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Experimental study of hybrid soft ballistic structures

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ABSTRACT

This paper presents studies on perforation and trauma resistance of hybrid soft structures. A selection of hybrid configurations were tested experimentally with a 7.62 × 25 mm Tokarev projectile. Hybrid packages included a wide range of textiles used for personal protection from laminates through plain-woven and multiaxial fabrics to felt. Their effectiveness was evaluated by reference to homogenous packages.

The conducted examination demonstrated that hybrid packages employing stiff anti-trauma liners can reduce backface deformation by about 10% compared to homogenous packages. However, too many stiff layers deteriorates perforation resistance by shortening the distance in which a projectile is arrested. Utilization of felt material has a positive effect on trauma and perforation resistance. Soft layers with substantial thickness decrease impulse force and allow projectiles to be stopped over a longer distance. Hybrid packages with felt material have one major drawback in that they are a few times thicker than the other structures tested. An optimal compromise between ballistic performance and thickness is provided by panels based on unidirectional laminates combined with felt and stiff anti-trauma layers. Coupling of plain woven fabric and unidirectional laminate was found to be less efficient than packages entirely made of unidirectional laminate.

1. Introduction

Textiles produced from high-tenacity fibers such as para-aramid fibers or ultra-high molecular weight polyethylene fibers are widely used in engineering applications due to their lightweight, impact resistance and high energy absorption ability, properties which make them especially useful for the production of soft body armor. There are a number of types of ballistic textiles, but plain-woven fabrics and unidirectional laminates are the most commonly used textiles for bulletproof vest inserts [1]. Plain-woven fabric is the simplest woven structure, in which warp and weft yarns interlace alternately forming a checkerboard pattern. These yarns are a group of interlocked fibers with considerable length and relatively small cross-section. The yarns that run along the length of the fabric are termed as the warp while the yarns that run from selvedge to selvedge are termed the weft. Unidirectional laminates are nonwoven structures composed of unidirectional layered sheets that are mutually rotated and bonded together. Sheets also known as prepregs are produced by a process of pre-impregnation of straight and parallel fibers with the use of resin or rubber. Fibers in unidirectional laminates have different orientations in different layers and the same orientation in a single layer [2].

Soft body armors must meet a number of requirements, some of which are specified in standards (e.g. NIJ Standard-0101.6). According to these standards, the primary task of ballistic inserts is to stop the projectile. The second and equally important issue is to limit deflection of the body armor which can cause non-penetrating injuries to internal organs, referred to as blunt trauma. The ability of ballistic packages to prevent internal injuries is known as trauma resistance, the measure of which is the depth of the indentation in the backing material which supports packages during ballistic tests. Indentation called backface signature (BFS) or backface deformation (BFD) should be less than 44 mm [3]. The function of backing material is performed by oil-based modeling clay (e.g. Roma Plastilina No.1) which preserves its shape after unloading. In addition to the standard requirements, soft armors should be adequately comfortable. Areal density, defined as the mass per unit area [4], and thickness of ballistic inserts are two parameters which are particularly relevant from the perspective of vest functionality. Reducing the values of these parameters is the main objective of current research and development. One way to achieve this target is to combine different textiles in the proper order. It is assumed that hybrid packages formed in this

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manner would possess better ballistic performance than homogenous ones due to the synergy effect.

Ballistic performance of textiles suitable for soft body armors has been widely examined using both experimental and numerical methods [5–17]. However, there are only a few reports on the ballistic behavior of soft hybrid packages, and most of them refer to hybrid systems composed of plain woven fabrics and unidirectional laminated composites. Chen et al. [18] have paid most attention to hybrid packages. They searched for an optimal sequence and ratio of layers in hybrid panels consisting of woven and unidirectional textiles made of ultra-high molecular weight polyethylene fibers. The effect of the order of layers of unidirectional/woven hybrid panels was also investigated by Park et al. [19]. They considered the perforation resistance of hybrid packages against a 5.56 mm fragment-simulating projectile as well as their blunt trauma resistance represented by the backface signature formed during the impact of 0.44 Magnum projectile. Test results of hybrid panels composed of unidirectional laminates and felt material against a 0.44 Magnum projectile were presented by Thomas [20]. He compared the backface signature of hybrid panels with homogenous ones entirely made of unidirectional laminates. Studies on comfort performance of soft body armors equipped with hybrid packages were carried out by Baker et al. [21], who compared comfort of use of woven/unidirectional ballistic panels against woven/unidirectional/felt ballistic panels protecting against a 9 mm FMJ projectile.

The aim of this paper is to investigate the possibility of further reduction of mass and thickness of soft body armors through utilization of hybrid ballistic packages. The study focused on both perforation and trauma resistance of hybrid panels. Their effectiveness was evaluated by comparison against the effectiveness of homogenous packages. A wide range of textiles and hybrid configurations were tested experimentally with 7.62 × 25 mm Tokarev cartridges. Presentation of extensive data collected during ballistic tests is followed by in-depth consideration which aims to identify the mechanisms responsible for the ballistic performance of the studied hybrid packages.

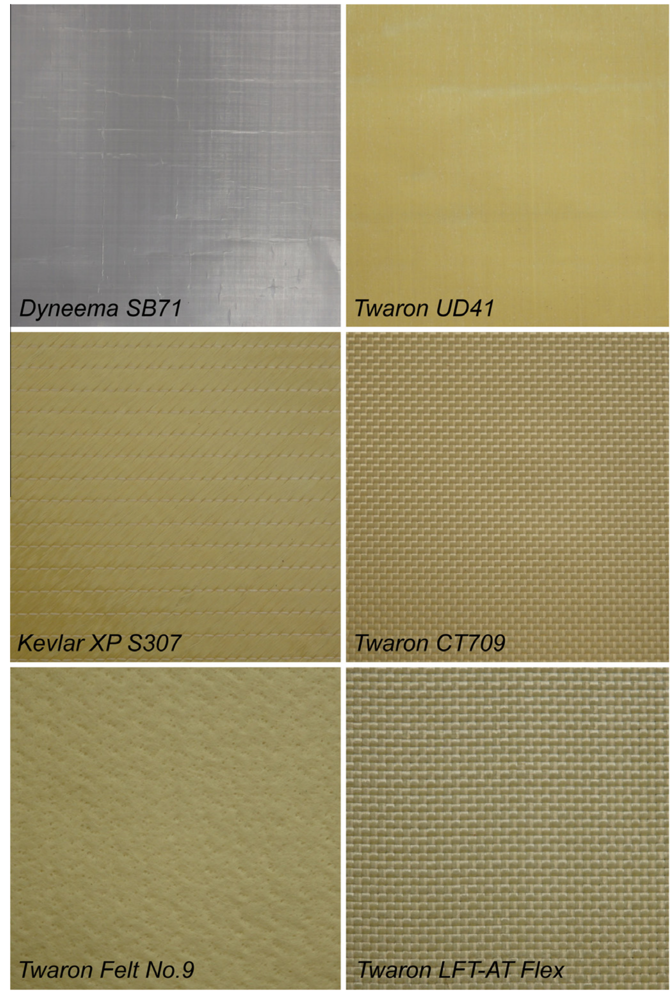

Fig. 1. Samples of investigated textiles.

2. Experimental procedure

2.1. Materials

The six different textiles described below were used to build hybrid panels. Tested packages included a wide range of structures used for personal protection from laminates through plain-woven and multiaxial fabrics to felt. The main application and the construction of the investigated textiles as well as the functional parameters which determine comfort of use such as areal density and thickness are listed in Table 1. Samples of these textiles are presented in Fig. 1.

Dyneema SB71 is a unidirectional laminated composite for soft armor applications. It is made of ultra-high molecular weight polyethylene fibers. Dyneema SB71 consists of six plies arranged in a 0°/90°/0°/90°/0°/90° orientation, consolidated with a rubber based matrix and covered with a protective film [22].

Twaron UD41 is another laminated composite. In contrast to Dyneema SB71 it is composed of four layers of unidirectional para-aramid fibers. The layers impregnated with resin are laminated together with thermoplastic film in a 0°/90°/0°/90° configuration [23].

Twaron CT 709 is plain-woven fabric based on para-aramid fibers. The linear density of its yarns is 930 and 1000dtex in the warp and weft directions, respectively. Its primary application is in vests protecting against soft-core bullets [23].

Kevlar XP S307, referred to as a multiaxial fabric, is a woven/laminated construction that combines attributes of both woven and unidirectional technology. It is composed of two layers of straight parallel yarns in the +45°/−45° direction and loop forming yarns interlaced transversely among each of the layers, wherein each of the layers is coated with high viscosity polymer [24].

Table 1
Selected properties of investigated textiles [22–24].

Textile	Main application	Areal density [g/m^2]	Thickness [mm]	Construction
Dyneema SB71	Bullet resistant vest	190	0.22	Unidirectional laminate
Twaron UD41	Bullet resistant vest	238	0.27	Unidirectional laminate
Twaron CT 709	Bullet resistant vest	200	0.30	Plain woven fabric
Kevlar XP S307	Bullet resistant vest	300	0.29	Multiaxial fabric
Twaron LFT-AT Flex	Anti-trauma liner	490	0.80	Laminate
Twaron Felt No.9	Stab resistant vest	350	2.90	Felt