CONSIDERATIONS REGARDING THE NEXT GENERATION OF BALLISTIC PROTECTIVE EQUIPMENT SUCH AS “LIQUID BODY ARMOR”

Luminița-Cristina Alil
aegyssusatm@yahoo.com

Military Technical Academy, Bucharest, Romania

Simona-Maria Badea
smsbadea@yahoo.com

Scientific Research Center for CBRN Defense and Ecology, Bucharest, Romania

Florin Ilie
ilieflorinv@yahoo.com

„Nicolaе Bălcescu” Land Forces Academy, Sibiu, Romania

Abstract
The development of ballistic protective equipment is marked by constant improvement of the performance and the level of protection while reducing the weight of the ballistic protection structures and individual armor. Generally, the protective systems are designed and implemented by the optimum combination of different types of materials, such as ceramics, metals, polymers, fibers and composite materials, in order to meet the specific requirements of the various types of threats. Thus, the ballistic protection is achieved by material layers with specific functions. Considering these aspects, research nowadays focuses on implementing simpler structures in terms of construction, enabling high mobility while keeping the same performance level or even a higher level of protection than previous generations. This article briefly presents some of the basic materials for one of the future solutions, the “liquid body armor”.

Keywords
Body armor, armor systems, shock wave, ballistic protection

1. Introduction
Over time, people have used various materials to protect themselves from wounds in battle or other type of dangerous situations. The first clothes and shields were made of animal skins. With the development of civilization, people began using shields of wood and metal. Metal armor is still associated with heavy medieval knight image. By the 1500s, the advent of firearms made metal armor to become ineffective. The only real protection was offered by
natural stone walls or obstacles (rocks, trees or ditches). Among the first records on the use of light armor is included the use of protective clothing made of natural silk in medieval Japan. This solution proved to be inefficient from a study conducted in the late nineteenth century by Americans.

A second generation of body armor appeared during the Second World War and was made of ballistic nylon. This type of armor was only partially effective because although it provided good protection from shrapnel, it was ineffective against bullets. Once the polyaramid fiber (Kevlar) was discovered in 1970 within the company of DuPont, the manufacturing industry of ballistic protective equipments knew new directions.

Significant advances achieved by research in chemistry in recent decades have resulted, inter alia, in obtaining polymers whose strength exceeds up to ten times that of steel, and ceramics whose hardness is approaching that of diamond [1]. Besides, the development of ballistic protective equipment is marked by the continuous improvement of the performance and the level of protection while reducing the weight of the ballistic protection structures and individual armor.

Generally, the protective systems are designed and implemented by the optimum combination of different types of materials, such as ceramics, metals, polymers, fibers and composite materials, in order to meet the specific requirements of the various types of threats [2]. The choice of materials and geometry, as well as how they are assembled, represent key factors in the design of armor. Each material component serves a specific purpose not only in stopping the projectile kinetic energy or in mitigating the effects of blast shock waves, but also in maintaining the structural integrity of the ballistic protection structure.

Diagram in Figure no. 1 describes the theoretical basic configuration of an armor, which includes both high-density ceramics and porous materials, but also fibers, coatings, polymeric binders and adhesive joints. Complex architecture shown in Figure no. 2 uses several different materials and methods of assembling, so that the ballistic protection function is to be achieved by material layers with specific functions.

Furthermore, the structural configuration of a ballistic protective vest can be schematized as shown in Figure no. 2. A ballistic protective vest has in its structure the following types of materials:

- base material (for example, type 560 Cordura fabric treated to resist fire and covered with waterproof tape);
- lining (e.g. cotton tercot 67 % and polyester 33 % – this cotton and polyester combination is used because cotton has a low resistance to the action of agents);
- ballistic protective material – ballistic package (e.g. 22 layers of Kevlar and a Twaron/ceramic composite plate, which represents an appropriate structure to achieve the level IV of ballistic protection, according to NIJ 0108.01).
- accessories: straps and Velcro tape.
Figure no. 1 Schematic representation of the cross-section of a typical armor tile specifically used for the ballistic protection of a vehicle, which highlights the complexity of the armor architecture, generally speaking. The assembly comprises different types of materials, such as porous and dense ceramics, composite fibers, thermoplastic polymers, and adhesives.

DEA – diethanolamine (this has the role of surfactant/corrosion inhibitor) [3].

Figure no. 2 Ballistic protective vest – layer structure [4].

The behavior of a protection assembly against a specific threat is not, however, the mere sum of its parts responses. Thus, an integrated approach considering experimental and calculation aspects, allowing the variation of the microstructures of materials and, respectively, the dynamic characterization of materials behavior at high speeds, by
themselves and as part of a protective structure, may underlie the development of better protection materials with lower density. Following, we present some potential materials for the realization of future generations of high-performance ballistic protection structures.

2. Generalities

One of the specific threats in theaters is explosion. The effect of an explosion which also represents the true threat for a military is the shock wave that propagates at very high speed. The human body is not homogeneous, it has many components with completely different structures. Some of the tissues are soft, others are more dense (depending on the content of water / liquid). Each organ, due to its physical characteristics, has a certain inertia, which makes the body a group of organs that are in a relative motion to each other, when applying a force in a specific area of the body. In the absence of a protective rigid structure, in case of explosion, the effect of the shock wave may cause pulling of the limbs, due to relative motion between them and trunk. (Figure no. 3).

The simplest model of protective equipment to comply with the above requirements would be represented by a totally rigid suit, but such equipment would eliminate almost all degrees of freedom, while the very definition of the fighter or intervention personnel presumes increased mobility of the wearer. Similarly, we can mention the fact that, currently, most of the body armor for ballistic protection currently in use consists of heavy structures that limit the mobility and slow down deploying.

3. Magnetorheological fluids

Magnetorheological fluids (MR) belong to the class of so-called fluids with controllable behavior (or controled fluids). A MR fluid is composed of dense micronic (range 0.1-10 μm) magnetic particles, held in suspension by a liquid medium (dispersion medium) of lower density, typically an oil (Figure no. 4).
When subjected to a magnetic field, the apparent viscosity of the fluid increases so much that it reaches a point where it behaves like a viscoelastic solid (Figure no. 5). Important to this behavior is that the yield stress of the fluid in the active state can be precisely controlled by varying the intensity of the applied magnetic field. It follows that it is possible to control the ability of the fluid of transmitting force by using an electromagnet.

The magnetorheological fluid applications include: shock absorption systems to earthquakes (for buildings), suspension for vehicles, human prosthesis and, of course, liquid body armor.

4. Rheopectic fluids

There are bodies which, at constant shear rate, show a change in time of the shear stress, and, hence, their apparent viscosity. Moreover, the rheological behavior of some objects also depends on their “shear history”, that is the size and duration of previous loads that were applied to the body. Such bodies have a rheological behavior dependent upon time.

By loading a fluid at constant shear rate, the shear stress may remain constant or may change over time.
The raise of stress in time indicates a rheoplectic behavior and vice versa, the stress lowering in time indicates a thixotropic behavior.

The thixotropic behavior is manifested by a decrease in isothermal viscosity at progressively increasing shear rate as a result of fluid destructuring. The progressive decrease in shear rate determines the restructuring of the fluid. The opposite behavior to the phenomena described is represented by the rheoplectic behavior, also known as the anti-thixotropic behavior [6].

On increasing the shear rate the fluid structures itself and on lowering the shear rate it destructures. The rheoplectic behavior was highlighted on: aqueous suspensions of clay, gypsum, bentonite earths, etc.

Currently, such a technology is tested and optimized in a “Liquid body armor” type structure by a group of researchers from Great Britain (BAE Systems).

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