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Energy absorption capability of nanomodified glass/epoxy laminates

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Abstract

The impact response of standard and clay-modified vacuum-infused glass/epoxy laminates was investigated. The activity was oriented to evaluate the enhancements in the energy absorption capability of the laminates due to the nanomodification. Nanomodification was achieved by using Cloisite 30B nanoclays by Southern Clay. Low velocity impact tests were carried out on flat samples of about 4 mm thickness by a drop-weight tower. The results clearly indicate that the nanomodified laminates have a greater capability to absorb the impact energy (with up to 30% increases in dissipated energy) with respect to the standard laminates, also in combination with a decrease of the peak impact force (from 10 to 15%). In some ways, this behaviour can be partly justified by the larger damage exhibited by nanomodified laminates, with projected damage areas more than double the damage areas of standard panels, for the same impact energy.

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1. Introduction

The use of nanomodification of polymers to improve their structural performances is almost a state of the art procedure. An endless scientific literature is available on this matter. Less investigated is instead the possibility to use nanomodified resins as matrix for ternary fiber reinforced laminates to improve matrix-controlled properties. An interesting, consolidated feature of nanomodified polymers is their improved toughness and energy absorption capability [1]. This feature may be "translated" into increase

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in the laminate toughness and, in some case, also in an increased resistance to impact or, better, in a larger amount of the impact energy absorbed during the impulsive event. Some results, in this direction, have already been reported in the literature [2-7].

Avila and co-workers reported improvements up to 50% of the energy absorption in vacuum-infused glass/clay-modified epoxy laminated composites and sandwich structures [2, 3]. Improvements in impact damage resistance and compression-after-impact strength (CAI), associated with a reduction in the damage area, was found by Iqbal et al. on carbon/epoxy laminates containing organoclays [4, 5]. The use of carbon nanotubes (CNTs) as matrix modifiers enhanced energy absorption, at least at high energy level, and CAI strength of carbon/epoxy laminates [6]. Even in the case of thermoplastic matrix (PPS), the addition of nanofillers improved the performances of final laminates. Liang, [7], reported improvements in strength, stiffness, and impact toughness properties of Glass/PPS composites modified with surface-treated nano-CaCO₃ particles.

A common theme in the different researches seems to be the correlation between the variation in the response of the nanomodified laminates and a change in the damage mechanics.

This work reports a summary of some of the results obtained in the frame of the Italian national project "Improvement of the mechanical properties of polymeric composite laminates by matrix nanomodification" supported by the Italian Ministry of Research and University. The research programme was oriented at evaluating, characterizing and quantifying the improvements achievable in a set of structural properties of glass/epoxy laminates by the dispersion of nanoclay in the polymeric matrix. This paper illustrates the results obtained investigating the low-velocity impact response of standard and clay-modified glass/epoxy laminates.

2. Materials and laminate manufacturing

A DGEBA-based epoxy resin (EC157) with an aminic hardener (W152LR) from *Elantas-Camattini* was used as polymeric matrix in this study. The system is especially suited for resin infusion techniques, thanks to the very low viscosity and long average pot life at 25 °C. Nano-modification of the matrix was achieved by a commercial nanoclay, the *Cloisite 30B®* from *Southern Clay Products* (USA). These clays are surface modified lamellae of montmorillonite, about 1 nm thick and with in-plane dimensions ranging from 70 to 150 nm according to the manufacturer data sheet. The specific surfactants allow to improve the hydrophobicity of the clay.

A 350 g/m² twill glass fibre fabric with generic sizing (VV-350T) supplied by G. Angeloni Srl was used as reinforcement in both neat and nano-modified epoxy laminates.

The nanoclays were first dispersed in the resin through a shear mixing (SM) process carried out with a *DISPERMAT TU* shear blender from *VMA-Getzmann*. Nanoclays were added into the resin while mixing at an average rate of about 3500 rpm and the mixing process was continued for about 1 hour, in order to get good nanofiller dispersion, to promote nanoclay intercalation/exfoliation, and to induce breaking of nanoclays clusters. At the end of the mixing process, the aminic hardener was added (30 parts over 100) to the mixture, which was shear-mixed for further 10 minutes to improve resin-hardener mixing. During the entire process the resin was cooled by an external bath so as to avoid large temperature rises and possible resin overheating. Three different clay volume fractions, 1%, 3% and 5%, were considered in the preparation of the nanomodified resin. An intense vacuum degassing was carried out before laminate moulding for about 30 min in order to reduce the amount of trapped air and, in turn, to minimize the presence of voids in the matrix. Flat laminated panels, about 500 mm x 600 mm in size and 3.8 mm in thickness, were fabricated by vacuum infusion of the neat or nanomodified resin into a vacuum bag. The reinforcing fibre stack consisted of 16 layers of glass fabric, all oriented at 0° with respect to the warp direction. After demoulding the panels were postcured for 15 hours at 60°C. Rectangular specimens 65 mm x 87.5 mm in size were finally cut from the laminated panels for low-velocity impact testing.

3. Impact testing and damage assessment

Impact tests were conducted using an instrumented drop-weight testing machine equipped with a 2.28 kg impactor. The impactor had a hemispherical indenter of 12.5 mm diameter and was instrumented with a semiconductor strain-gauge bridge for dynamic load acquisition. The velocity of the impactor immediately before and after the impact was obtained by an infra-red sensor, while the contact force between impactor and specimen was measured by means of the strain-gage bridge. A pneumatic catching mechanism was used to capture the impactor after the rebound so as to prevent multiple impacts on the plate. Energy and indenter displacement were calculated as a function of time by integration of the contact force versus time signal.

During impact, the specimens were supported by a steel plate having a rectangular opening 45 mm × 67.5 mm in size and held at four corners by rubber clamps. Laminated samples were impacted at the centre with energies ranging between 1 J and 10.6 J (which corresponds to impact velocities between 0.95 and 3.05 m/s), obtained by varying the drop height of the impactor. At least 2 impact tests were conducted at each impact energy level for any material system investigated.

Damage induced by impact was non-destructively observed and digitally recorded using strong back lighting, by exploiting the translucency of the material. In selected samples, the internal damage was also directly observed by optical microscopy after sectioning and polishing the specimen at specific locations.

4. Results and discussion

Typical force versus time and force versus displacement plots are shown in Figs. 1 and 2 for base and nanomodified (3% Cloisite30B) laminates impacted at different energy levels.

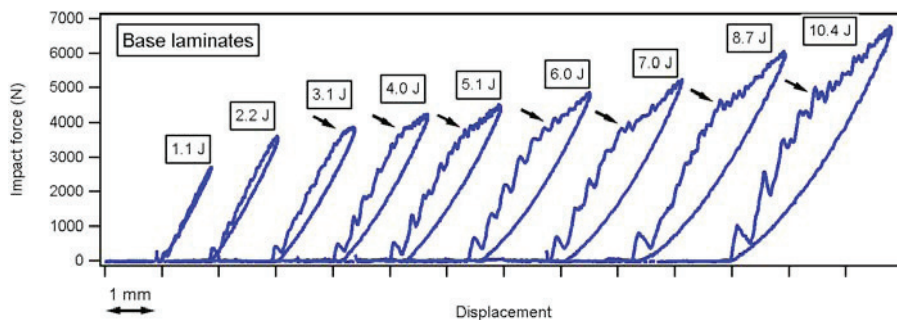


Fig. 1. Force vs displacement curves for base laminates

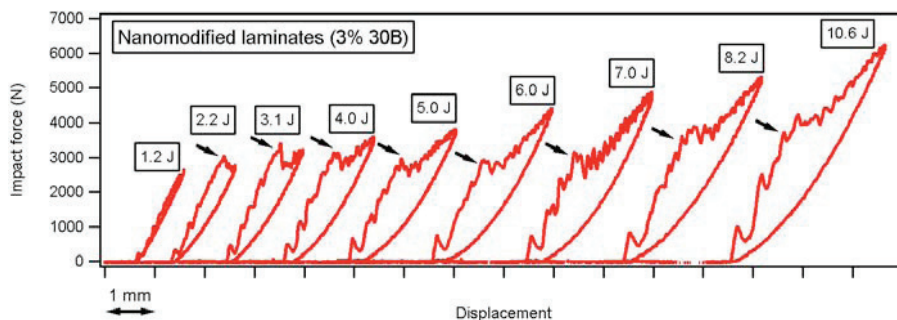


Fig. 2. Force vs displacement curves for nanomodified (3% Cloisite30B) laminates

After an initial phase of inertial oscillation, induced by the collision between the impactor and the specimen, laminates exhibit a regular rise in load, followed by a sudden change in stiffness when a threshold/critical force level (indicated by an arrow in the plots of Figs. 1 and 2) is reached. The stiffness change is often preceded by a sharp load drop in nanomodified laminates.

A direct comparison of the force-displacement plots of base and nanomodified laminates (representative trends are illustrated in Fig. 3) clearly indicates that the threshold force level at which the reduction in stiffness reduction is observed is significantly lower in nanomodified laminates with respect to base laminates. Similarly, the maximum force attained during the impact by nanomodified laminates is always lower than that characterizing the impact response of standard laminates.

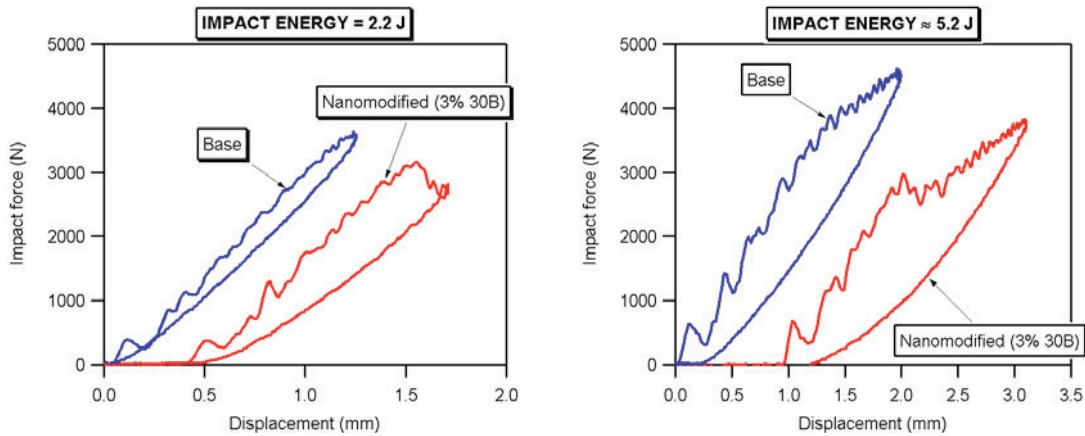


Fig. 3. Force vs. displacement curves of base and nanomodified laminates for two impact energy levels

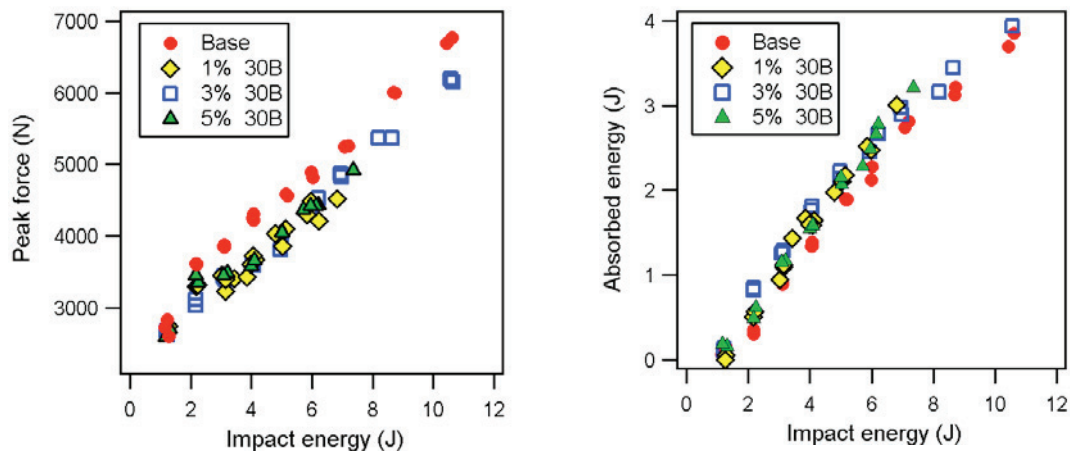


Fig. 4. Peak force and absorbed energy vs. impact energy for base and nanomodified laminates

The graphs of Fig. 4 report the values of two parameters, peak impact force and energy absorbed during the impact, specifically selected to globally describe the impact behaviour of the laminates in terms of crashworthiness and energy absorption capabilities. It is seen that, at least for impact energies

higher than about 1 J, the impact response of nanomodified laminates is characterized by lower peak force values (peak force reduction up to about 16% were recorded) and by better energy dissipation properties (with percentage increases in absorbed energy larger than 35%), thus suggesting nanomodification of the matrix as an effective way to modify or control energy absorption mechanism in structural applications associated to mitigation of the effects of crash or dynamic events.

Damaged areas induced by impact at different energy levels as obtained by backlight image acquisition are compared in Fig. 5, while typical micrographs of internal damage in impacted laminates are shown in Figs. 6 and 7. It is seen that damage areas have similar shapes and patterns in base and nanomodified laminates and that analogous matrix damage modes (mainly matrix cracks within bundles or in resin rich regions and delaminations between boundaries of fibre bundles) occur in the two classes of laminates.

On the other hand, as expected because of the superior energy absorption of nanomodified laminates, damage is much more extensive in nanomodified samples than in base samples. Further observations also indicate that the presence of nanoclay platelets in the matrix appears to promote, as compared to base laminates, the initiation and propagation of unstable fibre fracture (see Fig. 5), which is typically a highly energy dissipating fracture process.

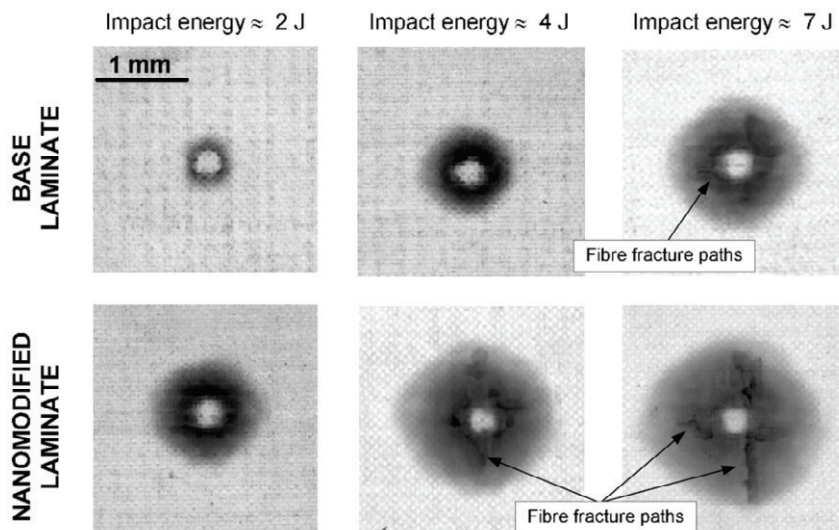


Fig. 5. Damage induced by impact in base and nanomodified (3% 30B) laminates

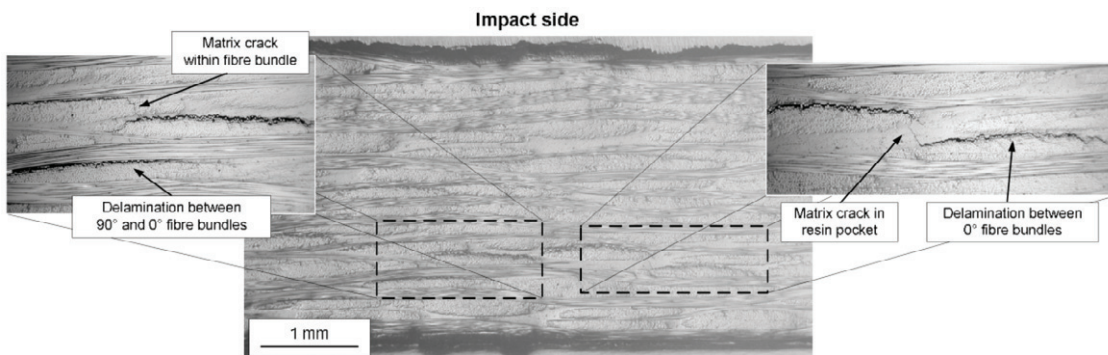


Fig. 6. Typical internal damage modes in a nanomodified laminate (3% 30B) impacted at 4 J

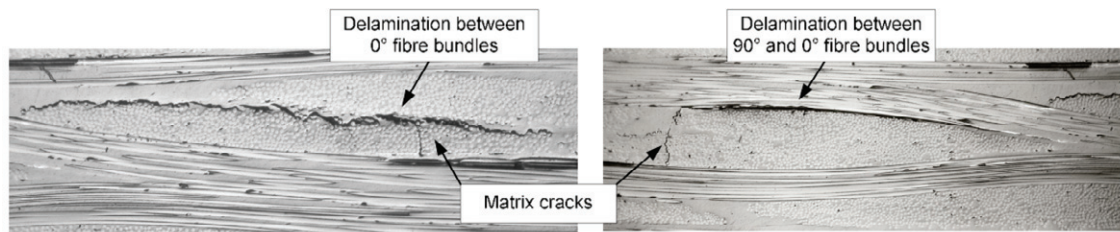


Fig. 7. Typical internal damage modes in a base laminate impacted at 4 J

5. Conclusions

The low-velocity impact response of standard and clay-modified glass/epoxy laminates was investigated. Results indicated a significant improvement in the energy absorption capability due to nanomodification also in combination with a reduction of the peak force during the impact. The reason for this behaviour was identified in a greater damage extension in nanomodified laminates where the presence of clays seems also to promote high dissipative mechanisms (i.e. fibre failure). Results are very important for structural applications, like human protection systems, where there is the combined design need of absorbing the highest possible fraction of the impact energy while keeping the acceleration (associated to the impact force) lower than a specified level.

Acknowledgements

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