EFFECT OF TEMPERATURE AND MOISTURE ON THE HIGH-VELOCITY IMPACT PERFORMANCE OF GLASS/CARBON HYBRID COMPOSITES

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Abstract
High performance composites (carbon and glass fiber reinforced polymers) are nowadays extensively used in applications requiring strength, stiffness and fatigue resistance as demanded in marine applications. However, an important drawback of such materials is related with the low damage tolerance behavior, especially when materials are subjected to out-of-plane loading, as occurring for instance, in the case of high velocity impacts representative of the service life of the structure. This paper presents a set of results obtained by UPM (Technical University of Madrid) in a project funded by the Office of Naval Research (ONR) in the field of evaluation of the mechanical performance of polymer composites subjected to environmental aging produced by temperature and humidity.

1. Introduction

Fiber reinforced polymer composites are increasingly used in many industrial sectors, thanks to their specific properties, such as strength/density ratio and stiffness/density ratio. In the naval industry, composites have been used to produce hulls of small boats and yachts since many years ago, replacing traditional materials like wood or steel.

In the last decades, there is an increasing interest to analyze the possible utilization of composites in the war naval industry, that is to produce hulls of battleships or even submarines. The weight reduction with respect to steel allows more efficient vessels. Although composites have been widely used to produce ship hulls of small length, like for instance minehunters or disembark boats,a few examples of battleships with composite materials hulls have been already manufactured [1-3].

It is well known that fiber reinforced polymer composites are highly susceptible to impact damage [4]. This problem is an important drawback for the utilization of composites for applications where components may be subjected to impulsive loading.

Although there is wide information about the performance of composites under low velocity impact, information about their performance when subjected to high velocity impact is much more scarce [4-7]. Experimental information about high speed impact performance of composites is almost limited to those fibers used for personnel and vehicles protection, such as aramid (Kevlar) or high density molecular (Dyneema) fibers [8-10].

Thus, it is important to investigate the response and failure of composites of naval relevance (glass, carbon fiber reinforced vinylester) under high speed impact to assess their reliability to produce components for the war naval industry.

On the other hand, components of a ship must with strands impact loads in the extreme environments of temperature and moisture of the ocean, especially when considering Arctic navigation. Consequently, the Office of Naval Research of the United States (ONR) financed a research aiming to analyze the couple effects (impulsive loading, temperature, humidity) on the high-speed performance of composites of naval relevance, inside the Solid Mechanics Program.

This paper presents some experimental results of the research performed, that is the behavior of S-2 glass, carbon and hybrid glass/carbon vinylester composites subjected to high-speed impact.

2. Materials

Two different fibers have been considered: S-2 glass and carbon. Plates of composites of approximate dimensions 400 x 600 mm have been manufactured following vacuum infusion of vinylester resin. With respect to the reinforcement five congurations have been considered:

- Plain glass woven fabric, 40 plies
- Plain carbon woven fabric 20 plies
- Mixed hybrid glass/carbon (1 ply C / 2 plies G) x 10
- Non mixed 10 plies of carbon, 20 plies of glass with glass in the front face and carbon in the rear
- Same configuration, but carbon in the front face and glass in the rear

All plates have approximate thickness of 6 mm. Plates were cut to produce specimens of approximate dimensions 100 x 100 mm. Aiming to analyze the influence of moisture on the performance of composites under high speed impact, several plates were conditioned by immersion into a sea water at 50˚C up to saturation, according to standard AECM EN2823.


a)

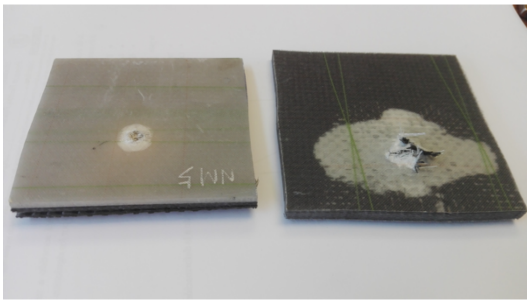
b)

Figure 1. a) Compressed air gas gun, b) Typical specimens after impact (mixed and non-mixed)

2.1Experimental set-up

Impact tests were performed by launching steel balls 6.49 mm diameter in a compressed gas gun of 7.62 mm caliber barrel and plastic sabot to achieve impact velocities in the range 200-800 m/s approximately, Figure 1a). Both the impact speed and the residual velocity after full perforation of the target were obtained by means of a video camera with 80000 fps and digital image.

Tests at high temperature (+50˚C) were performed by placing the targets, previously heated into a polystyrene box to reduce heat dissipation and checking target temperature by means of a thermocouple to ensure that the test was carried out at the desired temperature. A similar procedure was carried out for testing at low temperature (–50˚C). In this case the target was placed in the box with solid CO_2 pellets to keep the desired temperature up to testing time. Previously, firing tests on an empty box showed that the box walls influence on the impact velocity was negligible.

3. Experimental results

Experimental results are displayed in the form of graphics residual velocity vs impact velocity such as that shown in figure 2. It must be pointed out that each curve is obtained with at least 8 shots and the number of different conditions is 6 (3 temperatures and two conditioning conditions) and five materials, so that the number of tests is not less than 240, and the number of experimental curves like that shown in figure 1 is 30.

For better comparison, we use the concept of ballistic limit V_{50}, that is the impact velocity for which there is 50% probability of full perforation of the target. Ballistic limit values are easily derived from the abovementioned curves for each material and environmental condition. For instance, figure 2 a) and b) reproduces the ballistic curve corresponding to mixed and non-mixed hybrids at RT and -50ºC.

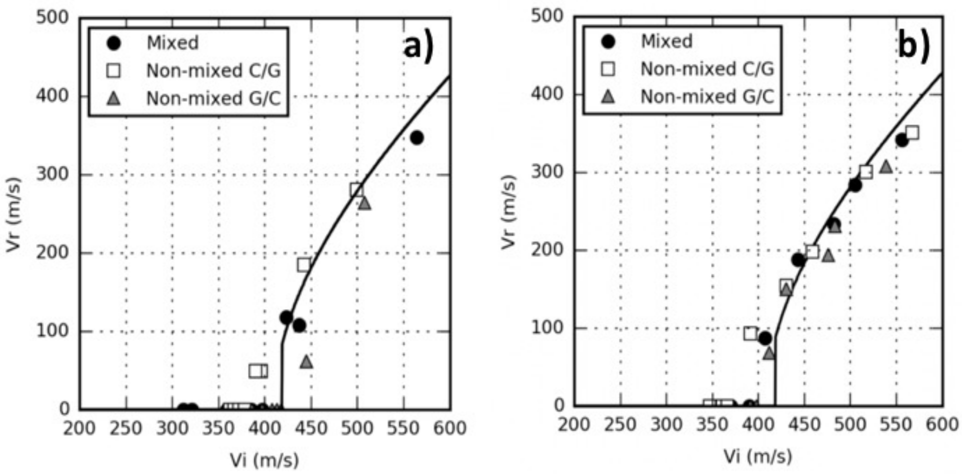

Figure 2. Ballistic curves for hybrid composites for: a) RT and b) -50º (mixed=dispersed plies, non-mixed=concentrated)

Ballistic limit data are illustrated in figure 3 and 4 where data are displayed for each material (pure carbon and glass in figure 3 and hybrids in figure 4) and temperature for the non conditioned materials and conditioned materials respectively. For a more clear analysis of the influence of water saturation the results are displayed again in figures 4 and 5.

4. Conclussions

Observation of figure 3 and especially of figure 4 allows to derive interesting conclusions of the experimental research performed. First of all, we may conclude that environmental conditions, temperature and seawater saturation have little influence on the high speed impact performance of glass, carbon and hybrid glass/carbon fiber reinforced composites, all ballistic limit values being in the range 370-450 m/s. The best performance is observed for non mixed hybrid glass/carbon when glass reinforcement is places in the front face and carbon in the rear.

Finally, a rather surprising result is the observation that seawater intake does not reduce ballistic limit except for very little conditions. This surprising observation might be explained by considering that the matrix has little effect on the resistance of the composite to high speed impact perforation, being the fibers the important factor to defeat the penetrator and on the other hand, fibers are almost unaffected by seawater saturation.

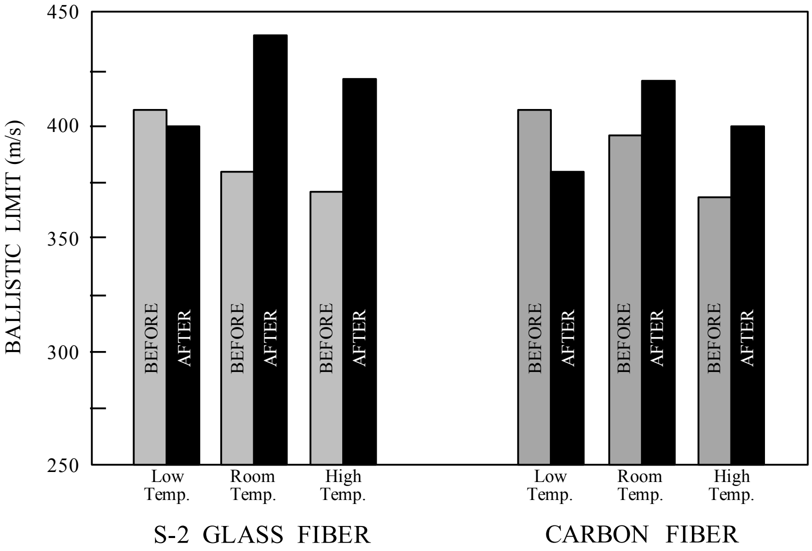

Figure 3. Graphical representation of the ballistic limit V_{50} for the S-2 GFRC and CFRC materials at the three different temperatures, comparing the effect of seawater saturation (before and after material conditioning).

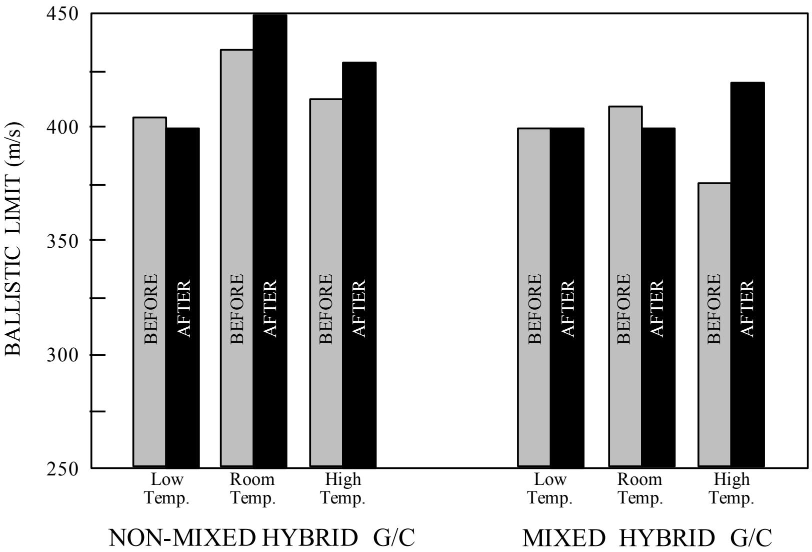

Figure 4. Graphical representation of the ballistic limit V_{50} for the mixed hybrid and non-mixed hybrid glass/carbon composite materials at the three different temperatures, comparing the effect of seawater saturation (before and after material conditioning).

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