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Experimental study of the deformation of a ballistic helmet impacted with pistol ammunition

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ABSTRACT

Currently, ballistic helmets are mostly designed to stop fragments from diverse explosive devices. Nowadays, new requirements have emerged for helmets, such as stopping direct impacts from revolver and pistol threats. The probability of these types of impacts on helmet systems is increasing due to the changes in warfare and military operations. Although, it is possible to stop this kind of projectile, there is a lack of studies regarding the possible injuries suffered by the user due to non-perforating impacts.

In this research, a comparison between the results obtained with a clay head form and a head surrogate with force sensors was done to estimate the load force on the skull during an impact. 9 × 19 mm FMJ projectiles were fired against a ballistic helmet to study the indentation and the force generated by the back face deformation against the two different head forms.

1. Introduction

Modern ballistic helmets are typically produced with composite material, based on aramid or ethylene fibres. They are designed to stop fragments from grenades, artillery shells and other explosive devices. This threat is generally simulated during testing using a Fragment Simulating Projectile (FSP) or Right Circular Cylinder (RCC). FSPs and RCCs are defined in a NATO standard [1]. They simulate a fragment ejected from an explosive device. They were developed for testing personal and vehicle ballistic protection with a good repeatability and without the necessity of producing a blast. They are scaled in different calibres in order to represent different threat levels. Generally, the 1.1 g FSP is used for testing personal armour systems, including helmets. It is fired against the helmet at a designated velocity, typically around 600 m/s for modern helmets. They are produced from high-strength rolled steel with a hardness of 30 Rockwell C.

For personal protection, it is not only important to stop the projectile but also to limit the injuries to the user. Even in the case of non-perforating impacts, the user might suffer from severe and possibly lethal injuries due to the propagation of shock waves caused by the impact and/or the dynamic deflection of the back face of the armour system. These injuries have hence been dubbed Behind Armour Blunt Trauma (BABT), or more specifically Behind Helmet Blunt Trauma (BHBT) for helmets impacts. A study performed with cadaveric heads exposed the risk of skull fracture for a user wearing a helmet for a non-penetrating 9 mm projectile [2]; however, it is difficult to find documented cases from the field [3].

This topic has so far not been fully addressed by standards, in part because of the lack of knowledge, leading only to partial testing solutions and the introduction of significant simplifications. For instance, standards use as a reference different types of clay material without any direct link with the human body. Amongst these standards, US ballistic testing standards are the most commonly used. For police body armour, they were implemented by the National Institute of Justice (NIJ), and they became some of the most important references in the field ([4,5]). They assess the BABT using the value of the Back Face Signature (BFS). Upon impact on the armour system, it may deform to accommodate the load produced by the projectile. This deformation - called Back Face Deformation (BFD) – in contact with the backing material, being some type of clay or plasticine, also produces a depression in the latter. This depression in the witness material is called the BFS. The deepest point of the cavity is measured orthogonally from the reference surface. In case of torso protection, the plasticine is used within a flat box. The reference surface is the plane defined by the level of the plasticine before the impact. For the helmet, the plasticine is placed in a head form, so the reference is the plane tangent to the head.

For torso protection, the NIJ standard marks 44 mm as the maximum allowable depth of the BFS [6]. Despite that the value was only

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based on tests with limited number of types of ammunition and armours, the value became a universal value [7], and it is used for any type of protection (soft and hard) against any threat (pistol, rifle and shotgun). The fact that mostly only minor injuries have been reported for incidents with in-service armours shows that this value is apparently quite conservative, although its limits are not exactly known.

Unfortunately for helmets, there is no such a consensus and there are several limit values mentioned in the different standards.

The US Army defined four impact points for helmet testing: the front, back and both sides of the head. They set the maximal BFS value as 16 mm for the lateral and 25.4 mm for the rest of the impact positions on the helmet using Roma Plastilina No 1, following the same approach as used for the body protection. A special head surrogate is used to mount the helmet on during the test. The head surrogate has a cavity filled with plasticine, as explained in the point 2.2.1.

In Europe, there are other standards, using a similar approach such as those established by the German standard agency (Vereinigung der Prüfstellen für angriffshemmende Materialien und Konstruktionen, VPAM) [8] or the Spanish Ministry of Defence [9]. The VPAM standard limits the allowable energy deposit to 25 J with a backing material of Weible Plastilina, whereas the Spanish standard has no specific limits: it is up to the user to specify the values. The Spanish Army limits the indentation in Roma Plastilina No 1 to 20 mm for the helmet in their specifications. Taking these previous examples into account, it is difficult to compare and define a clear criterion [10].

It seems evident that there is a relationship between the BFS and the risk of being injured. Nevertheless, the relationship is very difficult to quantify and depends on several parameters. As a consequence, it cannot be related directly to human injury tad is difficult to use to assess injury risk from BHBT [11]. Nowadays, it has become urgent to clarify this relationship because armies have to face new challenges and threats including pistol and rifle ammunition [12]. It is hence necessary to study how these helmets react and load the head of the user in case of a non-perforating impact. For this research, 9 × 19 mm FMJ projectiles were fired against the current ballistic helmet of the Belgian Army, manufactured by Schuberth Gmbh. The sample studied consisted of used helmets. At the time these helmets were purchased, there were no requirements regarding this type of threat; however this helmet is still in use with several Europeans armies and newer helmets have similar structure and are made of similar materials [13].

The aim of the present study was to measure the indentation of a helmet in the current head surrogate and compare it with the impact force loaded to a second more advanced head surrogate. Two different head surrogates were used; thus, it was not possible to measure both parameters during a single impact. Impacting at the same range of velocities in both surrogates however allows relating both measurements.

2. Description of the experimental setup

In order to estimate the ballistic performance of the considered ballistic helmets, a universal receiver with interchangeable barrel was used to fire the projectiles. The projectile velocity is measured with a double optical basis, DRELLO LS19 mounted on a frame. These light screens are suitable for being used in an indoor firing tunnel. The target is positioned 5 m ahead of the muzzle. The optical bases are positioned in the middle (Fig. 1). The measurement of the speed is corrected to take into account the deceleration of the projectile form the centre of the bases to the impact point [1].

2.1. Helmet

The helmet is an aramid composite helmet (Fig. 2). The inner structure (Fig. 3) consists of several plastic cylinders and a leather strip. It increases the thermal comfort and guarantees the stand-off between the head and the helmet. It also acts as a shock-absorbing layer for blunt

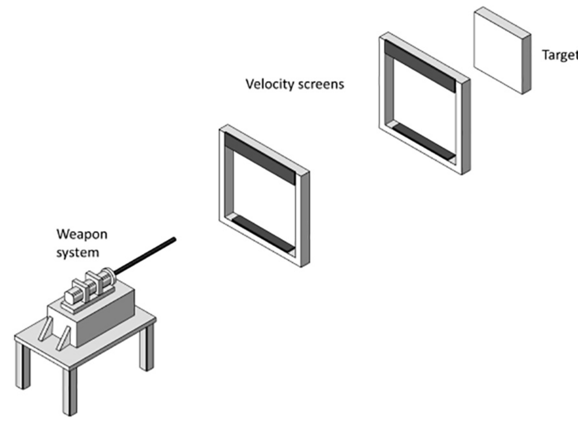

Fig. 1. Ballistic test setup.

Fig. 2. Belgian Army helmet used for the tests.

Fig. 3. Inner structure of the helmet.