Recycling of Apparel

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In Europe for end-of-life apparel a separate collection exists which is commonly carried out by charitable organizations. Thus domestic waste is reduced and the reutilization of clothes shows ecological benefits. However, a certain fraction remains which cannot be used any more. Hence an expensive disposal is necessary. A research project is currently starting up aiming to develop a mechanical processing in order to reuse this waste fraction of end-of-life apparel. A subsequent utilization in the field of construction materials could be economically feasible. The processing chain covers crushing, separation of non-fibrous components, tailoring and characterization. Finally a product consisting of individual fibers is generated. The fiber length has to be adapted to a desired value necessary for the subsequent application. The possible applications cover textiles or nonwovens as well as the use of short fibers for modifying viscosity of liquid or pasty materials.

1. Introduction

Fiber production is steadily growing and increased from 59.3 by 2002 to 71.6 million t by 2006 (Fiber Organon 2007). It is clear that about the same amount of fibers are disposed. Applications of fibers are widespread and thus also end-of-life fibers can be found in numerous types of wastes. This paper focuses on fibers used for apparel.

The total quantity of apparel was 4.63 million t in Western Europe by 2005 (CIRFS 2006). The annual apparel consumption in Germany ranges about 0.96 million t whereas about 17 % disappears during utilization due to abrasion and washing, about one third is collected separately and about half ends up in domestic waste (Klatt 2001).

In Europe it is well established that the collection of end-of-life apparel is carried out by charitable organizations. The collected clothes are separated and used as re-wearables, cleaning and wiping clothes, short cut for nonwovens as well as for the paper and cardboard industry (Cupit 1996, Klatt 2001). However, about 10 to 20 % of the collected apparel is not appropriate to further utilization and thus ends up in landfills or incinerators.

The development of proper recycling technologies for this waste fraction is evident from an economical as well as an ecological point of view. Due to changing regulatory frameworks (e.g., deposition ban in Austria and Germany) the cost for waste disposal is constantly increasing. It is also evident that fiber production requires more energy and resources than bulk materials. Thermal recycling recovers only a small portion of originally consumed energy for production. An extended life cycle of fibers will thus save energy and resources.

It is the aim of a research project to develop a method with which end-of-life textiles can be recycled economically. By applying exclusively mechanical processing steps today's waste will converted into a marketable product. An application of the recycled fibers seems possible in the field of construction materials where fibrous products can increase the viscosity of pasty or liquid products and/or cause reinforcing effects.

2. Research Project

2.1. Partners and Funding

The project is carried out under the leadership of Vienna University of Technology. The involved companies are Humana - Verein zur Förderung notleidender Menschen in der Dritten Welt (Austria), R+M Ressourcen + Management GmbH (Austria), UEG Umwelt- und Entsorgungstechnik AG (Austria), The Gaia-Movement Trust Living Earth Green World Action (Switzerland) and Green World Rec. Ltd. (UK). The research project is funded by a research and technology program on technologies for sustainable development ("Factory of Tomorrow") sponsored by the Austrian Federal Ministry of Transport, Innovation and Technology (project number 814961).

2.3. Process Chain

The process chain aims to convert end-of-life apparel into a well defined product principally consisting of fibers. All steps are based on mechanical processes and do not use any liquids. The energy consumption is thus relatively low since no drying is necessary. Furthermore the dry process avoids any waste water which would require further treatment. Below the respective processing steps are briefly presented.

Crushing

End-of-life apparel mainly consists of textiles with concomitant components. It is recommended to crush the textile material into small shreds from which undesirable by-components can be separated. The crushing process has to be insensitive against hard components such as buttons, zippers or even pocket knives which may be present in apparel. Possible aggregates are hammer crushers, shredders or similar units.

Magnetic separation

Assuming a sufficient crushing process all magnetizable compounds can be easily discharged by a magnetic separator. The separated fraction predominantly containing iron is a valuable material and can be reused in the steel industry. Preferably the ferrous fraction should be as pure as possible since impurities significantly reduce possible revenues.

Aerodynamic classification

In addition to the magnetic separation another process is necessary to get rid of non-magnetizable metals (e.g. brass, aluminum) and bulk plastics. It is necessary that all components which might interfere downstream processing are more or less completely removed. In particular residual metals would cause severe problems in a cutting mill. Possible equipment is a zigzag classifier, a pneumatic table or a similar aggregate. Furthermore the separated fraction can be split up into nonferrous metals and plastics ready for further recycling.

Tailoring

This process step generates individual fibers and has to disintegrate all residual textiles and yarns. On the one hand a process resulting in rather long fibers (> 2 mm) can be applied in order to obtain fibers of spinnable length. Feasible aggregates are fearnought openers or hammer mills. On the other hand a cutting mill can be used in order to obtain a product which is capable to flow and easy to dose. Hence the fiber length has to be fairly low (< 1 mm) and the product is similar to flock. These short fibers cannot be spun but their main area of application is viscosity modification and composite reinforcement.

Fiber Characterization

In order to evaluate the tailoring process and the quality of the recycled fibers a proper characterization method is essential. It is necessary to determine fiber length and width. Characterization of short fibers such as recycled fibers is not an easy task. Due to their rather short length common methods for fiber characterization fail. But at the same time, due to their extreme non-spherical shape, established methods for particle characterization are not applicable (Bartl 2004). It has been demonstrated previously that a MorFi analyzer, which was developed for pulp characterization (Passas 2001, Tourtollet 2001) is also suitable for characterization of short fibers (Bartl 2005).

2.5. Applications

The proper processing of end-of-life apparel into a well defined product is an inevitable but not a sufficient condition for successful apparel recycling. It is also necessary to find applications in which the recycling material can substitute more or less expensive state-of-the-art products.

In case of sufficient long fibers the recycled material can be used to produce nonwovens (Kunath 2006) or textiles (Cerny 2006). The products can be used for applications demanding rather low quality such as insulating mats.

It is well known that short fibers can significantly increase viscosity of liquids and change their flow behavior from Newtonian to thixotropic (Nawab 1958, Ganani 1985). Liquid or pasty products have to fulfill certain requirements in regard to viscosity and thus suitable additives are frequently used. Among a variety of additives also fibrous products are well established and could be substituted by fibers derived from end-of-life apparel (Bartl 2006).

Fibers are also used as reinforcing additive for a variety of matrices such as thermoplastics (Parvizi-Majidi 1993) or concrete (Friedrich 2001). The major categories of reinforcing fibers are glass, graphite (carbon), metals, ceramics and polymers. Natural fibers such jute and sisal are increasingly becoming more important (Parikh 2002). It seems also possible to substitute today’s state-of the-art fiber additives by recycled fibers.

In the following some important fields for applications of short fibers are briefly presented.

Adhesives

An adhesive is predominately composed of binders which determine its adhesiveness (adhesion) and its internal strength (cohesion). Commonly auxiliaries which influence particular end-use and processing characteristics are added. Frequently so called fillers such as pyrogenic and precipitated silica, spar or in special cases fibers and metal powder are used (Haller 2000). It seems possible that fibers derived from apparel could at least partially substitute prevalent additives.

Paints and Coatings

Paints or coatings are products which are applied to surfaces in layers of given thickness forming adherent films on the surface of the substrate (Stoye 2006). Basically paints contain volatile such as organic solvents or water as well as nonvolatile compounds including binders, resins, plasticizers, additives, dyes and pigments. Viscosity and flow behavior is a crucial property of paints and thus different additives are used for rheology control. Typical thickening agents are silicates, chelates, cellulose ethers and synthetic polymers (polyacrylates, polyvinylpyrrolidone, polyurethanes). Again apparel derived fibers could serve as viscosity modifier replacing expensive state-of-the-art solutions.

Dry mortars

Mortars are usually based on mineral binders like lime, cement or gypsum. In addition they may contain polymer binders, fillers and additives (Bayer 2003). Among the additives cellulose ethers are used as thickening and water retaining agents. The application of fibers is well established whereas fibers can be distinguished into two groups. On the one hand long fibers are mainly used for reinforcement of mortars. On the other hand short fibers (e.g., Arbocel® or Lignocel®) influence wet-mortar properties and water demand. Since the utilization of fibers in mortars is well established apparel derived fibers could be introduced rather easily.

Bitumen

Bitumen is composed of tarlike hydrocarbons derived from petroleum. It is mainly used for road constructions called asphalt as mixture with rocks and additives. Several other applications such as bitumen membranes or melted asphalts are of minor importance. The most obvious drawback of bitumen is its limited temperature range. It is thus state-of-the-art to use auxiliaries in order to improve high as well as low temperature properties. Common additives are thermoplastics (e.g., polyethylene, polypropylene) and elastomers (e.g., polybutadiene, natural rubber, styrene butadiene block copolymers). Special types of asphalt mixtures also contain fibers in order to increase load capacity and temperature resistance. Cellulosic fibers (e.g., Arbocel®, Rettenmaier 1988) but also synthetic fibers such as polyacrylonitriles (e.g., Dolanit®) are well established. It has already been shown that fibers derived from waste tires can substitute these customary products (Bartl 2005). It is thus very likely that recycled fibers derived from other sources will exhibit similar effects.

Cement and concrete

Concrete is a well known and widespread construction material. By 2004 approximately 2 136 million t of cement was produced worldwide to manufacture round 7 billion m^3 of concrete (Kropp 2008). Concrete is a brittle material and is thus commonly reinforced with steel bars. In order to increase concrete properties fibers can be added. Earlier asbestos was used which is nowadays replaced by polymeric (e.g., polypropylene, polyvinyl alcohols), carbon and glass fibers (Velpari 1980; Hatschek 1980). Recently it has also been reported that tire derived fibers can be used as favorably concrete additive (Li, 2004) Again the conclusion by analogy implies the utilization of other recycled fibers.

2.6. Saving Potentials

In 2006 natural and cellulosic fibers (of which 89 % is cotton) accounted for 42 % (30.4 million t) of total fiber production. The residual portion (41.3 million t) is covered by synthetic fibers (Fiber Organon 2007). It can be assumed that the proportions of natural and synthetic fibers used for apparel is not exactly the same but obviously both types of fiber materials play an important role.

Considering a collection rate for apparel (total amount: 4.63 million t) of approximately 30 % in Western Europe of which at least 10 % are unusable the total amount of 140 000 t of fibers could be used for another life cycle. For a rough estimation 70 000 t of both natural and synthetic fibers are taken into account. In the following a rough calculation is presented how many resources and energy could be saved if a complete utilization of today's waste faction is realized.

Natural and Cellulosic Fibers

Undoubtedly cotton is a renewable product but in regard of its cultivation method it cannot be seen as sustainable product. Worldwide large amounts of chemicals, water, energy and cropland are required for cotton production. The total land used for cotton cultivation is about 340 330 km². That is about the size of Germany and contributes to about 2.4 % to the total area available for cultivation (Paulitsch 2004). The production of 1 kg raw cotton demands around 20 m³ of water and up to 1 000 g of petroleum (i.e. round 42 MJ). Hence the caloric value of cotton which is about 17 MJ/kg is fairly low. Based on the estimation of 70 000 t/a of cotton fibers to be reused annually implies a saving potential of 1.3 million m³ water which is about half of the total consumption (industry, agriculture and households) of Austria (Sandner 2004).

Synthetic Fibers

The water consumption for the production of man-made fibers is significantly lower (up to 15 l H_2O per 1 kg fibers) than for cotton (Cupit 1996). Furthermore no pesticides, fungicides or fertilizers are required which can pollute the environment. The production of synthetic fibers demands for petroleum as raw material and as source for energy required for polymerization, spinning and finishing ranging at about 400 MJ/kg (Cupit 1996). Altogether it can be assumed that for 1 kg of synthetic fibers about 11 kg of petroleum are necessary. From this it is obvious that thermal utilization should be replaced by a proper recycling process. In regard of an assumed quantity of 70 000 t of synthetic fibers to be recycled identifies approximately 0.77 million t of petroleum to be saved annually. This amount corresponds to about 2.5 million t CO_2 which could be saved by the implementation of a more or less complete recycling of all collected end-of-life apparel.

3. Summary and Outlook

The paper presents a new research project in the field of apparel recycling. It is the aim to increase the recycling rate for end-of-life clothes up to almost 100 %. Currently for collected clothes a reuse or a recycling of only approximately 80 % is possible. One the one hand the planned schedule consists of a mechanical processing chain in order to separate interfering by-products and to generate a well defined fiber product. On the other hand it is also within the scope of the project to develop applications for the apparel derived fibers in the area of construction materials. The specific properties of fibers which are high surface and low mass must not be neglected and can serve as basis for an economically and ecologically feasible recycling process.

Several possible applications are presented. It is well demonstrated that the use of short fibers is already widespread for many construction materials and thus apparel derived fibers show a great potential as substitute. Furthermore the recycling process can result in spinnable fibers which can be further processed into nonwovens or textiles.

Apart from apparel it could also be possible to process other fiber containing types of waste in a similar way. Industrial production residues, shredder light fraction or carpets are commonly collected separately and could thus serve as raw materials for waste derived fibers. Based on the large production of fibers an enormous saving potential of energy and resources is obvious.

4. References

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