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Impact Performance of Nanophased Woven Fabric Carbon/Epoxy Composite Laminates

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Summary

In the present study, Nanomer® I-28E, organically modified montmorillonite nanoclay supplied by Nanocor Inc., was used to modify SC-15, a toughened epoxy system using sonication route. Different weight percentage ranging from 1-3% of nanoclay was used. The modified epoxy was then used to fabricate 15-layer plain weave carbon/epoxy composite laminates using vacuum assisted resin transfer molding (VARTM) method. Samples of size 100 x 100 mm were cut from the laminates and were subjected to low-velocity impact loading using an instrumented drop-weight system (Dynatup Model 8210) at three different energy levels of 10, 20 and 30J. Transient response of the samples was recorded and analyzed in terms to load-energy versus time relations. Impact damage was characterized by utilizing an ultrasonic nondestructive evaluation system (c-scan). Results of the study indicate that the infusion of nanoclay in the system reduced the impact damage though the impact response in terms of the peak load remained mostly unaltered.

Introduction

It has been demonstrated that effective dispersion of anisotropic nanoparticles can substantially improve reinforcement of the polymeric matrices. This dispersion of nanoparticles highly depends on processing techniques such as solution blending, shear mixing, in situ polymerization, ultrasonic cavitation, high pressure mixing [1-3]. Nanoparticles, like nanoclays, used in carbon fiber-reinforced polymeric composites, at very low concentrations seem to improve mechanical and thermo-mechanical properties of the composites [4]. However, impact resistance of such polymer composites is probably one of the most important and least understood phenomena. Very few studies on the effect of nanoclay platelets in polymer composites have been carried out. Low velocity impact testing of composites is a very crucial area for investigation. A major concern that limits the usage of composites is their susceptibility to damage due to impact loading. There are practical situations like tool drops, runway debris, bird strikes, hailstorms and ballistic loading, which induce considerable damage to the composite structures. Composites are inherently weak in transverse direction, i.e., the stiffness and the strength in through-the-thickness direction are poor since no fibers are present in that direction. Low-velocity impact is considered potentially dangerous mainly because the damage might be left undetected, as the surface may appear to be undamaged. Understanding the causes for the formation of such damages and improving the damage resistance characteristics of composites are very important. When subjected

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to impact loading, the energy is absorbed in the form of creation of new surfaces. The failure mechanisms include indentation, matrix cracking, delamination and ply splitting [5]. This will considerably reduce the residual mechanical properties of the laminate. The worst scenario occurs when the damage is at subsurface levels. It is known that the residual compressive strength, which is the most affected mechanical property, is reduced to almost up to 50% [6]. In many situations, the level of impact at which visible damage is formed is much higher than the level at which substantial loss of residual properties occurs. Even when no visible impact damage is observed at the surface (energies below Barely Visible Impact Damage, BVID), matrix cracking and interlaminar failure can occur, and the load carrying capacity of the composite laminates is considerably reduced. Visible damage occurs if an impact is above a threshold impact energy, which depends on the laminate stiffness.

In the present study, low velocity impact response of carbon/ nanoclay-epoxy composites is investigated. In addition to that, the damage area of these composite laminates was also studied through ultrasonic c-scan images to observe the effect of different weight percentages of nanoclay platelets on the polymer composites.

Materials and Fabrication of Nanocomposites

Sonics Vibra Cell ultrasonic processor (Ti-horn, 20 kHz, 100W/cm^2) was used to obtain a homogeneous mixture of epoxy resin and Nanocor Nanomer® I-28E nanoclay, a surface modified montmorillonite clay. To get rid of the moisture, nanoclay was heated up to 80^0- 90^0C for about 2 hours before sonication. At first, part A of SC-15 epoxy was sonicated with nanoclay at amplitude of 55% for about 30 min. After sonication, the homogeneous mixture was cooled down to room temperature. The sonicated part A with nanoclay was then mixed with part B of SC-15 epoxy at a ratio of 10:3 and the mixing was carried out mechanically for about 5 min using a high speed mechanical stirrer.

Carbon/ nanoclay-epoxy composites were manufactured by both VARTM process. 15-layer of 3k fiber tow- plain weave carbon fabric was used to fabricate the composite laminates. The VARTM process uses vacuum pressure to remove air from the fabric lay-up before and while the matrix resin is introduced to the fabric reinforcement. The pressure difference between the atmosphere and the vacuum is the driving force for infusion of the resin into the lay-up.

Low Velocity Impact Testing

All the impact tests in this study were conducted using an impact drop tower device- DYNATUP Model 8210 equipped with Impulse data acquisition system, version 3. Impulse. For each type of laminates, at least three samples were subjected to impact at 10, 20, 30 J. Data acquisition system records load vs. time data for each test. Along with this data and the velocity at impact data, the software calculates deflection, specimen velocity and energy absorbed by the specimen.

Ultrasonic C-Scan

Ultrasonic inspection of the laminates was conducted using an ultrasonic pulse-receiver unit by Sonix Inc. with FlexSCAN-C^{TM} software. The scanning was done in pulse- echo immersion mode using 1 MHz 50 mm-focus transducer. Scanning was done with the impacted surface facing the sensor to obtain the projected damage. Gate was set on the back surface echo. All the laminates were subjected to ultrasonic nondestructive evaluation both before and after impact testing. The ultrasonic testing before impact loading was carried out to ensure that there was no fabrication defect in the sample. Post impact ultrasonic testing was conducted to evaluate the extent of damage in the sample. From the c-scan images, the damage area as projected onto a plane was measured.

Results and Discussion

The specimens were tested under three energy levels namely 10 J, 20 J and 30 J. Figure 1 shows the load-time-energy response of Control samples, 1% nanoclay samples, 2% nanoclay samples, and 3% nanoclay samples at these three energy levels. It was observed that the average peak load, as shown in Figure 1(a), at which the control samples failed, was 1.40 kN for 10 J, 1.42 kN for 20 J, and 1.45 kN for 30J. As expected there was an increase in the peak load as the energy levels were increased. Similar trend was also seen in case of different weight percentages of nanoclay samples. The average peak load, as shown in Figure 1(b), at which the 1% nanoclay samples failed, was 1.42 kN for 10 J, 1.45 kN for 20 J, and 1.50 kN for 30J while as shown in Figure 1 (c), the average peak load at which the 2% nanoclay samples failed, was 1.35 kN for 10 J, 1.43 kN for 20 J, and 1.46 kN for 30J. The average peak load, as shown in Figure 1 (d), at which the 3% nanoclay samples failed, was 1.42 kN for 10 J, 1.52 kN for 20 J, and 1.41 kN for 30J.

In most of the cases the load-time-energy plot showed a smooth rise up to the maximum load indicating an elastic response up to that point. Whenever there was some oscillations till the load reaches the peak value indicates that there is perforation of the top surface followed by the oscillatory drop in load implying the progressive local failure of the ply. The slope of the load–time curve, which is designated as the contact stiffness, increases with the increasing amount of energy. The initial knee found in the load-time-energy plot is due to the inertia effect of the tup and the sample. Once the inertia of the tup and samples matched, a smooth load rise is seen.

Damage area due to impact loading is very crucial in determining the extent of damage. It is also very important to know if the damage due to impact is localized or global as the residual strength of the composites largely depends on it. Ultrasonic c-scan

images revealed the damages in the samples even though, in some cases, there

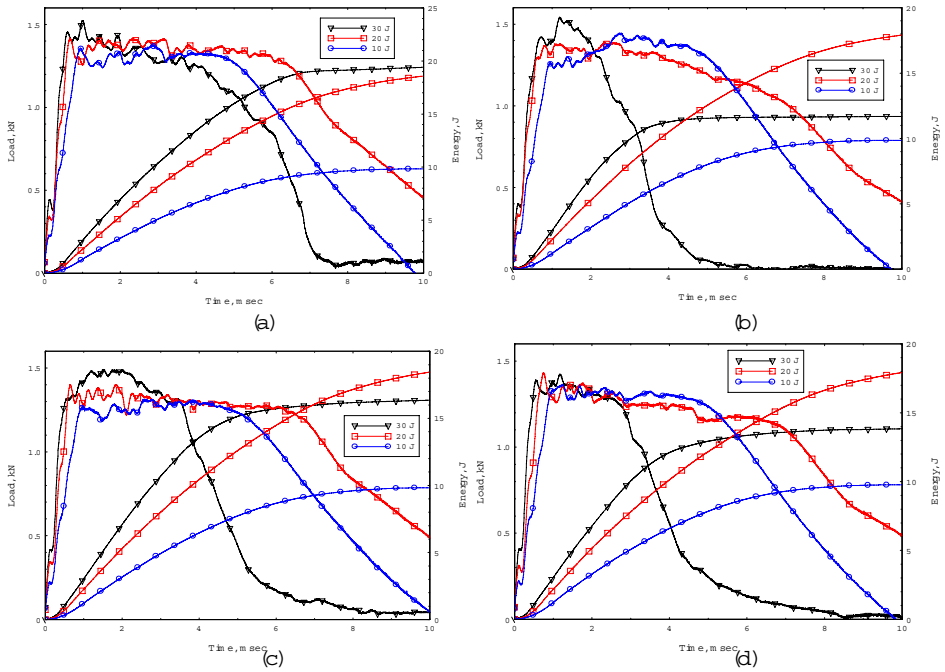

Figure 1: Load-time-energy response of VARTM (a) control samples, (b) 1% nanoclay samples, (c) 2% nanoclay samples, and (d) 3% nanoclay samples at three different energy levels

was not any visible damage in the surface. Table 1 summarizes the damage area of control, 1% nanoclay, 2% nanoclay, and 3% nanoclay samples as calculated from the ultrasonic c-scan images. This table gives an insight into the amount of damage in different types of samples. It shows the variation in damage area for each type of samples at different energy levels. It is seen that the control samples are more damage prone than the others. In terms of minimum damage area, the performance of 1% nanoclay samples and 2% nanoclay samples is significant. But for 3 wt % nanoclay samples, the damage is introduced even at 10 joule energy level. The damage area in 3 wt % nanoclay samples is also more as compared to 1 wt % nanoclay and 2 wt % nanoclay samples at other two energy levels. The small variation in data is also seen in this case. The reason for the increased damage area in 3 wt % nanoclay samples could be that there might be agglomerations of nanoclay which act as crack initiating sites. The greater stress concentrations around these agglomerations promulgate damages during impact loading.

Conclusions

Investigations on the response of plain weave carbon/epoxy-nanoclay nanocomposites to low-velocity impact loading were carried out for different weight percent-

Table 1: Projected damage area of different VARTM samples

Sample	Damage Area, mm^2			
	Control Sample	1% nanoclay	2% nanoclay	3% nanoclay
10J				
1	19.64	ND[1]	ND[1]	12.21
2	16.76	ND[1]	ND[1]	9.59
3	ND[1]	9.87	8.32	11.98
Avg.	-	-	-	11.26
20J				
1	125.54	444.09	497.30	107.22
2	679.35	426.07	476.21	LC of 7.45 mm
3	LC of 33.87 mm	233.10	418.48	169.84
Avg.	-	367.75	463.99	-
30J				
1	905.80	568.34	639.16	830.40
2	1144.30	516.17	659.13	920.66
3	1061.25	859.18	872.04	864.73
Avg.	1037.12	647.90	723.44	871.93
ND[1]= No damage is discernable LC = Linear crack				

age of nanoclay in the SC-15 epoxy ranging from 1 to 3%. Transient response of the laminates were recorded and analyzed. Ultrasonic C-scans were carried out to determine the damage due to impact. Following conclusions were drawn from the studies:

1. Peak load increased with increasing impact energy.
2. Absorbed energy increased from 10 J to 20 J. Laminates absorbed energy through creation of damages which include cracking of matrix at the point of impact, indentation, back face fibre fracture followed by the penetration.
3. At 10, the samples that exhibited damage had matrix cracks and small dent at the point of impact.
4. The impact damage at 20J however was considerable.
5. In almost all the samples loaded at 30 J, there was clear penetration.
6. Once the laminate is penetrated, the absorbed energy would be less as the tup will still have some kinetic energy that is not completely transferred to the sample.

7. All the nanophased composites exhibited lower impact damage when compared with the control samples even though there was not much change in the impact response.
8. Among the nanophased laminates, laminates with 1% nanoclay loading showed the best results in terms of the damage area.

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