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The Characterization of the Impact Resistance of the Multi-Panel Fiber Composite Structure through A Ballistic Test

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Abstract**:** *This study focused on evaluating the impact resistance of the composite laminate structure during the bullet test. The test specimens with the same totally thickness were grouped on two categories that consist of single and multiple laminate. The specimens were prepared using fiberglass/ unsaturated polyester prior to be exposed on the bullet test facility using rifle guns. This experiment has proved that the test specimen able to absorb the impact energy up to 1956 Joule. It was found that multi-panel configuration shows higher performance to cease a projectile, intead of single panel structure with similar thickness. It was also observed that the thicker laminate tends to show larger damage area and higher ballistic limit.*

Keywords: *Armor, Ballistic test, Bullet, Impact resistance, Multi-panel composite*

1. Introduction

Glass fiber reinforced polyester laminate laminates are widely employed in the fighter aircraft as well as navy naval and army ground-transport industries owing to the good mechanical properties, low manufacturing costs, and stealth. Although these kinds of laminates are not designed as Body Armor, they could be subjected to high-velocity impacts of low-mass fragments, and this requires fuller knowledge of their response to impacts of this type. The impact damage could significantly diminish their strength although this may not be visually detectable [1]. This is one of the main reasons why the use of laminate-type composite materials is limited [2].

Some parameter that can be used to calculate the strength of a laminate against perforation is the ballistic limit. This can be defined as the maximum velocity at which a particular projectile is expected to fail consistently to penetrate the specimen [3]. Another important parameter is the damage area, which is directly related to the residual strength of the specimen after the impact. It has been observed that in ballistic impacts on S-glass fiber composites the damage generated is quite widespread, and therefore it is considered a critical parameter in structural design [4]. The behavior of a multi-panel laminate is not the same as that of a single panel laminate. In the literature, there are many separate studies, either of multi-panel laminates or of single panel laminates. For comparisons of their ballistic behavior, the laminates must be target specimen to the same impact conditions while also maintaining the other parameters (material, geometry, etc.) under the same conditions.

This study analyzes the behavior of four single panel laminates of different thicknesses and three multi-panel laminates when subjected to high-velocity impact under the same testing conditions. In every case, the same S-glass fiber reinforced polyester fabric was used.

2. Experimental Procedure

Seven panel laminates made of S-glass fiber reinforced polyester woven laminate were studied: three multi-panel laminates designed as spaced panels, consisting of two panels, three panels and four panels. The experimental tests used an FN Pistol, manufactured by Belgium and FNC Riffle. The specimens were impacted by caliber 9 mm projectiles of Massa 8 gram, V_{50} 380 m/s, manufactured by PT-Pindad. The distance test of target with shooter is 5 meters. For impact velocities by FNC Riffle 980 m/s, distance test of target is 100 meters. Two different types of ammunition were used: FNC Riffle to achieve the highest velocities, and FN Pistol for the lowest velocities. The tests were recorded by a high-speed video camera (APX Photron Fastcam) with a data-acquisition system capable of taking up to 120,000 frames per second. For better recording quality, a high-intensity light source, model ARRISUN 12 plus, was used. Data gathered from the images were used to estimate the projectile velocity. For all of the laminates which were impacted, and given that the composite laminates were translucent, the extension of the damage area was determined with optical techniques [5].

3. Result and Discussion

Fig. 1 illustrates the basic concept of a ballistic pendulum system consisting of massive wooden blocks of *M* depending on the vertical rope. A bullet projectile that moves with velocity *v* hit the ballistic pendulum and immersed in it. If the impact time is very short compared to the timing of the pendulum swing, the practical hanging rope will remain vertical, meaning that during the impact there is no horizontal outer force acting on the pendulum, and the horizontal momentum is conserved.

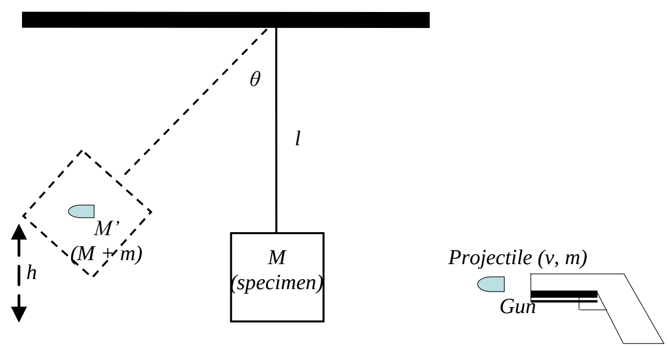

Fig. 1: Ballistic Test Pendulum

Then the pendulum swings the left and upward by forming angle θ to form the height *h* that occurs after the impact. So that the kinetic energy turns into gravitational potential energy (small friction effects can be ignored). Then we get the velocity of bullet projectile as follows:

$$v = \frac{(m+M)}{m}\sqrt{2gh} \tag{1}$$

Where, *m* is the mass of a bullet projectile, *M* is the mass of the specimen, *g* is the acceleration of gravity, and h is the height difference generated from the swing of the specimen.

The maximum damage areas were reached in the areas surrounding the ballistic limit. For velocities below the ballistic limit the damage area increased with velocity, while for velocities greater than the ballistic limit this decreases with the increase in velocity. For single panel laminates (Fig. 2), it was determined that the damage area increases with plate thickness. The 12-mm laminate showed a damaged area 2.4 times greater than that of the 3-mm laminate, giving a percentage similar to that of the difference in the ballistic limit.

(a) (b) (c)

Fig. 2: Multi panel test consisting of two panels (a), three panels (b) and four panels (c)

On the single panel laminates the ballistic limit increased with thickness, due to the greater areal density with the thickness; in the 12-mm laminate, the increase reached 2.6 times over that of the 3-mm thickness. A linear variation of ballistic limit with areal density has been found; a good correlation of data to a straight line is observed. This relationship can be useful in the estimation of the ballistic limit of a laminate. Only two sets of experimental tests of a laminate of the same material with two areal densities are required to calculate the ballistic limit for any areal density in the range considered.

Fig. 3 shows the damage area according to the impact velocity for the multi panel test consisting of two panels and the 6-mm single panel laminates. The maximum damage areas in the spaced plates and sandwich laminates are different. Near the ballistic limit in the multi-panel laminates, the presence of the core enlarged the damage area of the back face-sheet of the sandwich laminates 25% more than in spaced plates, while in the front face-sheet the damage area was twice less.

Fig. 3: Multi panel test consisting of two panels
Remark: The top is the first panel and the bottom is the second panel.
On the left is the front and the right is the back

This behavior could be due to the differences in the propagation of the stress waves produced by the impact between a milieu made of two materials (E-glass-polyester/foam/E-glass-polyester) and another made of two separated layers of the same materials (S-glass polyester/air/S-glass-polyester). In the first milieu the stress waves are propagated across the face-sheet/core interface, reaching the back face-sheet and increasing its damage. In contrast, in the second milieu the propagation of the stress-waves across the air between the two face-sheets is practically nil, increasing the damage in the front face sheet.

Fig. 4 shows the damage area according to the impact velocity for multi panel test consisting of three panels. Fig. 4 shows the damage area according to the multi-panel impact test speed consisting of three panels. The first and second panes show the same pattern as Fig. 3. The third panel shows a different pattern. The projectile is suspended in the second panel.

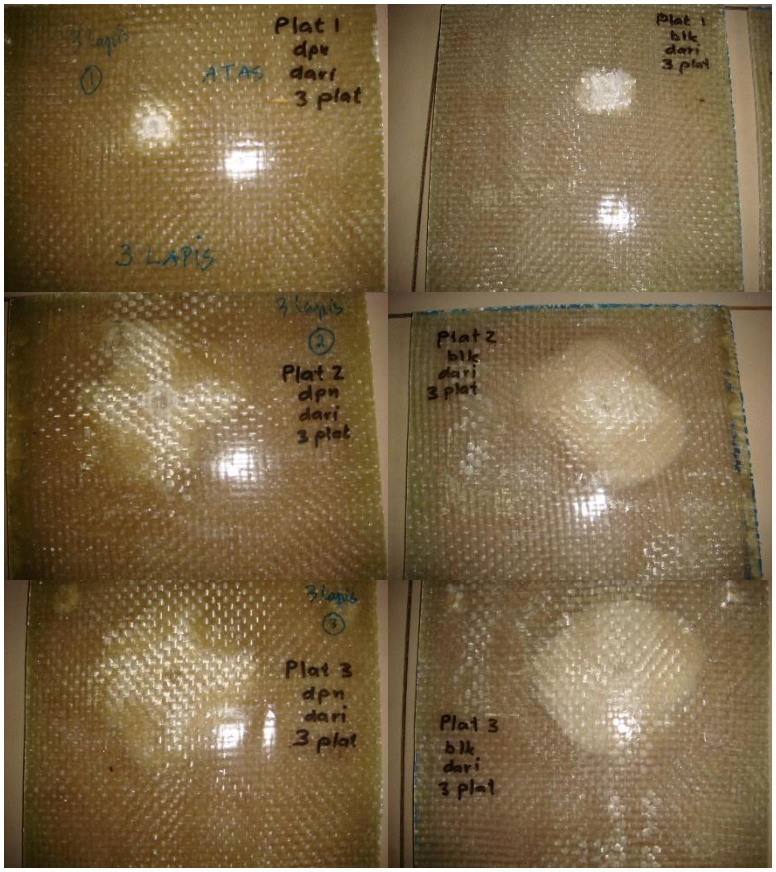

Fig. 4: Multi panel test consisting of three panels.
Remark: The top is the first panel, the middle is the second panel and the bottom is the third panel. On the left is the front and the right is the back.

Test on multi panels for the first experiment consisting of two panels. The first panel is translucent with a bullet projectile. Then the bullet projectile is stuck in the second panel. The impact marks on both panels indicate the distribution or energy distribution of the laminate layers. The energy distribution in the first panel with fiber failure breaks and forms a hole. The cracked matrix portion is twice the size of a bullet projectile. The first rear panel surface shows a wider matrix crack of about 2.5 times the bullet projectile.

In table 1 we can see the result of tensile measurement for multi panel on 2 panels. Visible weak areas in sample number 1, 2, and 4. This is due to the large concentration of impact energy in the area.

TABLE I: Tensile Strength Data from multi panel 2 panels

Sample	Force N	Area mm^2	Width mm	Thickness mm	Tensile MPa
1	3551.52	20	4	5	177.58
2	3551.52	20	4	5	177.58
3	3018.79	20	4	5	150.94
4	3551.52	20	4	5	177.58
5	3196.37	20	4	5	159.82
6	2486.06	20	4	5	124.3
7	2397.28	20	4	5	119.86

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In table 2 we can see the result of tensile measurement for multi panel on 3 panels. Visible weak areas in sample number 2 and 5. This is due to the large concentration of impact energy in the area.

TABLE II: Tensile Strength data from multi panel 3 panels

Sample	Force N	Area mm^2	Width mm	Thickness mm	Tensile MPa
1	4350.61	20	4	5	217.53
2	4883.34	20	4	5	244.17
3	4261.82	20	4	5	213.09
4	4261.82	20	4	5	213.09
5	4883.4	20	4	5	244.17
6	4261.82	20	4	5	213.09

4. Conclusion

The ballistic limit and the extension of the damage area increased with the thickness of the single panel laminates. The ballistic limit in a multi-panel laminate is similar to that of a single panel laminate of equal thickness. Nevertheless, the extension of the damage area is different, being greater in the back face-sheet of the multi panel than in the spaced plates, whereas the behavior of the front-face sheet is the opposite. These differences are influenced by the propagation of stress waves, which is controlled by the difference in the properties between air.

5. Acknowledgement

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