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Fiber Recovery from End-of-Life Apparel

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Apparel industry is handling large quantities of fibers having consumed a significant portion of energy and resources. Although in Europe a separate collection of end-of-life apparel is well established, a certain amount of collected textiles remains as waste. An improvement in fiber recycling technology could further increase the recovery rate and bring ecological benefit. A research project is currently being carried out to significantly increase the portion of fibers recovered and reused to help avoid unnecessary waste. On the one hand, improvement will increase the overall economic benefit of apparel collection. On the other hand, the reuse of fibers can save energy and resources.

1. Apparel Collection

In the EU waste collection and recycling is usually financed by the consumers or the communities. End-of-life apparel is a remarkable type of waste since its collection and recycling pays for itself. Frequently end-of-life apparel is collected separately from other types of waste. The collection is organized by charity organizations, communities and private companies. From this collection a rather pure and only slightly contaminated fraction is available which can be reused.
The collected clothes are further divided into several fractions (bsva, 2001). About half of the material can be used as rewearables. From this, however, there is only a small portion that can be sold in second hand shops. The major part of rewearables is given as charity donations for developing and emerging countries. These activities are in accordance with the aim of charity organizations but do not gain a commercial asset. Nevertheless, the profit which can be achieved with this reselling second hand clothes is rather high and can fund the other fractions.
The production of cleaning and wiping rags (17 %) as well as raveling (21 %) is rather cost intensive and the incomes do not cover the production costs. The residual waste (12 %) is the most cost-intensive fraction. Due to the deposition ban in Austria and Germany this fraction has to be fired. Waste incineration is very costly and significantly reduces the overall benefit of apparel collection.

2. Research Project

The presented results have been attained in the course of a research project aiming at a more or less complete reuse of fibers from end-of-life apparel. It is funded by the Austrian Federal Ministry of Transport, Innovation and Technology as well as by the part-

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ner companies Humana - People to People, R + M - Ressourcen + Management GmbH and UEG.
In order to improve the overall economic situation of apparel collection the project aims to develop new recycling technologies (Bartl and Marini, 2008). It is recommended to increase the portion of apparel which can be recycled economically. As sketched in Figure 1 the process consists of a set of mechanical processes in order to separate non-fibrous components and to produce a fiber fraction. In the last step ("tailoring"), the fiber length of the recycled fibers has to be adjusted to a desired value optimized for the subsequent application. On the one hand, a grinding procedure produces short fibers which can be used as additives for a variety of construction materials such as bitumen, concrete, mortars or adhesives. On the other hand, a fearnought opener or similar aggregates can be used to obtain longer fibers, which can be processed to textiles or nonwovens.
In the first step of the research project, end-of-life apparel fractions have been analyzed in regard to chemical and physical fiber properties. For this, the clothes have been comminuted in a shredder mill and subsequently ground in a cutting mill after a manual separation of contraries. All textile or nonwoven structures have been disintegrated obtaining very short, individual fibers. It was, therefore, possible to mix and homogenize the material in order to draw representative samples.

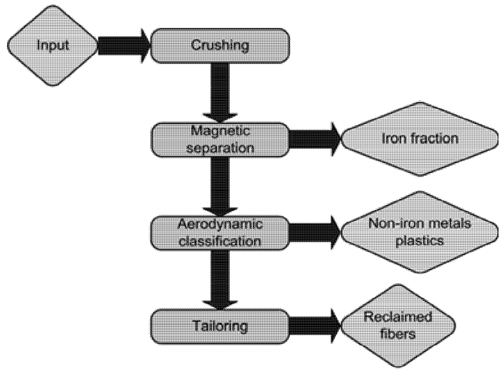


Figure 1 Scheme of process chain to derive fibers from non usable end-of-life apparel

3. Fiber Composition

For the determination of the fiber composition a set of various solvents was chosen, which show selective solubilities for the different fiber types (Shao and Filteau, 2004). The intensive but precise method does not demand expensive equipment and can distinguish between 11 fiber materials. It can be assumed that all fibers commonly used for the textile industry can be distinguished.
Four samples have been analyzed demonstrating that end-of-life apparel contains all 11 types of fiber materials which are accessible by the analyzing method. The results are summarized in Table 1 and compared to the portion of the respective fibers contributing to world fiber production.
Although fiber composition of different samples shows significant deviations, cotton is identified as a major component (up to 33 %) followed by polyester (up to 23 %). This result is a good agreement to the world fiber production, which is covered by cotton to about 35 % and by polyester to about 38 % (CIRFS, 2004). As the percentages suggest, these materials are the most important fiber types.
For polyester a quite large deviation was found (5 to 14 %). On the one hand, this seems to be caused by the fact that the portion of polyester is identified in the last step of the analyzing procedure and, therefore, the errors of the preceding solubility tests are sum-

marized. On the other hand, it seems quite natural that waste can show significant deviations. However, the amount of these two fibers in end-of-life apparel (mean 42 %) is significantly lower than compared to their respective production volumes (73 %).

Table 1 Results of the solubility tests of fibers derived from end-of-life apparel. The data are based on the analysis of four samples; all values are mass %

Fiber Type	Code*	Mean value	Minimum	Maximum	Production+
Cotton	CO	28.4	25.3	32.8	35
Polyester	PES	14.2	5.0	23.2	38
Viscose	CV	10.8	5.9	17.0	5#
Wool	WO	8.5	4.3	14.3	2
Silk	SE	6.1	1.2	11.5	0.2
Elastane	EL	5.2	2.4	9.7	-♣
Polyolefin	PE and PP	5.1	3.2	7.2	7
Polyamide	PA	5.1	1.2	7.1	7
Acetate	CA	4.6	3.1	6.8	5#
Acrylic	PAN	4.3	2.5	8.1	5
Triacetate	CTA	1.2	0.0	2.9	5#
Insoluble	-	6.6	4.4	9.1	-

* According to BISFA 2000 and DIN 1999

\+ Portion of world fiber production (CIRFS, 2004, Fiber Organon, 2007)

\# Total portion of cellulosics (CV + CA + CTA)

♣ No data available

Interestingly, the portion of viscose ranges at about 11 % even though cellulosics world production only contributes to about 5 %. The average total amount of cellulosics (viscose, acetate and triacetate) was determined to range at approximately 17 %. Also, wool (mean 8.5 %) and silk (mean 6.1 %) significantly exceed their respective portions of world fiber production (2 % for wool and 0.2 % for silk according to Fiber Organon 2007). Unfortunately, no reliable data are available concerning the exact fiber consumption of the apparel industry in regard to fiber materials. It seems, of course possible, that world fiber production and apparel fiber consumption show significant differences in regard of fiber types.

The portion of elastane (mean 5 %) is again much higher than compared to the fairly low production volume (< 0.1 %, no assured data available). It is likely that this elastic fiber is predominantly used for apparel but not for home textiles or industrial applications.

Comparing the determined portion in end-of-life apparel and respective production rates for Polyolefin, Polyamide and Acrylic reveals only minor deviations. The unexpected high portions of viscose, wool and elastane could be caused by obvious “contaminations” by home textiles. However, the high portion of silk is inexplicable.

A relatively high portion of insoluble material was found. This is partially caused by the fact that the shredder mill used for comminuting the apparel was previously used for other waste fractions. Actually the insoluble portion present in apparel will be much lower.

Table 2 summarizes the portion of the fiber categories. The fraction of natural fibers and cellulosic fibers, which count as man-made fibers, ranges at about ⅔. These fibers show hydrophilic behavior which has to be considered for any further application. The fraction of man-made fibers based on synthetic polymers, thus being hydrophobic, is about ⅓.

Table 2 Portion of fiber categories found in end-of-life apparel; insoluble portion is not evaluated

Category	Fiber types*	Portion [mass %]
Natural	CO, WO, SE	46.0
Cellulosics	CV, CA, CTA	17.7
Synthetics	PES, EL, PE, PP, PA, PAN	36.3

* Codes according to BISFA 2000 and DIN 1999

Comparing the composition of fibers derived from end-of-life apparel with tire derived fibers (TDF) reveals certain analogies (Table 3). The composition of TDF is rather constant and contains about 50 % viscose in Europe (Weisser and Czapay, 1991). The other half is covered by synthetic polymer fibers, polyester and to a minor content polyamide. It is, therefore, evident that both recycled materials consist of significant portions hydrophobic as well as hydrophilic fibers.

Table 2 Comparison of fibers derived from end-of-life tires and waste in terms of fiber materials

Tires	fibers*	Fiber category	fibers*	Apparel
50 %	CV	Natural & cellulosics	CV, CA, CTA	64 %
50 %	PES, PA	Man-made fibers	PES, EL, PE, PP, PA, PAN	36 %

* Codes according to BISFA 2000 and DIN 1999

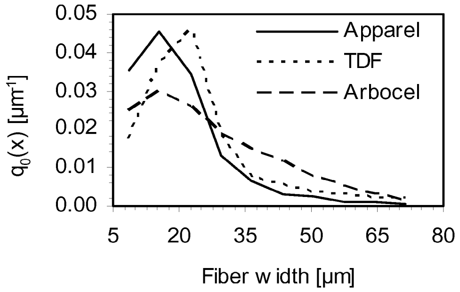
It seems likely that for fibers derived from end-of-life apparel, similar fields of applications are potential markets. Since TDF could already be successfully introduced as additive for bitumen, a comparable solution is obvious. Fibers recovered from apparel have the disadvantage of a greater variety of fiber types and fluctuating portions but do not contain a significant amount of by products (such as residual rubber in TDF).

4. Fiber Morphology

When thinking about any application of short fibers it is important to know the crucial morphologic parameters, which are fiber length and fiber width. While it is clear that fiber length can be influenced by the processing parameters, fiber width is barely changed during cutting and grinding. It was the aim to determine the width of apparel derived fibers and to compare these with other reclaimed fibers. Moreover, fiber length was also determined to get an idea about the possible size range for an industrial process.

An optical image analyzer, the MorFi system, has been used to determine fiber width and length of the homogenized apparel samples (see Chapter 2). The results are com-

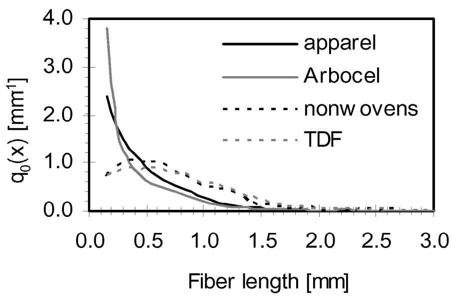
pared with TDF (Bartl et al., 2005), fibers reclaimed from nonwovens (Bartl et al., 2006) and with commercially available ground cellulose (Arbocel®).
Figure 2 shows the respective data for fiber width, a plot for density distribution function and the mean values. The most evident difference is the broad distribution for Arbocel® which is in accordance to its native origin (ground cellulose). Both, the fibers reclaimed from the apparel samples and the tire derived fibers, exhibit a rather narrow, very similar distribution with a clear maximum. However, the average width of TDF (26 µm) is higher than compared to fibers derived from apparel (20 µm).



Sample	Mean width
Apparel (this investigation)	19.9 µm
TDF (tire derived fibers (Bartl et al., 2005)	25.8 µm
Arbocel®	25.6 µm

Figure 2 Distribution function of fiber width and average diameter (weighted by number) determined with the MorFi analyzer

Figure 3 compares fiber length of Arbocel® and reclaimed fibers ground with a cutting mill using a mesh of 0.5mm. Similar grinding results can be achieved in industrial processes.
All fibers show a quite similar length ranging between 0.5 and 0.6 mm. However, regarding the distribution function significant differences are obvious. Both, Arbocel® and fibers reclaimed from the apparel samples contain a large portion of very short fibers with the maximum in the smallest size class (lower limit of MorFi analyzer: 0.1 mm). In contrast, the fibers reclaimed from nonwovens and tires show a maximum at about 0.5 mm with maximum lengths to about 2.0 mm.



Sample	Mean length
Apparel (this investigation)	0.48 mm
Arbocel®	0.55 mm
Nonwovens; needle punched (Bartl et al., 2006)	0.48 mm
TDF (Bartl et al., 2005)	0.60 mm

Figure 3 Distribution function of fiber length and average length (weighted by number) determined with the MorFi analyzer

This fact could be caused by the different nature of the fiber materials. As the fibers reclaimed from nonwovens consist of pure Lyocell (Bartl et al., 2006) and the TDF of viscose, polyester and polyamide, only man-made fibers are present but no natural cellulose fibers at all. Arbocel® exclusively consists of native cellulose and due to the high content of cotton, the fibers derived from the apparel also contain significant amounts of native cellulose. It can be assumed that the material properties of synthetic polymers and regenerated cellulose are quite different compared to native cellulose, which has, in particular, a lower elongation, resulting in shorter fibers during the cutting process.

In conclusion, a quite similar fiber length distribution of fibers reclaimed from apparel compared to Arbocel® is obvious. It is very likely that fibers reclaimed from apparel can easily enter markets which are currently served by ground cellulose. Since these products are already well established being used in many construction materials (e.g. asphalt pavements), an economic viable recycling route for fibers reclaimed from apparel is possible.

5. Summary and Outlook

In many European countries, end-of-life apparel is collected separately from other waste and it is possible to achieve a high rate for reuse, recovery and recycling. Currently, however, a certain portion of textile waste remains and some recycling routes are not cost effective. This research project aims both a significant decrease of the waste portion, as well as a distinct increase of cost efficiency.

In the first outcome of the project, it has been demonstrated that end-of-life apparel consists of a broad spectrum of fiber types exhibiting significant variances. It can, however, be stated that the reclaimed fibers consist of about ⅔ of cellulosic material (cotton as well as man-made fibers) and about ⅓ of synthetic polymers.

Preliminary grinding experiments revealed that both length and width of fibers reclaimed from apparel are quite comparable to well established fiber products and reclaimed fibers from other sources. Since a considerably large market for fibrous products already exists it seems very likely to replace these products by fibers reclaimed from end-of-life apparel.

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