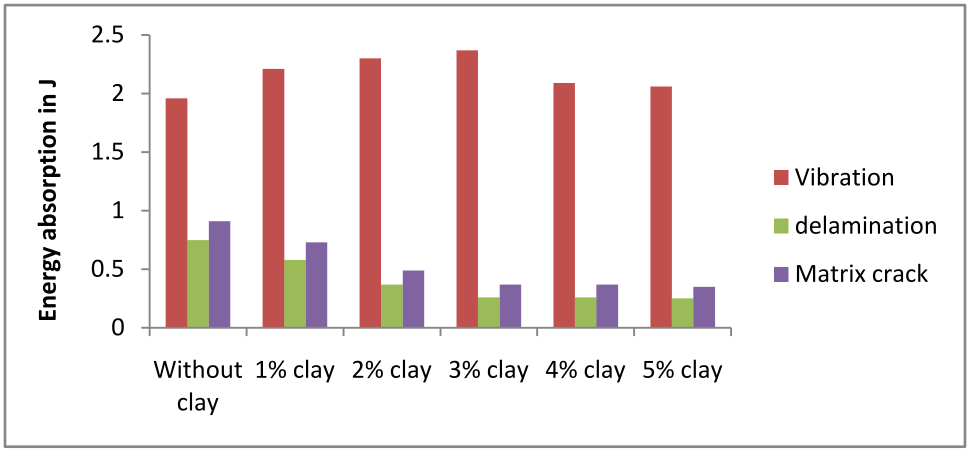

Figure 12: Showing the energy absorbed by the 5 mm thickness laminate when subjected to impact velocity 50 m/s

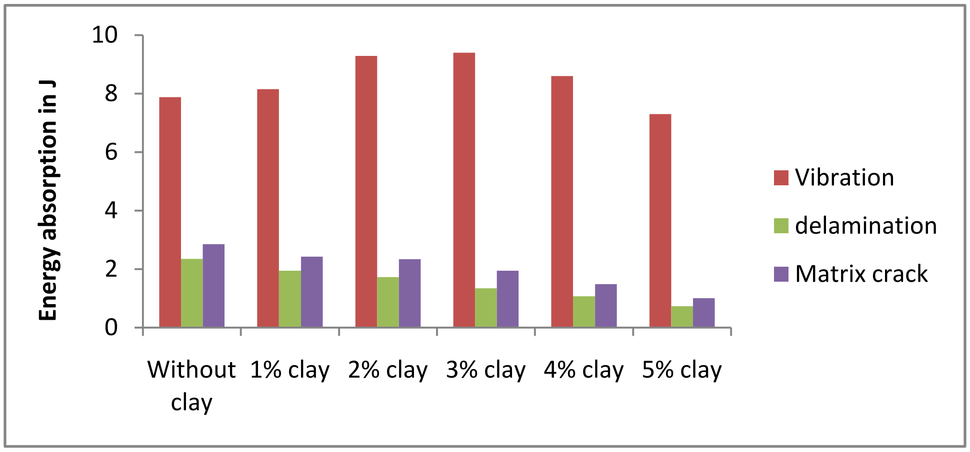

Figure 13: Showing the energy absorbed by the 5 mm thickness laminate when subjected to impact velocity 82 m/s

Figure 12 shows the energy absorption of the 5 mm thickness laminates when subjected to impact energy of 9.5 J. The energy absorbed in vibration is similar to 2 mm and 3 mm thickness laminates. The matrix crack energy is about 20% higher than the delamination energy in all the cases. The same trend is observed for input energy is 25.55 J which is shown in Figure 13. As the input energy of the laminate increases the energy absorbing capacity in vibration also increases. The laminates without clay absorb more energy in delamination than the composites with clay showing the same trend as other laminates. Among 2 mm, 3 mm and 5 mm thickness laminates, 2 mm thickness laminates dissipate more energy at lower velocity of impact, 3 mm and 5 mm thickness laminates dissipate more energy at higher velocity. This is due to increase in stiffness of thicker laminates. Thin laminates absorb energy in other failure modes at higher velocity of impact. The delamination and matrix crack energy of 2 mm thickness laminates are higher than 3 mm and 5 mm laminates. The reason is increase in failure area of laminates due to plastic stretching of the layers. Laminates of 5 mm thickness absorbs more energy in delamination and matrix crack than 3 mm thickness laminates. This is because of more damage area which is due to increase in distance between the mid plane and outer layer.

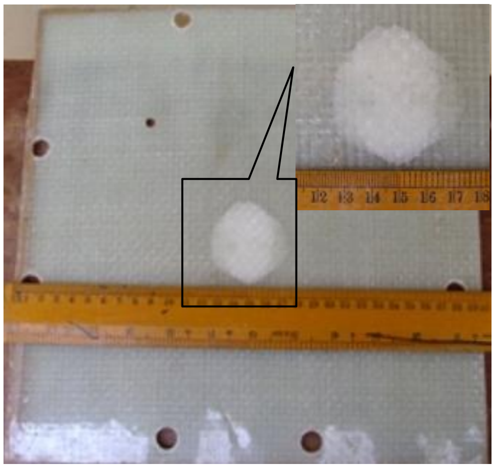

Figure 14: Showing the delamination area of 5 mm thickness glass/epoxy laminate without clay when subjected to 82 m/s

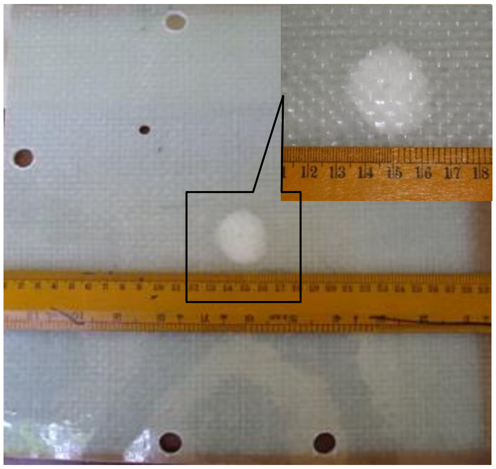

Figure 15: Showing the delamination area of 5 mm thickness glass/epoxy laminate with 2% clay when subjected to 82 m/s

Figure 14 and 15 shows the delamination area of laminates of 5 mm thickness, with and without clay respectively. In the laminate without clay the delamination area is 1256 sq. mm and the corresponding value of laminate with 2 % clay is 491 sq. mm. This shows that the presence of clay decreases the area to almost 1/3rd of the delamination area in laminates without clay. Hence it is understood that addition of clay very much controls the delamination area. This is one of the reasons for the increase in vibration energy of the laminates with clay.

5 CONCLUSIONS

Laminates of 2 mm, 3 mm and 5 mm thickness values were prepared by hand lay-up and compression molding process, and subjected to projectile impact for velocities between 35m/s and 82 m/s in clamped-clamped condition. The frequencies of vibration, damping factor and delamination area are obtained. The following conclusions are made.

- The addition of clay in the glass/epoxy composite improves stiffness and energy absorption in static penetration test.

- Laminate of 2 mm thickness dissipates maximum energy at higher frequencies than thicker laminates.

- The increase in frequency of vibration is observed in laminates with clay than laminates without clay.

- Addition of clay improves damping factor in all the laminates irrespective of the velocity of impact.

- Clay also improves the energy absorption capacity of laminates in vibration.

- As the velocity increases the energy absorption in vibration mode increases.

- Addition of clay controls the energy absorption of laminates in delamination.

- Delamination area is very much controlled due to dispersion of nano clay in the matrix.

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