Evaluation of mechanical behavior of ballistic armor

José Manuel Grilo Taveira Pinto

Abstract

Since the earliest Civilizations, men have sought to develop armours for extra protection against enemies' aggressions. In this sense, the scientific and technical development of armours counteracts the constant improvement of the weapons and their piercing power. In fact, the armours are often developed for specific purposes in order to enhance their performance in protecting people and equipment. To meet this objective, it is often necessary to use innovative solutions, in terms of materials and their quality/quantity used in the manufacture and the type of the armour itself.

The armour efficiency evaluation is extremely important to ensure the safety of the user in many activities, both military and civilian. However, this information is usually considered confidential, due to the risk that it poses to the military and civil society, and/or the strong economic interests of the companies that commercialize protective equipment. When these tests are performed, the results are generally restricted to merely qualitative aspects, such as the damage done by the projectile. However, it is not common to assess the value of the remaining energy of the impact that is not absorbed by the armour, which is transmitted to the user or equipment. In other words, is it sufficient the piercing of the armour to ensure the safety of the user?

The present thesis focused on the development of an innovative experimental methodology to quantify the residual energy transmitted through the armour to the user from the impact of the projectile. To allow the necessary ballistic tests under controlled laboratory conditions, a new electromagnetic impulse system has been developed. It has the advantages of the absence of noise, smoke or lights, and also allows testing different types of projectiles with continuous adjustment of the impact energy. The test methodology was assessed with different types of armour in service at the Portuguese Army. In fact, the present work fills the gap in the evaluation of personal armours, as an asset that can be applied in the future by the Portuguese army for an independent evaluation of personal armours.

Key - Words

Evaluation of shielding; Energy balance; Degradation of shielding; Impulse electromagnetic.

Introduction

The use of shielding is extremely important in the current scenario of modern warfare, as well as in the scenario of urban guerrilla warfare. Understand the level of ballistic protection in different scenarios (projectiles, shrapnel, knives, ..) is a necessity to ensure the safety of military and police. Thus, the development of methodologies for evaluating the mechanical behavior of shields are invaluable tools to allow selecting the most appropriate ballistic protection to the war scenario of the mission concerned. The ability to play different situations for firing in controlled laboratory conditions, where it is possible to vary the energy of impact or how the projectile strikes the shield, together with the monitoring of key physical variables of the interaction between the projectile and the shield, is fundamental importance for understanding the mechanism of energy dissipation of impact. It also seeks to create conditions for carrying out missile tests in different protection accessories (body armor, helmets, riot shields, etc.) and more than that to know one of the things that is not usually considered in this type of evaluation, but has great importance on the security of people and equipment, the impact energy is not absorbed by the shield. Calculation of remaining energy of impact is particularly critical in the case of helmets and flak vests. This research had two main objectives: 1) conception, design and manufacture of a methodology (based on equipment Hopkinson) and a shot of electromagnetic equipment, capable of propelling projectiles in energy conditions similar to those observed in firing and, monitor key parameters of fire, 2) the evaluation of mechanical behavior (penetration levels, induced damage and energy balance) of some personal armor used by the Portuguese Army (anti jackets - helmets, plates and anti riot) when requested in terms of actual shooting, simulated in controlled laboratory conditions. The projectiles used for the tests were the 5.56 mm NATO caliber and 9mm.

State of the Art - Evaluation of shields

Tests for evaluating shielding in Portugal, are mostly carried out in appropriate fields of fire (Shooting range of Alcochete, Campo Militar de Santa Margarida, Practical School of Artillery in Vendas Novas, among others), in accordance with the rules NEB / T E-316, NIJ Std 0108.01, and others. Tests are performed with the execution of three shots in the shield, forming a triangle (standard NATO

STANAG 4190) [1 and 2] as shown in Figure 1.The great gap in our country, with regard to this point, faced with the analysis of results, since the findings of such tests are purely qualitative, that is limited to verifying only losses in whether a particular type of projectile drills / or do not penetrate the armor. In addition to the shots made against the shields, one of qualitative methods, more common in ballistic research centers, given the use of ballistic gelatin. This is a kind of gelatinous solution which aims to simulate the density and viscosity of human muscle tissue to analyze the impact of the projectile on it. Thus, after the shot is held visual inspection ballistic gelatin to check for possible damage caused by the impact. This mirrors the results of expansion closer to reality, being the main method of comparison of the impact, but is simply a visual inspection. (Figure 2).

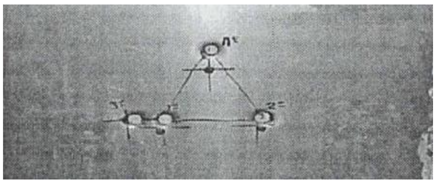


Figure 1 - Tests performed on ballistic aramid fabrics.

Figure 2 - cavity resulting from the test conducted by a 5.56mm bullet 200 meters**.**

All that are techniques / methods of analysis / evaluation of energy absorbed by the shield and the remaining transmitted to humans by the present work did not exist. This has made it difficult and it was a failure to evaluate the efficiency of shields used by the Army, for to do tests to assess the shields can not only assume the penetration of the projectile, but is necessary to determine whether the energy shield to minimize the energy remainder transmitted to the soldier.

Besides the traditional ballistics tests used by the Portuguese army, there are other techniques used by several foreign armies. One solution is used by HP White Laboratory, a company dedicated to the evaluation of shielding the American armies, and which is connected to the Department of Justice of the United States. The ballistic vests are tested qualitatively and quantitatively. To take measurements, is implemented in a sequential system, consisting of a firearm (responsible for the propulsion of the projectile), two speed sensors (and thus allow its value at some point you want) and ultimately support the shield to be analyzed (Figure 3). Through the available sensors is not possible to evaluate the energies involved in the process.

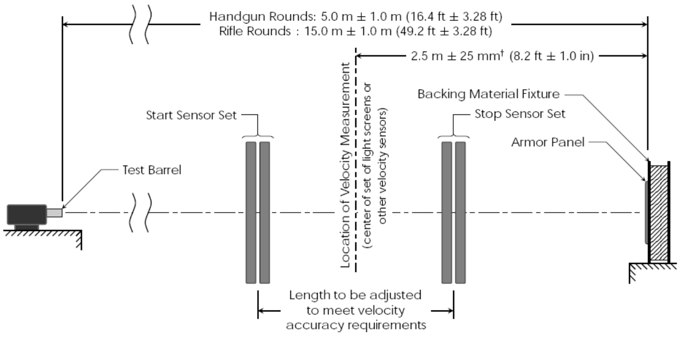


Figure 3 - Schematic picture of the sequential evaluation of shielding [3].

A further interesting point in this process is that the support of the shield is a box containing a homogeneous block of deformable material (oil-based clay modeled), which is placed in contact with the back of the armor (ballistic vest) during tests. In this way, when the test is set to "signing of the impact," which means the highest level of sustained indentation in homogeneous block, which is measured by the distance parallel to the upper and lower peaks perpendicular to the surface of impact (BFS) (Figure 4).

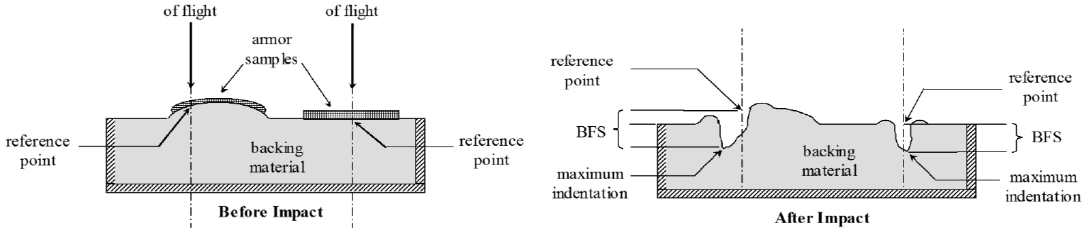


Figure 4 - Support the shielding box containing a homogeneous block of deformable material, before and after the impact of a projectile [3].

Finally also be noted that the vests are also tested for perforating objects such as swords, knives or even "ice pica. The method involves the use of a mechanism that is based on a common hammer fall.

Experimental Development

Concept Test Bench

With respect to the ballistic test bench (Figure 5) that is divided into two parts. The first, which consists of two structures, where one (the main structure of the trigger) is to serve as a support and attachment to the electromagnetic trigger (a) and other (secondary structure of the trigger) (b) which aims to give greater stability, stiffness and height to the trigger and still acts as a storage bank of power. The second part of another structure (structure of the apparatus) (c) where the apparatus called the bench test, which consists of: a bar incident (d) that has been engaging the projectile caliber 9 mm or 5.56 mm, the media of their bars and clamps, the transmitter bar (e), containing the strain needed to make the readings of the deformations, support for the samples of shielding (f) and the device fixation (g), and also the support and target displacement sensor (h).

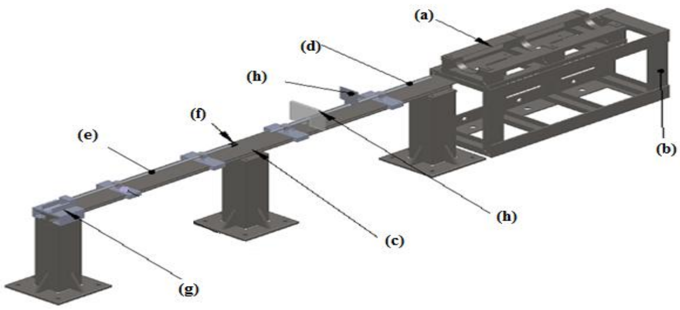


Figure 5 - 3D Model of Ballistic Test Bench

Electromagnetic Launcher

This electromagnetic trigger is designed so that it can be testing ballistic missiles with NATO standard caliber 9 mm and 5.56 mm, with energy levels equal / similar to a real fire, coming so close a loophole to the already existing very . This new structural design is to enable linear activations silent, without emission of fumes, with high rates of energy.

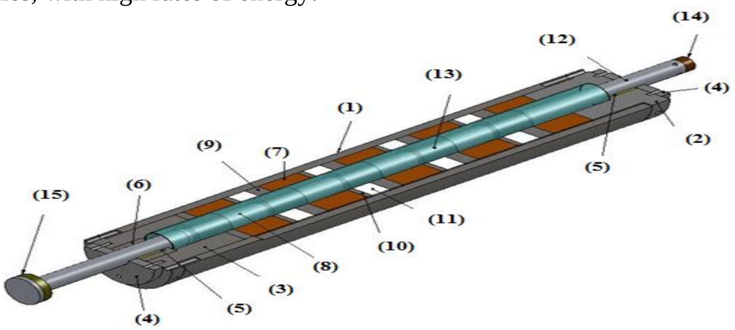


Figure 6 - Representation in detail the electromagnetic trigger - end view;

The developed system consists of: 1) Magnetic Shield, 2) Amount Lid, 3) Downstream lid, 4) cover; 5) Bushing, 6) Bearing, 7) Coil, 8) of the tube coils, 9) Tab ferromagnetic Upstream , 10) Tab ferromagnetic Downstream, 11) Tab Dielectric; 12) Bar Impact; 13) ferromagnetic core; 14) Stop Amount;15) Stop Downstream.

The operating principle of the trigger is the incorporation of multi-core ferromagnetic bar impact by matching one for each coil, allowing a sum of forces from each of the sets coil / core, and the shot fired simultaneously. The operation is characterized by the simultaneous and rapid passage of an electric current by each of the coils, using the database power of high voltage (Figure 7b). The passage of current through the coils induces the creation of a magnetic field, which causes the movement of ferromagnetic core to the center of its coil. This, for when the core approaches the field created by the coil is magnetized by it, acquiring a magnetization opposite to the field coil. This pole armature is attracted to the pole of the coil, resulting in an acceleration of the core, always towards the center of the coil. In turn, and how they are distributed in the bar series of impact, the nuclei give rise to the movement of the bar with an energy value corresponding to the sum of many binomials core / coil.

Stock Power

The power system is implemented in its essence, a set of five RLC circuit (Figure 7a). Each of these circuits then results in a set of four capacitors 450 volt 6000μF (EVOX RIFA - PEH200YX460BQU2) parallel connected to each coil. The capacitors are connected to the mains through a transformer 2000 volts, and this in turn connected to a variable transformer for regulating the load voltage of these. It should be noted that the capacitors are charged with a voltage value proportional to the speed that you want to activate the bar impact. A switch 25 A is the connection between the capacitors and the transformer, there is a rectifying bridge in order to rectify the wave from the grid (wave rectifier - KBPC2510). There are three resistors connected in parallel in the circuit, providing a load resistance to the capacitors. In parallel to the RLC circuit to drain the induced current induced by the kickback and to protect the coils when the discharge, there are diodes free-wheeling (Westcode Semiconductors - W0646WC120). The rapid discharge of capacitors is achieved through activation of thyristors (Semikron - SKT552/16E), these are linked to variables processors (1.5 to 12 volts) when the activation of relays (Siemens-V23101), provide that there is a rapid discharge. To activate the relays used with computer software, the need to have a shot as soon as possible. There is also a safety switch 25A so as to safeguard any possible bug in the system.

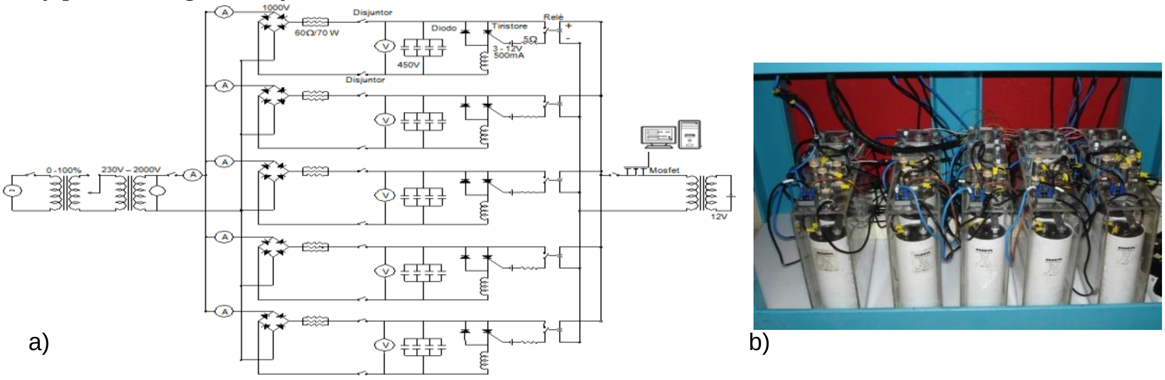


Figure 7 - a) - Wiring seat of power used to make the electric reels of magnetic reluctance actuator. b) - Bank Power Implemented.

Systems Data Acquisition and Monitoring

There are several methods to perform data acquisition in this type of testing. In this study we used two methods. The conventional method of a load cell, based on technology compressive (uniaxial strain, configured in a Wheatstone bridge) and has a displacement sensor (ECL100). The monitoring and control of the main system variables were performed using various equipment such as multimeters and ammeters. It was also intended to combine in one structure (Figure 8) all checks for closing and opening the circuit, all switches responsible for cutting overall power, loading and unloading of the circuit, as well

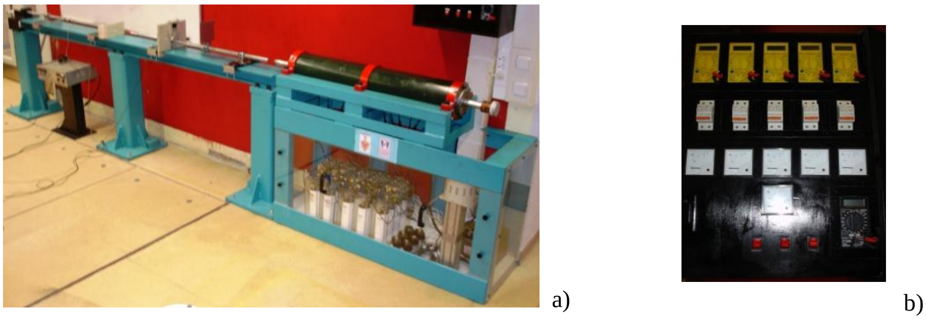


Figure 8 - a) - as a test for the evaluation of ballistic armor installed. b) - Box of checks and monitoring of loading and unloading of the circuit

as monitoring the load capacitors.

Results and Discussion

The application of electromagnetic shutter in conjunction with the rest system of missile tests, allowed to evaluate the behavior of armor (flak jackets, made of fabric or plastic aramid, anti-riot shields, made of polycarbonate and ballistic steel helmets and kevlar). Using the developed electromagnetic trigger, the impact of this bar, it moves against the bar incident (which is the structure of the apparatus), which is bound projectile (caliber and 9mm NATO or 5.56mm). This then moves against the shield, thus making the interaction of the projectile with the shield, thus making the test. By purchasing systems are acquired values of the variables of interest (force, displacement, and energy), allowing the evaluation of shielding in question. When tested the energy used immediately before impact was 320Joules, and the trigger settings always been strictly controlled to allow a consistent way the results presented.

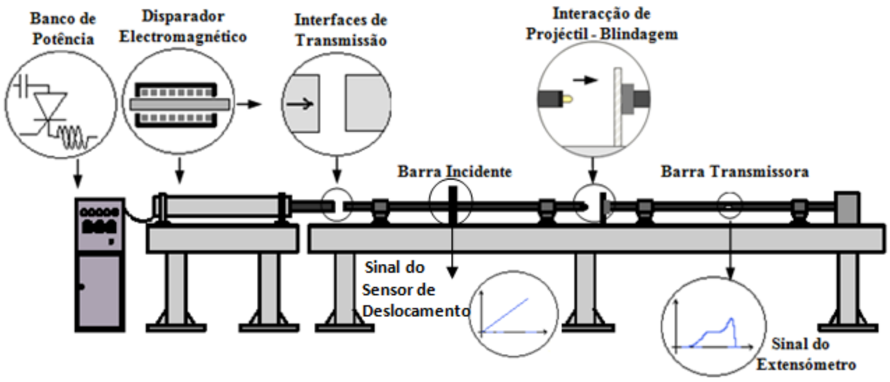


Figure 9 - Outline of Method of Operation

Test Plan

Before the tests was prepared a test plan. The methodology has the making of an impact on each type of shield to then impose themselves on the same site another impact, and thus be able to understand the degradation of shielding (in an extreme case) by analyzing the loss of capacity shield to absorb the energy. Stood still in case, if the first impact of drilling there, the second impact is an area immediately adjacent, to take back an extreme situation where the shield is already weakened. With the methodology, we intended to also make a comparison between different packages. With regard to testing ballistic helmets, the methodology was different, the main concern was the comparison of different materials that compose them. Thus took place only one impact (of each kind of projectile - 9mm and 5.56mm) on each helmet (steel and Kevlar).

Comparison of Mechanical Behavior shields

Upon completion of the first series of tests was possible to obtain the results for the ability to study the shielding to absorb the impact of projectiles. Figures 10 and 11 show the evolution of the pressure wave that travels through the bar as a function of transmitting displacement after one impact of shielding the samples from the shells of caliber 9 mm and 5.56 mm. In figure 10, you can see a greater capacity of kevlar vests used in anti - bullet in both tactical cards in tissue of the base material, to absorb the impact force compared to the polycarbonate used in the shields - turmoil. Can still occur, that due to the greater flexibility of aramid fabric, the projectile has a larger displacement (Figure 10a). As regards the results of ballistic helmets (Figure 11), here you can see a greater absorption of energy by the Kevlar helmet, which is logical since the steel has a hardness greater than the kevlar.

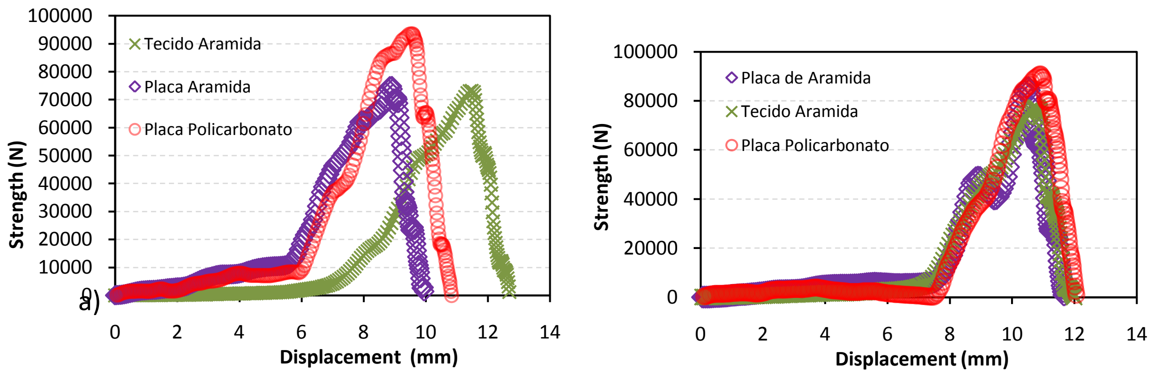


Figure 10 - Comparative evolution of the power transmitted by the shields after impact: a) - projectile caliber 9mm b) - the projectile of 5.56 mm.

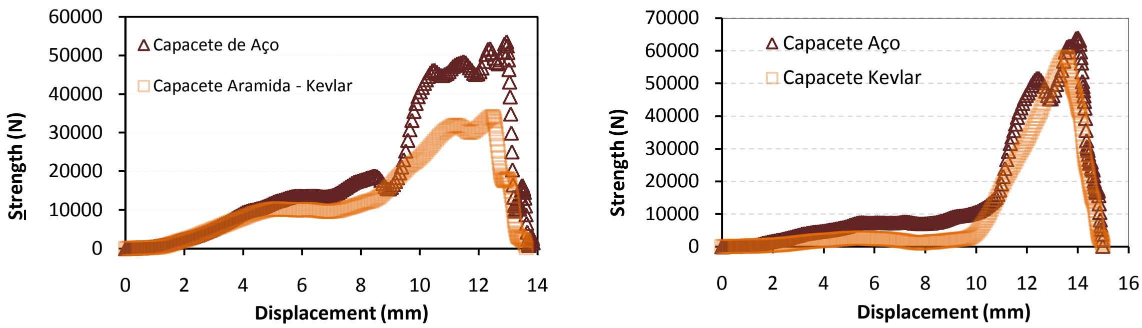


Figure 11 - Comparative evolution of the power transmitted by the armor (helmets) after impact: a) - the 9mm projectile, the projectile of 5.56 mm.

Then is then presented to the reader the power levels that the armor can absorb (Table 1).

	Energy absorbed by the shield when the impact of the projectile 9mm		Energy absorbed by the shield when the impact of the projectile 5,56mm	
	(%)	Absolute Value [J]	(%)	Absolute Value [J]
Card Aramid - Kevlar	35,3	112,96	36,9	118,08
Fabric Aramid - Kevlar	33,8	108,16	36,1	115,52
Plaque Polycarbonate	10,2	32,64	19,4	62,08
Helmet Head	17,3	55,36	25,4	81,28
Kevlar Helmet	36,7	44,04	48,1	113,92

Table 1 - Fraction of energy absorbed by the shields of the impacts made.

Making a deeper analysis of the data, one can interpret various stages of the projectile - shielding. Thus for a better understanding we have chosen two graphs with the evolution of the power transmitted after impact, for each projectile.

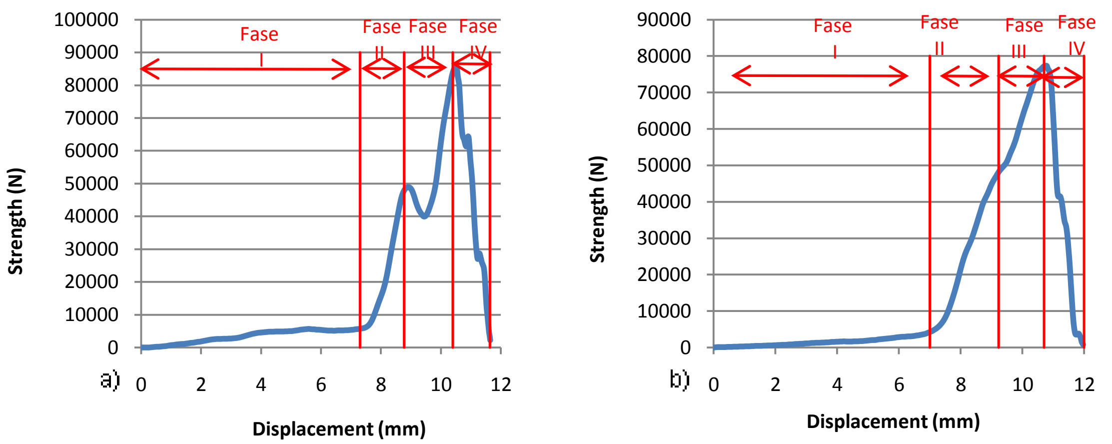


Figure 12 - Evolution of the power transmitted after the impact of 5.56mm caliber projectile, with the representation of the various phases existing in) - impact on the board of aramid b) impact on the aramid fabric.

For the ballistic tests carried out using the projectile of 5.56 mm, can identify four distinct phases (Figure 12). The first is associated with the adaptation of the projectile to the medium (screen), the second phase is the phase of light penetration of the projectile, the third phase is related to the energy remaining in bar incident which still corresponds to an energy that would allow the projectile continue its path. Finally the fourth stage which is connected to the decrease of the bar incident, and that energy must be enclosed in it for the impact of the projectile, to the extent that even though this energy is low, is still significant because it causes a slight decrease of the projectile (about 1 mm depending on the shield to be analyzed), this being reflected in a slight decrease slight edge as a proxy.

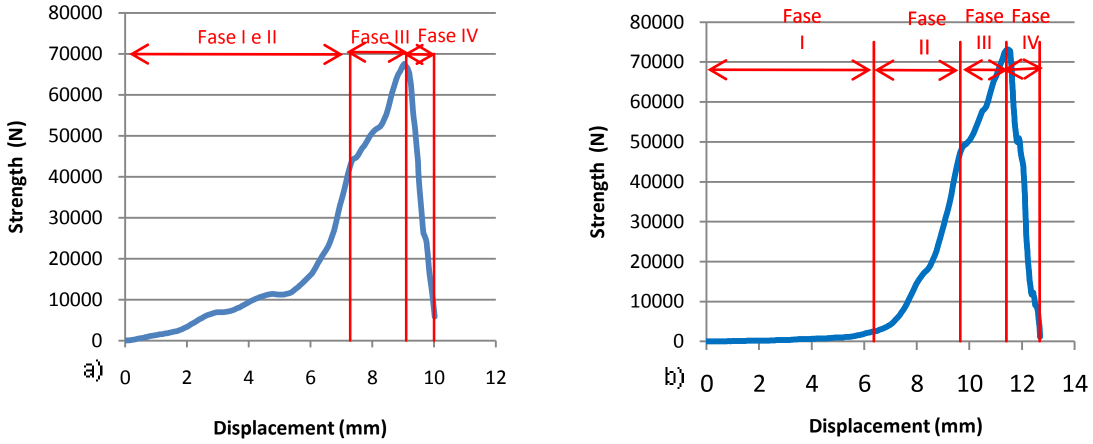


Figure 13 - Evolution of the power transmitted after the impact of the projectile caliber 9mm, with the representation of the various phases existing in) - impact on the board of aramid b) impact on the aramid fabric.

With regard to the tests conducted using the 9mm caliber projectile, we identified two possible cases. One that is on the boards of aramid, or the plates of polycarbonate and / or a helmet (you can see for example in Figure 13a, for the case of aramid plates). In this and due to the characteristics of the projectile (derrubante), the first and second stage explained above, identify themselves as virtually a stage. This can be seen that right from the beginning the power transmitted is much higher and there is some analogy between this phase and a compression test by the projectile in the armor. The remaining two phases are identical to those explained for the projectile of 5.56 mm.
The second case feasible to be identified is that of aramid fabric (Figure 13b), where due to the characteristics of the material in question (more flexibility), the first phase is to be re-adjusting the projectile to the armor. Here it is denoted with ease that the transmitted power compared to the first case is very low. As regards the second stage back to check a pure compression test by the projectile in the armor. The remaining stages (3 and 4) were as previously explained. As already mentioned slightly, although it falls outside the scope of this work, these results and in particular the results presented in Table 5, one can see an interesting question. It appears that for the 9mm projectile energy transmitted to the user is higher than 5.56 mm, right that makes perfect sense considering the functions that each projectile is intended.

Mechanical Behavior and Degradation of shields

In this section aims to show the reader the degradation of various shields selected. When it comes to degradation, we shall show the damage caused by the projectile in the armor (whether there is penetration or not) and analyze the loss or not, the capacity of energy absorption by the shield, when subjected to a second impact. With respect to the board of aramid and polycarbonate plate, when subjected to the impact of a 5.56 mm projectile they behave differently from the aramid fabric. We noted in the tests performed was that both the board aramid card such as polycarbonate, it withstood the impact of the projectile has penetrated and drilled it from one side to another plate. The aramid fabric (due to its flexible features), although there is penetration by the projectile, this can not drill in all the tissue. There is still an interesting curiosity registered, which is due to deformation of the projectile was minimal (Figure 14e).

a) b) c) d) e)

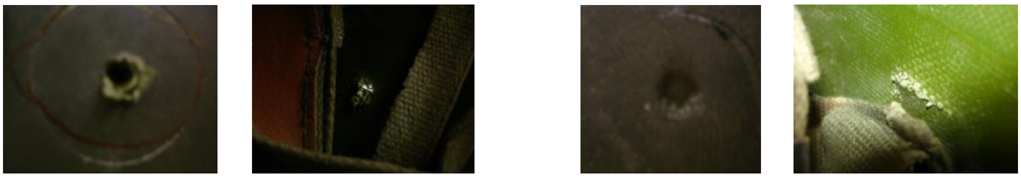
Figure 14 - Impacts on shields selected using the 5.56 mm projectile: a) - Board Aramid b) - Plate: Polycarbonate c) - Aramid Fabric. Comparison of a projectile of 5.56 mm: e) - No deformation d) - With deformation.

For the same armor, but when subjected to impacts from bullets of 9mm, its behavior is different at least in the tissues and aramid plates, even in the absence of penetration by the projectile (this also because of its characteristics - derrubante). In the plates of polycarbonate due to the characteristics of the material itself (little flexible and rigid) projectile can penetrate, but do not pierce the shield in its entirety. In these trials there are exception of the plates made of polycarbonate, as was assumed (since there is no drilling) projectiles were totally deformed.

a) b) c) e) f) g)

Figure 15 - Impacts on shields selected using the 9mm bullet: a) - Board Aramid b) - Plate: Polycarbonate c) - Aramid Fabric. Comparison of projectiles: e) - without deformation, f) - deflection from the tests carried out on board and aramid fabric g) - deflection from the test carried out on the board of polycarbonate.

The damage caused in ballistic helmets, this differed in the two types of material analysis. In ballistic Kevlar helmets, and the tests with the projectile of 5.56 mm, it was noted that there was a total penetration and perforation. For the same armor, but the rounds of 9mm, there was total drilling, and even then there was a still substantial damage in the armor, to the extent that such loss or damage suffered in its outer surface, either on its inner side.



a) b) c) d)

Figure 16 - Impact on kevlar helmet ballistic projectile using the 5.56 mm: a)-Face Pool; b) - Face interior. Impact on ballistic kevlar helmet using the 9mm bullet: c) Face-Pool; d) - Face interior.

With regard to ballistic steel helmets, they have a totally different response. In this screen, both for tests conducted using the 5.56 mm projectiles and for tests using the 9mm, there was never penetration by projectiles and also the damage was slight. Regarding the deformation of the projectile, the size of 9mm has a deformation similar to that presented in Figure 95b. The gauge was 5.56 mm for the first time a behavior never before (in all trials) found.

a) b) c)

Figure 17 - Impact on Steel ballistic helmet, a) - using the 5.56 mm projectile, b) - using the 9 mm projectile, c) - Deformation of the projectile of 5.56 mm used in the impact on the screen.

Before embarking on an analysis of armor subjected to a second impact, noted that the results show that the damage caused by the impact of a projectile of 5.56 mm caliber is much more localized than that of 9 mm, resulting in greater penetration into the shield. The impact of the projectile of 9 mm caliber damage a larger area but with less depth. With respect to loss or no capacity to absorb energy from the shield, when subjected to a second impact after the completion of the second series of tests was possible to obtain the results for the shielding ability in the study. Noted that the shielding of polycarbonate rather than in the plan of testing, there has been a second impact, for shielding already had a state of decay quite high, not allowing them to make a reliable analysis of the data. Was determined as the energy levels (in percentage) that the armor can absorb (Table 2) for a second impact.

	Energy absorbed by the shield when the impact of the projectile 9mm		Energy absorbed by the shield when the impact of the projectile 5,56mm	
	(%)	Absolute Value [J]	(%)	Absolute Value [J]
Card Aramid - Kevlar	30,7	98,24	31,8	101,76
Fabric Aramid - Kevlar	27,8	86,40	27,9	89,28
Plaque Polycarbonate	3	9,60		

Tabela 1 - Fracção de energia absorvida pelas blindagens após o segundo impacto realizado.

Comparing the figures in Table 1 and the 2, we can see a greater amount of energy transmitted between the first and second impact explained by successive degradation of the shielding. In this second analysis we identify two situations.The first relates to the fact that the energy absorbed by tissue aramid, where the impact of the projectile 9mm and 5.56 mm is very similar, this can be explained by the fact that the first test of the projectile 5, 56mm, have caused more damage, and even penetrated the armor. In effect the projectile of 5.56 mm found less resistance in the early stages (because the fabric was already partially stuck), which leads to realize that this way the screen has had a lower ability to absorb energy while present similar characteristics to the test conducted using the 9 mm projectile (which has features derrubantes, ie, these tests the energy transmitted to the user would normally be higher). The second analysis that can be done is on the plate tests of polycarbonate. In these, it is clear the lack of capacity by these shields to absorb the energies involved, is even more evident that in this second test. This finding is not surprising, because in reality the anti-riot shields are not designed to receive impact of projectiles, but the sharp objects large and at low speeds, although it may confer ballistic protection to level 2. The truth is that even the second impact, carried out with the 9mm bullet, no drilling of the total shielding.

Only finish by noting that in all trials at the plate and aramid fabric, although the shield is already weakened, there was only total penetration and perforation plates aramid by the projectile of 5.56 mm, all other tests, with either 5.56 mm, with either a 9mm shield responded similarly to already described in the first impact.

Conclusions

In this study, we complete an initial analysis of the electromagnetic trigger and all the experimental apparatus developed, are presented as an asset for ballistic testing. This new structural design allowed activations linear silent with high rates of energy. It also allowed the missile tests were conducted in a small room, in the absence of fumes and is therefore not necessary to use a rifle range. This new design allowed to evaluate the shielding not only quantitatively but also qualitatively. For the first time in Portugal, has emerged as a mechanism that allows knowing the energies that are actually absorbed by the shield and which are transmitted to the user. The only limitation that can be pointed to this apparatus, will be the need for the existence of electric current for powering the seat of power. Has developed a system that allows not only to evaluate screening, but also if necessary be used for the mechanical characterization of materials at high speed. The power unit developed and implemented yet allowed precisely adjusting the shutter speed and can be used any type of projectile weapons beds (depending on it to adjust the docking system of the projectile).

With respect to balistic tests developed can be concluded that:

- In the first analysis showed ballistic helmets not be suitable for the desired effect. It was found that the only positive response of these took place in kevlar helmet, when subjected to the impact of the 9mm bullet. Because the same helmet when subjected to the impact of the projectile of 5.56 mm can not take it, being drilled in its entirety. In the case of steel helmets, although these have never been drilled, denoted that the absorption of energy from these is limited, suffering its user a big impact. As this element of ballistic protection is to protect one of the key parts and more sensitive human being, the energies that go to your user in the case of steel helmets are too high, possibly causing internal damage to the user. So should certainly be rethought the policy of acquiring ballistic helmets, for those currently serving the Portuguese Army, have no guarantee that they are 100% safe.
- In a second analysis and with regard to the boards, aramid, aramid fabric and polycarbonate plates, we could see that when subjected to impacts of projectiles of 5.56 mm, the screen that behaved better was the fabric of aramid because despite having been pierced by the bullet that was not fully punched, as seen on the boards of aramid and polycarbonate. Whether this is somehow acceptable in the

case of polycarbonate plates (because it actually has a different destination, as discussed above), this is not permissible in aramid plates, as they were supposed to provide ballistic protection to the user. The aramid fabric was also combined with this factor (drilling), the fact was that she could better absorb the energies involved. With regard to the tests conducted using the bullet of 9mm, it was noted here that the response from the shielding is sufficiently satisfactory, with no drilling and taking the material has absorbed a significant proportion of energy involved (in the case of fabric and card aramid). Despite the protection ballistic present encouraging results with regard to the impacts of 9mm bullets, again comes back to reconsider the ballistic protection, as it was known that the aramid plates do not give adequate protection to the impacts from projectiles 5.56 mm.

- Finally, a third analysis could be seen that for the extreme case of a second impact on the same site of the first, the aramid fabric provides an excellent response to the impact of the projectile of 5.56 mm, resisting the total drilling. It is also concluded that in terms of energy absorption is also gives a good response, bearing in mind also that generally this type of shielding is not to be subjected to a second impact at the same place because there is always a part of the military constant concern to avoid being hit. Note also that the methodology allowed us to analyze the shielding in the extreme case, thereby affirming that, if they hang on this, has held any other case affecting them.

References

[1] STANAG 4190, *Test Procedures for Measuring Behind–Armour Effects of Anti–Armour Ammunition*, 1999;

[2] STANAG, *Ballistic test method for personal armour materials and combat clothing*, edition 2;

[3] http://www.hpwhite.com/resources/;