data regarding the product and equivalent ones, thus enables improving the product as well, as easy identification of competition's weak points.

Bibliography

1. *Dyrektywy Europejskiej 93/42/EWG „Wyroby medyczne"*
2. *PN-EN ISO 14971:2007 „Wyroby medyczne. Zastosowanie zarządzania ryzykiem do wyrobów medycznych"*
3. *PN-EN ISO 22442-1:2008 „Wyroby medyczne wykorzystujące tkanki zwierzęce i ich pochodne -- Część 1: Zastosowanie zarządzania ryzykiem"*
4. *Ballistic Resistance of Personal Body Armor (NIJ Standard—0101.04)*
5. *Solicitation: Body Armor for Law Enforcement and Corrections, http://www.ncjrs.gov/pdffiles1/nij/sl000764.pdf*
6. *NIJ Body Armor Research and Evaluation Results, http://www.ojp.usdoj.gov/bvpbasi/docs/SupplementII_08_12_05.pdf*
7. *NIJ Body Armor Research and Evaluation Results, http://www.ojp.usdoj.gov/newsroom/pressreleases/2007/NIJ07057.htm*
8. *Alim A. Fatah, Richard D. Arcilesi Jr., Kenneth J. Ewing, Charlotte H. Lattin, Michael S. Helinski, NCJ 184449, June 2000, NIJ Guide, Guide for the Selection of Chemical Agent and Toxic Industrial Material Detection Equipment for Emergency First Responders NIJ Guide 100-00, Volume I,*
9. *Selection and Application Guide to Personal Body Armor, NIJ Guide 100-01 (Update to NIJ Guide 100-98), NCJ 189633, November 2001, NIJ Guide, by National Law Enforcement and Corrections Technology Center*
10. *Selection and Application Guide to Police Body Armor, NCJ 169587, October 1998*

On Non-Stationary Energy Absorption when Interacting High-Speed Striker with Textile Armor Materials

Ye. F. Kharchenko, A. F. Yermolenko

Last years, questions of energy absorption when interacting strikers with various ballistic materials are of all greater interest. This interest is based on the attempt to find a scientific approach to the problem of designing optimum armor materials and protection systems on their basis.

Assume a ballistic efficiency as a parameter for evaluating the ability of material (a sample) to absorb kinetic energy of a hitting element falling at effective contact area S_0.

In our experiments, the ballistic efficiency was determined from the expression (1),

$$\beta_t = \frac{\Delta E}{m} \ \text{(J/kg)} \qquad (1)$$

where ΔE is energy absorbed by a barrier, $\Delta E = E_1 - E_2$ and E_2 are the striker kinetic energy values before and after the barrier respectively, m is material weight on the contact site (sample weight).

Taking into account changing kinetic energy of the striker when piercing each layer, it must not be used too many layers to characterize materials under study. At the same time, energy absorption is effected by not only the single layer properties but and the interaction of layers with each other, for example, the frictional interaction which always takes place in the actual armor protection system.

In this connection, we have selected for our experiments a packet of 4 layers of fabrics with surface density from 130 to 240 g/m2 and measuring 20 cm x 20 cm in a plane. Figure 1 presents energy absorption of 4 different types of textile armor materials as a function of striker speed over the range of 250 m/s to 750 m/s.

It is seen that over the studied range of fragment speeds, we deal, in reality, with the energy absorption spec-

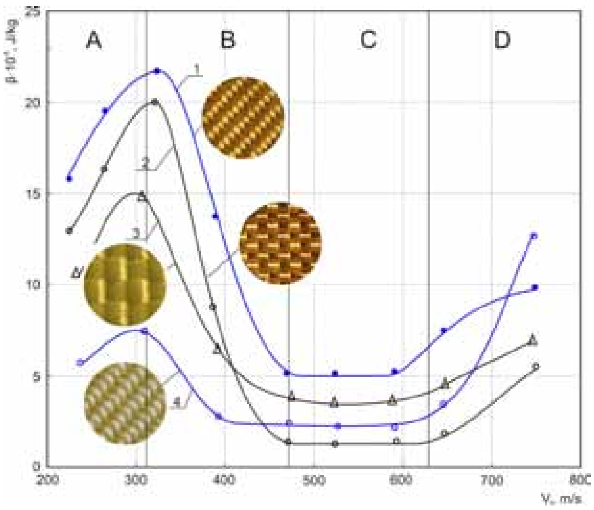


Figure 1. Ballistic efficiency (b) of 4-layer packet of fabrics as a function of fragment speed:
1 - twill fabric of Arus filament, 29 tex;
2 - linen fabric of Arus filament, 58 tex;
3 - linen fabric of Twaron filament, 110 tex;
4 - twill fabric of polyethylene filaments, 40 tex.

trum which is changed almost on a order. The most efficiency of studied materials takes place over the speed range from 250 to 320 m/s. The extremely low energy absorption is typical for the range of 500 to 600 m/s, where only about 10-20 % from the maximum energy absorption level remains.

This is a very negative circumstance because the majority of fragmentation protective systems are planned precisely for this fragment speed range.

As a whole, as we can see in Figure 1, the twill textile armor of Rusar filaments with minimum linear density of 29 tex has the best protective properties at any speed (curve 1).

The decrease of efficiency of armor materials accompanies the increase of linear density of filaments from which the fabric was made (curves 2 & 3). The least energy absorption over the range of 250 to 600 m/s were shown by fabric of polyethylene filaments (curve 4).

It is highly notable that all curves in Figure 1 have a general trend. It witnesses the presence of common failure regularities for studied materials expressed

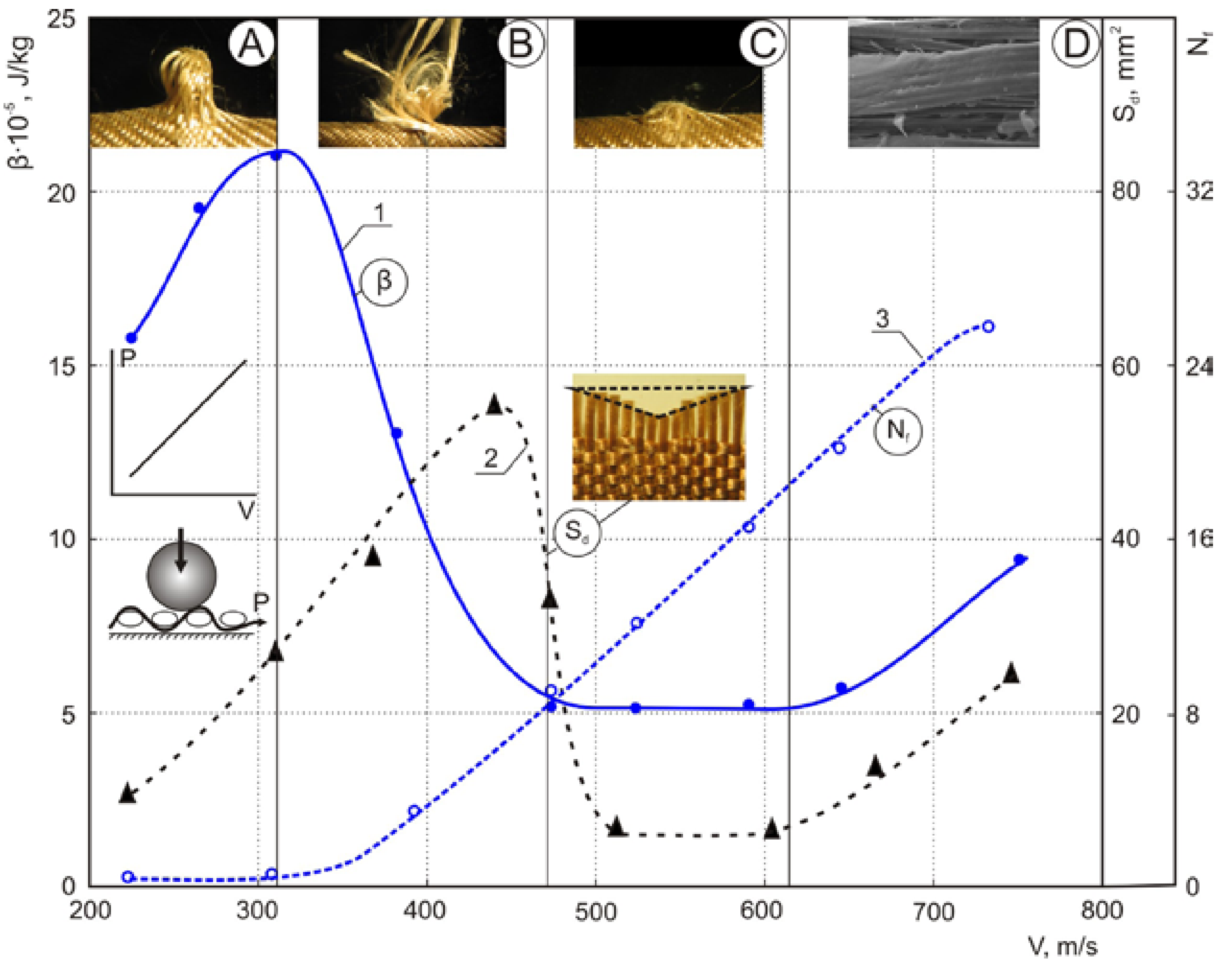
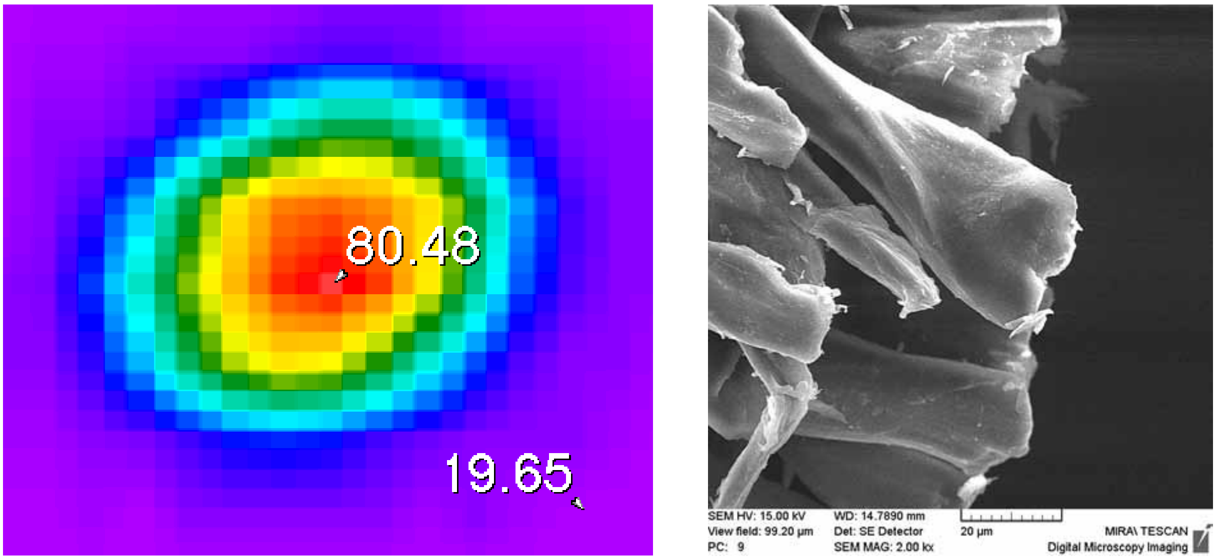


Figure 2. Change of ballistic efficiency of the 29-tex filament twill aramid fabric (1), movement area - filament pulling (2) and broken filament number (3).



a b

Figure 3. Termal imaged pattern in a zone of fragment impact with a speed of about 500 m/s into aramid textile material (a), fiber failure section in impact zone (b).

to a different extent. Apparently, there are 4 basic zones A - D, where one or another tendency is prevalent.

It is very important to understand what precisely has an influence on the material behavior over one or another speed range. Some answers can be received on the basis of data from Figure 2, using the 29-tex Arus filament fabric as an example.

The behavior of materials in zone A, where there is no yet through piercing the material, yields to explanation best of all. Here we have the primary operating of the friction components of interaction process, i.e. pulling filaments out of fabric. It is clear that the lateral pressure on the sample increases with increasing the striker fly-up speed (V), so and the force of pulling a filament out of structure, i.e. work to be performed, also increases.

This takes place until a speed about 320 m/s, beyond which the filaments begin to break (see a photo above). Stage B seems to be the most responsible not only that here there are the most visible changes - energy absorption decreases by 4 times - but and owing to the complex totality of several interaction mechanisms.

Curve 3 witnesses that the number of broken filaments continuously increases, beginning from a speed of 320 to 350 m/s. The trend of curve 2 shows that the filament pulling area in the major part of zone B increases that would have to increase energy absorption, however, parameter b, when approaching to a speed of 470 to 480 m/s, decreases to minimum.

Evidently at these speeds and over, other factors seem to be connected up. Firstly, it is the movement

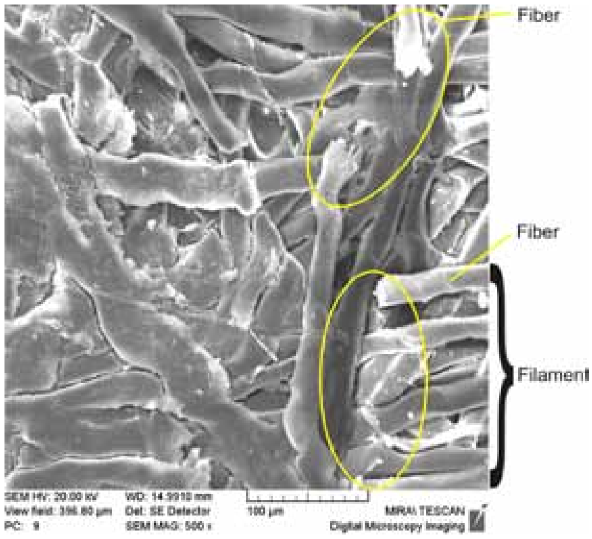


Figure 4. Scanned electronic photograph of fiber failure in filament intersection zones.

of filaments aside, i.e., their displacement perpendicularly to an axis. We showed long ago that the size of opening formed from broken filaments in fabric is by 3-4 times less than a striker diameter. So the unbroken filaments go to the side from the trajectory of fragment or bullet motion.

Secondly, at fragment speeds more than 400 m/s, heat effects also begin to play their negative part. Using the thermal imager, we established that the temperature in the moment of fragment impact against armor material substantially increases (by 60 to 70°C). In consequence of dynamic heat-mechanical action,

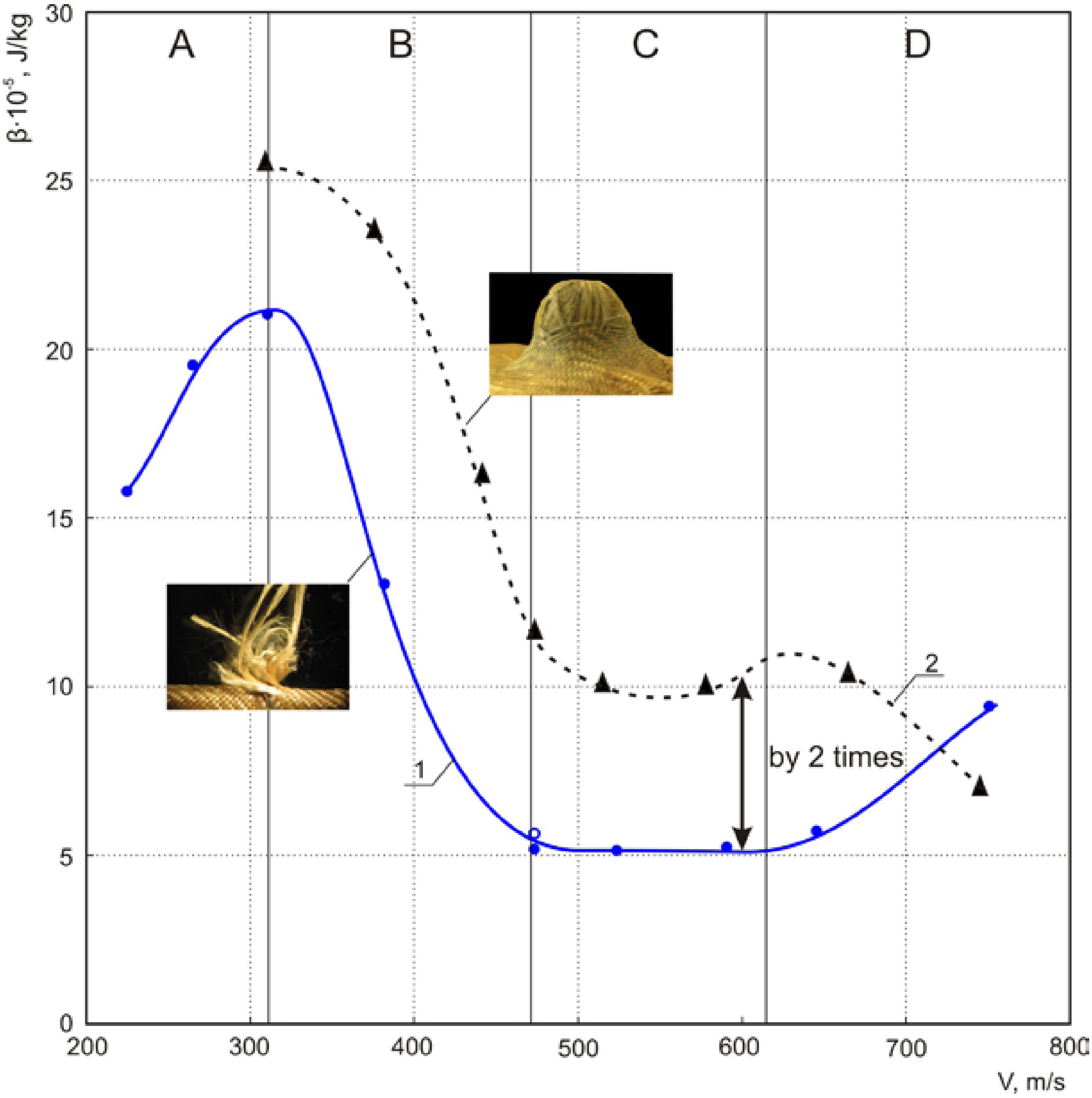


Figure 5. Ballistic efficiency of the 29-tex filament twill aramid fabric (1) and hybrid material based on the same fabric with isotropic aramid material gaskets (2).

fibers in filaments can be broken under considerably lesser stresses. The scanned electronic photographs in Figure 3b confirm a break in the impact zone untypical for fibers.

Apparently because of strong heat-mechanical impact action, the armor material in zone C at speed of 500 to 600 m/s has a minimum fragment penetration resistance - the hole pattern in this zone sharply differs from zones A and B, i.e. pulling and volume break of filaments are absent and the failure zone is localized (see a photograph in Fig.2). Scanned electronic photographs in Figures 3b and 4 witness a peculiar effect of «cutting into two» the fibes in zones of their weave.

One can suppose that if filaments and fibers in textile armor materials are mainly UD-oriented, without bending, as this takes place, for example, in unidirectional structures, the minimum energy absorption areas like zone C will be less.

The ascending branches of curves in area D, where evidently there is an effect of welding the fibers in their parallel lay-up zones, but not «cutting into two», are the indirect confirmation of this (see a photograph in zone D).

In any case, the presence of areas with very low ballistic efficiency leads to that a coefficient of using high potentialities of superstrong aramid and other fibers remains very low and according to our repeated estimations is not more than 0.7. And this is clear since the hitting element flying up to armor protection has a maximally possible speed (frequently 550 to 750 m/s).

The textile material in outer layers keeps only 10-20% from the maximally possible energy absorption (in zone A). And only when the striker speed reaches 300 to 350 m/s, the material, somewhere in the middle of the packet, reaches the ballistic efficiency maximum.

The main and practically important question remains: how to remove the so-called «transparency windows» at the hitting element speeds over 500 m/s?

There are several ways. Firstly, using non-woven UD-type materials and axially stitched structures. Secondly, placing other types of materials that are more effective over the high-speed range and «soften» the first and the most strong impact impulse, in outer (frontal) layers of aramid textile armor.

We succeeded in reducing the ballistic efficiency losses at speeds of 500 to 600 m/s almost by 2 times at the expense of introducing interlayer gaskets from other materials (see Figure 5).

Thirdly, perfecting the textile structure of aramid and polyethylene fibrous materials, including also at the expense of introducing the interfibre polymer additives into them.

Study of Wear Resistance of Aramid Fabrics with Various Textile Structures

Ye. F. Kharchenko, V. A. Aniskovich, D. Yu. Kurmashova

During using armor vests and some other body armors, aramid fabrics included as their compound are subject to multiple abrasion .

Analysis of the state of vests after their long wearing showed that mechanical wear of ballistic fabric, in the main, its outer layers is the main factor of vest ageing.

This work presents the results of studying the influence of the type of weave in ballistic fabric, linear density and filamentarity of aramid thread in the fabric on its wear resistance. The study was carried out for linen- and twill-weave fabrics made of filaments with linear density of 100 tex, 58.8 tex and 29.4 tex. In addition, filaments with linear density of 58.8 tex and 29.4 tex consisted of different number of microfilaments.

The tests were conducted using the DIT-M unit under normal conditions. In these tests, the abrasion of fabric is made along a plane in the process of planetary motion of travellers. The stop of the unit is conducted automatically as soon as the fabric gets a wear-out. The load between an abrasive and fabric was 9.8 N

Table 1. Wear resistance of various ballistic fabrics (abrasive paper as an abrasive)

Sample №	Characteristic of Fabric			Number of Cycles under Loading, N	
	Type of Weave	Linear Density of Filament, tex	Filament	9.8 N	29.4 N
1	Twill	29.4	Standard	371	161
2	Twill	29.4	Microfilament	531	171
3	Linen	58.8	Standard	261	213
4	Linen	58.8	Microfilament	804	440
5	Twill	58.8	Microfilament	351	118
6	Linen	100	Standard	178	102