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Abrasion Resistance of High Performance Fabrics

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1. Introduction

The second half of the 20th century was marked by the widespread use of textile materials in a variety of non-textile areas - from the application of fibre composites, high structural materials, a variety of materials and products used in industry, vehicles (cars, boats, planes, spaceships), professional sports, agriculture, road building and construction, protection of people and animals, environment protection, to medicine. Such textile materials are referred to as Technical Textiles, and are manufactured mostly of the fibres with some specific properties, such as high-tech fibres that under the environmental conditions retain their physical characteristics for a longer time, characterized by their high quality. These new generations of high-quality textile materials, manufactured employing most advanced technological processes, offered the road to making fabrics characterized by enhanced physical and mechanical properties and resistance to different impacts in use, while at the same time retaining their textile properties, such as colour fastness, dimensional stability, strength, good resistance to abrasion, etc. These materials, in the form of clothing, textile cartridges for shoes or any other end-use product, offer the retention of good looks, and thus extended usage. However, when it comes to satisfying the needs of soldiers, policemen, mountaineers and many other specific users, whose life depends on good abrasion resistance of textile materials they use, high performance acquires completely different meaning.

High performance materials are no longer a mystery; it is just a matter of time when the next generation of better and smarter fabrics will appear. As in everyday life, people like to be surrounded with textile materials that retain their original properties for a long time, together with high wear resistance under the conditions of use, i.e. high resistance to abrasion. It is necessary to choose the best method and appropriate procedures to test them, as well as the manners of expressing test results. This may be a good starting point for the development of new methods and test procedures, as well as an impulse for the construction of appropriate measurement equipment.

Today, there are several different types of apparatuses for testing abrasion resistance. They have evolved over time to include different kinds of loading conditions and materials, in order to be truer and closer to real conditions. Their results are not mutually comparable and often opposing results have been reported using different instruments. Lately, resistance to wear has been most common tested by Martindale, while the processes of circular wear with the tangential direction by Schopper have been mostly abandoned.

However, testing abrasion resistance by Schopper has its advantages and disadvantages. The use of SiC paper provides intensive wear at lower number of cycles and tangential contact sample with the abrading material. When using the Martindale method, the sample moves according to the Lissajous figure, standard wool fabric being abraded over the entire surface and this certainly contributes to getting reliable results.

This method is ideal for everyday fabrics, but when it comes to the fabrics in the high performance fabrics group, the method can be modified, which we discussed before [Somogyi et al. 2008].

Why is this important? It is well known that a textile material with high resistance to abrasion, such as Cordura®, can stand 100 thousand rubs by Martindale without a mass loss or specimen breakdown. Obviously, this kind of material will abrade a woven wool fabric, and not the other way around. Thus, the question arises whether the determination of Cordura® abrasion resistance, or some other the similar high performance fabric, using the Martindale methods, is suitable or the methods should be modified in order to obtain significant results?

In addition to the modification of Martindale in the manner described before [Somogyi et al. 2008], some modifications of standard methods of testing abrasion resistance by Martindale are also possible, all of them aiming at obtaining significant results. The Department of Materials, Fibres and Textile Testing, the Faculty of Textile Technology, University of Zagreb, has been involved in testing high quality fabrics intended for military and police use for some time. A number of high performance fabrics have been investigated and the need to determine wet abrasion resistance showed to be one of the key requirements throughout the investigation.

Fabrics intended for military and police uniforms are exposed to a number of physical and chemical agents in the course of regular use, rain and moisture being most frequently encountered. This means that, apart from testing dry abrasion resistance, as required by current standard, standard should be complemented by including testing wet abrasion.

Such a method for determining abrasion resistance is particularly suitable for damage detection, as damaged textile materials show more pronounced reduction in strength in wet state. The advantage of the modification is that the testing proposed can be done using the same methods, procedures and equipment as with dry materials. Similar to the above, permeability of air and resistance to water with good resistance to abrasion are very important for high performance fabrics used by mountain climbers, soldiers, policemen, firemen, etc. The Martindale method can again be ideally modified to suit the purpose; using the same apparatus, procedure and slightly modified methods it offers proper insight into the influence of wear on water or air permeability. Additional knowledge on the impact of testing abrasion resistance, as related to air permeability and water resistance, will be acquired in this way as well.

In general, the development of the materials today is not followed by the adequate development in testing methods and testing equipment. Numerous testing laboratories are in problems when testing high-performance fabrics. The authors wish to demonstrate the necessity to develop methods and equipment that would be able to follow the development of contemporary high-performance fabrics.

1.1 Abrasion resistance

For a long time it was considered that the tests of wear resistance i.e. abrasion resistance of textiles was a procedure providing an assessment of product durability i.e. its suitability for the intended purpose. However, over time, research has shown that it is not always so, but this does not mean the procedure has lost any of its importance. This is confirmed by the development of measuring techniques over the years, aimed to get the truer results, closer to reality. Eventually it has become clear that it is not even theoretically possible to construct a machine for measuring fabric wear generally, and systems should be improved for measuring wear of fibres, yarns and fabrics for specific loadings and for each type of textiles.

Abrasion occurs with textiles (test bodies) running relatively to some means of resistance, and is caused by friction, resulting in textile material wear. Investigations in real time can only deal with textiles and/or abrading agents, simultaneously or separately. The process of wear i.e. abrasion can proceed for some time with no visible damage. The term "to abrade" is used for this procedure. If the process is carried out to visible damage or failure of the material, the appearance of holes in the fabrics, then the expression "specimen breakdown" is used [Čunko R. 1989].

Resistance to abrasion is evaluated measuring the following values:

- loss of mass that occurs after a particular procedure of tear,
- the loss of material strength after the tear,
- the increase in air permeability after the tear in the fabric,
- the increase of light bandwidth after the tear in the fabric,
- the reduction of thickness in tear and
- the appearance of the worn surface (number of loops, thickening, lumps, etc.) [Čunko R. 1989].

The wear of textiles, abrasion, and hence the results of the tests, are affected by numerous factors related to the textile material, the environment in which the tests are conducted and testing conditions. Factors concerned with textile material are:

- fibre type,
- fibre properties,
- yarn twist,
- fabric structure and
- surface characteristics (hairiness, smooth, finishing, etc.).

The size of testing area is of key importance together with humidity and temperature, meaning that testing should be performed in the standard atmosphere for testing. The most important factors regarding the procedure of performing tests are:

- abrasion type,
- abradant type,
- pressure,
- speed,
- tension,
- the direction of abrasion,
- test tube tension,
- test tube carrier types,
- the duration of wear and
- the removal of the dust arising from textile materials [Čunko R. 1989; Saville B.P. 1999].

The impact factor of this group of factors is particularly high. It should be noted that the conditions of carrying out tests employing different methods differ significantly. It is therefore impossible to compare test results obtained by different methods, as well as the results obtained in any particular procedure, if the test conditions were not equal. Therefore, the results of testing relative wear are mostly descriptive, although they are of a significant general importance.

In practice, the most precisely tested aspect of fabric abrasion resistance, in assessing product performance in use, is its durability, since in most cases testing deals with clothing exposed to wear during use, or with fabrics designed for bed linen, furniture, technical textiles and others abraded under similar conditions. A range of test procedures and related equipment has been developed, mainly classified according to the method of performing the tests, the manner of staring and wearing the body of the sample, and the method of wear. In practice, most commonly used methods is circular blade wear, whether on a permanent contact throughout the test area, or in contact with certain parts of the surface during the procedure, with no preferential direction of the tear.

2. Experimental

2.1 Tested samples

High performance fabrics for different end-uses – military (sample no. 1, 2 and 3) and police (sample no. 4 and 5) were used.

Samples no. 1, 4 and 5 had a polyester membrane. It was a closed hydrophilic polyester membrane with pores that could not be penetrated by liquid water, but water molecules could be transported from the inside to outwards, employing adequate physical and chemical processes. The advantage of using such membranes is that they can be completely recycled. This type of sample is known as laminated textiles.

The sample no. 2 was classified as a super durable polyamide fabric. The sample no. 3 was made from super durable polyamide yarns. Some basic characteristic of the textile were defined according to the standards, as listed in Tab. 1, before modifying abrasion resistance according to the Martindale method.

Before sampling, test specimens were exposed to the standard atmosphere for 24 hours, in accordance with ISO 12947-3 and the modified method, free from tension, on a smooth horizontal surface. The standard temperate atmosphere for conditioning and testing textiles was used, e.g. the temperature of (20 ± 2) °C and the relative humidity of (65 ± 4) %, in accordance with ISO 139.

Testing parameters	Test method	Sample				
		1	2	3	4	5
Raw material content: -face -membrane -back	NN 41/2010 HRN ISO 1833: 2003	PES PES PES	PA	Cotton/PA	PES PES PES	PES PES PES
Mass per unit area [gm-2]	HRN ISO 3801:2003	226.2	382.7	225.1	193.8	279.4
Thickness [mm]	HRN EN ISO 5084:2003	0.48	0.61	0.40	0.34	0.99
Breaking force [N] - warp - weft	HRN EN ISO 13934-1: 2008	1286 980	3537 3163	1119 829	1294 1181	816 619
Breaking elongation [%] - warp - weft	HRN EN ISO 13934-1: 2008	30.22 44.68	38.77 44.56	27.48 17.35	/ /	38.2 22.2
Purpose		army			police	

Table 1. Characterisation of the used samples

2.2 Abrasion resistance

Abrasion resistance of high performance fabrics by the Martindale method was done in accordance with the HRN EN ISO 12947-1: 2008, Textiles – Determination of the abrasion resistance of fabrics by the Martindale method, Part 1: Martindale abrasion testing apparatus, applicable for the testing of:

- woven and knitted fabrics,
- pile textiles having pile height of up to 2 mm and
- nonwovens.

The standard defines the requirements for the test apparatus according to Martindale and the auxiliary materials in order to determine the resistance of textile fabrics to wear. Martindale tester consists of the apparatus and accessories (Fig. 1). The equipment is easy to operate, but requires additional time to prepare the samples and perform other preparation tasks.

Fig. 1. Martindale abrasion testing apparatus

Martindale abrasion testing apparatus is designed to give a controlled amount of abrasion between fabric surfaces at comparatively low pressures in continuously changing directions.

ISO 12947 consist of the following parts under the general title - Textiles – Determination of the abrasion resistance of fabrics by the Martindale method:

- Part 1: Martindale abrasion testing apparatus,
- Part 2: Determination of specimen breakdown,
- Part 3: Determination of mass loss,
- Part 4: Assessment of appearance change [HRN EN ISO 12947-1:2008].

Abrasion resistance of high performance fabrics was tested according to the HRN EN ISO 12 947–3: Textiles – Determination of the abrasion resistance of fabrics by the Martindale method – Part 3: Determination of mass loss.

Specimen mass loss was determined for predetermined number of rubs. In our case, mass loss was determined at the following number of rubs: 1000, 5000, 25 000, 50 000 and 100 000. Mass loss was determined for each test, to the nearest 1 mg from the difference between test specimen mass before testing and the mass after testing.

Abrasion resistance of high performance fabrics by the Martindale method was first determined strictly in accordance with the ISO 12 947-3, and then the method was modified in two different ways:

1. determining abrasion resistance in wet state, and
2. determining abrasion resistance with separately prepared samples and wool abradant fabric for later determination of permeability (water and air).

Abrasion resistance of 5 different high performance fabrics was determined by the Martindale method. Modifications were carried out on the Martindale abrasion testing apparatus regarding different ways and conditions from the standard method. In both methods, mass loss (gravimetrically) and abraded surface appearance (microscopically) were determined. Microscopic examination was performed by reflected light using the universal microscope Dino-lite, with the magnification 60x, suitable for conventional laboratory control. Water and air permeability were provided according to the ISO standards too.

Modifications of the Martindale method were very important, especially the modification for the work in wet state, which was to serve as a basis for the determination of relative mass loss in wet state (f_w).

Relative mass loss in wet state could be determined after determining high performance fabric abrasion resistance in dry and wet state. We considered it highly important and calculated it using the equation (f_w):

$$f_w = \frac{m_{wet}}{m_{dry}} \cdot 100 \ [\%] \qquad (1)$$

As far as we knew, there has been no way devised to calculate relative wet mass loss (f_w) for so far. In this respect, the obtained knowledge could be a good and reliable basis for the improvements in abrasion resistance testing.

2.2.1 Abrasion resistance in accordance with the standard

Determination of abrasion resistance of high performance fabrics was done in accordance with the ISO 12947-3 as described above.

The Martindale abrasion tester uses a circular specimen, 38 mm in a diameter, cut by the appropriate cutter to a defined load, and rubs it against an abrasive medium (wool abradant fabric) in a translational movement, tracing a Lissajous figure, as shown in Fig. 2 [HRN EN ISO 12947-1:2008]. Lissajous figure is a motion resultant from two simple harmonic motions at right angles to one another.

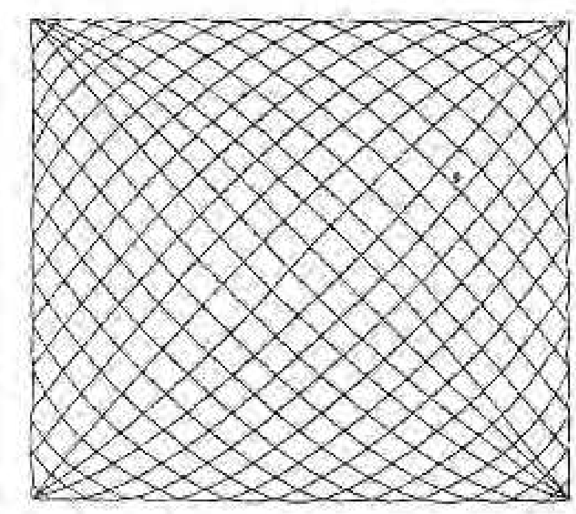


Fig. 2. Lissajous figure [HRN EN ISO 12947-1:2008]

The specimen was mounted in the holder with a circle of standard foam. The standard foam was a polyetherurethane foam material used as underlay for the test specimen, with the mass per unit area lower than 500 g/m^2. The foam was 38 mm in diameter, placed between the test specimen and the specimen holder insert.

Woven wool felt was placed on the abrading table and wool abradant fabric on the felt. They were pressed with a weight of the mass of (2.5 ± 0.5) kg and the diameter of (120 ± 10) mm and the ring was clamped with a clamping mechanism [HRN EN ISO 12947-3:2008].

Before determining abrasion resistance of high performance fabrics, Lissajous figure was checked for each work station by the method described in the annex A (ISO 12947-1).

The mass of the specimen holder and adequate loading piece was (795 ± 7) g, and the nominal pressure of 12 kPa (fabrics for technical use) was used, depending on the purpose of the high performance fabrics tested.

The specimens were subjected to abrasive wear for a predetermined number of rubs:

- 1000,
- 5000,
- 25 000,
- 50 000 and
- 100 000.

The mass of each conditioned test specimen was determined to the nearest 1 mg. Dry mass loss was determined according to the HRN EN ISO 12947-3, Textiles -- Determination of the abrasion resistance of fabrics by the Martindale method -- Part 3: Determination of mass loss.

2.2.2 Abrasion resistance in wet state

Abrasion resistance of high performance fabrics was determined in accordance with the ISO 12947-3, but not in all details. Before determining abrasion resistance of high performance fabrics, Lissajous figure was checked for each work station by the method described in the Annex A (ISO 12947-1), the same as when determining it in dry state (HRN EN ISO 12947-3:2008).

Specimens were first cut with the same cutter as the foam and then placed in Petri dish. Distilled water with a softening agent was in the Petri dish. The specimens spent 5 minutes there, prior to every 5000 rubs (Fig. 3). After that, the specimens were mounted in the specimen holders, with a circle of standard foam, as described in the standard (ISO 12947-3) and in 2.2.1.

Fig. 3. Samples during wetting

Woven wool felts, wool abradant fabric and foam were also placed in the Petri dish, together with distilled water and a softening agent, prior to every 5000 rubs (Fig. 4).

Fig. 4. Auxiliary materials during wetting

After 5 minutes, woven wool felts, wool abradant fabric and foam were placed on cellulose wadding, in order to remove excess liquid.

Woven felts were then placed on the abrading table, protected with a transparent film. Wool abradant fabrics were placed on them and pressed with the weight of the mass described in 2.2.1. (Fig. 5).

Fig. 5. Abrading table with a transparent film before clamping the ring

The specimens were subjected to abrasive wear for a predetermined number of rubs, the same as in determining abrasion resistance, in accordance with the standard:

- 1000,
- 5000,
- 25 000,
- 50 000 and
- 100 000.

The mass of each conditioned test specimen was determined to the nearest 1 mg, before and after wetting. Mass loss in wet state was determined according to the HRN EN ISO 12947-3. Relative mass loss in wet state (f_w) was also determined.

Martindale abrasion tester for the determination of abrasion resistance in wet state was prepared as shown in Fig. 6.

Fig. 6. Martindale abrasion tester prepared for wet abrasion

2.2.3 Abrasion resistance and permeability

Abrasion resistance was determined using previously prepared samples and wool abradant fabric, for the purpose of determining air permeability and water resistance. The procedure partly followed the requirements of the ISO 12947-3. The chief reason for the modification of the Martindale method was again to obtain a sample with the diameter adequate to determine air permeability and water resistance.

The specimen was placed on a woven wool plate, instead of wool abradant fabrics. They were pressed with the weight of the mass of (2.5 ± 0.5) kg and diameter of (120 ± 10) mm in clamping the ring with a clamping mechanism, in the same manner as for dry abrasion resistance.

Wool abradant fabric was mounted in the specimen holder (instead of the specimen) with a circle of standard foam. The mass of the specimen holder and appropriate loading piece was (795 ± 7) g, with the nominal pressure of 12 kPa (fabrics for technical use), used depending on the purpose of the high performance fabrics tested.

The specimens were subjected to abrasive wear for a predetermined number of rubs (the same as for dry and wet abrasion testing):

- 1000,
- 5000,
- 25 000,
- 50 000 and
- 100 000.

The mass of each conditioned test specimen was determined to the nearest 1 mg. Dry mass loss for the sample (abrasive) and wool abradant fabric (as a sample) were determined according to the *HRN EN ISO 12947-3, Textiles -- Determination of the abrasion resistance of fabrics by the Martindale method -- Part 3: Determination of mass loss.*

2.3 Determining air permeability

The permeability of the samples to air, after abrasion, was determined in accordance with the *HRN EN ISO 9237:2003*, Textiles -- Determination of the permeability of fabrics to air (ISO 9237:1995; EN ISO 9237:1995).

The test samples were conditioned prior to testing in standard atmosphere for testing. Standard permeability here meant the rate of air flow passing perpendicularly through a given area of fabric. It was measured at a given pressure difference across the fabric test area over a given time period.

This study complied with the recommended test conditions, meaning test surface area was 20 cm^2 and pressure drop 200 Pa (for technical textiles). For some samples, for which we kept standard notes on pressure, an alternative pressure drop of 50 Pa or 500 Pa was used.

Arithmetic mean of the individual readings and the coefficient of variation were calculated. Air permeability, R, was expressed in millimetres per second, and was calculated using the following equation [HRN EN ISO 9237:2003]:

$$R= \frac{q_v}{A} \cdot 167 \quad (2)$$

where
q_v is the arithmetic mean air flow rate (l/min),
A is the area of the fabric tested (cm^2) and
167 is the conversion factor from cubic decimetres (or litres) per minute per square centimetre to millimetres per second.

2.4 Determining water permeability

Water permeability was determined in accordance with the HRN EN 20811:2003, Textile fabrics -- Determination of resistance to water penetration -- Hydrostatic pressure test (ISO 811:1981; EN 20811:1992).

The hydrostatic pressure test method measured the resistance of the fabric to the penetration of water under hydrostatic pressure [HRN EN 20811:2003]. The test material was subjected to steadily increasing water pressure on the face, until water penetrated to the opposite face in three separate locations. These were identified as first, second and third water droplet. The pressure at which water penetrated the material was recorded in millibars, where the higher millibar value meant higher material resistance to water penetration. Millibars were transformed to Pascals for easier monitoring of the results.

3. Results and discussion

3.1 Results of abrasion resistance in accordance with the standard

After implementing the described method, the abraded samples were analyzed for mass loss and abraded surface, as shown in Tab. 2.

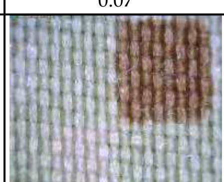
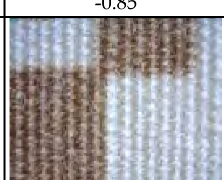
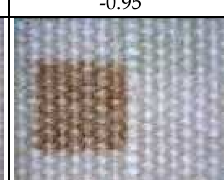
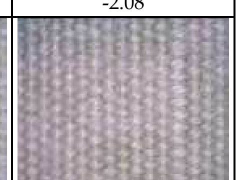
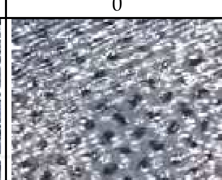
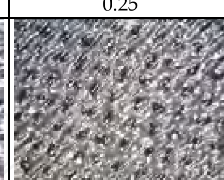
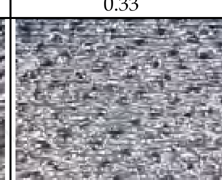
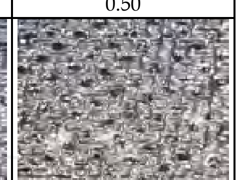
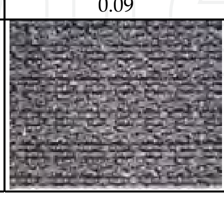
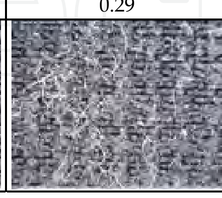
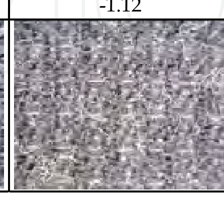
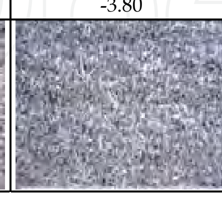
Table 2 shows that the samples no. 1 and 5 had a high loss of mass, in correlation with surface appearance. This is even more noticeable for the sample no. 5. At the beginning of testing (1000 rubs), the surface was uniform, with no protruding hairs of fibres, and at the end (100 000 rubs) the face of the fabric was smooth but not abraded as “conventional” fabrics; the result that could be seen is a membrane with smooth face.

The sample no. 1 was abraded too, but this was not as obvious from surface appearance as was from the results of mass loss. However, compared with the results of "conventional" fabric wear, this mass loss and the mass loss of the sample 5 were negligible (Tab. 4).

Sample no. 4 had visually distinct larger pore openings after 100 000 rubs and little mass loss, but both of these parameters were not significant.

The rest of the samples, especially the sample no. 2 and 3 did not exhibit any significant mass loss or change in surface appearance. Thus was expected, as the sample no. 2 was classified as a super durable polyamide fabric and no. 3 was made from durable polyamide yarns.

This determination of dry abrasion resistance in accordance with the standard showed that the samples such as no. 2, 3 and 4 exhibited little, practically negligible mass loss and change in surface appearance, so the method could not be considered suitable for the purpose. Why? Out experience indicates we could wear the samples for much more rubs (i.e. 500 000 or even more) and still surface appearance change and mass loss would be negligible. Such samples require a different test, either in terms of apparatus or the method itself. However, since the method according to Martindale is so widespread, there is no need to invent a new method, when this one could be easily modified. The additional advantage is retaining the advantage of wearing the fabric by the Lissajous figure motion, while obtaining results comparable to those obtained in actual use.

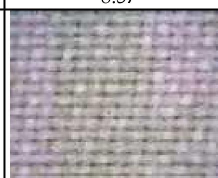
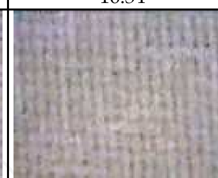
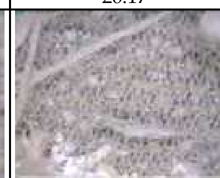
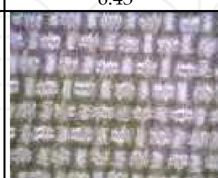
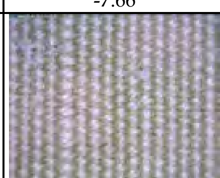
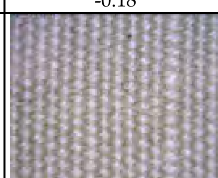
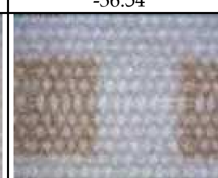
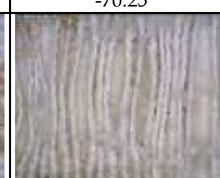
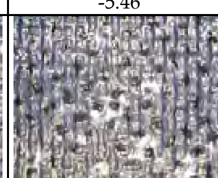
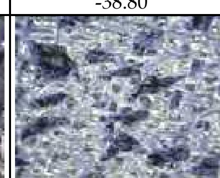
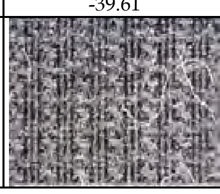
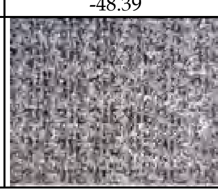
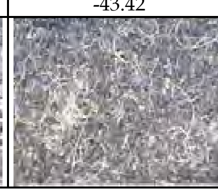
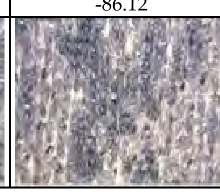
Sample /Testing parameters		1000 rubs	5000 rubs	25 000 rubs	50 000 rubs	100 000 rubs
1	Δm [%]	0.07	-0.18	-0.85	-4.61	-9.48
	Surface appearance					
2	Δm [%]	-0.23	0.36	1.09	1.20	1.04
	Surface appearance					
3	Δm [%]	-0.85	-0.81	-0.95	-0.93	-2.08
	Surface appearance					
4	Δm [%]	0.13	0	0.25	0.33	0.50
	Surface appearance					
5	Δm [%]	0.09	0.29	-1.12	-3.80	-15.11
	Surface appearance					

Δm minus (-) means mass loss, while plus (+) means mass increase.

Table 2. The results of mass loss after abrasion in dry state

3.2 Results of abrasion resistance in wet state

After employing the described method, the abraded samples were analyzed for mass loss and abraded surface as shown in Tab. 3.

Sample / Testing parameters		1000 rubs	5000 rubs	25 000 rubs	50 000 rubs	100 000 rubs
1	Δm [%]	-13.89	-8.57	-46.63	-16.34	-26.17
	Surface appearance					
2	Δm [%]	-1.02	6.43	-21.76	-2.67	-26.49
	Surface appearance					
3	Δm [%]	-7.66	-0.18	-45.19	-36.54	-70.25
	Surface appearance					
4	Δm [%]	-16.63	-21.79	-34.09	-5.46	-38.80
	Surface appearance					
5	Δm [%]	-39.61	-48.39	-80.62	-43.42	-86.12
	Surface appearance					

Δm minus (-) means mass loss and plus (+) means mass increase

Table 3. The results of mass loss after abrasion in wet state

Table 3 showed that testing with the modified Martindale method in wet state was more rigorous. All the tested samples exhibited significant mass loss in the range from 1000 to 100 000 rubs.

Such behaviour was exhibited even by the sample no. 2, which was classified as a super durable polyamide fabric and no. 3, made from durable polyamide yarns. Small remains of a wool abradant fabric were found on the surface of the sample no. 2, i.e. between the warp and weft threads. The sample no. 3 had only warp threads after 100 000 rubs, while weft threads were broken.

The sample no. 1 had fully abraded face and the membrane could be seen at 100 000 rubs.

Pores did not exist anymore on the face of the sample no. 4, after 100 000 rubs. They were smoothened out to the membrane and the back of the sample.

Surface appearance of the sample no. 5, after 100 000 rubs, showed abraded face of the fabric as well as abraded membrane, so the back of the fabric could be seen.

Based on the results obtained for mass loss and surface appearance, it could be concluded that intensive wear occurred in wet state. This also showed that, when compared with dry testing, this method was much more significant, and therefore more suitable for testing fabrics intended for military and police use, particularly as the simulated conditions of wear at work were most often in wet state.

Testing performed clearly pointed to the need for testing high performance fabrics in wet state, since the changes in dry state were negligible. This is especially true when the fabrics were designed to protect human body under conditions other than ideal i.e. in everyday use.

The investigations of this type should be conducted for high performance fabrics only, because most "conventional" fabrics cannot withstand more than 5000 cycles of abrasion in wet state, as shown in Tab. 4.

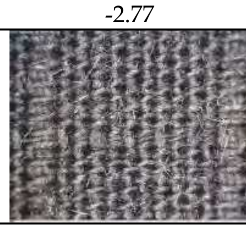
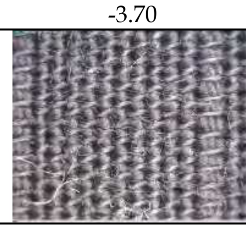
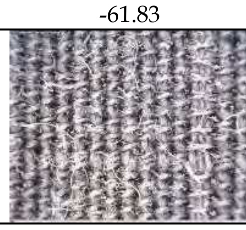
Testing parameters /Sample	"Conventional" fabric for protective clothing	
Rubs	1000	5000
Δm [%]	-2.77	-3.70
Dry surface appearance		
Δm [%]	-61.83	-37.94
Wet surface appearance		

Table 4. The results of mass loss on "conventional" fabrics after abrasion in wet state

Relative mass loss in wet state was calculated in accordance with the equation no. 1. This type of test could be particularly interesting on the materials made from natural cellulose. Generally, they exhibit a greater loss of mass in the wet than in the dry samples. However, this investigation was concerned with synthetic fibres, and the results shown in Table 5 deal with them.

Sample	f_w [%]				
	1000 rubs	5000 rubs	25 000 rubs	50 000 rubs	100 000 rubs
1	24.9	13.2	81.1	18.2	0.5
2	1.2	7.4	29.5	2.7	36.8
3	14.9	35.5	102.8	55.6	168.3
4	20.4	31.5	54.4	5.8	63.5
5	164.0	251.2	453.5	72.3	511.9

Table 5. Relative mass loss in wet state

The sample no. 3 was a mixture of natural cellulose and polyamide fibres and exhibited a significant mass loss in wet state. However, comparing these results with the sample no. 5, we could see that the polyester sample had a higher mass loss.

Even the sample no. 4 exhibited a relatively high mass loss, as did the samples no. 3 and 5, while the mass loss for the sample no. 2 was slightly smaller.

The measurements on the sample no. 2 showed that super durable polyamide fabrics did not show superior wear resistance in the wet state, as it did in the dry state (Tab. 6).

These results confirmed the thesis that higher wear occurred in the wet than in dry state, for all the samples, regardless of the raw material composition. This is of high importance, proving this method could be generally applied.

Anyhow, the potential of the modified method could be further expanded and investigated, before considering the update of any other method or changing the standard.

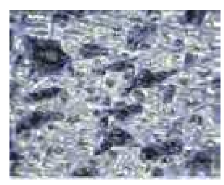
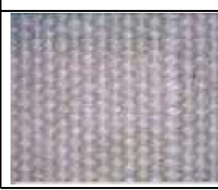
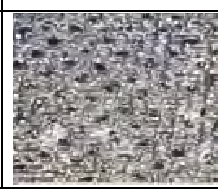
Sample /rubs	Wet surface appearance				
	1	2	3	4	5
100 000 rubs					
	Dry surface appearance				
	1	2	3	4	5
					

Table 6. Final comparison of surface appearance for wet and dry abraded high performance samples at 100 000 rubs

3.3 The results for the impact of abrasion resistance on air permeability and water resistance

After applying the prescribed methods, the abraded samples were analyzed to determine air permeability and water resistance. The results are presented in Tab. 7.

According to the results presented in Tab. 7 it can be concluded that this method is not as rigorous as the previous one.

The investigated samples of high performance fabrics retained their original properties. This suggested insufficient modification of the testing method employed. Specifically, wool abradant fabric was insufficient, i.e. too small (in the sample holder) to produce any significant result. Surface appearance of the samples in Tab. 7 confirmed this.

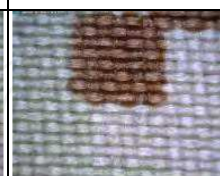
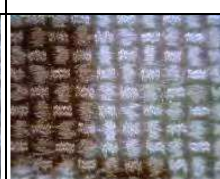
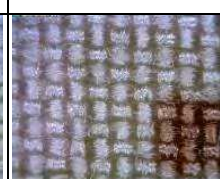
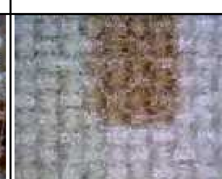
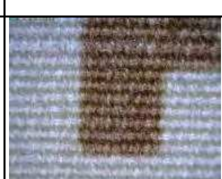
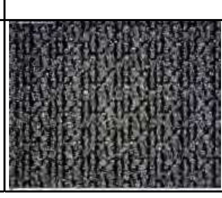
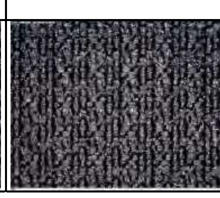
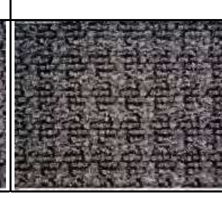
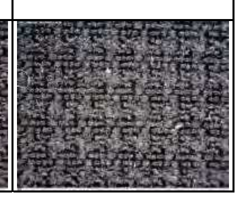
Sample / Testing parameters		1000 rubs	5000 rubs	25 000 rubs	50 000 rubs	100 000 rubs
1	Air permeability [mm/s]	3.2	3.8	4.3	3.5	2.4
	Water penetration [Pa]	> 100 000	> 100 000	> 100 000	> 100 000	> 100 000
	Surface appearance					
2	Air permeability [mm/s]	10.1	9.8	8.4	8.7	8.6
	Water penetration [Pa]	5 000	5 000	10 000	20 000	20 000
	Surface appearance					
3	Air permeability [mm/s]	27.6	25.7	25.7	25.7	24.5
	Water penetration [Pa]	0	0	0	0	0
	Surface appearance					
4	Air permeability [mm/s]	impermeable	impermeable	impermeable	impermeable	impermeable
	Water penetration [Pa]	20 000	2 500	5 000	5 000	5 000
	Surface appearance					
5	Air permeability [mm/s]	impermeable	impermeable	impermeable	impermeable	impermeable
	Water penetration [Pa]	> 100 000	> 100 000	> 100 000	> 100 000	> 100 000
	Surface appearance					

Table 7. The results of air permeability and water resistance after wear test

To achieve significant results, sandpaper or some other agent more active on the surface of the test sample should be used instead of wool fabric. The samples tested showed excellent water resistance and good air permeability characteristics. These results were confirmed by the appearance of the surface. Visual inspection using Dino-lite system showed no difference between the samples at 1000 rubs and the samples at 100 000 rubs.

4. Conclusion

The modifications of the standard Martindale method used to determine fabric abrasion resistance may result in knowledge of high performance material properties. The investigations presented offer scientific and practical contributions to the modification of abrasion resistance testing methods for high performance fabrics.

Original modifications have been carried out in this way and textile technology is offered a new and uncharted territory. Analysing mass loss and appearance of the abraded fabric surface it can be concluded that the standardized method for abrasion characterisation by Martindale is not suitable for high performance fabrics.

The results obtained indicate a more appropriate way of testing the resistance of high performance fabrics to abrasion, using the modified Martindale method in wet state, as presented in this chapter.

The tests were conducted on five commercially available textile products. These tests will contribute to the development of new methods of testing abrasion resistance of high performance fabrics.

As far as the authors know, the relative mass loss in wet state (f_w) has not been calculated so far. The knowledge obtained by the investigation presented can be a good and reliable basis for improving abrasion resistance tests in wet state.

The method according to Martindale is in widespread use and this method (or methods) can be easily modified for the above purpose. In this way, the advantage of wearing by the Lissajous figure will be retained, while, on the other hand, the results obtained will be quite near to those obtained in actual use of the fabrics.

5. Acknowledgment

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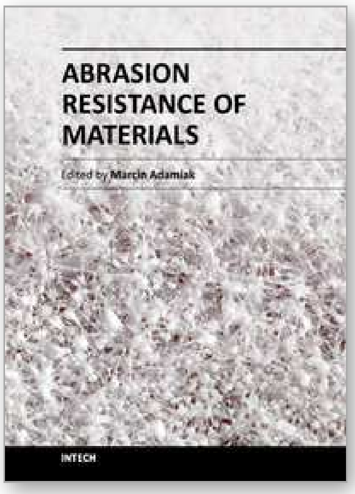

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