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Abrasion resistance of textiles: Gaining insight into the damaging mechanisms of different test procedures

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Abstract

Three established test methods employed for evaluating the abrasion or wear resistance of textile materials were compared to gain deeper insight into the specific damaging mechanisms to better understand a possible comparability of the results of the different tests. The knowledge of these mechanisms is necessary for a systematic development of finishing agents improving the wear resistance of textiles. Martindale, Schopper, and Einlehner tests were used to analyze two different fabrics made of natural (cotton) or synthetic (polyethylene terephthalate) fibers, respectively. Samples were investigated by digital microscopy and scanning electron microscopy to visualize the damage. Damage symptoms are compared and discussed with respect to differences in the damaging mechanisms.

Keywords

Abrasion resistance, wear resistance, Martindale test, Einlehner test, Schopper test, damage mechanism

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Introduction

The wear resistance of textiles is of importance for clothing, furniture as well as for technical textiles. Wear or abrasion might initially "only" influence the appearance, but eventually might lead to the destruction of the textile product. Therefore, wear or abrasion resistance has been the focus of numerous investigations.[1–8] Especially for fabrics woven or knitted from staple fiber yarns, the pilling behavior is a problem. In the case of wool fabrics, a rubbing strain will yield a certain felting of the product. The three-dimensional structure of the fabrics might exhibit a displacement and/or pull-out of fibers or complete fiber bundles. Abrasive stress can also result in complete destruction, which means a tearing of the yarn, no matter if it is a filament or staple fiber yarn. Especially from filament yarns based on synthetic fibers, there will be an abrasive material removal yielding an increasing weakening of the fibers and finally a complete rub-through or rupture, respectively. The complete textile's structure and stability will be destroyed as a constant mechanical stress during the test will abrade and rupture more and more fibers (or yarns).

Apart from the pure mechanical damage of the fiber, the influence on certain properties could be a predominant problem. Abrading a fluorocarbon finishing from the surface would lower the repellence for liquids. The crock fastness is a typical problem of, for example, blue denim since

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Table 1. Different wear or abrasion test methods with relevance for testing textiles.

Abrasive		Method	Norm
Textile	Standard wool fabric	Martindale test	ISO 12947-1:1998 ASTM D4966-98
	Cotton fabric, plain weave	Wyzenbeek test	ASTM D4157
Mineral abrading medium	Emery paper	Schopper abrasion tester	DIN 53863, Part 2 GME Standard 60345 GMW Standard 328 3
	Abrasive wheel	Taber abrader/abraser	ASTM D3884 AS 2001.2.8-2001
Abrasive slurry	Aqueous $CaCO_3$ slurry	Einlehner abrasion test	Commercially available, no official norm

rubbing removes indigo dyestuff from the fiber surface and transfers it to an adjacent fabric. If a rubbing process flattens the surface, the result might also be an increased and unwanted glance. Yun et al.[9] or Morris and Prato[10] also investigated the mechanical damage during laundering.

Textile finishing or surface modification, respectively, can be employed to improve the abrasion resistance of a given fabric by changing the slip resistance, applying hard coatings,[11,12] or by lowering the frictional resistance.[13]

Different testing methods are established to test and/or predict the durability of textiles and its finishings as well as to test modifications improving the durability,[14] which simulate a mechanical and/or abrasive long-term stress. One of the most important tests for apparel and home textiles in Germany and many European countries is the Martindale abrasion test according to DIN EN ISO 12947-1. Applying a specific weight loading, a standard test fabric (made of wool) is rubbed across the textile sample's surface. The degree of abrasive wear is controlled at given time intervals and judged by the occurrence of a visible damage of fibers of the test sample. Without doubt, the suitability of different products or materials for numerous applications with respect to wear resistance can be evaluated easily employing this test. Seat covers for furniture in private use should withstand 15,000 rubbing cycles without any damage, while those used in workplaces have to guarantee a higher durability and should last for at least 35,000 cycles.

In industrial practice, other testing methods than the Martindale test are applied depending on the specific measuring task or the product's application. For the Wyzenbeek test, which is comparable to the Martindale test, the samples are also rubbed against a defined textile material. In the case of, for example, car seats, the upholstery is typically tested by an abrasion tester named "Schopper" according to DIN 53863/2 (or GME Standard 60345 or GMW Standard 328). In contrast to the Martindale test, the textile to be tested is rubbed against sandpaper instead of a wool fabric.

The Taber abrader as described, for example, by ASTM D3884 is well known from non-textile applications but is also suitable to investigate certain technical textiles. For Taber abrader testing, two abrading wheels (available in different hardness) roll over the samples at a given load.

The Einlehner test is a test sometimes employed for technical textiles. It differs significantly from the other methods since the sample to be tested is fixed on a rotating drum which is immersed into a slurry containing abrasive particles.

The aim of this work was to compare and understand differences of industrially relevant abrasion tests. Only few researchers investigated the general damaging mechanisms due to different wear and abrasion processes, notable examples being Hamburger[15] and Ozdil et al.[3] Cayer-Barrioz et al.[16] investigated the *abrasive wear micromechanisms* of fibers but, focusing on basic research, neglected the specific idiosyncrasies of relevant industrial testing methods.

Within a research project[17] aiming on improvements of the abrasion resistance of fabrics, the mechanisms of damage have been investigated. Based on these investigations, basic approaches shall be derived for a better understanding of how to protect textiles from abrasive damaging.

Testing methods for evaluating abrasion resistance

Different methods for evaluating the wear or abrasion resistance are relevant for different products and applications. These methods can be grouped by the type of abrasive material that rubs against the samples to be tested as presented in Table 1.

The mentioned methods are requested for different fields of application. Especially in Germany, the Martindale test is a typical test for working clothes, the Schopper abrasion test is requested for car seatings, and the Einlehner test for conveyor belts as used, for example, in paper production.

These three methods generate very different stress conditions that are responsible for the abrasive damaging of the test samples. When rubbing two fabrics against each other, the abrasive material is a "gentle" abrasive material compared to the mineral abrasive grains of a sand paper. While the wool fabric of the Martindale test exhibits a comparably soft and smooth surface, the abrasive grains are very hard and sharp edged. Therefore, it is obvious that the number of rubbing cycles a product has to withstand in the Martindale test is much higher than that in the Schopper abrasion test, since the damaging of a textile will occur much faster when using sand paper. A question, which to our best knowledge has been neither investigated nor discussed properly in the literature so far, is whether the general damaging mechanisms of the fibers or fabrics imparted by the different tests are comparable or lead to comparable results.

A more detailed understanding of the damage mechanisms occurring in the test procedures is especially of importance for the development of finishes that aim to improve the abrasion or wear resistance. If the damaging caused by different test methods follows the same mechanism, it could be expected that the effects of a certain finishing would be characterized by any of the tests in sufficient accuracy. On the other hand, if the "response" of the different tests showed significant differences, tests would have to be chosen according the stress scenarios of specific applications and—potentially—finishing concepts optimized for the applications.

Experimental part

Samples

Test fabrics were supplied by WfK Testgewebe GmbH (Brüggen, Germany). The technical data for the cotton fabric are as follows: CO (10 A): 170 g/m^2, 270/270 pick/dm, plain weave (1/1), 295/295 dtex. Technical data for the polyester fabric are as follows: polyethylene terephthalate (PET) (30 A): 170 g/m^2, 270/270 pick/dm, plain weave (1/1), 295/295 dtex.

Einlehner test

The Einlehner test was carried out as follows: a textile sample is fixed around a rotating ceramic drum which is immersed into a calcium carbonate slurry (0.8 wt%) The running distance is calculated from the circumference of the drum and the number of turns. Running distance is 5 km. Equipment used is the *Einlehner 2000 AT* (Xell GmbH, Eberstalzell, Austria).

Martindale test

Circular samples with a diameter of 40 mm are subjected to 5000 rubbing cycles for cotton and 50,000 rubbing cycles for PET samples both with a load of 12 kPa. Tests were carried out using certified Martindale test units (either NU Martindale from James Heal, Halifax, UK or *M235 Martindale* from SDL Atlas Textile Testing Solutions, Rock Hill, USA). The abrasive woolen cloth (circular samples, 140 mm diameter) was a test fabric specified as Martindale SM 25 (according to ISO 12947-1).

Abrasion test—design Schopper

The Schopper test (also known as the Frank Hauser abrasion test) was carried out according to DIN 53863. The tested surface is 50 cm^2. An emery paper (silicon carbide coarse grit: 280) abrades the surface with a load of 5 N. The test is carried out with a rotary movement of 85 r/min. A total of 1500 rubbing cycles were specified for PET and PET/CO blended samples or 400 for the cotton samples.

Analysis

After performing the test, the treated samples are investigated to obtain insight into the damaging mechanisms. Scanning electron microscopy (SEM) or digital microscopy can be helpful for comparing the damage symptoms and detecting the damaging mechanisms. Digital microscopy offers a wide overview of the sample's surfaces. Due to the higher magnification of the SEM, it allows investigating the yarns or fibers, respectively, in more details. SEM micrographs were prepared using an S-3400N II instrument (Hitachi High-Technologies Europe, Krefeld, Germany). For digital microscopy images, a VHX-700FD microscope (Keyence, Neu-Isenburg, Germany) was used.

Results and discussion

The analyses by SEM and digital microscopy (cf. Figure 1) reveal that the damaging symptoms imparted by the Martindale, Schopper, and Einlehner tests are very different with regard to a specific sample—for example, the PET fabric—but quite similar, when the very same test method was applied to fabrics of different materials as carried out here for the PET and CO fabrics.

Following the Martindale and the Schopper test, broken fiber ends poking out of the fabric surfaces are observed. In the case of the Einlehner test, only a very few fibers poke out of the surfaces but a distinct flattening of the fiber's surfaces can be noticed. For the cotton fabrics, a strong fibrillation of the fibers occurs (cf. Figure 1). This fibrillation will be found at the yarn breakages but also at the yarn surfaces in areas where no breakage occurred. The strongest fibrillation is observed on samples subjected to the Martindale test and less fibrillation is observed for the Schopper test, while no fibrillation occurs during the Einlehner test.

As was to be expected, no fibrillation is observed in the case of the PET fibers. Instead, the SEM micrographs reveal fraying at the yarn breakages, which is more distinctive for the Martindale test than for the Schopper test.

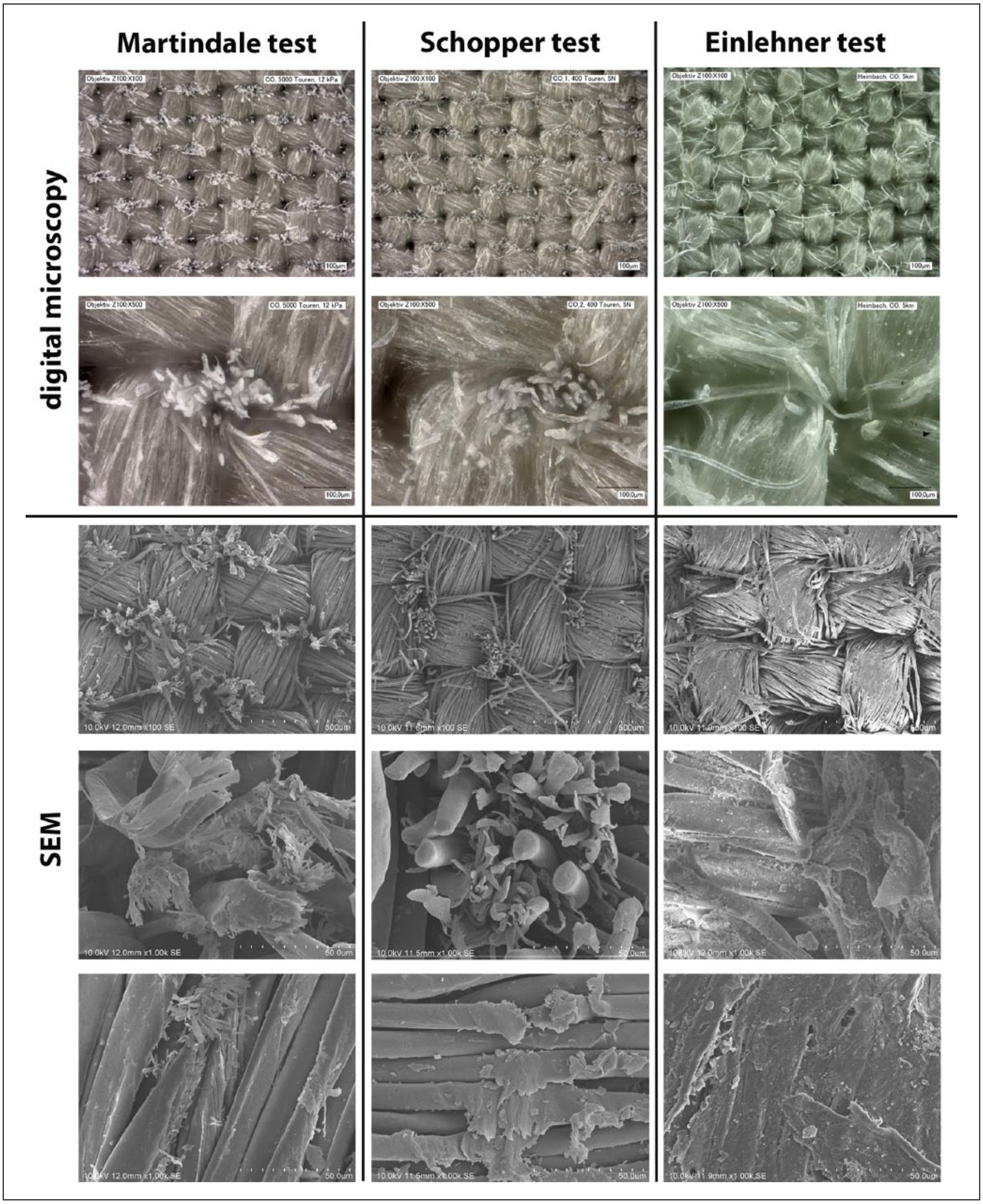

Figure 1. Comparison of the damaging symptoms for a cotton fabric.

In addition to these frayed fiber ends, digital micrographs of the samples subjected to the Schopper indicate fiber ends with a round profile as well. The circular profile can be referred to a clear cut. In the case of the Einlehner test, the analyses show that the filament surfaces are abraded and flattened. The ends of those fibers that are rubbed through do not poke out and fibers seem to be hardly displaced from their initial positions.

For both cotton and polyester, a deposition of the grinding material of the Einlehner test is observed. In the case of the PET fabrics, the damaging symptoms for the Einlehner as well as the Schopper test show distinct similarities (Figure 2). For cotton, these similarities are not observed, but it shows a stronger deposition of the grinding material into the fiber. The lower hardness of CO fibers compared to the hardness of PET fibers leads to a

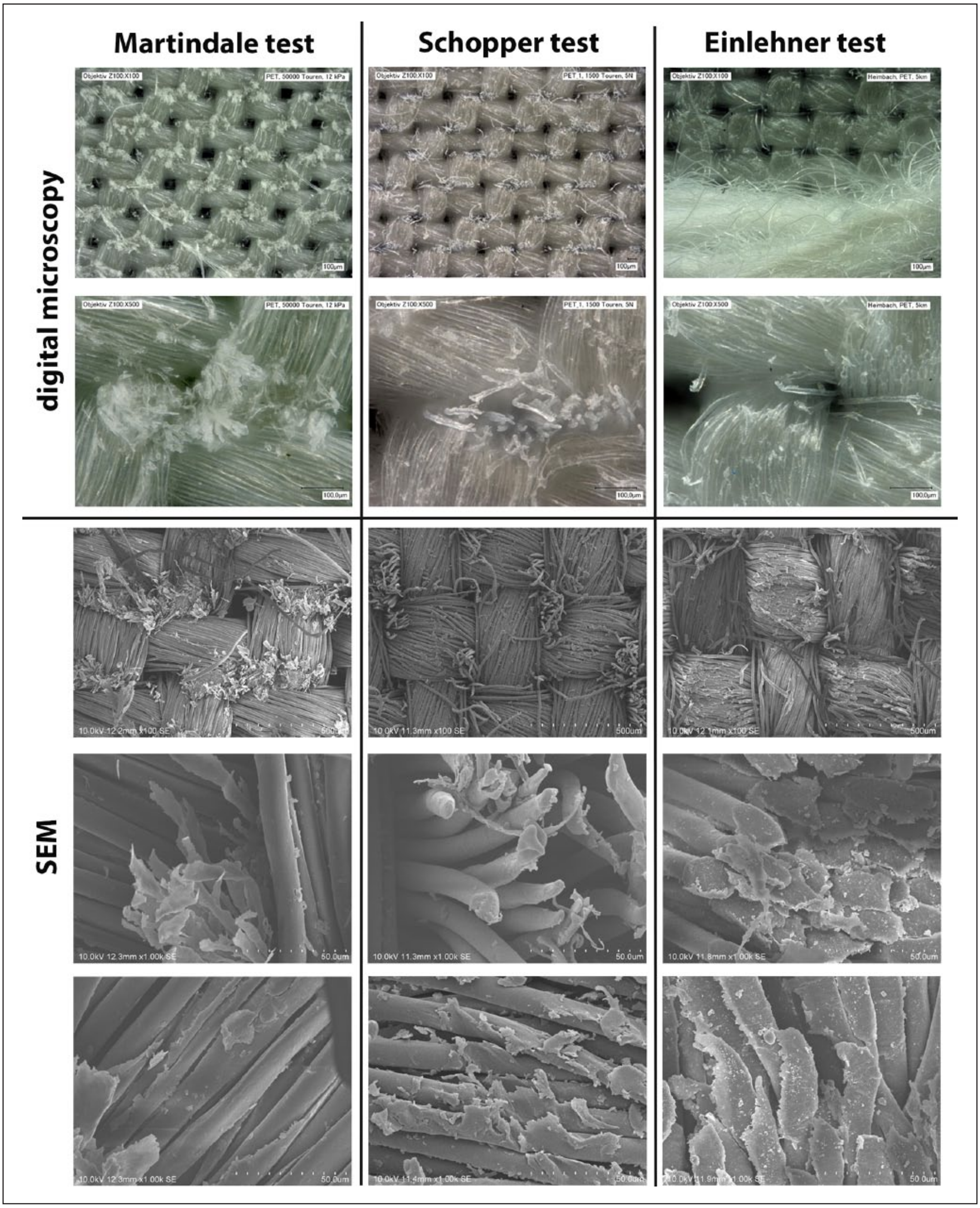

Figure 2. Comparison of the damaging symptoms for a PET fabric.

more pronounced grinding of the CO. For the CO tested in the Einlehner test, grinding with $CaCO_3$ induces a smoothing of the surface.

From the observations described, it can be concluded that when rubbing the fabrics to be tested against a standard fabric or alternatively against some mineral grinding material, different damaging mechanisms are responsible for the damaging—which is certainly not surprising.

The strong fibrillation and fraying occurring when rubbing fabric versus fabric indicate a predominant damaging by mechanical—bending and tensile—stress instead of a damaging by an abrading effect since no indications of a sanding material removal have been found. Fibers are deflected in changing directions by the mechanical strain during the rubbing cycles. This influence of a periodically repeated deflection of the fibers during the rubbing cycles

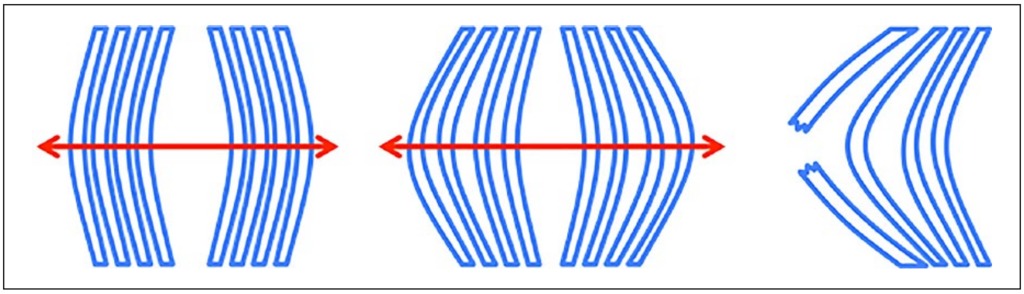

Figure 3. Increasing deflection of the fibers/filaments during the continuous rubbing process finally leading to a rupture of fiber material.

is additionally emphasized by the strong fibrillation occurring for the cotton fabric. More and more fine fibrils are formed that finally rupture. In the case of PET yarns, the filaments are basically stretched by the periodic mechanical stress. As a consequence of this stretching filaments rupture successively. Figure 3 shows a schematic description of the proposed mechanism.

By the repeated rubbing across the fabric's surface, the fibers are bended and shifted in the rubbing direction. The fibers at or near the surface of the fabric have to withstand the highest stress. During periodic rubbing, the fibers will be deflected alternately in opposite directions. The higher the number of rubbing cycles, the stronger the deflection of the fibers and the higher the tension that builds up. Due to this alternating movement and the increasing tension, the filaments will finally rupture at a certain point. In the case of cotton, the fibers will fibrillate, which supports the rupture since the fibrils bearing the stress are much finer and therefore less robust against a given mechanical stress compared to the non-fibrillated fibers.

For the Schopper test, it is obvious from the micrographs that the grinding material will first harm the surface of the yarns/filaments by a cutting and disruptive effect. Clear cuts give evidence for a cutting of yarns and filaments, while the disruptive action is indicated by the frayed fiber ends. If the cleavage is due to a successive abrasion culminating in the complete removal of polymer material (instead of a rupture of the fiber), this will lead to more or less smooth fiber ends with a circular to elliptical edge. In the case of the Einlehner test, the abrasive material removal is obvious. A significant removal of material from the very surface without disruption of fibers takes place. The SEM micrographs suggest that probably no disruption will occur during the Einlehner test. The fibers at the fabric surfaces might be gradually rubbed through, this presumption is additionally supported by the oval profile of the damaged fiber ends. Differences between Schopper and Einlehner test are explained by the fact that in the case of Einlehner test the grinding material is very fine grained and suspended in a liquid of low viscosity, while for the Schopper test coarse and sharp-edged grains embedded in a sand paper contact the fabric. In difference to the Schopper test, a pull-out and rupture of filaments is therefore excluded in the case of the Einlehner test.

Taking all observations into account, an important difference between the mentioned damaging mechanisms can be concluded. A sample with a basic hardness comparable to the abrading material used in the test—as is the case in the Martindale test—will be damaged by reversed bending loads. A true abrasive material removal occurs only in the Schopper and Einlehner tests. For both tests, the kind of abrading material as well as its particle size plays an important role. A coarse, sharp-edged, and immobilized grinding material effects cutting and disruption, while dispersed and fine-grained material promotes a constant removal of material from the fiber surfaces.

Conclusion

When investigating the abrasion resistance of textiles, one has to clearly differentiate for what purpose the abrasion resistance has to be assessed. The abrasion resistance can be investigated rubbing against a standard fabric or grinding material as is commonly used to test, for example, wood or metal surfaces. By choosing a certain method, specific damaging mechanisms will have to be taken into account. A more pronounced mechanical fatigue of the fibers and yarn will occur when testing against a fabric, and more pronounced abrading, cutting, and rupture of fibers will occur when testing against sand paper, or a constant erosion of polymer materials from the fiber surface when applying an abrasive slurry.

Accordingly, the studied testing methods will not provide comparable results and cannot be employed at will.

This insight might not be surprising, but it is of importance for the development of finishes meant to improve the abrasion resistance of textiles. A fiber equipped with a thin and hard protection layer would most probably improve the abrasion resistance and could ideally be tested with the Einlehner test. At the same time, the "successful" protection of the fibers would most probably not show when tested with the Schopper test—the fiber protected against "erosion" would be simply cut and disrupted in the Schopper test. In the Martindale test, improvements of the wear resistance will be more obvious for finishes enhancing the resistance by maintaining the fiber integration or influencing the slip resistance, respectively. In the case of testing against a coarse and hard mineral grain, an improved tensile strength combined with a high slip resistance and a strong integration of the fiber into the fabric are as important as a protective hard coating.

Based on this, the authors actually started to develop new finishes and auxiliaries to a target-oriented improvement of the abrasion resistance of textile materials employed in different applications. In parallel, the authors continue their work to better understand the damage mechanisms in the abrasion resistance tests to allow a better prediction of resistances.

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References

1. Schiefer HF and Werntz CW. Interpretation of tests for resistance to abrasion of textiles. *Text Res J* 1952; 22: 1–12.
2. Mayer-Gall T, Gutmann JS and Textor T. New method for damage assessment in Martindale abrasion testing. *Melliand Int* 2018; 1: 36–38.
3. Ozdil N, Kayseri GO and Menguc GS. Analysis of abrasion characteristics in textiles. In: Adamiak M (ed.) *Abrasion resistance of materials*. Rijeka: InTech, 2012, pp. 119–146.
4. Raheel M. Effect of abrasion on stress-strain properties of two polyester/cotton fabrics in low-level laboratory abrasion and wear trials. *Text Res J* 1980; 50: 381–386.
5. Chippindale P. 40—wear, abrasion, and laundering of cotton fabrics. *J Text Inst Trans* 1963; 54: T445–T463.
6. Morris MA and Prato HH. Edge abrasion of durable-press fabrics due to launderin and wear. *Home Econ Res J* 1975; 3: 171–185.
7. Škoc MS and Pezelj E. Abrasion resistance of high performance fabrics. In: Adamiak M (ed.) *Abrasion resistance of materials*. Rijeka: InTech, 2012, pp. 35–52.
8. Can Y and Akaydin M. Effects of laundering process on abrasion and wrinkle resistance of cotton plain fabric. *Tekst Konfeksiyon* 2013; 23: 49–54.
9. Yun C, Cho Y and Park CH. Washing efficiency and fabric damage by beating and rubbing movements in comparison with a front-loading washer. *Text Res J* 2017; 87: 708–714.
10. Morris MA and Prato HH. Fabric damage during laundering. *Calif Agr* 1976; 9, http://calag.ucanr.edu/archive/?type=pdf&article=ca.v030n12p9
11. Brzeziński S, kowalczyk D, Borak B, et al. Applying the sol-gel method to the deposition of nanocoats on textiles to improve their abrasion resistance. *J Appl Polym Sci* 2012; 125: 3058–3067.
12. Brzeziński S, kowalczyk D, borak B, et al. Nanocoat finishing of polyester/cotton fabrics by the sol-gel method to improve their wear resistance. *Fibres Text East Eur* 2011; 89: 83–88.
13. Li G, Joo Lee H and Michielsen S. Design of abrasion resistant super-antiwetting nylon surfaces. *New J Chem* 2017; 5: 13593–13599.
14. Abrasion resistance: considerations for textile specifiers, 2011, http://contracttextiles.org/wp-content/uploads/2016/12/act_wp_synopsis_060211.pdf
15. Hamburger WJ. Mechanics of abrasion of textile materials. *Text Res J* 1945; 15: 169–177.
16. Cayer-Barrioz J, Mazuyer D, Kapsa P, et al. Abrasive wear micromechanisms of oriented polymers. *Polymer* 2004; 45: 2729–2736.
17. Mayer-Gall T, Textor T and Gutmann JS. *Ausrüstung zur Verbesserung der Abrasionsbeständigkeit von textilen Flächengebilden: finishing for improving the abrasion resistance of textile fabrics*. DTNW-Mitteilung 108, DTNW, Krefeld, 2017.