Characterization and Modeling of Ballistic Protection Behavior

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Abstract

The ballistic protection is important regarding the safety of the soldier at the battlefield. The value of the impact energy that can´t be absorbed by the shield, is dependent on the constituent material. The remaining energy represents the total energy that soldier will have to endure, it´s important to take it in consideration to develop the best element of individual protection.
The present research includes the study and manufacture of the composite panels to be tested and the development of an experimental methodology to evaluate the behavior of different materials when submitted to high speed impacts. The specimens have a different number of layers and different reinforcement fibers orientation. The experimental tests were the uniaxial compression at the Hopkinson Bar and the three-point-bending. Furthermore, was developed a machine that ensure the realization of ballistic tests in laboratory conditions. Was proposed as well an impiric model that allows to estimate the value of the remain energy, relating the number of layers and the orientation of the reinforcing fibers.

Keywords: ballistic protection, composite panels, impact, high velocity projectile.

1. Introduction to ballistic protection

Protection Elements

An equipment with the purpose of guaranteeing the soldier protection will always have a compromise between the protection ratio *vs* weight. With the increase of the level of protection, the weight of the military equipment rises as well, the composite materials offer the most balanced choice regarding these two variables. The main function of the ballistic panels is to resist to high speed impacts by preventing the penetration of the bullet. The ballistic protection panels are typically formed by multiple layers of fabric with high mechanical resistance resistant properties. The fiber orientation, the density, the number of layers, among others parameters will establish the level of protection of that material [1].

Bullet and external ballistics

The projectile is the most important component of the body of the ammunition, because is the only component that goes through the gun barrel and has the function to cause the desired effects on the target. It must have certain characteristics in order to better carry out its mission. The constituent material, should present a high density to achieve a high energy, considering the friction between the projectile and the gun barrel, the material must be infusible.
It is important to make a reference to the behavior of the projectile outside of the gun barrel. This behavior is explained by the science of external ballistics which considers that the main forces acting on the bullet, while describing the trajectory, are the force of gravity and the resistance of the air that has greater influence in the trajectory. [2]. The action of these forces will impose a loss of kinetic energy and speed accordingly. A ballistic impact can be characterized by causing high rates of deformation on the target. Given the high speed involved in the process, the target is response is characterized by a local damage that emphasizes the effects of propagation of waves of compressive stress. It is also important to mention that the major focus of the ballistic protection is to absorb as much kinetic energy as possible [3].

Ballistic Limit

When it comes to the ballistic impact, there are three possible cases: (i) the bullet pierces the target and presents an output speed different from zero. In this case, the kinetic energy of the projectile is greater than the energy that the target can absorb or dissipate; (ii) the bullet pierces partially the target becoming immobilized, which is the opposite of what happens in the previous case, now the initial kinetic energy of the projectile is lower than the energy that the target can absorb or dissipate; (iii) the bullet pierces the target and presents an output speed of zero. This example requires that the kinetic energy of the projectile has to be exactly equal to the energy that the target can absorb or dissipate [1].

The ballistic limit can be defined as a speed limit characteristic of the pair projectile - target. There are two definitions accepted by the scientific community: V_0 and V_{50}. The speed V_0 is representative of the speed that the projectile should have to perforate the target leaving with a speed of zero. The speed V_{50} is the speed that the projectile must have to be 50% of probability of perforating into the target [4].

2. Materials

The most common materials used as ballistic protection nowadays are: aramid fibers, ultra-high-molecular-weight-polyethyleno and ceramic materials.

Aramid fibers - are chemically and mechanically resistant, impact and fatigue resistant, resistant to organic solvents, fuels and lubricants, have a good vibration damping capacity and good dielectric characteristics.

Due to the good properties of this fiber and high capacity of energy absorption, it is widely used in the ballistics, more precisely in the production of shields and bullet-proof vests. The resins used in these fibers are the phenolic, vinyl ester and polyester, if the main goal is to achieve better mechanical characteristics the percentage of resin has to be between 30% and 50% [5].

Ultra-high-molecular-weight polyethyleno (UHMWPE), usually marketed as Spectra® and Dyneema®. Due to its chemical composition and molecular structure these fibers have high resistance to any type of aggressive agents and environmental influences, the ballistic properties of the fiber will not be affected by cycles of wetting/drying.

Concerning its use as ballistic protection, the fibers are not only used in the form of tissue (woven fabrics) but also in the form of unidirectional fabrics (non-woven). The woven fabrics present better ballistic properties, due to the crossing of fibers which leads to dissipation of impact energy dissipation.

The use of ceramic materials arises with the need to provide ballistic protection equipment the ability to resist to more specific impacts, for example ammunition of the type P.A. (perforating ammunition). Can be used with composite polyethylene fibers of very high molecular weight in the form of curved panels or plans, being combined with ceramic plates [2].

The purpose of adding ceramic plates is related to the fact that the ceramic materials, despite being fragile materials, when combined with polymers, can absorb large amounts of energy due to deformation imposed in the projectile. These plates are typically used to protect the vital points of the human body and the main structures of military vehicles [6]

3. Failure Modes

There are some factors that directly influence the modes of failure of the systems subject to projectile impacts: the speed and mass of the projectile, the obliquity of the collision, the geometry of the projectile, materials, the dimensions and supports of the target.

In order to frame the problem in terms of failure mechanisms the table below represents the classification based on the type of target [7].

Table 1 - classification of the Target

Semi-infinite	There is no influence of the opposite wall in the process of penetration
Thick	Influence of the opposite wall after penetration has already been partially implemented

Intermediates	The opposite wall influence significantly the deformation process
Thin	There is no stress gradients or deformation through the thickness of the target

The definition of failure mode is based on the knowledge of the stress fields and deformation associated with the impact and the transition of modes along the structural response may also occur.

In composite materials, the performance is directly dependent of the matrix, the fibers and the interface [8]. Failure can occur by: delamination, cracking of the matrix, loss of fiber-matrix adhesion and pullout strength of the fibers.

The failure mode will always be associated with the material and the action to which it is subjected. The modes of fracture, when considering a composite structure subject to the impact of a projectile, he behavior can be characterized by classic modes of fracture: simple or combined. He behavior is based on the structure and geometry, as well as the conditions inherent to the impact. For speeds above 50 m/s the effects will be localized, there is still the possibility to occur damage in the surrounding area due to shock waves resulting from the impact [2].

The models of analysis emerged as instruments for the characterization of this phenomena, it is inevitable not to associate with scientific study, allowing to recreate experiences in a controlled environment. The analysis and characterization of a ballistic impact presents a high degree of difficulty inherent to the high number of variables present in the process. When considering targets in a composite material the result tends to increase the difficulty in the characterization of the impact, mainly due to the anisotropy of the material, and also the increased number of possible modes of failure [1]. The models of analysis may be experimental, analytical or numerical.

4. Energy transfer in ballistic impacts

Assuming that the system is closed, the total energy present in the phenomenon of transfer of power is the kinetic energy of the projectile in the moment in which gives the impact.

$$E_c^{inicial} = \frac{1}{2} m_p v_{in}^2 \qquad (1)$$

The specimen may dissipate energy due to failure by tension of primary fibers (fp), deformation of the secondary fibers (fs), delamination (dl), cracking of the matrix (fm), shear plugging (sp) and the formation of the cone of the opposite face (cfo).

$$E_i^{dissipada} = E_i^{fp} + E_i^{fs} + E_i^{dl} + E_i^{fm} + E_i^{sp} + E_i^{cfo} \qquad (2)$$

Knowing that at some point the kinetic energy of the projectile shall be equal to the energy absorbed by the mechanisms of deformation of the target:

$$E_c^{inicial} = E_i^{cp} + E_i^{cfo} + E_i^{dissipada} \qquad (3)$$

The energy absorbed by the primary fiber translates into:

$$E_i^{fp} = N_i^{fp} e^{fp} \qquad (4)$$

N_i^{fp} - Number of primary fibers that reach the breaking point at the moment of time i.

The energy absorbed by the secondary fibers is equal to:

$$E_i^{fs} = \int_{\frac{d}{\sqrt{2}}}^{r_i} \int_0^{\varepsilon(r)_i} \sigma(r) \left[2\pi r - 8 \sin^{-1}\left(\frac{d}{2r}\right) \right] h \, dr d\varepsilon \qquad (5)$$

The matrix cracking and delamination:

$$E^{fm} = \sum_{n=1}^{i} \varepsilon^{fm} e^{fm} V_m \pi [(r_i)^2 - (r_{i-1})^2] \qquad (6)$$

$$E^{dl} = \sum_{n=1}^{i} \varepsilon^{fm} G_{II} S \pi [(r_i)^2 - (r_{i-1})^2] \qquad (7)$$

Where: ε^{fm} the matrix specific limit of deformation, e^{fm} the energy dissipated by cracking per unit volume, V_m the density ration of the matrix, G_{II} the critical rate for the liberation of energy due to delamination, S the anisotropy of the target and r_i the radius of the damaged area.

Shear plugging:

$$E^{sp} = \sum_{n=1}^{i} \eta_i^{sp} \, E^{sp} \tag{8}$$

η^{sp} Is the number of layers affected and E^{sp} the energy required for a layer break by shear plug.

5. Manufacture of composite panels

Manufacturing processes

There are different methods that can be used for the manufacture of composite panels, divided into two groups:

- Closed Mold Processes for fiber reinforced plastics: compression molding, injection molding, sheet molding process of continuous pultrusion;
- Open mold processes for fiber-reinforced plastics: manual molding process, a spray process, wrap wire process, the autoclave process in vacuum packaging;

The processes of closed mold for fiber - reinforced plastics are mainly used when the final piece requires a dimensional control of more rigorous thickness and greater control over the surface finish. These processes are usually more complex and more expensive than the processes of open mold.

The most commonly used resins for the manufacture of fiber-reinforced plastics are the unsaturated polyester resins and epoxy resins. [9]

Pre-impregnated

They are characterized by being the raw material for the manufacture of structural composites and presents itself as an intermediate product, does not need any procedure to the molding and is defined as a mixture of fiber reinforcement and polymeric matrix, termorigid or thermoplastic. Three factors must be considered when selecting the type of impregnated to use in the process: the equipment available for the process of the workpiece, the nature of the part to be produced, for example the geometry and the required properties. The mechanical properties of composite materials are directly dependent on the orientation of the fiber reinforcement, the fraction density, the length of the fiber and the fiber matrix interface [10].

6. Ballistic Test Machine

Project

Experimental tests begin with the manufacture of specimens to be tested that will represent the ballistic protection to be tested, the assembly of the tests can be done in several ways, however there are some rules that must be followed to ensure that the safety of operators is guaranteed. It is normal to have recourse to high speed cameras with the purpose of observing with more detail the pre and post impact, allowing to analyze the behavior of the tested material.

A source of artificial light can and should be added to the structure ensuring a correct lighting in the course of the test, as well as in the images acquired using high-speed cameras. Another aspect to be considered in experimental trials is the location of the impact of the projectile, once the performance of constituent fibers of the panel is highly dependent on the same, in this way the perfect alignment must be guaranteed. The structure is based on the following diagram:

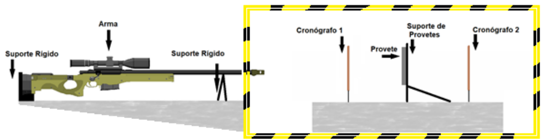


Figure 1 - Diagram representing an experimental test

Manufacture

The structure in Bosch profile allows a large transforming capacity, adaptability and versatility anticipating any changes that might arise in the course of its development, for example the need to create a support shelf and the coupling of the arm where he sat the support for the weapon. The machine has an isolated environment from outside where it is carried out the test itself, in this capsule are installed the chronographs, the support of the specimen, the camera to shoot in slow motion. It is possible to find two holes in each capsule profile side, which allow the

passage of the projectile after impact to the system of collection of projectiles, and another where is inserted the barrel of the gun, this guarantees that any type of gas resulting from the triggering is confined within the capsule. The access to the interior of the closed environment is accomplished by raising the profile front and top of the capsule with the aid of two arms and to support the structure while the data is collected or the specimen substituted.
The fixation of the panels is achieved using two parts designed and manufactured specifically for this purpose ensuring the correct mounting of the specimen and allowing to test the panel, using a mechanical press the two parts are compressed against each other conceding the correct positioning and alignment of the target with the timers and with the system of collection of projectiles.

a) b) c)

Figure 2 - a) paddle support of target (b) paddle and specimen (c) mechanical press

It was necessary the development of a piece, where it was possible to install the bracket for the weapon guaranteeing a fixed shooting position, stable, horizontal and perfectly aligned with the whole structure. This task was easier by the fact that the main structure is in profile Bosch. It was also necessary the production of a piece that guarantee the collection of the projectile after the test, ensuring that this would be confined to the space of the test and do not put the safety of others at risk, it is able to dissipate the kinetic energy that animates the bullet after impact, it corrects any oscillations of the trajectory end and was a storage compartment.

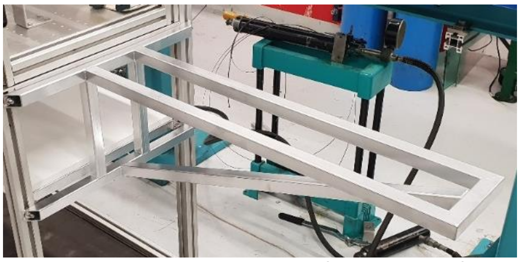


Figure 3 - The support table for support of the weapon

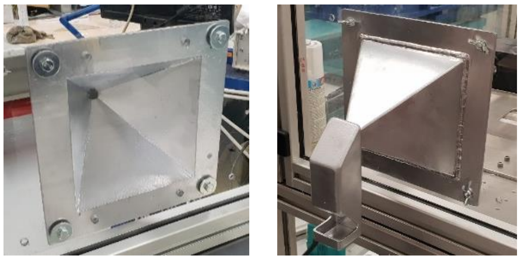


Figure 4 - System of collection of projectiles

Were acquired two chronographs to measure and record the initial velocity of the projectile after leaving the gun barrel, and the final speed after the impact on target, this way with these measurements is possible to identify the energy variation that occurs for the different targets tested and compare with the results obtained in the tests carried out in the Hopkinson bar and at three-point bending.

Instrumentation

They were attached to the frame two arms to ensure the frame support whenever is needed to access the internal environment. A lighting system was mounted to ensure a correct illumination of the work table, and to increase the quality of the footage made during the tests, as to improve the quality of the environment where the test is performed.
Were acquired six different types of projectiles, and performed a battery of tests to identify which would be the adopted for the tests, the selection criterion was the greatest penetrating power, resulting in the selection of the projectile Prometheus Excite.
After the selection of the projectile were initiated the tests with the pieces produced, having been made 3 shots for each specimen with this bullet, were measured initial and final speeds and calculated the energy variation after the impact in each composite panel, allowing to classify them by their ability to absorb the impact energy of the selected

projectile. Were photographed the panels after the impact to be possible to compare the status of each specimen.

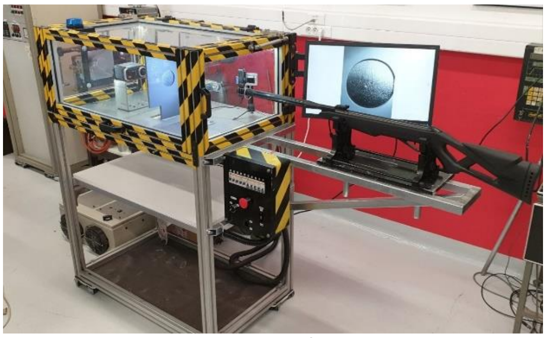


Figure 5 - Machine of ballistic tests

7. Materials and Methods

The panels produced are characterised by a pre-impregnated with a matrix end-hardenable, with 60% of fiber reinforcement and 40% of epoxy resin, nominated T700S. Were produced 10 panels with different number of layers and different orientations of fiber reinforcement, the process used was the casting in autoclave respecting the curing cycle as defined by the manufacturer. Were obtained the following panels:

Table 2 - Characterization of panels produced

Panel	Nº of Layers	Orientation of the fiber reinforcement	Average thickness (mm)
1	1	0°	0,197
2	2	0°/0°	0,327
3	3	0°/0°/0°	0,434
4	4	0°/0°/0°/0°	0,690
5	2	0°/90°	0,356
6	3	0°/90°/0°	0,445
7	4	0°/90°/90°/0°	0,765
8	3	-45°/0°/45°	0,482
9	3	-30°/0°/30°	0,490
10	7	0°/30°/60°/90°/-60°/-30°/0°	0,938

Tests Performed

Three different tests were conducted concerning this study: the three point bending where was applied a defined load on all specimens supported on two of its sides, then was measured the deformation of each one, were also performed uniaxial compression tests in the Hopkinson bar in order to study the evolution of force in function of the displacement and tension in function of the extension, finally regarding the machine of ballistic tests constructed was performed real shot using a weapon of air pressure to obtained the values of energy absorbed after Impact for each panel and the state of destruction of each piece.

8. Results and Discussion

Three Point Bending

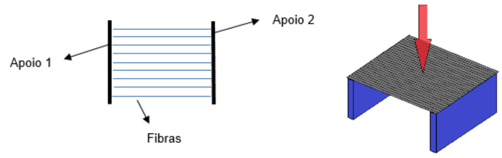


Figure 6 - Diagram representing the test

Tests were performed in two distinct directions (Figure 6), with the fibers perpendicular to the two supports and with angles different of 90°, trying to understand the influence of the orientation of the fibers in the deformed measurement, the values obtained for each specimen appear in the table below:

Table 3 - Summary table of values obtained in the tests

Panel	Average deformation (mm)
1 (0°)	D1 = 3.50 D2 = 5.98
2 (0°/0°)	D1 = 1.17 D2 = 4.23
3 (0°/0°/0°)	D1 = 0.84 D2 = 2.15
4 (0°/0°/0°/0°)	D1 = 0.28 D2 = 0.91
5 (0°/90°)	D1 = 1.05
6 (0°/90°/0°)	D1 = 0.73 D2 = 1.81
7 (0°/90°/90°/0°)	D1 = 0.38 D2 = 0.56
8 (-45°/0°/45°)	D1 = 1.10
9 (-30°/0°/30°)	D1 = 0.95 D2 = 1.53
10 (0°/30°/60°/90°/-60°/-30°/0°)	D1 = 0.16 D2 = 0.20

The value of deformation is dependent on the orientation of the fiber as was expected, when the fibers are oriented perpendicular to the two supports offer greater resistance when compared to the tests where they are arranged with a different angle, this is due to the fact that the fibers are selected with the aim of being requested to efforts along its length in detriment of its width. Also the number of layers influences the behavior of the panels, to the extent that a greater number of layers results in less deformed.

Uniaxial compression tests in quasi-static conditions

Complete the sequence of tests for each panel manufactured and after the processing of data performed was necessary to find an equation that match the values obtained in each test, trying to compare the different panels.

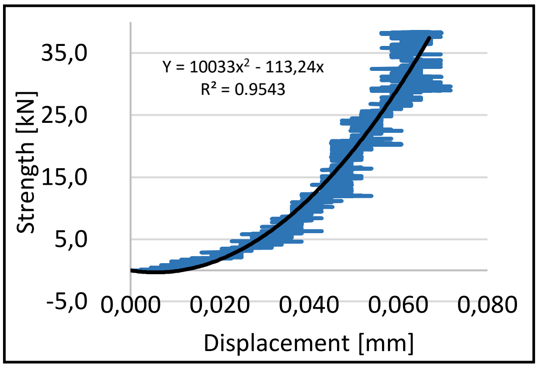


Figure 7 - Evolution of force in function of the displacement and the polynomial approximation

The next figure is the graph force/displacement to the panels 1, 2, 3 and 4 formed only by parallel fibers at 0º.

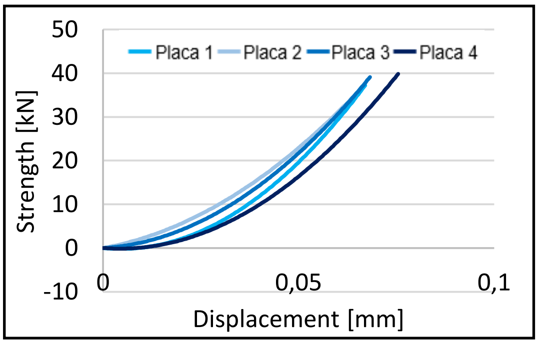


Figure 8- Influence the number of layers in the evolution of strength with the offset for the same orientation of fibers (0°)

Analyzing the previous figure, based on the characteristics of each of the panels, more specifically the number of layers that constitute each of them:

1st panel, a layer with 0º, thickness equal to 0.211mm;
2nd panel, two layers with 0º, thickness equal to 0.311mm;
3rd panel, three layers with 0º, thickness equal to 0.427mm;
4th panel, four layers with 0º, thickness equal to 0.684mm.

The main difference between the four panels is the total thickness resulting from the number of overlapping layers, being the thickest the panel 4 and thinner the panel 1. Considering the approximate value of 40 kN the panel 1, 2 and 3 presents a close displacement in the order of 0,065 mm, turn to the thicker panel 4 presents the larger displacement checked, approximately 0,075 mm. These results were the expected, the thicker the specimen is the greater capacity of deformation it was.

An energy analysis was performed by using the force/displacement graphs, using the equation of the curve that translates. The integral of the equation that approaches the test data was calculated this represents the calculation of the area bounded by the abscises axis and the curve of approximation to the test, this way the energy absorbed by each board for the performed tests are in the following table:

Table 4 - Energy absorbed by the different tested boards

Panel	Average power absorbed by impacted Board [J]
1 (0°)	3,319
2 (0°/0°)	3,575
3 (0°/0°/0°)	4,642
4 (0°/0°/0°/0°)	7,160
5 (0°/90°)	4,373
6 (0°/90°/0°)	5,652
7 (0°/90°/90°/0°)	7,968
(-45/0°/45°)	5,221
9 (-35°/0°/35°)	5,133
10 (0°/30°/60°/90°/-60°/-30°/0°)	16,014

We can conclude that the energy that each panel can absorb its different depending on its thickness, and inside of the specimens that feature thicknesses close to the same number of layers, the orientation of the fibers defines which have greater capacity to absorb energy. Panels with different orientations of reinforcement fibers in their structure layers have a greater capacity to absorb energy, when compared with panels composed only by parallel reinforcement fibers. Being that panels with reinforcement fibers at 90º presented higher values of energy absorbed when compared with panels with fibers at 30º and 45º, and these have a value of absorbed energy above the panels with composed by fibers at 0º. This interpretation is supported also in the analysis of graphs tension/extension where were compared panels with the same number of layers and different orientation of fibers such as shown in the next figure regarding the panels 2 and 5.

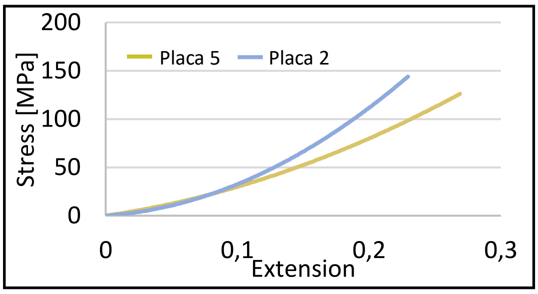


Figure 9 - Influence of orientation of fibers (0 º/0 º and 0 º/90 º) in the development of tension with the extension for the same number of layers

Dynamic tests in Hopkinson Bar

Using the following formulas was performed the conversion into physical values of the data obtained in the dynamic tests. Being the stress given by equation (9), the actual stress by (10) and the actual extention by equation (11).

$$S = \frac{F}{A} \qquad (9)$$

$$\sigma = S \times (1 + e) \qquad (10)$$

$$\varepsilon = ln\left(\frac{l}{l_0}\right) \qquad (11)$$

Also in the dynamic tests, it was necessary to find an equation that match the graph of the test. The Figure 10 represents the graph of the evolution of stress with the extension to the panels 1, 2, 3 and 4:

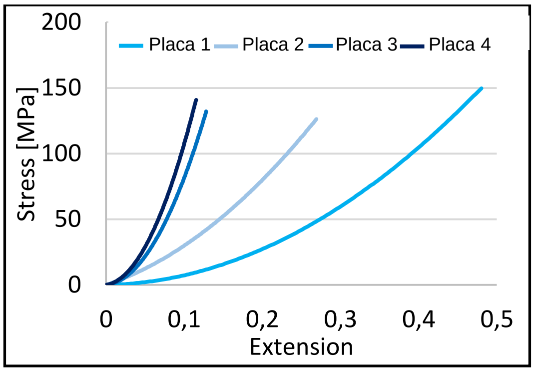


Figure 10 - Influence the number of layers in the evolution of stress with the extension to the same orientation of fibers (0°)

The increasing number of layers and consequently the total thickness lead to a decrease in the value of the extension for the same stress values, this happens due to the increase in resistance to transversal compression of the composite material with the increase in the number of layers.

With the graphs was made a comparison identical to that preformed in the uniaxial compression tests in quasi-static conditions where were compared specimens with the same number of layers and different orientation of fiber reinforcement.

The results obtained with these tests allow us to reach the conclusion that the number of layers and the orientation of the reinforcement fibers provide different capabilities of deformation of the test specimens. It was concluded that the panels with fewer layers offer less resistance to impact, deforming more for identical values of stress applied. Panels formed by parallel fibers present a higher extension when compared to panels formed by layers arranged with angles of 30º and 45º and these deform more than panels that feature layers with fibers arranged perpendicularly among themselves.

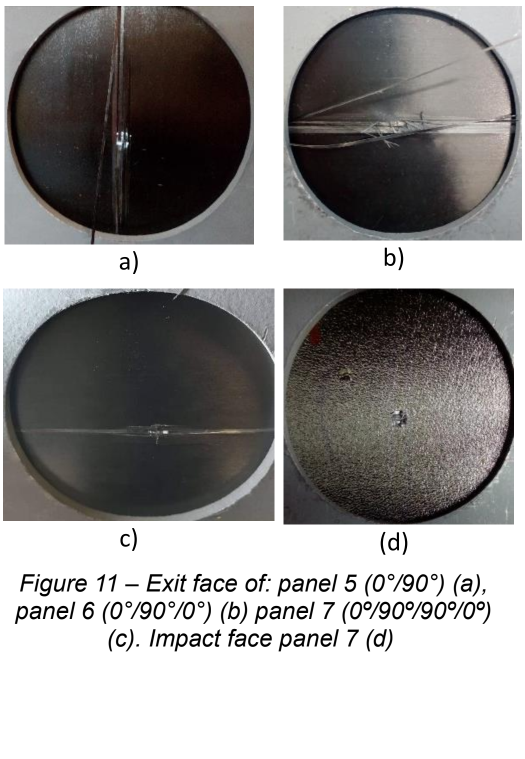
Ballistic Tests

After these three tests for each of the panels produced with recourse to the projectile selected the Prometheus, were calculated the values of average variation of projectile energy for each specimen tested, these values set out in the table below:

Table 5 - Average energy absorbed for each specimen tested

Panel	Average variation of energy (J)
1 (0°)	0.91
2 (0°/0°)	0.93
3 (0°/0°/0°)	1.23
4 (0°/0°/0°/0°)	1.98
5 (0°/90°)	1.57
6 (0°/90°/0°)	1.83
7 (0°/90°/90°/0°)	2.35
8 (-45°/0°/45°)	1.47
9 (-30°/0°/30°)	1.60
10 (0°/30°/60°/90°/-60°/-30°/0°)	3.36

Based on the previous table, can be easily to conclude that panels 1, 2, 3 and 4 composed by 0º fibers, with the increasing number of constituent layers, there is an increment of energy that the specimen is able to absorb. When we changed the comparison between panels with the same number of layers but different orientations of reinforcement fibers for example: panel 2 and 5 it is observable the influence of the angle formed between the fibers and the energy absorbed by the panel 5 is higher than in the panel 2. The same happens with the panels 4 and 7, and with the panels 3, 6, 8 and 9, where is also noticeable that the panel 3 (0°/0°/0°) absorbs less energy than the panels 8 (-45º/0°/45°) and 9 (-30º/0°/30°), and they absorb less that the panel 6 (0º/90º/0º). The following figure represents the damage that the specimens presented after the completion of the test.



a) b) c) (d)

Figure 11 – Exit face of: panel 5 (0°/90°) (a), panel 6 (0°/90°/0°) (b) panel 7 (0º/90º/90º/0º) (c). Impact face panel 7 (d)

Material Law Calibration

Based on the preformed tests and analyzing the influence of the increase in the angle formed by the reinforcement fiber (θ) and the number of layers (N) regarding the values of energy absorbed, was found an equation that returns the energy absorbed by a certain composite panel:

$$E = N(0.069N - 0.0861) + (0.0045\,\theta + 1.0013) \qquad (12)$$

The values of energy obtained using the equation above are satisfactory, returning identical energy values when compared to the ones obtained by the tests carried out on the machine of ballistic tests, as shown in the following table:

Table 6 - Comparative table of absorbed energy

Panel	Energy absorbed (tests) [J]	Absorbed energy (equation) [J]
1	0.97	0.98
2	1.07	1.11
3	1.35	1.36
4	39.70	39.70
5	1.53	1.51
6	1.78	1.77
7	2.18	2.17
8	1.47	1.57
9	1.56	1.50

It is not possible by the equation presented to obtain the value of the energy absorbed in panel 10, because the formula only consider panels whose constituent layers are oriented among themselves with a fixed angle set.

9. Conclusions

It was possible, using the tests to conclude that the thickness is the parameter with greater importance when preformed transversal efforts, such as those mencioned before.

The main conclusion, taking into account all the tests performed and the consistency in the results obtained, is that for composite materials with similar thicknesses is expected an increase in the resistance to impact when this is composed by more than one orientation of reinforcement fibers, and even that include the increases ability to absorb impact energy, with the increase in the angle between the reinforcement fibers up to a maximum of 90º. When deemed thin panels, composed by more than one layer, where the first is always at 0º, if the second layer is prepared with a different angle of 0º, for example 30º, 45º or 90º, the panel composed by 0º/0º will always present a lower value of absorbed energy that a panel composed by 0º/30º or 0º/45º and this in turn lower value compared to one with 0º/90º that represents an increase of absorption capacity in the order of 45%.

The project, planning and conception of the apparatus that allows testing ballistic protection, as well as projectiles, in controlled conditions. Were found the technical aspects that are necessary to cover for this type of tests, it is possible to build it in a reduced space guaranteed the necessary conditions of safety. It became possible to characterize the type of behavior of ballistics protection and the projectiles itself, defining this way which best suits the needs imposed, being of extreme importance to provide the Security Forces as well as the Armed Forces of an identical apparatus, allowing it to be put to the test the materials purchased to equip our military, guaranteeing the ability to test the equipment with their own resources, without being necessary to blindly trust in the manufacturer's specifications. It also serves as a guiding line, so that it is possible to equip the military forces with this competency that will add value to the institutions.

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10. References

[1] J. Santos, "Methods of Analysis of ballistic impacts," Faculty of Engineering, University of Porto, 2015.

[2] M. A. Suliman and O. K. Mahmoud, "Computational Investigation of Base Drag Reduction for a projectile at Different Flight Regimes Introduction :," *13th Int. Conf. Aerosp. Sci. Aviat. Technol.*, no. April, pp. 1-13, 2009.

[3] I. L. Ciesielska-Wróbel, "Contemporary Personal Ballistic Protection (PBP)," in *textiles for Advanced Applications*, B. Kumar, Ed. Delhi, India: intech Open, 2017.

[4] J. Barker, C. Black, and R. Cloud, "Confort comparison of ballistic vest panels for police officers," *J. Text. Apparel, Technol. Manag.*, 2010.

[5] P. S. Monteiro, "Evaluation of the performance of the shields protecting people and equipment", Instituto Superior Técnico, 2007.

[6] A. B. de Morais, A. G. de Magalhães, and M. F. S. F. Moura, *Composite Materials - materials, manufacturing and mechanical behavior*, Vol. 2. Port: Publindústria, technical issues, 2011.

[7] J. A. et al. Zukas, *Impact Dynamics*, J. Wiley &. 1982.

[8] M. A. G. Silva, *Introduction to the modeling of ballistic helmets*, vol. 1. .