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PRACTICAL ASPECTS OF DYNAMIC TESTING OF THE SHOCK ABSORBING MATERIALS INCORPORABLE INTO INDIVIDUAL COMBAT EQUIPMENT

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Abstract *The Traumatic Brain Injury (TBI), a previously neglected issue, became a hot research subject nowadays. Military helmets are currently design to mitigate the shocks that can affect the brain. Therefore an absorbent layer is used in this purpose. The efficiency of such layer is usually assessed through impact lab tests. The working principle of such test is analyzed and discussed.*

Keywords: *TBI, impact test, helmet, shock absorbent*

1. Introduction

The need to equip people who carry out recreational activities with a high degree of danger and of personnel whose responsibilities involve dangerous activities is no longer something new, but a norm of society. Undoubtedly, military norms precede this state of affairs. For reasons that are easy to understand, regardless of the era and the name adopted for the specific protective equipment, head protection has been a priority for those concerned with the subject of survival and protection of bodily integrity. A wide range of such safety helmets are currently marketed on the market. The design of such products starts mainly from the estimated risks and from the protection norms/standards established at national or international level.

In line with the previously presented considerations, the present paper aims to discuss the current subject of Traumatic Brain Injury and the solutions adopted for military helmets in connection with this subject. A special attention is paid to the technical means used to evaluate the effectiveness of such layers of protection.

2. Traumatic Brain Injury

In the last years, medical investigations and military and civilian statistics had revealed a neglected issue in the previous stages of protecting helmets development. Previously the test rules and the testing assessments were focused exclusively on the integrity of the equipment and on the lack of detectable head injuries. Recently the scientific community has become increasingly aware that undetectable injuries, Traumatic Brain Injury (TBI) are a real problem for individuals who have suffered accidents or incidents.

To understand the size of the phenomenon, it is sufficient to analyze the data provided by the Improving TBI Protection Measures and Standards for Combat Helmets from 2011 [1]. It was estimated that approximately 1.5-2 million of Civil TBI cases are recorded annually, with a hospitalization rate of 200 cases per 100,000 people, and about a total number of 56,000 deaths per year, corresponding to a death rate of ~ 20 to 100,000 people. Approximately 50% of TBI cases are caused by car accidents and about 20% are caused by sports accidents. Most TBI cases are not fatal and are classified as mild traumatic brain injuries (MTBI) or contusions. It was also noted an increase in MTBI produced during the practice of leisure sports.

The TBI is also an acute issue for military personnel, fact which is demonstrated by medical treatments [1]: of the approximately 1.4 million soldiers who served in Iraq and Afghanistan by 2007, about 3.6% were injured and approximately 60% of the wounded soldiers have a form of MTBI or TBI. Among the cases of TBI approximately 10000 of wounded soldiers are serious cases. The cost of treatment for each soldier with serious TBI is estimated between 600,000 and $ 5,000,000 per patient throughout his life. This estimates of total spending over 27 billion dollars, without taking into account future cases. And the perspective is gloomy: the current percentages are expected to grow as diagnostic modalities are improving [1].

The assessments of the same specialists have revealed that for these types of injuries military helmets are currently far behind the helmets for recreational/sports activities, such as helmets carried by athletes practicing American football. Also, test methods and standards in force for such equipments are deficient by focus on the behaviour at the ballistic impact (i.e. the admission criterion provided by the NIJ standard 0106.01 for the ballistic helmets is limited to a maximum permissible depth in the ballistic plastilina introduced into standard head surrogate). For this reason, there is a justified concern to improve test methodologies by using samples with pressure sensors and accelerometers and diversifying the types of loads [2].

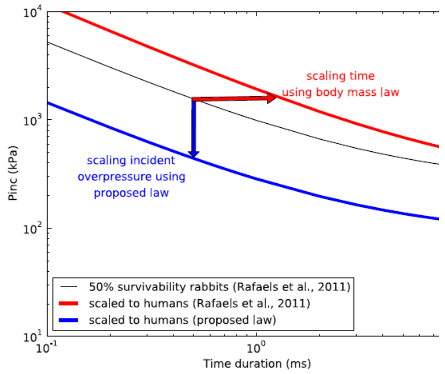

Fig. 2 Human brain injury criterion derived from test data on rabbits [3]

The general opinion of the researchers involved in this is shocked by overpressures occurred within the cranial box or by its impact with the skull. These shocks disrupt the neuronal activity of the brain generating transient or permanent effects in the behaviour of individuals [1]. As regards the limit values over which TBI is expected to manifest, experimental studies have led to laws that link the maximum pressure and pulse duration, Fig. 2 [3].

3. Shock absorbers in military helmets

Of all categories of helmets, military helmets involve the widest range of loads, in terms of duration and intensity, which they have to deal with. Thus, if in industry and in recreational/sports activities helmets are designed to eliminate the risks related to blunt impacts, in the military field the threats related to ballistic impact and shock waves are also considered.

Also, the optimal solution to the TBI issue is not to provide adequate medical treatment, but to reduce the accelerations suffered by the brain in the situation of dynamic or impulsive loads through those protective helmets. For this reason a constructive solution of the protective helmets must incorporates one hard exterior layer, which limits or

Fig. 3 Shock absorbent structures integrated in military helmets [4-5]

eliminates the visible injuries, such as skull fracture in the case of a blunt impact or penetration by the bullet or the ballistic fragment in the case of a ballistic impact, and a deformable inner layer, able to absorb energy and to mitigate the intensity of accelerations. For ergonomics, this inner layer cannot be thick or heavy. The chosen solution must judge these two features, going to an optimal.

As a result of the above considerations, the new generations of military helmets are provided with various constructive solutions incorporating rubber spacers or buffers from polymeric foams. For example, in Fig. 2 is showed the constructive solutions currently used in the family of protection helmets produced by SESTAN-BUSCH [4] in Croatia and the structural composition of Advanced Combat Helmet used by the US Army [5].

Motivated by the goal of improving performance, current global research aims to replace these solutions with other materials, such as polyurea [5] or foams soaked in dilating liquids (non-Newtonian shear thickening liquids) [6- 7].

Another solution proposed by UPB [8] consists in the use of flexible capsules, made of an extremely compressible porous layer, partially soaked with a fluid with special rheological characteristics (visco-plastic fluids, obtained by mixing with nano-particles).

4. Efficiency assessment through impact tests

In general, a material used to attenuate the impact or shocks must yield at the application of a force of low intensity, but also it must be very compressible. The material should dissipate and reflect some of the energy, thus reducing the magnitude of the forces reaching the protected target area (i.e. human head) and limiting these forces below values considered critical. .

Previous studies, related to the attenuation of shock waves and impact, indicate that the process of energy dissipation is closely related to the ability of the material to suffer volumetric deformations [9-13].

Materials that support consistent volumetric strains fall into two distinct categories: (1) elastic-plastic materials, which have a distinct point of yield (linear-plastic-linear compressible solids) and plastic-elastic materials, without such a point (bilinear compressible solids) [14]. Regardless of which category they belong to, such materials have a so-called blocking point. Beyond the blocking point of the material, its volume can be further reduced, but only by significant increases of the pressure to which it is subjected. When the impact or the application of a shock is on a large surface, its dimensions allow the use of the hypothesis according to which the movement of the deformed structure is restricted laterally, the strains appearing only in the direction of application of the load. A special case is the fluid-soaked crushable materials, where material ejections can occur in radial directions [15].

The easiest way to dynamically test such materials is to crush them between a striker and a massive anvil. Both the striker and the anvil have flat end surfaces, Fig. 3 [16].

When pneumatic propulsion systems are used, impact velocities of the order of tens of meters can be reached, respectively strain rates higher than those reached in the tests in which the striker is accelerated by free fall.

The relevant data that can be recorded during such a test are summarized by the evolution of the striker's velocity and the force exerted by the sample tested on the anvil. If the force can be measured with the help of a force transducer, the evolution of the speed is measured with a high speed camera.

Fig. 3 Experimental set-up [16]

Using an image analysis software can be determined the evolution of striker speed. Because the curves thus determined are highly oscillating in nature, due to the method of determination (the method is based on the tracking of groups of pixels), it is necessary to perform additional filtering. After the filtering, both the impact velocity and the return velocity of the striker can be determined. Figure 4 shows velocity variations for a sample made of polymer foam, both raw data and filtered data.

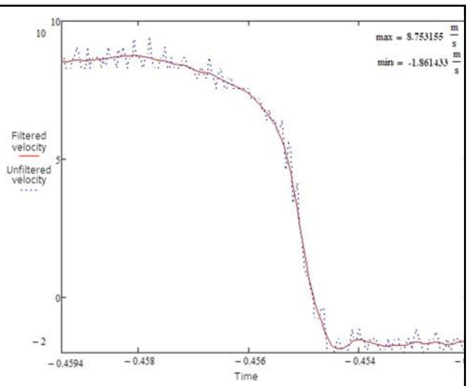

Fig. 4 Evolution of the striker velocity [16]

Using the mass of the striker and the conservation equation of the momentum, the force that acted on the projectile over time is obtained. Fig 5 compares the force determined based on the images (F_{img}), with that determined using the force transducer on the anvil (F_{trad}). It is remarkable both the similarity of the maximum values and of the segment of the curves corresponding to the blocking phase. For this reason the measurement methods are practically validated on each other. The apparent desynchronization of the force oscillations on the plastic strain segment is attributed to the fact that in the initial phases of the impact the sample is practically not in a state of dynamic equilibrium, the plastic waves crossing it from one end to the other at low speed.

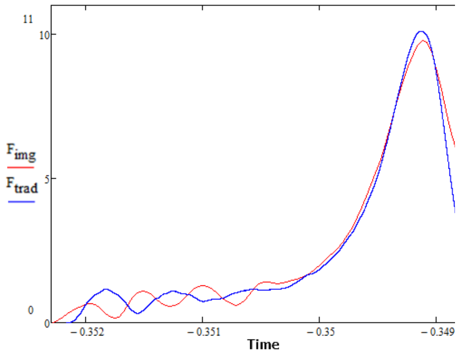

Fig. 5 Image based data vs recorded transducer data [16]

Having the time evolution of the striker velocity, the space travelled by the striker can be calculated. These data, put in connection with the ratio between the value of the force in time and the cross-sectional area of the sample, allow the determination of the stress/volume strain diagram, Fig. 6.

In addition to plotting the stress-volume diagram, the recorded data allowed a more in-depth analysis of the process: the calculation of the absorbed, dissipated or recovered energy. The values of dissipated energy by the tested specimens are calculated as the differences between the kinetic energy of the striker at impact and its kinetic energy resulting from the impact. For example, for one tested sample, the dissipation capacity was around 1 J/cm^3 for a volume reduction of 92.5%. The same property expressed in relation to mass indicates a dissipation capacity of 17.19 J/g [16].

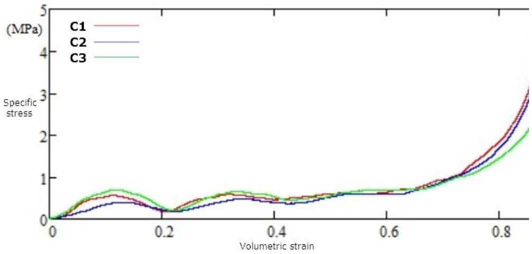

Fig. 6 Specific stress vs volumetric strain [16]

In the case of materials with complex behaviour, such as soaked porous materials, this configuration used for testing allows highlighting of fluid expulsion phenomenon. Also is determined how the presence of fluid ensures the reduction of impact forces. It was shown that in the presence of damping cells with soaked porous materials the impact force is reduced to less than half [15]. In fig. 7 are presented as an example the results of impact tests with high kinetic energies (E = 165J) in 3 conditions: without damping cell, respectively with damping cell with and without a layer of Kevlar sheets. The positive effect of the damping cell is obvious and it is equally clear that the presence of Kevlar sheets did not significantly change this effect.

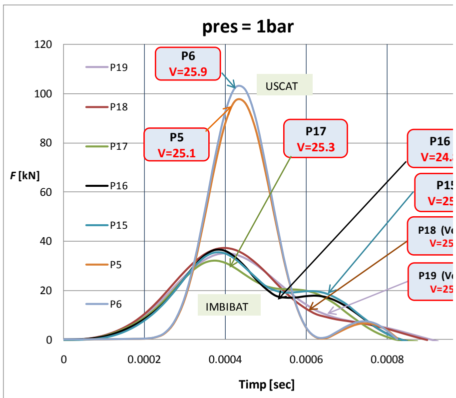

Fig. 7 Effect of damping cell on impact force [15]

5. Conclusions

Based on previous considerations, the following conclusions can be drawn:

- The TBI is a major subject in the field of military personnel protection
- The new helmets must incorporate an crushable layer to avoid TBI occurrence
- The lab impact tests may provide relevant data used in the assessment of the crushable layer efficiency

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