RECYCLING

Solid-state NMR method for the quantification of cellulose and polyester in textile blends

Haslinger, S., Hietala, S., Hummel, M., Maunu, S.L. and Sixta, H. 2019. Solid-state NMR method for the quantification of cellulose and polyester in textile blends. C*arbohydrate polymers, 207*, 11-16

The valorization of cellulose rich textile waste is promoted by the development of a novel solid-state NMR method for the quantification of cellulose and polyester in textile blends. We applied C-13 CP-MAS NMR as a tool for the quantification and structural characterization of cellulose in cotton polyester blends. Gaussian functions were used to integrate the spectra obtained from a set of calibration standards in order to calculate a sigmoidal calibration curve. Acid hydrolysis was chosen as a reference method. The results demonstrated that solid-state NMR enables a reliable determination of cellulose and polyester in both preconsumer and postconsumer waste textiles and suggests a possible extension of the concept to blends of man-made cellulose fibers (MMCFs) and polyester.

Recycling of vat and reactive dyed textile waste to new colored man-made cellulose fibers

Haslinger, S., Wang, Y., Rissanen, M., Lossa, M.B., Tanttu, M., Ilen, E., Määttänen, M., Harlin, A., Hummel, M. and Sixta, H. 2019. Recycling of vat and reactive dyed textile waste to new colored man-made cellulose fibers. *Green Chemistry*, *21*(20), 5598-5610

The successful recycling of colored textile waste and reuse of respective dyes would represent a major milestone of global efforts to reduce the environmental impact of the textile industry. The chemical upcycling of dyed pre- and postconsumer cotton waste is promoted by studying the spinability and color fastness of seven vat and reactive dyes (i.e. Indanthren Blue BC 3%, Indanthren Red FBB coll, Indanthren Brilliant Green FBB coll, Levafix Brilliant Red E-4BA, Levafix Blue E-GRN gran, Remazol Brilliant Blue R spec, and Remazol Black B 133%) during dry-jet wet spinning. Apart from the fabrics dyed with Levafix Brilliant Red E-4BA, all samples dissolved in 1,5-diazabicyclo[4.3.0]non-5-ene actetate, a superbase based ionic liquid, and could be converted to new colored man-made cellulose fibers. It was found that there is a clear discrepancy between the recyclability of dyed pre- and postconsumer cotton waste, resulting in significantly higher fiber properties up to tenacities of 59.8 cN/tex and elongations of 13.1% in case of the latter. All recycled fibers displayed a noticeable color change in the CIELab space (Delta E = 8.8-25.6) throughout the spinning process. Despite these deviations, almost all fibers and demo fabrics produced thereof exhibited bright colors that can be reused in textile industry. Only Remazol Black B 133% did not sufficiently translate to the new textile product. The wash and rubbing fastness of the fabrics knitted from the regenerated fibers was superior to the dyed waste fabrics mainly because of the homogenous distribution of the dyes along the fiber cross-section.

[Separation of waste polyester/cotton blended fabrics by phosphotungstic acid and preparation of terephthalic acid]

Ling, C., Shi, S., Hou, W., Yan, Z. 2019. Separation of waste polyester/cotton blended fabrics by phosphotungstic acid and preparation of terephthalic acid, *Polymer Degradation and Stability, 161*, 157-165

In order to recycle waste polyester/cotton blended fabrics (WBFs), an environmentally friendly process was designed for separating WBFs with phosphotungstic acid (H3PW12O40, HPW). Polyester and microcrystalline cellulose (MCC) were obtained after the process and the polyester was further degraded into terephthalic acid (TPA) by neutral hydrolysis. The effects of separation conditions were investigated, and the optimum conditions were determined as follows: HPW concentration of 3.47 mmol/L, a solid/liquid ratio of 1:20, reaction temperature of 140 °C, and reaction time of 6 h. Under the optimum conditions, the yields of polyester and MCC were 99.77% and 85.12%, respectively. HPW could be extracted and recycled easily with diethyl ether without affecting the yields of polyester and MCC. In addition, the separated polyester, MCC and prepared TPA were characterized. The results showed that the crystallinity of polyester decreased, and the cotton was hydrolyzed to MCC after the separation treatment. TPA was prepared with a high purity of 99.92%, and exhibited high crystallinity, favorable thermal stability, and small particle size.

[Renewable High-Performance Fibers from the Chemical Recycling of Cotton Waste Utilizing an Ionic Liquid]

Asaadi, S., Hummel, M., Hellsten, S., Härkäsalmi, T., Ma, Y., Michud, A. and Sixta, H. 2016. Renewable high-performance fibers from the chemical recycling of cotton waste utilizing an ionic liquid. *ChemSusChem, 9*(22), 3250-3258

A new chemical recycling method for waste cotton is presented that allows the production of virgin textile fibers of substantially higher quality than that from the mechanical recycling methods that are used currently. Cotton postconsumer textile wastes were solubilized fully in the cellulose-dissolving ionic liquid 1,5-diazabicyclo[4.3.0] non-5-enium acetate ([DBNH]OAc) to be processed into continuous filaments. As a result of the heterogeneous raw material that had a different molar mass distribution and degree of polymerization, pre-treatment to adjust the cellulose degree of polymerization by acid hydrolysis, enzyme hydrolysis, or blending the waste cotton with birch prehydrolyzed kraft pulp was necessary to ensure spinnability. The physical properties of the spun fibers and the effect of the processing parameters on the ultrastructural changes of the fibers were measured. Fibers with a tenacity (tensile strength) of up to 58 cN tex(-1) (870 MPa) were prepared, which exceeds that of native cotton and commercial man-made cellulosic fibers.

Behavior in simulated soil of recycled expanded polystyrene/waste cotton composites

Borsoi, C., Berwig, K.H., Scienza, L.C., Zoppas, B.C., Brandalise, R.N. and Zattera, A.J. 2014. Behavior in simulated soil of recycled expanded polystyrene/waste cotton composites. *Materials Research, 17*(1), 275-283

Composites consisting of waste cotton yarn (CF) from the textile industry and postconsumer expanded polystyrene (EPS) was followed during 90 days of exposure in simulated soil. The mechanical properties, morphologies and chemical natures of the composites were determined before and after exposure in simulated soil. The composites were made using a single-screw extrusion, a twin-screw extrusion and injection molding. The composites showed an increase of the mechanical properties nearly 50% in relation to the recycled expanded polystyrene (rEPS). After exposure in simulated soil the composites presented losses of mechanical properties. Evidence of the oxidation of the samples was demonstrated by the increase in the values of the carbonyl index after 30 days of exposure in simulated soil. Changes in the color of the surface of the sample were observed after 90 days of exposure and are due to the fungi and bacteria colonization on the surface.

Poly (ethylene terephthalate) recycling for high value added textiles

Park, S.H., Kim, S.H. 2014. Poly (ethylene terephthalate) recycling for high value added textiles, *Fashion and Textiles, 1*(1)

This study reviews the problems in the use and disposal of poly (ethylene terephthalate) (PET) and includes the concise background of virgin and recycled PET as well as their possible applications. The current state of knowledge with respect to PET recycling method is presented. Recycling of PET is the most desirable method for waste management, providing an opportunity for reductions in oil usage, carbon dioxide emissions and PET waste requiring disposal because of its non-degradability. Advanced technologies and systems for reducing contamination, mechanical and chemical recycling, and their applications are discussed, and the possibility of diverting the majority of PET waste from landfills or incineration to recycling is suggested.

Sustainable waste management strategies in the fashion industry sector

Dissanayake, G., Sinha, P. 2013. Sustainable waste management strategies in the fashion industry sector, *International Journal of Environmental Sustainability, 8*(1), 77-90

The environmental impact of production and consumption has been addressed globally since the 1992 Rio Earth Summit; and in 2002 at the Johannesburg World Summit a 10-year framework was developed to promote sustainable production and consumption patterns (Ferrara and Serret, 2008). Agenda 21 from the Rio Earth Summit highlighted the fact that sustainable consumption is an issue that needs to be addressed in terms of waste reduction, resource conversion, and control of pollution. Section II of the framework focuses on waste management: minimising waste and maximising reuse and recycling of environmentally sound waste.

Fashion consumption and sustainability are often opposing ideas. Fashion consumption is a highly resource-intensive, wasteful practice; and sustainability frowns on wasteful consumption. Sustainability in the fashion business is still an emerging agenda, not yet established, and many authors have recognised the importance of investigating how sustainability could be achieved (Young et al 2004, Pears 2006, Fletcher 2008). Reuse or recycling of discarded fashion items reduces the environmental impact significantly compared to the purchase of new fashion products. It has been found that approximately 65kWh of energy is saved for every kilogram of cotton replaced by used clothing, and 90 kWh of energy is saved for every kilogram of polyester replaced (Woolridge et al, 2006). Additionally, closing the materials and product cycles is becoming an increasingly important aspect of any recovery option (Michaud and Llerena, 2006).

In order to understand how the clothing end-of-life management is practically handled in the UK, this study examined the current processes and strategies within the UK to utilizing textile wastes with the aim of reducing the volume of textiles and clothing sent to landfill. Based on the study, this paper presents an overview of three end-of-life waste management strategies: reusing, recycling and refashioning. We discuss the advantages and implications of each strategy and conclude by providing recommendations for the development of waste diversion programs and sustainable business models.

An introduction of structure, synthesis and safety concerning polypropylene applications

Sun, H., Xie, L. 2013. An introduction of structure, synthesis and safety concerning polypropylene applications, *Polypropylene: Synthesis, Applications and Environmental Concerns*, 1-10

Polypropylene, a thermoplastic polymer, can be made from the monomer propylene by Ziegler-Natta polymerization and by metallocene catalysis polymerization. According to three-dimensional structure or tacticity, polypropylene can be classified into three types: isotactic, syndiotactic, and atactic. All the methyl groups in isotactic propylene are on the same side of the chain, methyl groups in syndiotactic propylene are positioned alternately, and the methyl groups in atactic polypropylene are placed randomly on both sides of the chain. The relative orientation of methyl groups has a strong effect on the polymer's ability to form crystals, which affects the polymer's physical properties and its application. Isotactic polypropylene, which has high crystallinity, is rugged and unusually resistant to many chemical solvents, bases and acids. It is used in a wide variety of applications including packaging, textiles, furniture, stationery, reusable containers, appliances, automotive components, and construction materials. Syndiotactic polypropylene with low crystallinity has a promising application prospect in films, medical tubing, and medical adhesive. Atactic polypropylene is rubbery and widely used as hot melt adhesives, sealing materials, emulsifiers, paint and etc. Since polypropylene contains only carbon and hydrogen atoms, it does not poison the environment after its disposal, but deterioration time in the land field will be long. The best way to limit PP disposal is to recycle the PP wastes, or incinerate the wastes especially when they are seriously polluted. Thus, from the aspect of environmental protection and public health assurance, PP wastes should be recycled as much as possible. However, the recycled PP products should not be used as pharmaceutical packaging materials due to technical and hygienic reasons.

An air-based automated material recycling system for postconsumer footwear products

Lee, M.J. and Rahimifard, S. 2012. An air-based automated material recycling system for postconsumer footwear products. *Resources, Conservation and Recycling, 69*, 90-99

The worldwide consumption of footwear is estimated to be in excess of 20 billion pairs of shoes per year. To date very little work has been done to develop material recycling solutions for mixed footwear products. In fact less than 5% of end-of-life shoes are being recycled, with most being disposed of in landfill sites around the globe. One of the primary reasons is that most modern footwear products contain a complex mixture of leather, rubber, textile, polymers and metallic materials, that makes it difficult to perform complete separation and reclamation of material streams in an economically sustainable manner. This paper discusses the development of an economically feasible automated material recycling process for mixed postconsumer footwear waste. Central to this process are bespoke air-based separation technologies that separate granulated shoe particles based upon the difference in size and weight. Experimental studies with three different types of postconsumer footwear products show that it is possible to reclaim four usable material streams; leathers, textiles, foams and rubbers. For each of the reclaimed materials there are a variety of applications such as surfacing materials, insulation boards and underlay products.

Chemical recycling of PET flakes into yarn

Upasani, P.S., Jain, A.K., Save, N., Agarwal, U.S. and Kelkar, A.K. 2012. Chemical recycling of PET flakes into yarn. *Journal of Applied Polymer Science, 123*(1), 520-525

Polyesters such as polyethylene terephthalate are widely used in textile fibers, films, and packaging of food and beverages. Originally driven by environmental reasons, recycling of postconsumer polyester bottles into textile fibers is now becoming commercially attractive. We studied the chemical recycling wherein part of the virgin raw-materials during preparation of polyester was replaced by washed post consumer polyester. During the process, the postconsumer polyester undergoes partial depolymerization before repolymerization. Role of reactor-agitator configuration in achieving the solid-slurry and solid-melt mixing, and in depolymerization, was studied. Finally, suitability of the polymer for melt spinning and drawing of polymer into yarn was examined.

Reuse and recycling of textile solid wastes

Adivarekar, R.V., Pisal, S. 2009. Reuse and recycling of textile solid wastes, *Journal of the Textile Association, 70*(3), 118-126

Due to increased awareness and strict laws, disposal of waste is strictly avoided through the use of recycling technologies. The most practical way to reduce pollution is to reuse and recycle the waste several times before it is discarded. Though textiles are nearly 100% recyclable, in reality, the rate of recycling in textiles, both preconsumer and postconsumer is not very high. This paper sheds light on the recycling industry, on the scope of recycling the textile solid waste through various mechanical and chemical processes and also recycling from an energy saving perspective. The importance of the recycling behavior through the micro and macro approach is also emphasized.

Carpet Fiber Recycling Technologies

Wang, Y. 2007. Carpet Fiber Recycling Technologies, *Ecotextiles: The Way Forward for Sustainable Development in Textiles*, 26-32

Significant progress has been made in waste minimization and pollution prevention in textile manufacturing processes. Because most carpets and textiles are for replacement, recycling post-consumer fibrous waste should be an integral part of sustainability for textile products. Currently in the United States alone, over 2 million tons of postconsumer carpet waste is discarded into landfills each year, and the amount is expected to increase to over 3 million tons by 2012. Very little post-consumer carpet at present is recycled. To establish a sustainable commercial network to recycle fibrous waste, operations based on different technologies must coexist such that different types of materials collected can be recycled to the greatest extent. This paper reviews technologies for carpet waste recycling.

Convenience and frequency of recycling - Implications for including textiles in curbside recycling programs

Domina, T. and Koch, K. 2002. Convenience and frequency of recycling: implications for including textiles in curbside recycling programs. *Environment and behavior, 34*(2), 216-238

This research investigated the effect of convenience on recycling frequency and variables that could be used as indicators in the prediction of recycling behavior as a basis for including textiles in curbside recycling programs. Results clearly indicated that access to curbside recycling significantly affected the amount and variety of materials recycled. Logistic regression results pointed to the variables of access, shopping behaviors, age, family size, and income as significant predictors of recycling activity, regardless of how recycling activity was defined. Despite reduced access to textile recycling opportunities, textile recycling overall was still high. The authors concluded that households with high recycling activity could be identified and targeted for extending curbside recycling programs to include textiles. To continue to reduce the amount of solid waste that is diverted to landfills, curbside recycling programs must be extended to include a greater diversity of postconsumer waste products such as textiles and apparel.

The introduction of postconsumer recycled material into TYVEK®: Production, marketing, and organizational challenges

Sharfman, M., Ellington, R.T., Meo, M. 2001. The introduction of postconsumer recycled material into TYVEK®: Production, marketing, and organizational challenges, *Journal of Industrial Ecology, 5*(1), 127-146

In the late 1980s, with the advent of increased consumer environmental awareness, DuPont faced a challenge with its TYVEK® family of nonwoven polyethylene textile products. TYVEK is used in a wide variety of applications ranging from house wrap to medical packaging. One of the most visible portions of the business is envelopes used by FedEx (previously known as Federal Express), the well-known courier and delivery service and by the U.S. Postal Service. As early as 1988, end users began asking questions about the environmental characteristics of TYVEK envelopes. As these questions increased, DuPont began to address the concerns directly, In response to the market's concern and because of the increased availability of postconsumer-recycled (PCP) polyethylene, DuPont decided to put PCR polyethylene into TYVEK, beginning with the envelope business. Further, DuPont developed a recycling infrastructure for TYVEK because, although TYVEK consists entirely of high-density polyethylene, which is highly recyclable, no infrastructure was in place to recycle the material. These decisions produced a wide variety of technical and organizational challenges the firm had to overcome. This case study examines how DuPont made these choices and overcame the difficulties created by implementing needed changes. Whereas the envelope market for TYVEK embraced PCR polyethylene, other product markets resisted the innovation. The article closes with a discussion of the lessons learned from DuPont's experience.