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FIBER RECYCLING TECHNOLOGIES

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Abstract

Fiber, textile, carpet, and apparel industries form one of the largest manufacturing sectors in the United States, employing over one half million workers with an annual payroll exceeding $15 billion. 17 billion pounds of fibers is consumed by the industries with 3.5 billion pounds used in carpet manufacturing. Most of the fibrous products are purchased as replacement, resulting in over 14 billion pounds of fibrous waste (apparel, carpet, and textiles) being disposed of in landfills each year. As consumer demand for recycled products, landfill costs and environmental regulations increase, treating this large amount of fibrous waste as a resource for raw material by converting it into useful products is the most desirable solution. Toward this end, significant research has been carried out by industry and academia with the support of various government agencies, leading to many commercial operations. This paper reviews some of the fiber recycling technologies, with a focus on work conducted at the Georgia Institute of Technology.

Introduction

According to the US Environmental Protection Agency (EPA), the municipal solid waste generated in the US is about 210 million tons per year, among them about 40% being paper products, 9% plastics, and 4% carpets and textiles. It is estimated that the textile (including carpet, textile and apparel) waste generated in 1996 was about 8 million tons, including 2.3 million tons of carpet and rug, 5.3 million tons of clothing and footwear, and 0.75 million tons of towels and sheets. About 1 million tons of textiles waste were reused or recycled, and about 7 million tons of waste was disposed of in landfills. Most of the fibrous waste is composed of materials such as cotton, polyester, nylon, polypropylene, among others. The practice of landfill disposal requires constant creation of new landfill spaces, which is in contradiction to the nation's environmental goals including ecosystem protection. Clearly, there is an urgent need to address the problem of fibrous waste disposal.

Many carpet and textile manufacturers, fiber and chemical suppliers, recycling companies, and academic institutions are actively pursuing various methods to recycle fibrous waste. In the past decade a broad-based research program has been carried out at the Georgia Institute of Technology (Georgia Tech) on carpet and textile recycling in close cooperation with the industry. These approaches include depolymerization, melt processing, recycling logistics, life cycle analysis, waste characterization, material component separation, composite materials, and reinforcements for concrete and soil. This paper provides an overview of some of these activities and technologies for fibrous waste utilization.

Carpet Recycling Logistics Tool

Many technologies, including those being developed at Georgia Tech, are available to convert textile waste into usable products, and as a result, the demand for the recycled materials will increase. For textile recycling to be economical, the process of collecting, sorting, and distributing the fibrous waste must be optimized. A recycling logistics tool is being developed by Professors M. Realff and J. Ammons to help the industry to make sound economic decisions regarding these operations. The tool consists a generic model that evaluates the economic feasibility of establishing and operating a carpet recycling network consisting of strategically located collection sites, sorting facilities, and a distribution system to transport the waste. The initial studies have focused on carpet waste recycling. The tool has been applied in the decision making process for a limited number of commercial recycling networks in the US.

Depolymerization of Nylon

Several depolymerization processes are available to convert nylon and other polymers into monomers, but most of them involve extreme processing conditions. The objective of this study, led by Professor M. B. Polk, is to develop a low temperature, atmospheric pressure process for the depolymerization of nylon 6 and nylon 6,6 utilizing phase transfer catalysis. A series of experiments were run in order to examine the applicability and efficiency of benzyltrimethylammonium bromide (BTEMB) as a phase transfer catalyst in the depolymerization of nylon 6,6. The results suggest that in the absence of phase transfer agent, only oligomers are formed; however, soluble low molecular weight products are formed in the presence of phase transfer agent at relatively low temperature and atmospheric pressure.

Glass Mat Thermoplastics

Glass mat reinforced thermoplastic (GMT) using virgin materials has been attracting growing attention, particularly for use in the automotive sector. Polypropylene is a commonly used thermoplastic matrix in GMT's. In the studies led by Professors J. Muzzy and S. Kumar, two types of carpet waste have been used: one is edge trim carpet waste, the other is separated polypropylene from post-consumer carpet waste. The GMT preparation included three steps: debulking, stacking with glass mats and consolidation. The properties of GMT using carpet waste have been compared with the commercial GMT which uses virgin polypropylene, and similar (or better) results in tensile strength, modulus and elongation have been observed. GMT's manufactured using carpet and other textile waste are currently being studied in greater depth from the point of view of optimization of consolidation and processing parameters.

Composites and Laminates from Carpet and Textile Waste

Dr. A. Kotliar is exploring another approach to use the face yarn in carpets and the fibers in textiles as a fibrous filler for a composite or laminate and the polypropylene component to supply the necessary flow in processing. The proper choice of the adhesive will result in a high modulus material that is creep resistant and has good weathering characteristics. The initial work emphasized shredded carpet selvage to which various amounts of cut waste fibers such as nylon 6, nylon 66, polyester and cotton were added. Test results show that the molded composites can have good flexural modulus and strength properties, and they are suitable for many outdoor applications in the replacement of marine plywood and metal in the transportation area. Laminates directly from waste carpet pieces were also made. The mechanical properties of laminates made by coating the face yarn with a phenol formaldehyde resin and molding the carpet pieces back to back with the face yarn on the outside to achieve the higher flexural modulus. Additional work has been done to make honeycomb sandwich structures for high flexural stiffness and light weight.

Reactive Extrusion of Carpet Waste

The basic polymeric components (nylon and polypropylene) in carpet do not mix and bond well when melted. The use of maleic anhydride grafted polypropylene (PP-g-MAH) as a compatibilizer for reactive extrusion of carpet face (nylon) and backing (polypropylene) could produce low cost plastic parts with reasonable mechanical properties. Experimental work on the reactive extrusion at Monsanto and at Georgia Tech led by Professor S. Kumar, has demonstrated a potential for the utilization of carpet as a plastic resin. The initial experiments showed that by blending, compatibilizing, and extruding the carpet, the tensile strength as good as or better than the tensile strength of polypropylene could be achieved. However, the tensile failure strain of the extruded carpet was rather low. Attempts to improve the tensile strain have been made by altering the composition and processing conditions.

Injection Molding and Press Molding

In the injection molding study led by Professors J. Muzzy and S. Kumar, shredded selvage trim was first debulked and then cut or ground into small pieces suitable for injection molding. Tensile bars were injection molded. The sample containing polypropylene, nylon 6, nylon 66, and calcium carbonate exhibited a tensile strength of 180 MPa and strain to failure of 9.4%. Injection molding experiments have also been carried out on nylon lint from several carpet mills. Test results indicate that the lint samples have tensile strength similar to that of virgin nylon, though the strain to failure is much lower than the virgin material.

In the press molding study, carpet waste was debulked at 204°C using a compression molding press. To give a smooth finish to these sheets, the debulked sheets from carpet waste were hot pressed between virgin polyethylene films. The carpet sheets sandwiched between the virgin polyethylene sheets had an excellent texture. Such are excellent candidates for potential vinyl floor tile replacement. Further processing development work is needed to reliably measure the properties of such sheet material and compare them to the properties of the currently used vinyl floor tiles.

Carpet Waste Fiber for Concrete Reinforcement

A carpet typically consists of two layers of backing (usually fabrics from polypropylene tape yarns), joined by $CaCO_3$ filled styrene-butadiene latex rubber (SBR), and face fibers (majority being nylon 6 and nylon 66 textured yarns). Such nylon and polypropylene fibers can be used for concrete reinforcement. A laboratory study led by Professor Y. Wang on concrete reinforcement with carpet waste fibers was carried out at Georgia Tech. The concrete mix weight ratios are: Type I Portland cement (1.0), river sand (0.85), crushed granite (0.61), water (0.35) and a small amount of superplasticizer. Recycled carpet waste fibers used were disassembled from hard carpet waste (Typical length 12 to 25 mm). Fiber volume fractions for the waste fibers were 1% and 2%.

Four point flexural test and cylinder compressive test were conducted. In the compressive tests, the plain concrete specimens failed in a brittle manner and shattered into pieces. In contrast, all the FRC samples after reaching the peak load could still remain as an integral piece, with fibers holding the concrete matrices tightly together. In the flexural test, it was observed that the plain concrete samples broke into two pieces once the peak load was reached, with very little energy absorption. The FRC specimens, on the other hand, exhibited a pseudo ductile behavior and fibers bridging the beam crack can be seen. Because of the fiber bridging mechanism, the energy absorption during flexural failure was significantly higher than that for plain concrete.

The laboratory study has indicated that the carpet waste fiber was very effective in improving the toughness and shrinkage properties of concrete. Shaw Industries, Inc. in 1994 completed a 11,000 m^2 R&D Center in Dalton, Georgia which used concrete reinforced with carpet waste fibers in the construction project. About 20 tons of carpet production waste was consumed in the project, which would otherwise be sent to a landfill. The amount of waste fiber included was 5.95 kg/m^3. Mixing was done by adding fibers to the mixing truck directly, after which the fibers were found to be uniformly dispersed in the concrete without balling or clumping. Mixing, pouring, and finishing followed standard procedures, used conventional equipment, and went smoothly. The compressive and flexural strengths exceeded specifications, and reduced shrinkage cracking was observed. Such concrete containing waste fibers was used for floor slabs, driveways, and walls of the building. The project demonstrated the feasibility of using large amount of carpet waste for concrete reinforcement in a full scale construction project.

Carpet Waste Fibers for Soil Reinforcement

At Georgia Tech, Professors Y. Wang and J. D. Frost are investigating the feasibility of using shredded carpet waste for soil reinforcement in road construction. It has been widely reported that the properties (especially the shear strength) of soil can be enhanced by fiber reinforcement, resulting in a more stable soil structure with improved load-bearing capacities and durability.

The study involves the carpet/fiber industry, several Georgia counties, Georgia Department of Transportation and Georgia Institute of Technology along with other government agencies. Field trial sites for unpaved county roads were selected to represent typical types of soils found in Georgia. Trial sections with carpet waste fibers and virgin fibers were installed in a few unpaved roads. Preliminary assessment by visual inspections confirms that fibers in soil can indeed improve the durability of unpaved roads, and thus reducing the need for frequent regrading. Base on the experience gained during these trials, installation procedures and equipment are being improved.

To evaluate materials for use in improving soil performance, it is vital to have a fundamental understanding of the mechanisms controlling the behavior of the material and soil. This can be done through an integrated set of laboratory tests which assess the mechanical properties and engineering behavior of fiber-soil systems prepared under controlled conditions. This task is carried out at Georgia Tech where a series of laboratory strength and deformation tests are performed to evaluate the relative performance of unstabilized and carpet waste fiber stabilized soils. Test results indicate that under certain conditions such as large deformation, fibers are especially effective in enhancing the performance of the soil.

Summary

Because of the large amount of fibrous waste generated each year and the potential for significant economical benefit, many promising technologies are being developed to convert the fibrous waste into useful products, and some of them have been commercialized. To facilitate the exchange of information on the latest developments in fibrous waste recycling technologies and applications, Georgia Tech has been organizing annual conferences on "Recycling of Fibrous Textile and Carpet Waste" since 1996.

Significant research and development has been conducted at the Georgia Institute of Technology as part of its mission to serve the industry. A brief description is provided in this paper on studies of recycling logistics, waste fiber depolymerization, melt processing, waste characterization, composite products derived from fibrous waste, and the use of waste fibers for concrete and soil reinforcement.

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