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Standardization in testing ballistic protection systems

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Abstract. Even more than in other field of activities, standardization in ballistic protection is in trends of CEN/CENELEC declaration that "standards build trust", promoting innovation and introduction of new, performant solutions based on test procedures and protocols that are able to point out quality and safety for such systems. Ballistic testing standards have particular specifications for ballistic materials, differentiation of tests being made especially on the purpose of the ballistic protection product. In the last decades, test methods have been refined and measurement devices have become more complex. The main set of standards is developed by military organizations (as NATO), highly industrialized countries, where the military and research in the field are priorities (USA, European Community, Asian countries, South Africa). Some states refer to American standards by using them as guides. Depending on the destination of the ballistic product, specifications in standards are different. The authors give examples of how standards requirements are implemented in testing ballistic protection systems, in order to point out the particularities of introducing and verifying new and classical products in this domain. Generally, the results of the ballistic tests are evaluated by acceptance or rejecting the tested product, based on specific criteria, included in standards.

1. Introduction

Even more than in other field of activities, standardization in ballistic protection is in the trends of CEN/CENELEC declaration that "standards build trust" [1] and promote innovation and the introduction of new, performant solutions, based on test procedures and protocols that are able to point out quality and safety for such systems. Ballistic testing standards have particular specifications for materials, differentiation of tests being done especially based on the purpose of the ballistic protection product. In the last decades, test methods have been refined and the measurement devices have become more complex [2]. They also establish a clear terminology, useful for the quality assessment of ballistic protection systems.

Standards and specification evaluations are used for:

- assessing the quality and the performances by testing,
- evaluation of new materials and design solutions under the same conditions as for "classical" ones,
- investigating and understanding failure mechanisms of protection systems,
- a logical approach of designing solutions for more lethal ballistic threats,

- understanding and avoiding the consequences of a hit on humans and technical systems,
- protecting with keeping the performances of personnel and systems at an efficient level.

Standards supply test procedures, requirements for measuring equipment, conditions and terminology for determining the ballistic protection of different solutions and purpose (metallic, non- metallic, composites, ceramics or, more often, hybrids of the above mentioned materials).

Tests for ballistic protection always take place under particular and imposed conditions. Actually, in situ conditions may differ. If a protection glass is fixed in a frame, once rigidly and once flexibly, it may stop the projectile on one occasion, but it is penetrated on the other occasion. Factors like humidity, dust, light and chemical agents could diminish the protection performance. Specialists have to know the sensitivity of each product to the test conditions. A test condition is evaluated as sensitive if a minor modification is sufficient to produce a considerably different test result [3].

A regulation may be elaborated according to two different basic principles, taking into account either the attack potential (attack-orientated regulation) or the protection potential (protection-orientated regulation). Regulations can be divided into two groups:

– standards included in law and nationally recognized regulations; they are elaborated by the national or nationally recognized standards institutes, and become mandatory,

– guidelines not included in law; they are test instructions, established by public or private institutions in order to achieve uniform testing of certain products.

Taking into account standards and guidelines [4], [5], [6], [7], [8], [9], [10], [11] for body armors and light protection of vehicles, Table 1 presents the information included in a ballistic test report. Results have to be compared, qualitatively and quantitatively, to standard requirements and supplementary demands, if required by any interested part.

Table 1. Information to be found in a ballistic report

• Contractor information • Measuring and recording devices • Contact information	• Personnel conducting the test and any witness • Weapon used • Information of used projectiles: code, mass, design, materials, dimension, supplier
• Lot number and quantities • Item specification number	• Information of propellant: type, weight of propellant for each shot • Results include: impact velocity used in computing V_{50}, with the highest partial penetration, the lowest complete penetration, spread intervals for test parameters and results and velocities of each rounds and shot.
• Tested product specifications • Armor material description • Material identification for each sample	• Witness plate characteristics, partial or complete • Remarks to the conduct of the test, or material behavior • Photos, films
• Temperature and humidity at test facilities	• (If required) failure mechanisms
• Date of the test	• Standard number or regulation

Test methods have two variants, usually applied both for each product:

– testing a defined minimal mean penetration velocity (v_{50}) that provides information on a ballistic protection since it also reveals the production quality and the manufacturing variation of protection system,

– testing at a defined impact velocity at which none, for an imposed number of rounds, may penetrate the protection system.

A non-encompassing list of standards and requirements for individual armor is also given in [12]. This includes threat ammunitions and their characteristic velocities to be applied for this testing protocol. A still discussed issue is the value for which back face signature (BFS) is lethal. Interested governmental institutions have adopted a BFS standard not exceeding 44 mm. The army, for hard armor, has used a BFS standard less than 43 mm without penalty. Many specialists consider this value is too high for human trauma acceptance. Figure 1 presents several issues related to standard and non-standards tests for ballistic protection. In standards, threats are classified in levels and, consequently, the system provides protection against a certain threat level. There is no permission of supposing that a higher level recommends a lower level without testing for the required levels.

The main families of standards are developed by military organizations (NATO), highly industrialized states where military research are priorities (USA, European Community, Asian countries, South Africa). Typical examples of standards are regulations of DIN (German Institute for Standardization), Ö-Norm (Austrian Standards Institute) or SNV (Swiss Standards Association).

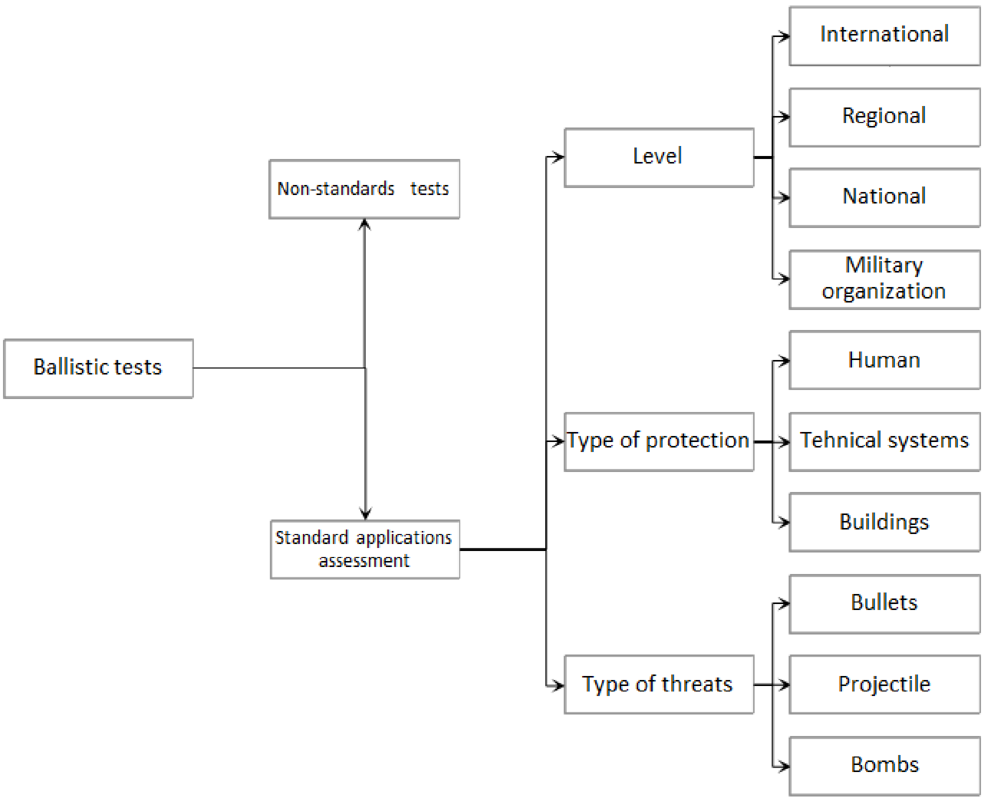

Figure 1. Standard tests for ballistic protection.

Guidelines mostly emerge as prior references for the procurement of equipment for the army or police, as NATO STANAG guidelines or guidelines of the PFA (police records academy) in Muenster (Westphalia). Some states refer to American standards by using them as reference guides.

Depending on the destination of the ballistic product, specifications in standards are different. For example, in standard NIJ 0101.04 and NIJ 0101.08 for vests impact resistance, there are specific issues related to limit the trauma the human body is subjected to. For armored vehicles, the specifications are tailored to vehicle type (truck, helicopters etc.) and the threat they face, and ballistic products may be subject to additional fire resistance, weathering etc.

Hard body armors have to comply with regulations for testing in order to decide the more suitable product. From 2007, the US Army conducted ballistic testing against hard body armor, completed analyses of test results and developed a statistically-based test procedure providing a high level of confidence for resistance to penetration and backface signature (BFS) [12]. Specialists and end-users (army and low enforcement staff) require standard test references, procedures and analyses for every type of ballistic protection, including hard body armor testing, vehicle armor or building protection.

New hybrid composites gain this market due to their improvements over the classical materials in terms of strength to weight ratio, better life expectancy and enhanced thermal properties [14].

At CEN, Technical Committee 33 is responsible for elaborating and up-dating the standards related to ballistic protection, the representative standards being: EN 1063:1999 [4], EN 1522:1998 [5] EN 1523:1998 [6]. ISO16935:2007 (reconfirmed in 2017) [10] and test procedures for evaluating resistance of security glazing materials and products (for both interior and exterior use) against ballistic impact with classification by weapon and ammunition. It is assumed the glazing is adequately fixed, but it does not apply to glazing system or surrounding materials and structure [10]. EN 1063 [5] is a security glazing standard for measuring the protective strength of bullet-resistant glass. It is commonly used with EN 1522 [5] to form a ballistic classification system, by which armored vehicles and structures are tested and rated. A similar classification system used in the United States is NIJ Standard 0108, which includes glass and armor plate.

NATO introduced STANAG 2920 [15] for quantifying materials ability to stop fragments and shrapnel. The measuring technique was initially developed for body armor, but now it could be used in events that generate fragments with high risk of impact, including for armored vehicles. Standard tests are conducted by shooting FSPs (fragment simulating projectiles) onto the target sample with different velocities, while measuring the velocity of each FSP. By varying the velocities, after a number of shots, an estimate of the ballistic limit can be obtained, which is the velocity to which the protection system defeats the fragment. Combat troops rarely suffer injury or fatality from bullets, but are at high risk from primary (direct) and secondary (environmental) fragmentation. The V_{50} test is the internationally recognized standard for assessing the fragmentation resistance of personal protection. The higher the ballistic velocity, the higher the rating of the protecting armor, The V_{50} is the average of the velocities recorded for six fair impacts consisting of the three lowest velocities for complete penetration and the three highest velocities for partial penetration, provided the spread is not greater than 40 m/s [15].

NATO AEP-55 STANAG 4569 [8] includes standard techniques and reproducible test procedures for evaluating the ballistic resistance of vehicle armor components (integral, add-on, opaque and transparent), as well as the required vehicle vulnerable area assessment.

Figure 2 presents a diagram resulted from a NIJ standard for testing protection systems and the main factors influencing the requirements, procedures and results analysis.

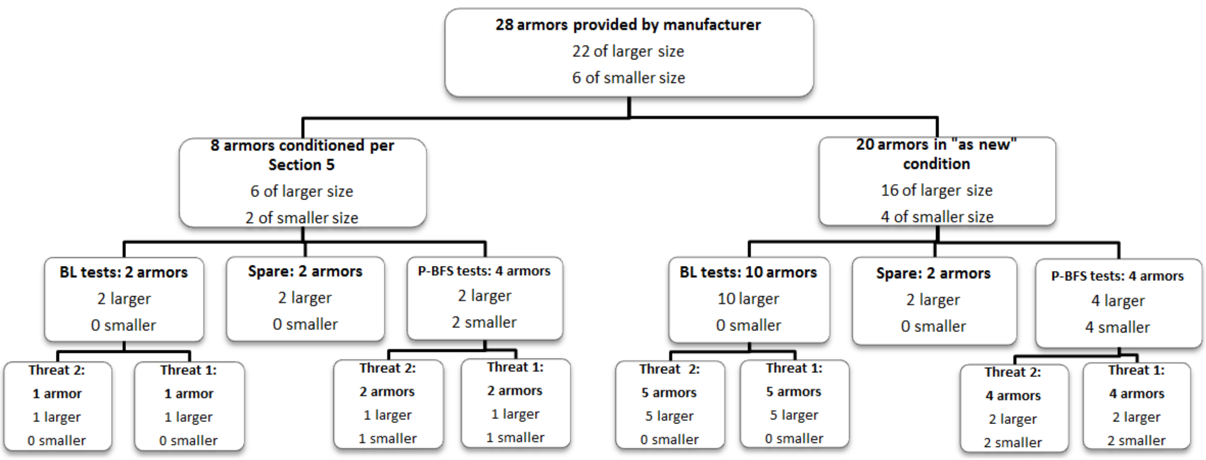

Figure 2. Sample quantity and utilization for armor types IIA, II, and IIIA [16].

The advantages of non-standard samples are:
- available for laboratory fabrication (square samples of 100 mm to 250 mm a side),
- easy to fix on the laboratory frames,
- easy to use supplementary investigation equipment like fast camera and thermal camera,
- easier to use non-destructive investigations like SEM, laser profilometer etc.

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The disadvantages of using standard non-complying samples could include:

- difficulty in extrapolating the panel response to larger one,
- small dimensions of the samples could emphasis some failure processes and could hide others,
- the fixing type could induce different response as compared to that of the actual panel that could be mounted in a more sophisticated frame.

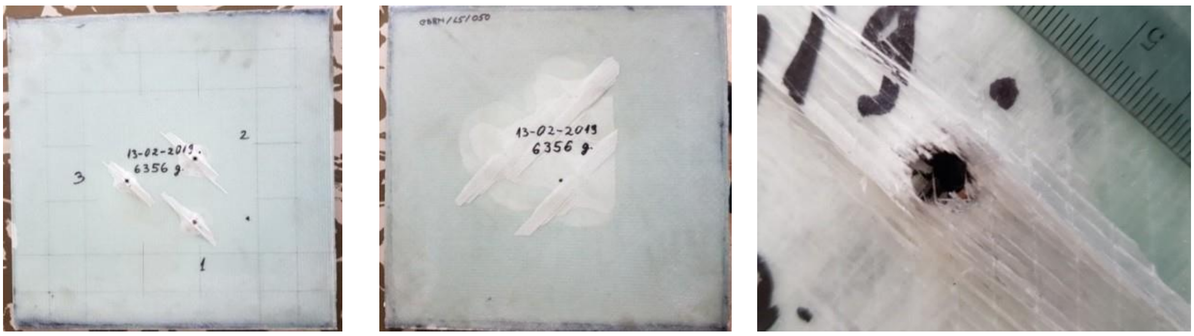
Samples for standard tests are larger. For instance, for panels of individual armors, the dimensions are 500 mm x 500 mm, as also for vehicle panels [4]. For buildings and non-mobile systems, the standards recommend larger panels. These samples, even if they react to impact more likely to panels in actual applications, are too large for small-scale investigations (SEM, FTIR, EDX) and they require to be cut with a method that does not influence (too much) the impacted zone. Panels made of aramid fabrics are difficult to be cut and it is very probably to disturb fiber positions and their matrix when cutting. Panels made of glass fiber fabrics are prone to supplementary delaminate when cutting small samples. In a review on textiles and fibre-reinforced composite impact responses, Abtew et al. [17] underlines by photos the influence of sample size, clamping and projectile design, shape, size and velocity, concluding that the more reliable tests are those "imitating" closely the field situations.

Pach et al. [18] tested ballistic resistance of hybrid shields: three types of two-layer composites. The first shield layer has plates of tungsten carbide, ceramic balls Al_2O_3 or steel balls (100Cr6), in a polymer matrix. The second layer was a laminate of 10 layers of aramid fabric in a matrix of styrene-butadiene-styrene. Samples were overshot along the ballistic track from the Beryl rifle. The 5.56x45 mm ammunition with the bullet of SS109 MESCO type was used. Non-standard methods were used, panels being small (100 mm x 100 mm), shooting distance 10 m from the target, shooting angle 90°, the projectile impact velocity 870...890 m/s.

Kilic [19] determined ballistic performance of an armor, being helped by finite element methods for approximating ballistic limit thickness of armor steels. The tests were done to validate the model and the ballistic resistance of high hardness armor steels against 7.62 mm armor piercing ammunition. Ballistic shot tests on 20 mm thickness target were performed according to standard Stanag 4569 [8].

2. Test campaign for ballistics

After reviewing the open literature, one may notice that there are differences between standards tests and laboratory tests for ballistic protection. The authors experienced tests for a ballistic panel (see figure 3), designed for vehicle protection and pointed out the differences between laboratory tests and those required by specific standards [13].



a) the panel face b) the back face of the panel c) detail

Figure 3. Tests for a protection panel for level IIIA in agreement with SR EN ISO 1523 2004 [13], at standard distance for proving or not fragments detached from the panel.

There are standards for bulletproof vests, but few are used extensively [20]. Among these, there are stab and ballistic test norms for vests, like NIJ Standard-0101.06 [16]. "Since NIJ started its testing, more than 3,000 officers' lives have been saved" [21]. Also, the standards of the United Kingdom's Home Office Scientific Development Branch are widely used in several countries. Countries will use these standards and incorporate the basics and modify them to fit the threats of interest. This ballistic standard rates vests on a scale against penetration and trauma protection.

The test campaign, regardless the standard, has the following components: method, test and in-situ investigation equipment, samples, including one to remain as whiteness, the ballistic test report. Photographs of all samples are not expressly required but, photographs at different scale (micro - obtained with scanning electron microscope and macro - obtained with high resolution camera) could reveal deficiencies, failures or unusual results, this being useful information to both the armor manufacturer, the conformity assessment body and the end-user.

For ballistic protection, test standards are elaborated in order not to be limited at conventional or already known threats, but also to be applicable for new entries of threats and materials. For instance, the ballistic-resistant protective materials covered by NIJ 0101.06 [16] are classified into the following levels of ballistic performance: type I (22 I.R; 38 Special), type IIA (9 mm FMJ, 357 Magnum), type II (9 mm FMJ, 357 Magnum), Type IIIA (9 mm FMJ, 44 Magnum), type III (M80 ball), type IV (30-06 AP), type special, this being added to face progress in threats performances.

3. Comments concerning standard test procedures

Taking into account the discussion on tests for assessing the ballistic protection, the research included in project [13], [21] did non-standard and finally standard tests.

Body armors have to be tested for two reasons: penetration resistance against bullets and the back-face signature (BFS) that is associated with the personnel's risk to be wounded. The impact energy is found by shooting the armor mounted in front of a backing material (clay), which is used at a precise temperature and confirmed for impact flow. After the test, the obtained indentation in clay is measured [20]. Comparing the BFS may be tricky if the tests are done following requirements of different standards. Even using the same type of bullets, but from different suppliers, and different clay grades (even considered equivalent) may give hidden "errors", In European, German and British standards, there is an allowable value of 20 to 25 mm for the back face signature. The American NIJ standard admits 44 mm, which could produce internal injuries and it has been controversial since its introduction. New non-destructive investigation equipment's allow for characterizing more complex the BFS. Wetting conditions degrade a vest. Room temperature water will not affect para-aramid. But either basic or acid liquids decrease strength of aramid fiber fabrics and standards demand tests on wet armors and even after exposing them in heated, airtight enclosures [22].

Gillepsie et al. [23] tested panels of dimensions 30.5 cm x 30.5 cm were impacted using a fragment simulating projectile (FSP), following a NIJ Standard. For the unstitched (baseline) and stitched panels without tile, a 12.7 mm fragment simulating projectile and a velocity of 465 m/s was used, corresponding to a kinetic energy of 5.8 kJ, while the tiled panels were impacted at a much larger velocity, i.e., 810 m/s, by a larger, 20 mm projectile (17.6 kJ impact energy). Damage size was much smaller and the residual compression strength after ballistic impact was much larger for the processed composites than for the hand laid-up glass–polyester composite. This seems to suggest that the new proposed manufacturing process has higher quality. Processed glass–vinyl ester and glass–epoxy panels with a ceramic tile bonded to the front surface were impacted by a much larger energy projectile. Despite the high impact energy, the tile prevented penetration of the projectile, and the damage pattern was quite uniform through the panel thickness due to the changed stress wave propagation through the panel. Stitching reduced the damage size and increased the residual compression strength of the tiled panels, but not very much.

Nunes et al. [24] pointed out that when the impact velocity approaches the ballistic limit, the impact process becomes very sensitive to initial conditions (e.g. material defects, impact speed or angle), and even small variations may lead to significant differences in the outcome of the test (perforation or not, of the target). Therefore, the results for this condition must be examined with care. Due to their low specific gravity, and high stiffness, hardness, strength and thermal stability, the ceramic-based systems have shown potential for improving upon current standards for ballistic performance, which includes multi-hit capability. During experimental methods, the effect of different target configuration and target mechanical properties on ballistic performance of the material can be observed when struck by various standard bullet or FSP at the different velocities [25]. The experimental approach while ballistic impact test could also help to determine the energy absorbed by the target and transmitted beyond the target based on different parameters while using in body armours [26]. After the test, the impacted projectile could be either perforated the material or trapped inside the target. In the non-perforation situation, the projectile might be either stopped inside the material or bounce back by leaving the trauma indentation at the backing material. This ability of the target which prevents the happening of internal injuries is known as trauma resistance and ballistic tests are mainly carried out according to different standards [27], [28], [29]. The two most common standards are the National Institute of Justice NIJ-standard 0101.06 [16] and Home Office Scientific Development Branch (HOSDB) ballistic body armor standards for UK Police.

A study tried to investigate the effect of thickness and to determine the minimum value to avoid perforation while ballistic impact of aramid (Kevlar®) fabric laminate, subjected to 7.62 mm ammunition, at a speed of 800 m/s, with standard procedure [30]. Based on the result, 96 layers (~50 mm) of aramid fabric thickness was required to capture the bullet, which was much higher than the necessary thickness for stopping 7.62 mm bullet at the specified speeds.

The performance of samples designed by [31], to have penetration resistance, was assessed based on NIJ standard, at test level III. Each sample was placed on a steel frame, 15 m in line with the gun barrel, and subjected by an impact with 7.62 x 51 mm bullet, at a velocity of 847±9.1 m/s, at an angle of 90° to specimen, for one shot, at the center. Based on results, S glass fiber reinforced PBA could be effectively used as strike panel to substitute the conventional ceramic tile and E glass fiber composite. An integration of S glass composite backed by aramid fiber reinforced composite was potentially used as hard ballistic armor providing full protection, based on NIJ standard level III in terms of penetration resistance, lower weight and less bulkiness as compared to E-glass composite.

Many researchers start a project with a preliminary test campaign that include several standard requirements, especially threat, distance to the target, but not necessary all the requirements of the standard. This initial campaign is important in order to establish technology, thickness and shape of the panel. After doing such an investigation and establishing the failure mechanisms, a probability to failure, the engineer could organize the campaign that will meet all the standard demand. The results of such a study for body armors made of fabrics SB1plus (from Teijin) is given in Figure 4 presenting details of the panel (face and back of each layer) for a panel made of 12 layers that bear complete penetration with 9 mm FMJ, at impact velocity of 400±15 m/s. At 8 layers there were some panels with complete penetration and some that arrested the bullet and for a panel with 12 layers all BFS were bellow the admissible one of 22...24 mm. Standards are the subject of continuing research, development and testing, review and modification, as appropriate [16].

Generally, the results of the ballistic tests are evaluated by acceptance or rejecting the tested product, based on specific criteria, included in standards. For instance, for body protection, a vest is accepted if it fulfils the following conditions:

- the projectile is arrested within the panel (partial penetration);
- the backface signature does not overpass a maximum value, given in standard,
- the test is valid only for a certain ammunition and a particular set of fire conditions, this is why fire are done with actual guns or laboratory stands that make the projectile to hit the target under the same characteristics (for instance, same impact velocity, energy, shape and components of the projectile.

For vehicle armors, the conditions may be different, depending on vehicle type, threat, particular requirements for their use etc.

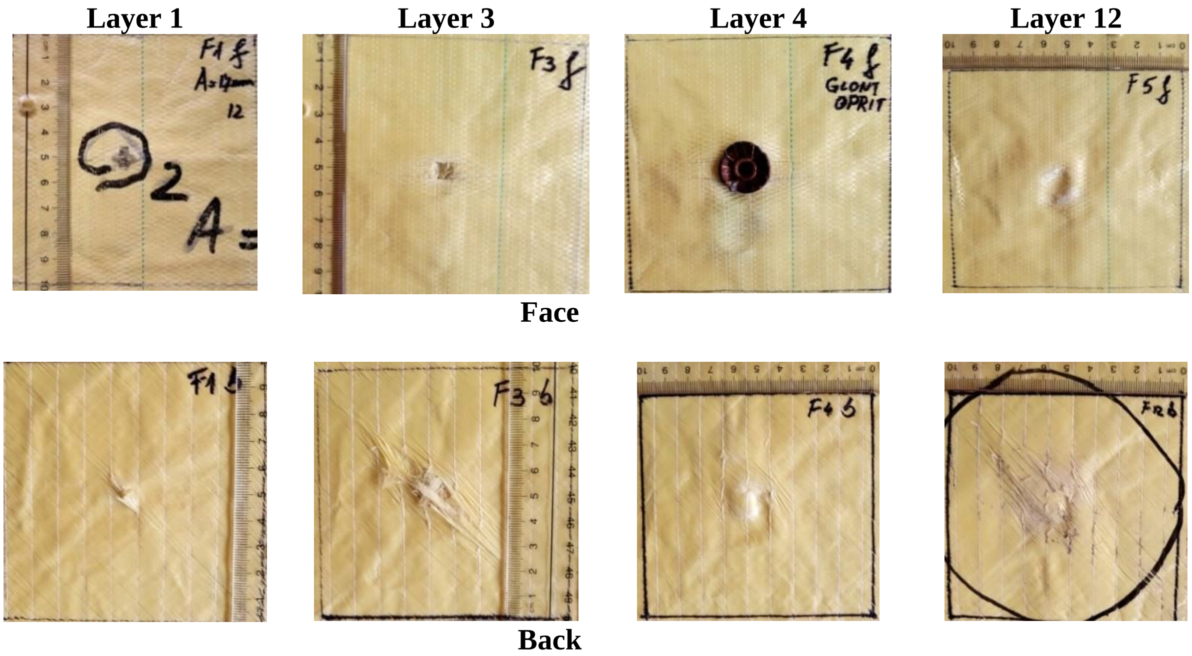


Figure 4. Preliminary tests for panel made of 12 layers of LFT SB1 plus (Teijin) [32].

4. Conclusions

Standards test procedures are usually applied after preliminary tests at laboratory scale, those fulfilling a part of the standard requirements, especially those related to threats (projectile type and its mass and impact velocity). Usually, the technology for manufacturing the samples depend on sample size and thus, the response of the non-standard test could differ when it is compared to that complying with the standard requirements. Also, the actual solution for implementing the ballistic protection could differ, including fixing design, the presence of other components of the system that will be protected (as, for instance, edges and corner for fixing the ballistic protection panels.

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