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

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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

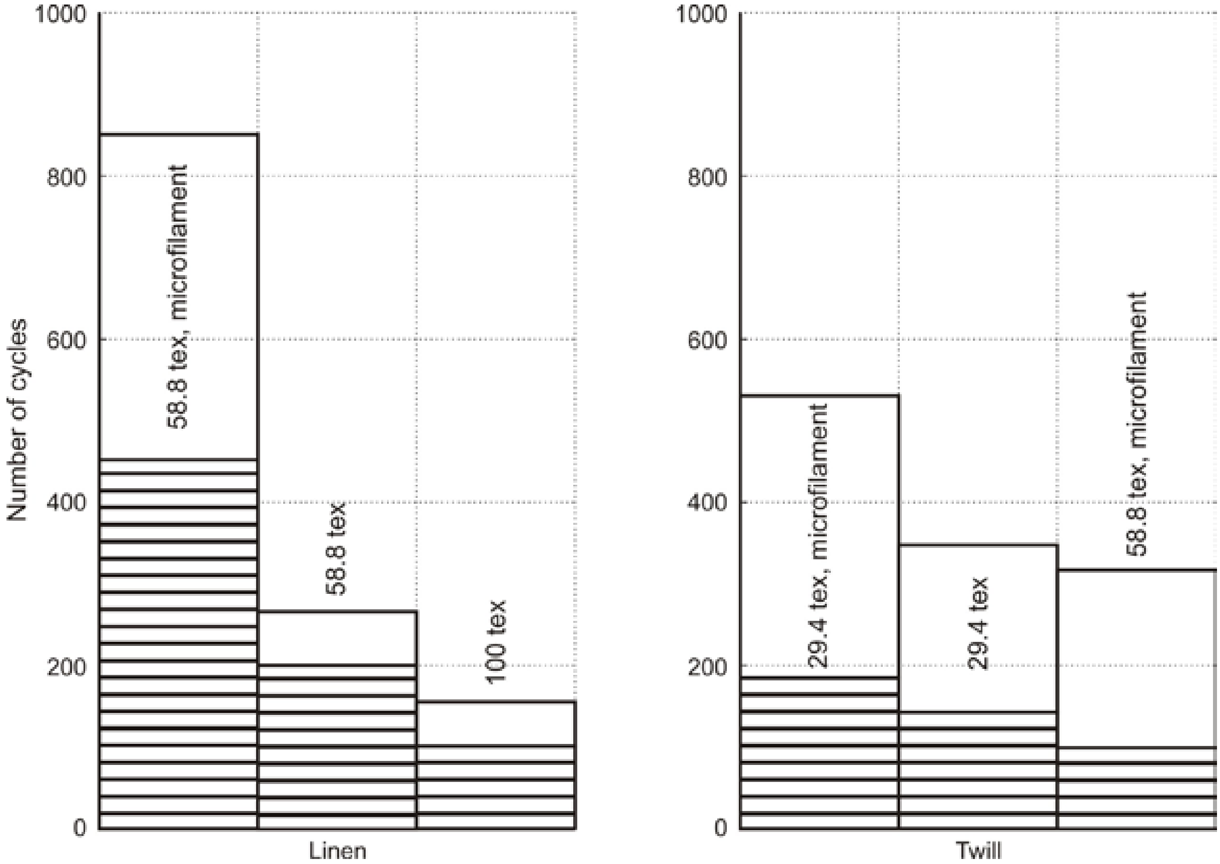

Figure 1. Number of abrasion cycles as a function of fabric textile structure, linear density and thread filamentarity:
- a load between abrasive and fabric of 9.8 N and 29.4 N respectively.

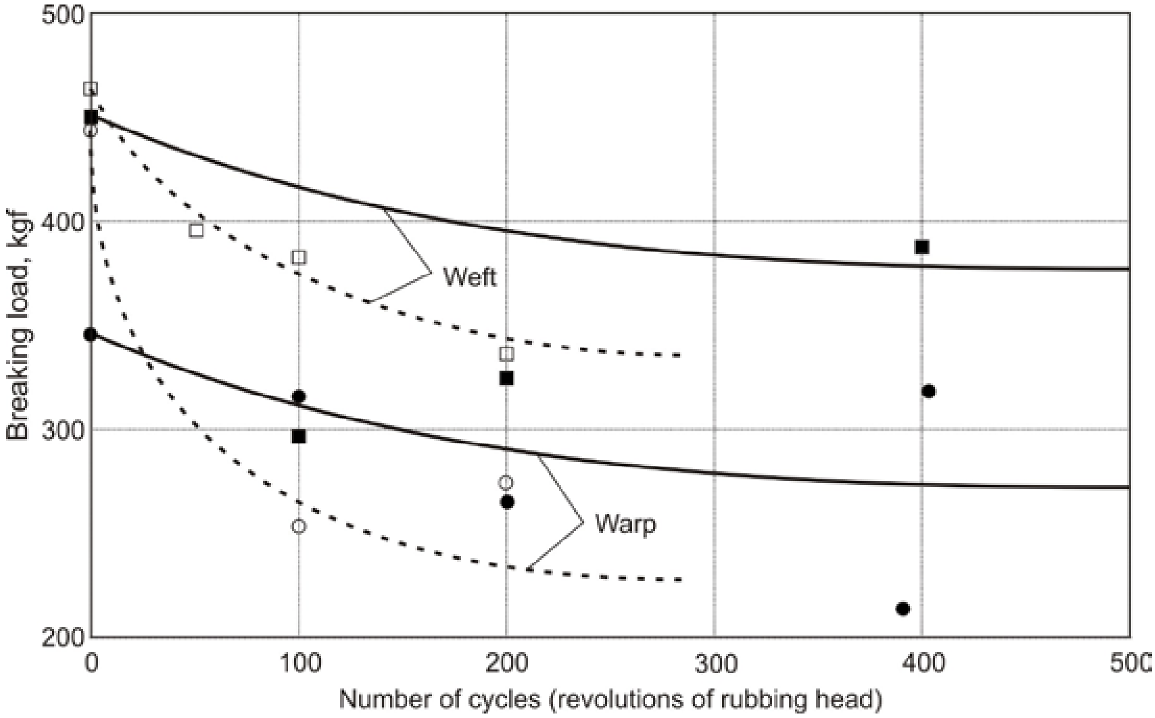

Figure 2. Breaking load along warp and weft as a function of number of abrasion cycles conducted for aramid fabric of filaments with linear density of 29.4 tex:
●, ■, — : microfilament (weight loss of 1.5%);
○, □, - - - : standard filament (weight loss of 0.9%)

or 29.4 N (1 or 3 kgf). A counter shows rotational speed (number of cycles) of the rubbing head to fabric failure (until a hole).

The abrasion of samples was conducted with rotational speed of rubbing heads equal to 200 minutes^{-1}. For each load (9.8 N and 29.4 N), 6 samples of every name of fabric were prepared. The abrasive paper No.600 was used as an abrasive for aramid fabrics.

During abrading, complex filaments are divided into individual filaments with subsequent their failure. Depending on weave, there are different failure mechanisms: for twill weave the structure of separate filaments is seen even after abrasion failure; for linen weave the failed fabric is a "non-weave linen". It is possibly bound up with that the mobility of separate filaments in linen weave is less than in twill one, therefore during abrading in the first case the fabric works, and in second case the filament works. The arithmetic mean of the number of cycles which samples withstand until full failure under given mode of operation is an wear resistance characteristic of fabric. Test results for aramid fabrics with various textile structures are presented in Table 1 and Figure 1.

All woven materials made of microfilaments have a considerable advantage in wear resistance compared with similar fabrics of usual filaments.

To evaluate the influence of abrasion process, that imitates the fabric operation under actual conditions, on strength properties of fabric, the following parameters have been measured:

- breaking load along fabric warp and weft after abrasion depending on number of cycles;
- weight loss depending on number of cycles.

The breaking load was measured for samples with a base of 8.5 cm and a width of 2.5 cm. It is bound up with dimensions of samples to be required for abrasion tests. Results of the study are presented in Fig. 2-4.

For all kinds of fabrics studied, the strength decrease along warp is more significant than along weft. It can be explained by features of textile structure of the fabric: warp filaments are more curved and therefore exposed to abrasion in the first instance.

On the basis of the results obtained, the following conclusions can be made:

1. All woven materials made of microfilaments are more resistant to abrasion than similar fabrics of usual aramid filaments.

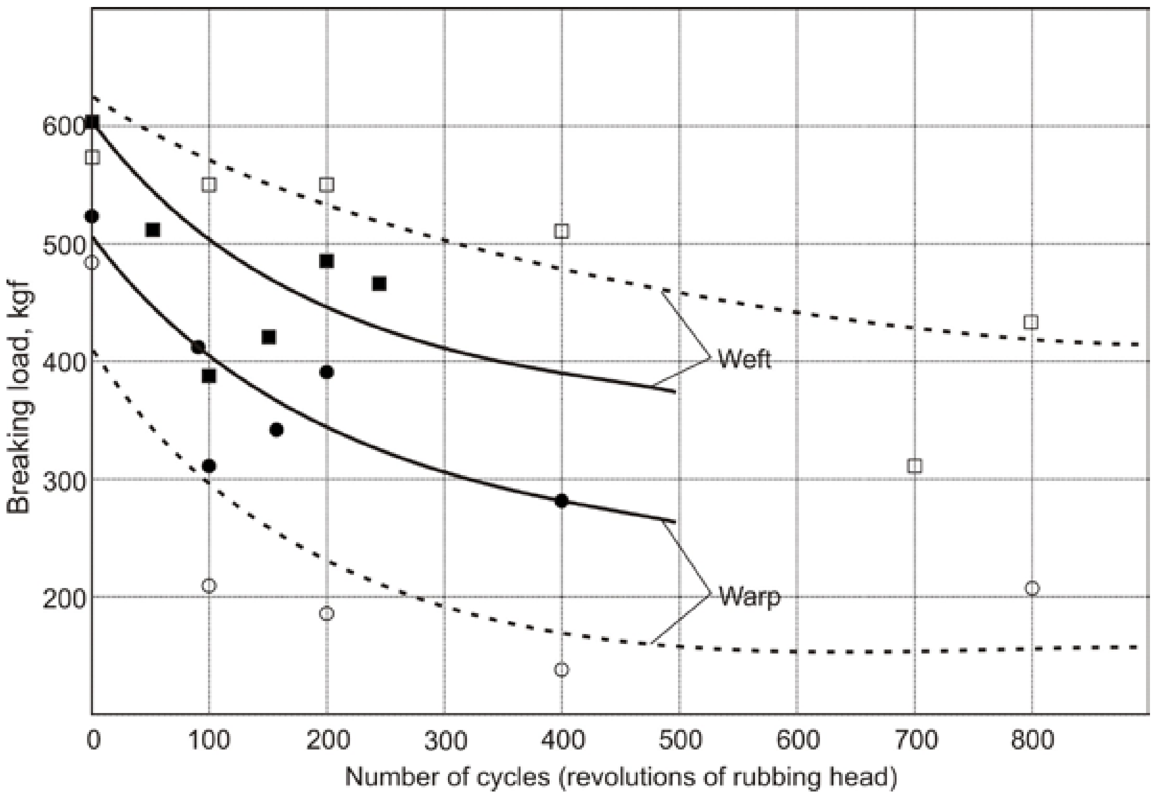

Figure 3. Breaking load along warp and weft as a function of number of abrasion cycles conducted for aramid fabric of microfilaments with linear density of 58.8 tex:
●, ■, — : twill weave (weight loss of 0.9%);
○, □, - - - : linen weave (weight loss of 2.0%)

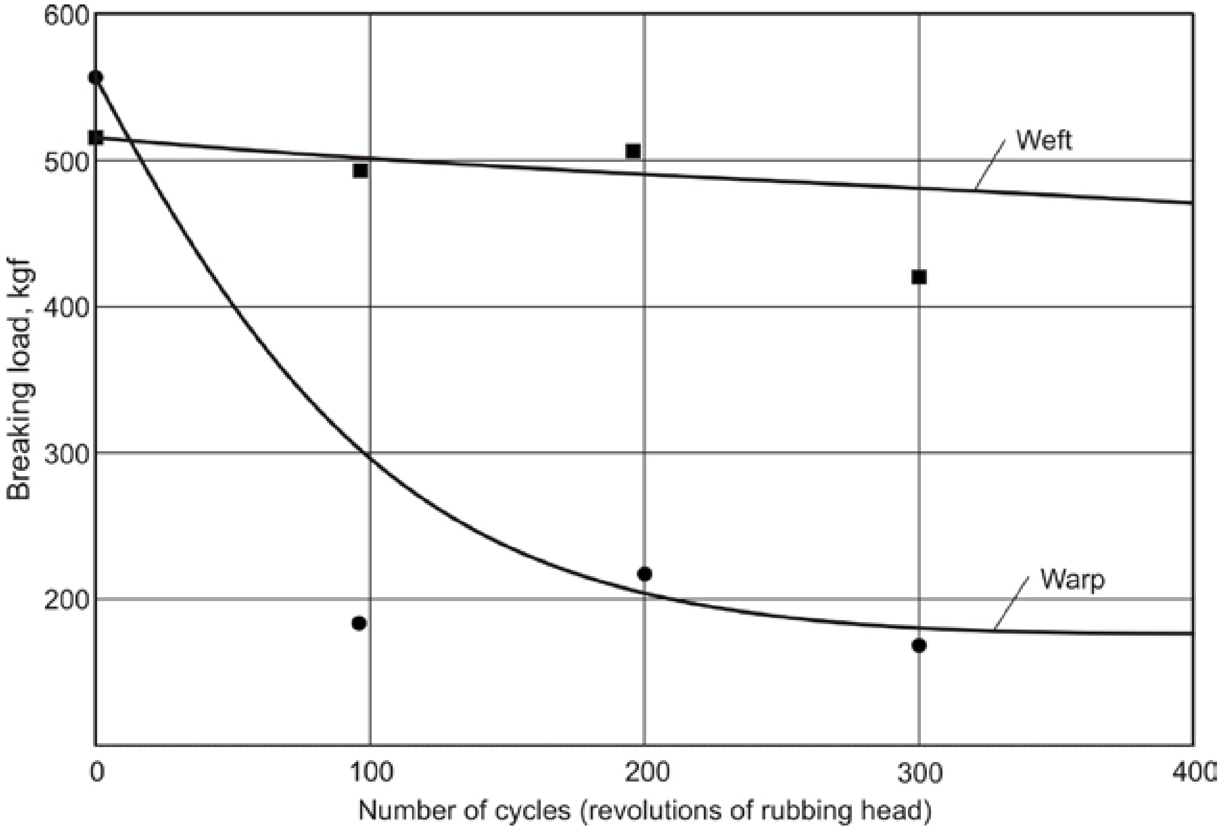

Figure 4. Breaking load along warp and weft as a function of number of abrasion cycles conducted for aramid fabric of filaments with linear density of 100 tex (weight loss of 1.9%).

2. With decreasing linear density of filaments (100 tex, 58.8 tex, 29.4 tex) used for manufacturing the fabric, its wear resistance is increased. Thus, for example, the fabric based on filament with linear density of 100 tex withstands not more than 300 cycles.
3. In twill-weave fabrics, the number of individual filaments in a filament and linear density affect the wear resistance not so substantially as in linen-weave fabrics. It is obvious that here we have an influence of degree of fastening filaments in fabric structure: in twill, the filaments have more freedom (mobility) and therefore are less subject to traumatizing (can deviate from the rubbing head).
4. For linen-weave fabrics of usual filaments, the influence of load value on wearability is slight compared with twill-weave fabrics.
5. Among fabrics studied, the linen-weave fabric of microfilament with linear density of 58.8 tex has the most wear resistance.
6. For all kinds of fabrics studied, the strength decrease is more significant along warp than along weft. It can be explained by features of textile processing the filament (warp filaments are more curved and therefore subject to abrasion in the first instance). It is possible, this feature would be taken into account when designing soft armor systems.