HIGH VELOCITY IMPACT IN COMPOSITE MATERIALS WITH NANOCLAYS

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Abstract: *A series of high velocity impact tests on composite is reported. The target structures are circular plates made of composite materials, to which nanoclay were added. The plates were subjected to the impact of rigid spheres traveling at velocities up to 150m/s. The tests allowed the determination of the ballistic limit for the various plates made up of different nanoclay concentration. Some details of the test apparatus, which comprises a gas-gun projectile launcher, a high speed camera and a velocity measurement system, are also given.*

Keywords*: composites, nanocomposites, impact, gas-gun, ballistic.*

1. INTRODUCTION

High strength fiber reinforced polymeric composite materials have been competed with light-weight alloys in aero spacial structural applications due that their superiority in terms of some important mechanical properties, such as strength-to-weight ratio and very high resistance to fatigue and corrosion. Design and production of new very-light executive jets built with composite materials has been announced by the aeronautical industry. CESSNA recently announced the launching of MUSTANG, an airplane whose structure is totally made of carbon fiber; EMBRAER is now using composite materials in important structural parts of its airplanes. Such structures are frequently subjected to the impact of projectiles during landings or takes-off or even during flight. Examples of such dynamic loadings are small projectiles launched off the ground, as pebbles or metallic parts of other airplanes left accidentally in the track, or even the impact of birds against the leading edge of aircrafts. These incidents may cause great problems for the companies of this sector. Thus, it is important the study of the phenomenon of impact of projectiles against composite materials structures and, therefore the study of this material behavior when subjected to this kind of loading.

An apparatus used for high impact velocity tests is the so called gas gun projectile launcher, a device able to launch projectiles at medium to high velocities. Experimental tests using this methodology have often been used to approach the problem, as in Antoun et al. (1992), Jackson and Fasanella (2000) or in Johnson and Holzapfel (2003). More recently, aiming the numerical-experimental analysis of the bird strike phenomenon, Airoldi and Cacchione (2005) had studied the impact of different substitute birds against the cockpit of a helicopter made of polycarbonate and against empennages of airplanes made of carbon fiber. In their work, a gas gun was also used, launching projectiles against such structures with velocities between 80 and 140 m/s and causing significant damage.

The available materials to the present work are S2-glass/epoxy composite laminates, with balanced plain weave configuration, i.e. showing the same fiber fraction in the two perpendicular directions at every lamina. Besides, two different fiber concentrations (52% and 65%) and the addition of montmorillonite nanoclays (0%, 5% e 10% in weight of the matrix) are considered. Manufacturing aspects related to this kind of composite can be found in the works of Hanque *et al.* (2003) and Yasmin *et al.* (2003), whereas the mechanical characterization of modified epoxy/montimorillonite composites is presented by Yilmazer *et al.* (2003). Ávila *et al.* (2005) has presented low-velocity impact tests by using the same type of material adopted in the present work, observing that the resistance to the impact grows until the limit of 5% of nanoclays addition and this concentration onwards the material presents a reduction of its properties.

This work presents a series of high velocity impact tests against circular composite plates made of fiber glass/epoxy with nanoclays, using a gas gun projectile launcher. The results of the presented work will be used as a parameter of comparison for future numerical simulations of impact against such materials. The launched projectiles are rigid metallic spheres and soft commercial modeling compound cylinders.

2. COMPOSITE DESCRIPTION

S2-glass/epoxy composite laminates with added nanoclays were used for manufacturing the 350 x 350mm, 4mm thick plates at the Mechanics of Composites Laboratory of Federal University of Minas Gerais (UFMG) (Ávila *et al. (2005)*). The fiber configuration is of the plain weave balanced type, formed by equal fractions of fibers in the longitudinal and transversal directions at each layer. Its superficial density is 200 g/m^2, and was manufactured by TEXGLASS. The epoxy resin is constituted by ARALDITE M® and HY 956 hardener, with specific mass of 1,1g/m^3.

The added nanoclays are composed by montmorillonite from NANOCOR I 30E manufacturer with 0%, 5% and 10% fraction in weight of matrix. The composite laminates were assembled with 24 and 32 layers, corresponding to fiber fractions of 52% and 65% in weight, respectively. Table 1 summarizes the different kinds of laminates employed in this study:

Table 1: Amount of laminates available for the tests.

	0% of nanoclays	5% of nanoclays	10% of nanoclays
24 layers (52% in weight)	3	3	3
32 layers (65% in weight)	1	1	1

To identify the specimens the following nomenclature will be adopted in this study: a label "Fg", denoting the fiber glass composite type, followed by two numbers referring to nanoclays concentration. Thus, 00, 05 and 10 correspond, respectively, to 0%, 5% e 10% of nanoclays addition. Finally, two additional digits were used to distinguish the number of layers of the laminate (see Tab. 2).

Table 2: Material identification nomenclature.

Identification	Material	
	Nanoclays concentration	Number of layers
Fg00-32	0%	32
Fg05-32	5%	32
Fg10-32	10%	32
Fg00-24	0%	24
Fg05-24	5%	24
Fg10-24	10%	24

The plates come from a second generation process of composite manufacture with nanoclays and the manufacturing process, detailed in the work of Ávila *et al. (2005*), can be summarized as:

1. The nanoclay is mixed to acetone;
2. The solution is added to the hardener or resin, forming a homogeneous emulsion;
3. This emulsion is degassing for two hours, to eliminate de bubbles and the acetone;
4. The hardener with only the nanoclays is added to the other part of mixture, formin de epoxy resin;
5. The resin impregnate to the fiber glass;
6. The layers are joined, building the laminate;
7. It is made the first cure at the vacuum and ambient temperature;
8. The pos-cure is made at temperature of 60° along 4 hours.

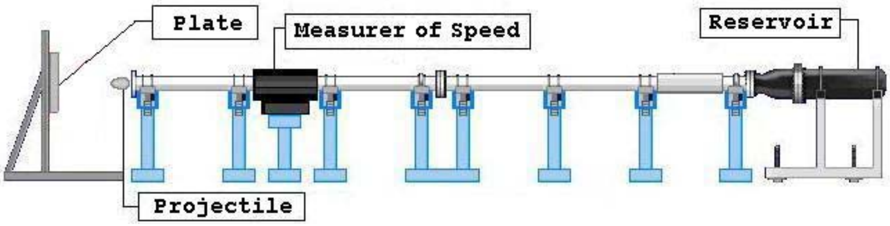
Previous works show that the vacuum cure technique leads to less voids formation. To manufacture the coupons a water-cut machine is used, with diamond tools giving a finishing surface. These procedures prevent the heating of the material what it would harm the cohesion between the layers of the laminate. A back-light technique is then used to verify voids existence and manufacturing defects. This technique allows the visualization of internal defects, such as nanoclays accumulation and inter-ply premature delamination. The same technique was employed after the impact tests to check the failure process caused by the impact event, as presented in sections 4.1 e 4.2.

3. EXPERIMENTAL METHODS

The gas gun projectile launcher is a device that has been largely employed in structural impact studies. Developed in contribution with the Impact Research Center (Liverpool, England), the gas-gun used in this study, Fig. 1, was constructed in the year of 2004 in the laboratory of the Group of Solid Mechanics and Structural Impact of University of São Paulo, being capable of providing impact energies of about 120000 J. This equipment was used for the impact tests of rigid and soft projectiles. In both cases the detonations is carried through against the plates described before.

The equipment maximum launch velocities are, respectively, 180m/s (648 km/h) and 120m/s (432 km/h) to the rigid steel sphere and the soft modeling compound cylinder. The gas-gun is composed of a metallic cylinder, a pressure valve, an acceleration pipe and a fixed target, as presented schematically in Fig. 1. The operation of launching can be summarized as follows: the projectile is fixed to the pipe of acceleration together with one sabot; a fixed pressure and volume of air is stored in a cylinder. Once the valve is open, the air flow is set free off the cylinder, speeding up the sabot with the projectile throughout the pipe. In the extremity of the pipe, the projectile is broken up off the sabot, following its trajectory in the direction of the target.


(a)



(b)

Figure 1: (a) Views of gas gun projectile launcher; (b) Simplified operation scheme.

The gas-gun has also a chronoscope SCAN-AIR in the final extremity of the acceleration pipe to detect projectile speed just before the impact event. A PHOTRON high speed camera, model APXRS, able to capture up to 250000 pictures for second, is used for qualitative analysis of the event. A laser vibrometrer POLYTEC, model OFV-323, is used to acquire velocity and displacement values of a predetermined point of the plate, to allow comparison with correspondent numerical results.

Throughout the work some adaptations in the equipment were necessary to conduct the tests. The sphere-sabot separation system was changed to correct deviations in the trajectory of the projectile that occurred with the original system. Thus, a rigid limiter was added to the final extremity of the pipe, allowing only the sphere release. This system made possible greater repeatability in the tests, and ensured that the impact was carried through always in the same region of the plate. A calibration curve, relating final speed of the projectile and pressure applied in the cylinder, was obtained through the accomplishment of successive detonations under different levels of pressure and measurement of the respective final velocities. This curve, shown in Fig. 2, is of utmost importance for the essays, for it allows determining the pressure to be applied in order to obtain a given velocity of interest.

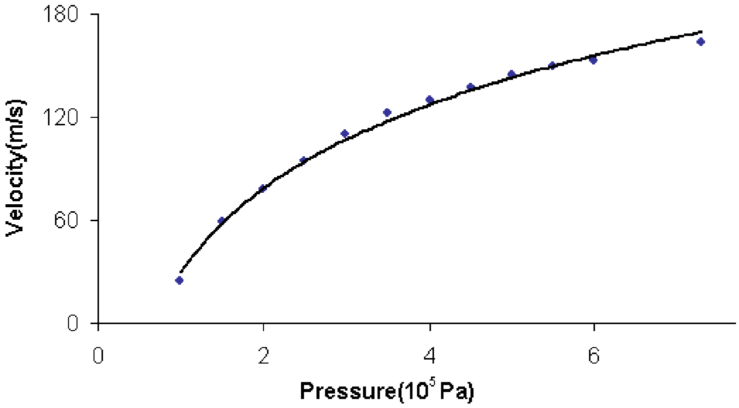
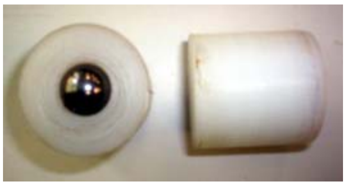


Figure 2: Gas gun calibration curve.

The targets were in the present set of tests were the clamped circular plates, i.e. with its circumference completely constrained as boundary conditions. Rigid steel spheres of 20 mm of diameter, with weight of 0.034 kg, had been used, resembling the impact of rigid bodies of small dimensions. The impact of projectiles of soft bodies was also investigated using a cylindrical body, 50 mm diameter, 100 mm of height, weighing 0.110 kg, made of commercial modeling compound, usually sold as a children's toy. For these later tests a special sabot was developed to keep the integrity of the test body until it exited the acceleration pipe. These two projectile types are shown in Fig. 3.



(a)

(b)

Figure 3: Projectiles employed in the tests: (a) Rigid sphere next to sabot; (b) Modeling compound cylinder.

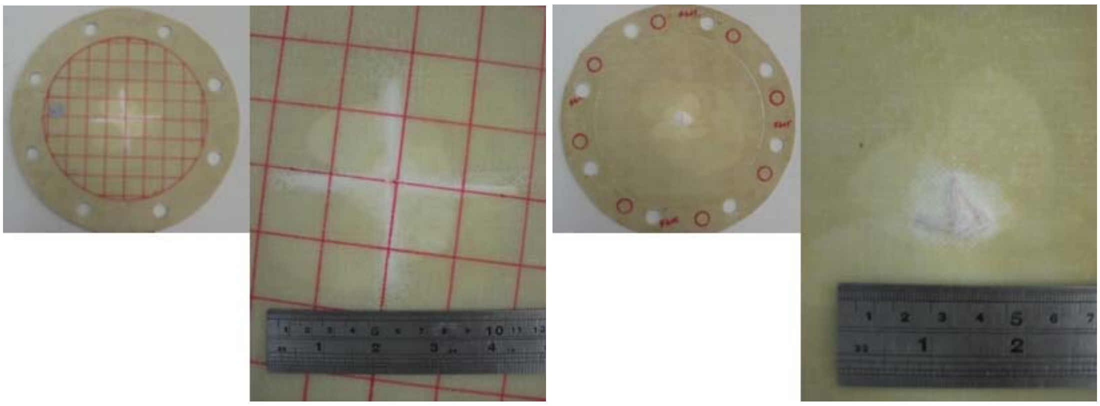
4. EXPERIMENTAL RESULTS AND DISCUSSION

This section presents impact test results obtained with the two different projectiles adopted in this work. In accordance with the type of projectile, the tests and their respective results were divided in:

- Rigid sphere detonations;
- Soft cylindrical body detonations.

4.1 Rigid sphere detonations

In the sequel the results with material composites with 32 layers will be presented. Due to the little amount of the material, an impact velocity was estimated at the imminence of the perforation of the material, following the low velocity impact tests carried through by Avila et (2005). The estimated velocity was of 110 m/s and this was kept constant for all the detonations against this material. In Fig. 4 the visual analyzes of the detonation against the Fg05-32 material are presented and Tab. 3 synthesizes the experiment results.



(a) (b)

Figure 4: Rigid sphere impact against plate Fg05-32: (a) top view; (b) bottom view.

Table 3: Rigid sphere impact against 32-layers (65% in weight) plates: summary of the results

	Fg00-32	**Fg05-32**	**Fg10-32**
Test result	Perforation	No perforation	Perforation

It was possible with this material to conduct all the tests with the sphere impacting the plate at the same location and with great repeatability of the impact velocity values. As observed in these tests, the plate with 5% of nanoclays addition (Fg05-32) was not perforated, whereas those with no nanoclays addition (Fg00-32) and with 10 % (Fg10-32) were both perforated, indicating that the impact mechanical behavior is sensitive to the presence of this additive. It was also observed that the increase of nanoclays favors the inter-ply delamination, since that the delamination area grew with the increase of nanoclays.

In the impact tests of rigid spheres against the materials with 24 layers (52% in weight) it was possible the accomplishment of a greater number of experiments. Thus, the ballistic limit to each configuration could be obtained. Ballistic limit is the minimum impact velocity that causes the perforation of the material, so that the sphere crosses the impacted plate. This parameter is of foremost importance for numerical simulations, since from these value the accuracy of the numerical model, when compared with experimental result, can be cross-checked. The test results obtained with this material are presented in Fig. 5. Visualizations by using the back-light technique before and after the impact are presented in Fig. 6.

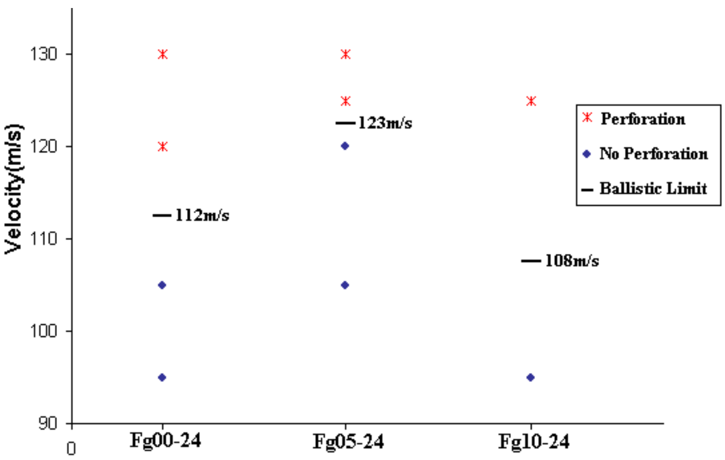
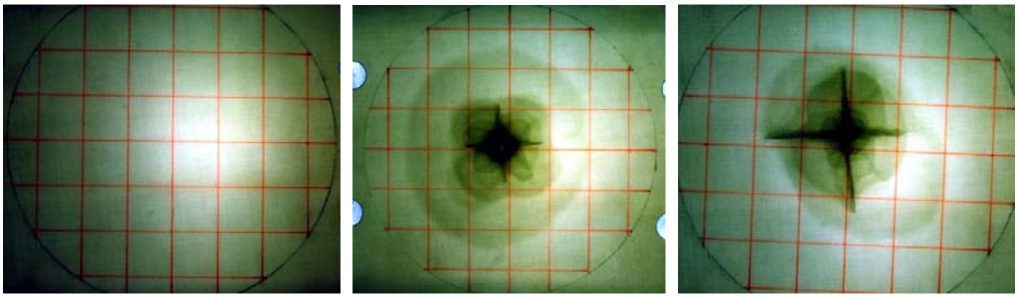


Figure 5: Impact velocities against plates Fg00-24, Fg05-24 and Fg10-24.



(a) (b) (c)

Figure 6: Images of the Fg05-24 material using the back-light technique: (a) before the impact, (b) after the impact, without total perforation and (c) after the impact with perforation.

It can be observed that the material with 24 layers has impact behavior sensible to the concentration of nanoclays. Decrease of the mechanical properties under impact is observed with increase of nanoclays concentration from 5 %, and the ballistic limit of the material with 5% of nanoclays is bigger than those of the materials with 0% and 10%.

4.2 Soft cylindrical body detonations

These tests had been carried through against the plates of Fg05-24 materials and Fg10-24 only. It was not possible to reach the ballistic limit with these projectiles. The impact velocities used in the tests are presented in Tab. 4. In all the tests the impact generated a generalized curvature of the plate, which practically vanished one day after the experiment.

Figure 7 presents the evolution of the impact from a high-speed film against the Fg10-24 material, being possible to observe the projectile's fluid-like behavior after the impact. In Fig. 8, the back-light images before and after the impact of this material are presented. It is observed that in this case the effect of the impact are not restrained to the center of the plate, being possible to detect small inter-ply delamination marks along all the extension of the plate.

Table 4: Soft body impact velocities.

	Fg05-24	**Fg10-24 (Specimen 1)**	**Fg10-24 (Specimen 2)**
Velocity (m/s)	139.5 m/s	112.4 m/s	112.5 m/s

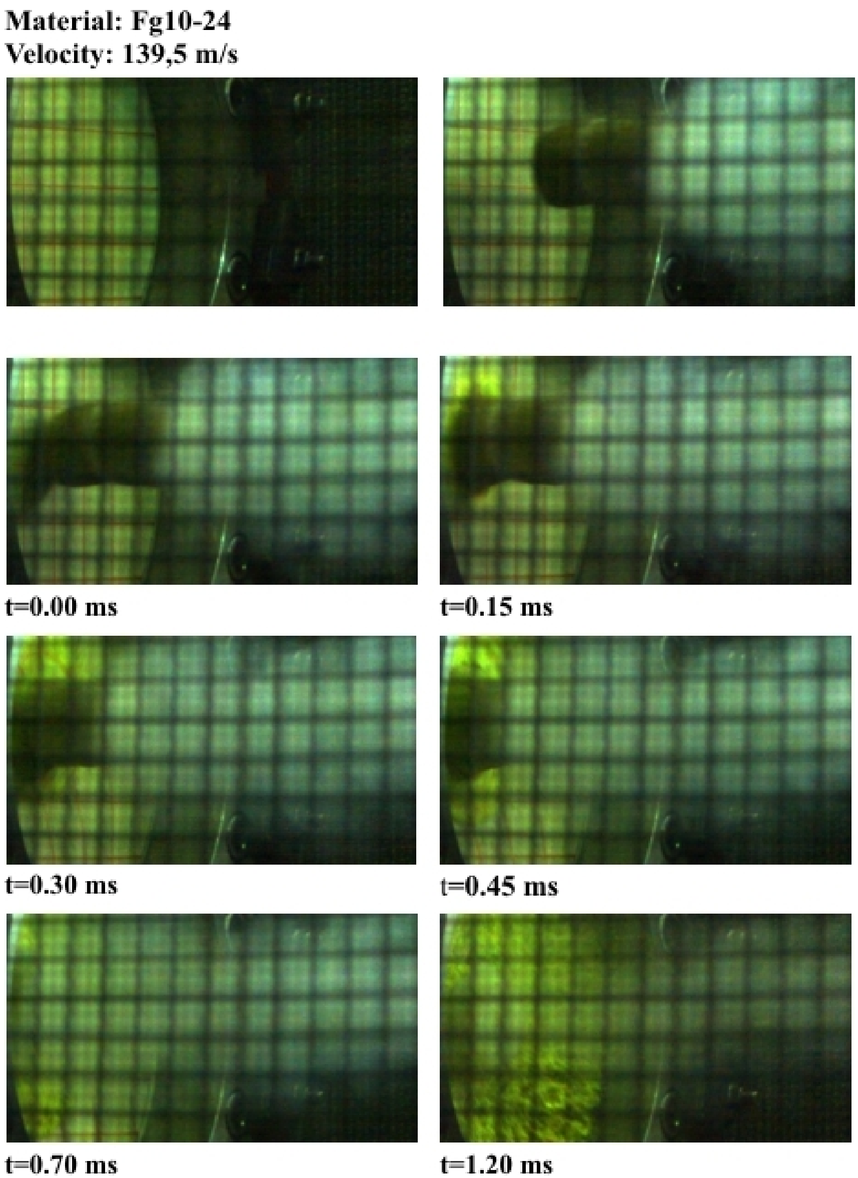
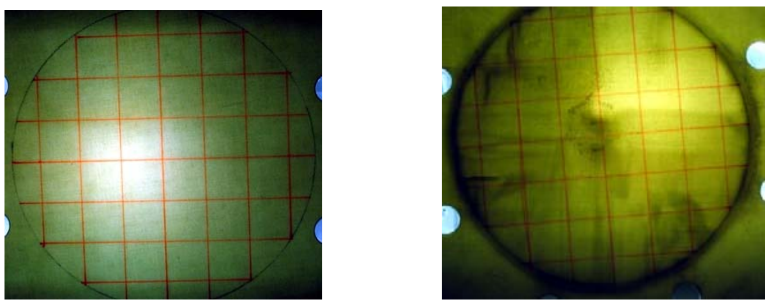


Figure 7: Soft body impact test: time evolution captured by the high speed camera.



(a) (b)

Figure 8: Images of the Fg10-24 material using the back-light technique: (a) before the impact and (b) after the impact.

5. CONCLUSIONS

An experimental framework for the impact response of S2/glass fibre/epoxy composite laminates was presented in this work. From the gas gun launcher impact tests with rigid and soft bodies can be concluded that:

- The under impact mechanical behavior of the composed material in study is sensitive to the concentration of nanoclays. It was observed that the materials with 5% of nanoclays present a better mechanical behavior than those with 0% and 10% showing, therefore, that the material has its mechanical properties optimized for a given concentration of nanoclays;

- The increase of the concentrations of nanoclays favors the inter-ply delamination occurrence;

- The experiment points to a saturation limit of the nanoclays concentration, from which the impact resistance decreases as the concentration is increased. Similar behavior of this very same material was reported by Ávila (2005) in low velocity (drop weight) tests;

- As for the impact tests with soft bodies, it was not possible to reach failure of the material, but a generalized bending of the plate occurred, returning to its initial configuration in approximately one day after the experiment. The analysis of this phenomenon is left for future works;

- The images obtained from the impact with soft bodies and the severe distortions presented by the projectile confirm the hypothesis of consideration of soft body as a fluid-like material in numerical simulation of this phenomenon, as usually done;

- The gas-gun tests allowed to get valuable parameters for comparison with numerical simulations from real impact events. Ballistic limit and delamination areas are examples of such parameters.

6. ACKNOWLEDGEMENTS

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