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Recycling and Reuse of Mixed-Fiber Fabric Remnants **(Spandex, Cotton & Polyester)**

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Recycling and Reuse of Mixed-Fiber Fabric Remnants (Spandex, Cotton & Polyester)

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1. ABSTRACT

Cut and shredded textile waste containing spandex, cotton, and polyester was processed through a carding machine. Yarn and fabric were produced, but the waste levels in the experimental manufacturing were high and the output quality was poor. An attempt to improve this performance by treating the material with solvents to weaken the spandex actually reduced manufacturing performance. Experiments also aimed to optimize the mechanical action in carding and to reduce the amount of new carrier fiber added to the virgin/recycled blend.

The conversion of the material to a nonwoven fabric is also discussed. A review of the literature on use of recycled fiber in nonwovens was performed. Needle-punched nonwoven fabrics were produced in the laboratory and waste from this process was evaluated for oleophilic and hygroscopic properties.

Possible flock applications for these fibers are also discussed: a review of the literature was performed, the flocking process and potential products were reviewed, and recycled fibers were successfully converted into flock at a commercial manufacturing plant. Subsequently, the flock's ability to absorb energy and its frictional properties were characterized.

The oil absorption characteristics of the selected materials were studied. Results showed that the shredded fabric absorbs oil at a faster rate than typical fibers used for oil-spill clean-up applications. It was concluded that these fibrous wastes, filled into knitted sock booms or pads, could be used where a high initial rate of cleanup of spilled oil is desirable.

2. BACKGROUND

Textile manufacturers in southeastern Massachusetts are expanding into new product lines, generating textile waste disposal problems. This material, worth \$15 to \$25 per square yard when new, loses all value when it is landfilled.

Remnants of cloth from apparel manufacturing in particular are a disposal and cost problem. This is true especially for mixed fiber blends, including those containing spandex. Currently there is no effort to recycle the mixed-fiber fabric remnants.

Griffin Manufacturing Company of Fall River, Massachusetts, produces a line of jogging bras made from mixed fabric fiber that includes between 10 and 15% Lycra spandex, blended with cotton and polyester. The company landfills an estimated six tons of this specific material per month, in addition to other fabrics. That volume has doubled in the last few years and should continue to grow.

3. SCOPE OF WORK

This research project assesses, evaluates, and develops the feasibility of recycling fabric remnants that are produced in the manufacture of sports clothing. The remnant cloth product consists of dissimilar fibers, some of which are very elastic. Because of the dissimilarity of the fibers, stretchable and non-stretchable, reuse has been viewed as uneconomical. A recycled fabric with a value approaching that of the original fibers would divert waste from landfills and preserve the value of the material.

The goals of this research were:

1. to evaluate the problems inherent in separating these fibers, and
2. to develop technology that will allow Griffin Manufacturing and other companies to reprocess waste fabric into textile and/or other products that can be sold.

The research objective is to develop a process to convert the mixed fiber waste into a usable value-added end product by:

1. developing methods to separate the cloth remnant into respective fibers that can be converted into yarn, or
2. developing a new nonwoven mixed-fiber fabric that can be manufactured and marketed at a profit.

4. APPROACH TO WORK AND WORK COMPLETED

The approach to the project has been as follows:

1. Review the literature on relevant subjects:
 - Magnitude of the mixed fiber waste problem
 - Spandex production data and trends
 - Environmental issues with spandex production
 - The recycling process
 - Additional processes such as willowing and garnetting
 - Nonwoven fabrics
2. Evaluate and characterize the remnant material.
3. Perform fiber separation trial at recycling plant.
4. Conduct laboratory-scale processing and testing of the recycled remnants to separate individual fibers, and to card, draw, and spin them into yarn.

5. Improve the yield and quality of the spun yarn by experimenting with chemical treatments to weaken and/or dissolve the spandex fibers.
6. Optimize the yarn-making process and produce a sample knitted fabric from the optimized yarns.
7. Optimize fiber processing sequences to include cotton fibers in the blend, for use as a nonwoven fabric with needlepunch technology.
8. Evaluate waste from this process as a stuffing material for oil booms to absorb oil spills and as a product to absorb water.
9. Study the suitability of the recycled materials as flock. Perform a literature survey and review the flocking process and possible markets for flock obtained from this recycled material. Grind samples of the cut and shredded material into flock at a commercial flock manufacturer.
10. Characterize the flocked material's energy absorption and frictional properties.
11. Characterize the oil absorbing properties of the selected material and determine possible products.

5. Literature Reviews

5.1 Review of Literature on Spandex

Overview

Four companies manufactured spandex in the early 1960s when production started in earnest:

E.I. DuPont deNemours (Lycra spandex)
Monsanto
Globe Manufacturing (Glospan® and Cleerspan® spandex)
American Cyanamid

At that time DuPont controlled approximately 80% of the market. Since then, Monsanto and Cyanamid have ceased manufacturing, and DuPont has expanded international production. Additional competitors have appeared on both the national and international scene. In the United States, Lycra spandex is the best known product.

Since its introduction, spandex has replaced rubber in applications such as girdles and brasseries. Other applications include support hosiery and “active wear” like running and cycling garments, which are made of knitted and woven fabrics containing natural fibers,

notably cotton, and/or synthetic fibers such as nylon or polyester. A small quantity of spandex, usually 10-15% by weight, is incorporated in these fabrics to give controlled stretch and recovery properties to the material.

One might assume that the fibers from these fabrics could be reclaimed, as is the case with many other textiles. However the recycling industry does not attempt to reclaim spandex because of negative experience with the stretchy fibers wrapping up and entangling the recycling machinery. It may be feasible, however, to recycle fabrics containing only 10-15% spandex.

Magnitude of the Problem

One garment manufacturer, Griffin Manufacturing Company, of Fall River, Massachusetts, a partner in this research project, produces a jogging bra constructed of alternating layers of dyed and white knitted fabric. The dyed fabric contains 43% cotton, 43% polyester, and 14% Lycra™ spandex. The white fabric contains 90% CoolMax™ and 10% Lycra spandex (1). CoolMax is a Dupont trademark for fabric containing Dupont tetra-channel Dacron™ polyester fiber (2,3).

1997 data generated by Griffin Manufacturing Co. indicates the possible size of the problem (4):

- 2, 693,273 individual garments manufactured containing Lycra spandex
- Lycra usage equivalent to
 - 107,082 yards of fabric purchased
 - 88,878 yards of fabric used
 - 18,204 yards of fabric thrown away
- Poundage of Lycra spandex/cotton/polyester mixed together and thrown away:
6.6 tons of Lycra spandex, 23 tons of polyester, 36 tons of cotton

It is not known how many garment manufacturers use spandex-containing fabrics, nor how many pounds are landfilled or incinerated. However DuPont lists 26 CoolMax fabric and yarn suppliers in North America and 39 internationally (5).

Of the two fabrics being studied from Griffin Manufacturing Co., the white fabric contains CoolMax and Lycra spandex. The dyed fabric contains a blend of cotton, polyester, and Lycra spandex.

CoolMax fabrics are promoted for active wear, where perspiration is generated. DuPont cites applications in World Team tennis T-shirts and athletic socks, golfing apparel, and N.Y.P.D. bicycle patrol clothing (6). The fabric contains fibers described by DuPont as “tetra-channel” Dacron (3). Synthetic fibers are produced with different cross-sectional shapes depending on the extrusion technology (e.g., melt, solvent, or wet spun) and the end-use application. The cross-sections of these fibers contain four lobes, thus the

description “tetra-channel.” The channels wick perspiration away from the skin surface towards an outer layer of fabric that in turn absorbs the liquid (7). Dupont’s claims about the fabric are summarized in Exhibit 1.

Exhibit 1: DuPont Claims Regarding CoolMax and the Competition (8)

Fabric type	Moisture control	Breathability	Ease-of-care
CoolMax	Fastest drying Wicking	Designed to breathe	Machine wash/ dry. Shrink resistant
Polypropylene	Fast drying No wicking	Affected by fabric structure	Shrinks in dryer.
Electrostatic/ Chemical Treated	Medium drying Sweat clings to chemical treatment	Sweat absorption can reduce breathability	Depends on fabric content
Nylon	Medium drying. Sweat clings to chemical treatment	Affected by fabric structure	Machine wash/ dry
Cotton	Slow drying	Sweat swells fibers: can’t breathe	Shrinks. Looses strength

Spandex Production Data and Trends

In 1997 worldwide production of spandex exceeded 95,000 metric tons. Production is forecasted to grow at a rate of 8.3% per year to almost 114,000 metric tons by the year 2000 (9). Strong growth is predicted for North America: 37,400 metric tons in 2000 versus 24,000 metric tons in 1994. DuPont is still the largest producer by far with nine manufacturing plants. The Waynesboro, Virginia, site has a capacity of 15,000 metric tons, and the other eight plants have a total capacity of about double that amount. DuPont dominates the North American market and has about 50% of the worldwide business.

As DuPont has expanded manufacturing at its Waynesboro site and builds a joint venture production capacity in China, the competition continues to grow. In the United States in particular, Globe Manufacturing (10) doubled its capacity by opening a new plant in Alabama. Globe planned to make yarns of between 15 and 280 denier for sheer hosiery, intimate apparel, body shaping/intimate garments, swimsuits, and active wear.

Also in the United States, the Bayer Group is expanding its recently constructed plant in South Carolina, increasing capacity to 6,400 tons per year. Bayer’s Dorlasten® spandex is sold to the markets described above, as well as to manufacturers of woven goods and medical and industrial products (11).

New and Emerging Markets for Spandex

DuPont claims that 60% of the panty hose sold (according to 1994 data) contains Lycra spandex. Besides this traditional market, new applications, such as socks containing

Lycra covered with air-jet textured yarn, are developing. Globe Manufacturing believes sweaters and men's trousers are potential applications for their Glospan and Cleerspan spandex fibers (12).

The ready-to-wear market has shown interest in adding spandex to products that traditionally don't contain that fiber, for example in blends with cashmere, triacetate, wool and rayon in dress pants and skiwear, and silk in slippers. Nylon/spandex blends have appeared in apparel ranging from bathing suits to evening gowns (13). Spandex enhances fibers that by themselves have certain disadvantages. For example, acetate knits, while crisp to the touch, have very little elasticity. Similarly, cashmere's softness can be complemented with the additional stretch provided by spandex.

Lycra Soft™ is a new DuPont product made from a spandex with more stretch. The aim of this product is to reduce red marks and constriction in men's socks and women's knee-highs, to make them more comfortable and less restrictive (14). Lycra Type 178C, another new product, is a yarn developed to improve a fabric trademarked as Lycra 3-D sheer leg wear. The yarn is 18 denier, making it a very thin material (this is about the same thickness as the finest of Globe's Type S-85 and Bayer's yarns). DuPont is also combining Lycra Soft in the waistband with Lycra 3-D in the legs of pantyhose.

In general, the technology of manufacturing stretch-woven fabrics is not widely understood. However Globe Manufacturing views it as the next big market, possibly matching the boom in circular knits in the late 1980s (15).

More traditional fibers are experiencing new developments concurrent with these market and product changes in spandex. BASF predicts continued success of stretch fabrics using spandex and nylon (15). Accordingly, BASF introduced a family of very fine denier, high filament-count nylon for increased softness and better wicking of moisture. Cytec has seen growth in its acrylic microfiber business, and Hoechst Celanese is promoting the antimicrobial properties of its acetate. All of these fibers could be combined with spandex for new products, creating additional challenges for recycling of fabric remnants.

Environmental Issues With Spandex Production

Terathane polytetramethylene ether glycol (PTMEG) is the feedstock for the production of Lycra spandex and other elastomers. A new process has been developed that uses a proprietary acidic catalyst for polymerization. The process drastically cuts the production of acid waste (16). Unlike the earlier process, the catalyst can be recycled within the new process (17).

Both the Occupational Safety and Health Administration (OSHA) and the U.S. Environmental Protection Agency (EPA) are writing regulations that will make it more difficult to use chlorine-based bleaching agents, including hypochlorite, the traditional bleach used in the cotton hosiery industry. The industry is moving towards the use of

hydrogen peroxide instead. This is a fortuitous trend since the strength and recovery powers of spandex can be degraded by hypochlorite.

Studies on the effects of hydrogen peroxide and sodium hypochlorite bleaching on the strength of 40 denier Lycra T-146 spandex show that the spandex lost most of its strength when treated with hypochlorite for fifteen minutes at low pH values (pH <11). But it was virtually unaffected when exposed to peroxide at those levels of pH for twice that time (18).

5.2 Review of Literature on Mixed-Fabric Remnant Recycling

For mixed fabric remnants, the recycling process involves (a) cutting fabric pieces into smaller pieces, (b) tearing at the fabric pieces to obtain relatively isolated fibers, and (c) packaging the fibers into bales.

The process may also be supplemented with the following steps:

- Bale cutting: to automatically cut textile bales and feed them to the next process. The material is fed on a conveyor belt and cut by a powerful knife (19).
- Electronic metal detection: to stop the machinery when metallic objects are detected.
- Fiber blending: to obtain the desired mixture of fibers for optimum quality.

A typical process is as follows:

- Fabrics are removed from the bales, manually or with a bale cutter.
- Fabric pieces are blended (20).
- Fabric pieces are cut with a rotary blade. The principle is similar to that of a lawn mower with a rotary blade. Some cutters are capable of separating metallic objects from the fibrous material (21).
- “Picking,” “pulling,” and “tearing” are three names for the process that separates the fibers from the fabric. Spiked surfaces on drums make contact with the fabrics and remove fibers. The process can involve from one to six machines in a sequence, depending on level of aggressiveness required. Each machine in the sequence has progressively finer but denser spikes (22).
- Fibers are blended. This might take fibers from several machines and place them sandwich-like on a conveyor belt (23). Alternately the fibers could be mixed in a silo-like container (24) or vertically entered into narrow chambers and removed horizontally (25).
- Fibers are baled.

Production rates depend on machine capacity and the type of material being processed, but figures quoted range from 300-3000 kg/hour per production line (26).

At least two of the equipment producers are headquartered in Prato, Italy. Italian textile manufacturers have used recycled fiber as a feedstock for their operations. However this segment of the textile business has been slow. Thus recycling machinery manufacturers have increased their export activities, particularly to Germany, the United States, and Turkey (27).

Additional recycling processes might include willowing or garnetting. Willowing is a process similar to the textile carding process where fibers in the grip of metallic teeth on the surface of a drum are dragged through the teeth of other surfaces. The machine opens and partly cleans compact and entangled fibers including unscoured wool, wool fibers matted from wet processing, and hard-compact man-made fibers. It might be used as a post-recycling process prior to carding and spinning. (28).

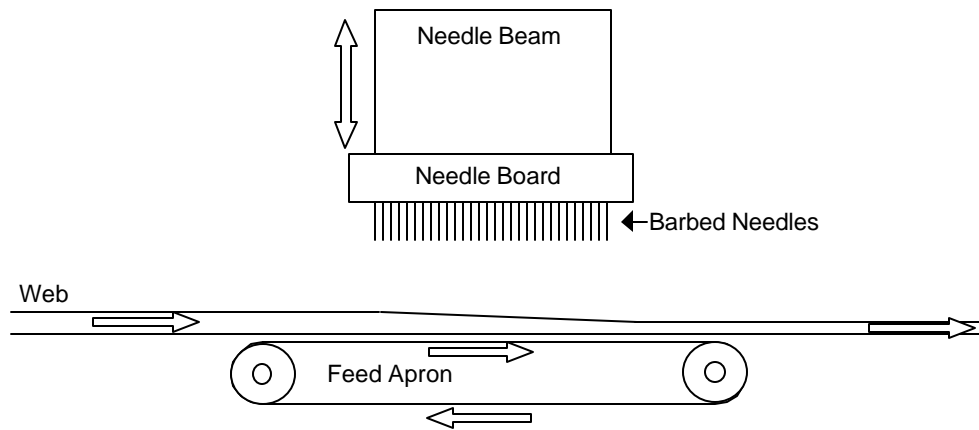
The garnett machine was developed nearly 150 years ago in West Yorkshire, England. It is capable not only of processing the type of material described above, but also can reduce cord, thread, carpet backing, filament, and fabric trim to fibers. The machines have four main rotating cylinders covered with a saw-tooth wire that sit below a series of worker rollers. A carding of the fibers occurs between the surfaces of the main and worker cylinders. Garnett machines have a production capacity of 50-300 kg/hour (29).

5.3 Review of Literature on Nonwovens

The Textile Institute (30) defines nonwoven fabrics as textile structures made directly from fiber rather than yarn. These fabrics normally are made from continuous filaments or from fiber webs or batts strengthened by bonding, using various techniques including adhesive bonding, mechanical interlocking by needling or fluid jet entanglement, thermal bonding, and stitch bonding.

Laboratory experiments used the needlepunch method for fabricmaking. The Textile Institute defines needling (or needlepunching, needlefelting, or needlebonding) as the use of barb needles to entangle a fiber web or batt by mechanical reorientation of some of these fibers within its structure. In the needle loom itself, the needle beam reciprocates up to 2000 cycles per minute (in 1991) causing barbed needles, mounted on a needle board in a density of 300-5000 per meter, to pass through the web or batt, which in turn is supported between plates containing holes through which the needles pass.

Exhibit 2: The Needling Process



The TexGuide web site (31) describes various ways, besides needlepunching, of producing nonwoven fabrics:

1. Dry Process in which the fibers are prepared using traditional opening and carding textile machines adapted for the purpose. The card produces webs that are placed one on top of the other in various geometric arrangements. Names given to some of these arrangements are parallel, cross, composite, and random. Each arrangement gives different fiber orientation. Then the fibers in the web are reinforced by one of the following techniques:
 - Needlepunching as described above.
 - Stitchbonding where the webs are reinforced by yarn stitching, a principle similar to warp knitting.
2. Chemical Bonding System in which a chemical is used to reinforce the web, typically a rubber-based, thermoreactive, or thermoplastic bonding agent in solution, powder, or fiber forms.
 - Solution bonding. A solution such as acrylic latex is used.
 - Powder adhesives. The most popular type is thermoplastic.
 - Fiber adhesives. Between 5-40% by weight of these fibers is mixed in with the base fibers. The web is then hot-calendered to cause the bond to form. The binder fibers must have a lower melting point than the fibers in the web and will be softened or melted by a hot-calendering process, causing the bond to form.
3. Spunbonded Fabrics are those in which a web structure is produced by randomly oriented continuous filament fibers that self-bond to one another by chemical or heat

treatments. A very wide range of spunbonded products are made, but because the starting material is a polymer, not reclaimed fiber/fabrics, further discussion of this technology is not particularly relevant to this project.

4. Spunlaced Fabrics are those in which the fibers in a web are entangled in a repeating pattern to form a strong fabric, free of binders.

Markets for Needlepunched Fabrics

One company, The Felters Group (32), manufactures a line of felt-like materials named Fiberloc™. The product is available in various forms, densities, and finishes, and can be made from synthetic and/or natural materials. Thickness can range from 1/16 inch to 1 ½ inches. The company states that since they maintain over 7,000 dies made in-house, they can customize client-specific felt parts. These are about half of the markets for felted products:

Lubrication and seals	Automotive anti-rattlers	Polishing
Liquid filtration	Felt circles and discs	Equestrian
Specialty gaskets and seals	Boots and shoes	Insulation
Noise dampening products	Eraser felts	Orthopedic
Vibration	Washers	Weather-stripping

Home Furnishings. The nonwovens.com web site (33) discusses the market for nonwovens in home furnishings. This is a large-volume, relatively low-margin market for nonwovens. It breaks down into two major product categories, furniture and bedding, followed by much smaller markets for drapery linings, blankets, wallcoverings, and mattress pads. The U.S. market for these products is described as mature with an annual projected growth of 5% per year. This growth is explained in terms of the baby boomer generation having reached the “historically prime age for the purchase of furniture and bedding.” At this rate, the industry projects that the total volume of nonwovens consumed in the domestic market, in the specific home furnishing areas of furniture and bedding, to increase to 600 million square yards, up from 425 million square yards in 1991.

Upholstered Furniture. Prior to the popularity of nonwovens, fabrics such as wool, horsehair, jute, and cotton were used to cover furniture. Today nonwovens are used as internal construction fabrics in the arms and backs of chairs and sofas and as spring insulators. The specific fiber most commonly used in these applications is high-loft variants of polypropylene fiber called “fiberfill.” It is important to note two facts. The first is that in the early 1990s the furniture industry adopted the Upholstery Furniture Action Council guidelines concerning stringent fire safety codes in the U. S. The net effect was that the waste cotton filling used up to that period was replaced by synthetic fiberfill. Secondly, the waste fabric in the present study contains over 40% cotton. Because it is thought that many states will adopt California’s CAL 133 or similar flammability requirements for contract furniture, there could be problems in using the reclaimed fiber in this study for furniture applications.

Bedding Fabric. Nonwovens are used for spring insulators, spring wraps, dust covers, and quilt backing. Some stitchbonded and needled fabrics are used in low-end mattress and foundation ticking in the upper cushioning layers just beneath the mattress ticking. (Ticking is defined as a general term applied to fabrics used for mattress covers, pillows, etc. in *Textile Terms and Definitions*, *Textile Institute*, 1991.) Major players in this area are DuPont Nonwovens, KoSa, CMI Industries, and Veratec, a Walpole, Massachusetts, company that made a product called Everloft™ before being purchased by BBA Nonwovens.

DuPont’s Comforel™ contains fibers that have a spiral shape, simulating down/feathers. Besides being sold as a pillow stuffing, Comforel has been marketed as a mattress topper. The KoSa product, Serene™, is another bedding product with claims that it does not lump or mat, and is nonallergenic, machine washable, and soft. CMI Industries produces Fiberwoven, made from polyester and marketed for the young bed-wetting market and the older incontinence market. Veratec’s Everloft was a treated cotton material that had high resiliency and durability. Applications included pillows, quilts, mattress pads, comforters, bedspreads, and wallcoverings.

Geotextiles. These items are defined as “any permeable textile material used for filtration, drainage, separation, reinforcement, and stabilization purposes as an integral part of civil engineering structures of earth, rock, or other constructional materials” (*Textile Terms and Definitions*). This is a large and growing market with projections of U. S. sales of almost 600 million square yards by the year 2000. Although wovens and knitted fabrics are produced for this market, spunbonded and needlepunched nonwoven fabrics have always been the predominant form of fabric construction, primarily because of cost and performance.

The Industrial Fabrics Association International (IFAI) projected in its publication *Geosynthetic Market Support* (34) growth in the geotextile/civil engineering market as shown in Exhibit 3.

Exhibit 3: Geotextile/ Civil Engineering Market Segments
(Millions of Square Yards)

Market Sector	1995	2000 (est)
Soil Stabilization/Separation	118	175
Asphalt Overlay	107	123
Liners	80	131
Reinforcements	30	47
Drainage	46	55
Erosion Control	24	33
Silt Fences	23	32

Environmental Protection Fabrics. This market received a boost in the early 1990s when the U.S. Environmental Protection Agency issued the first federal standards for municipal solid waste landfills. The standards require liners to prevent leakage and protect groundwater and soil. Needlepunched fabrics are used as a geotextile cushion specifically where there is need for puncture protection on top of the liner, as blankets in drainage systems inside the landfill, as a tarpaulin on the outside of the landfill, and as underneath riprap (gravel-like material) for erosion control.

5.4 Review of Literature on Recycling of Nonwoven Textiles

Although the literature contains many articles on nonwoven fabrics, a search of *Textile Technology Digest* with specific reference to the subject of nonwovens from recycled fibers uncovered only a few relevant papers. In one, Walker (35) discusses the complexity of the fiber recycling business, which involves the interaction among manufacturers, dealers, and brokers. The author's list of potential markets for nonwovens from recycled fiber includes healthcare and surgical supplies, home furnishings and automotive fabrics (e.g., trunk liners, insulation). Walker discusses the risks associated with this business and states that "fiber recycling is a risk-taking entrepreneurial pursuit that is best suited to smaller companies that can adjust quickly to changing market conditions."

Boettcher and Schilde (36) note that the use of recycled fiber in the manufacture of nonwoven fabrics is increasing. However the lack of uniform quality of the recycled fiber is a serious problem. They refer in particular to improperly opened fibers and too much variability in fiber length. They suggest that the development of an effective device for separating long and short fibers would contribute to the growth of this business.

Articles by Watzl (37, 38) provide an overview of the sources of textile waste in Europe. He places this waste into the following categories: (1) textile production waste (fibrous materials/textiles), (2) used textiles (worn out and/or no longer used), and (3) textile secondary raw materials (fibrous waste generated in the production of textiles or nontextiles from recycled material). He notes that textile plants, in particular those furthest down stream such as fiber manufacturers and yarn spinners, tend to recycle as much as possible. On the other hand the sorting of used textiles, such as clothing, used to be relatively simple. But as the number of fiber blends (such as polyester/cotton, wool/nylon) has increased, it has become more difficult to standardize further processing.

Watzl lists some automotive applications for nonwovens from recycled fibers. Those from resin-bonded webs are formed into flat molded parts with self-adhesive surfaces or are provided with a heavy coating and serve as sound and shock absorbing materials. A second group consists of molded parts with or without textile lamination and serves both as sound insulators and as self-supporting stylish components, for example, insulation fitted under the hood, in the roof section, and in trunk linings. A third group consists of hard-pressed parts used to line doors, backs of seats, and roofs.

6. Experimental Results

6.1 Producing Yarn and Woven Materials

6.1.1 Fiber Separation Trial at a Recycling Plant

The Process

This trial was designed to study the problems inherent in breaking down the fabric remnants into smaller pieces and ultimately into fibers (which, as discussed above, could be separated into spandex and cotton/polyester components). Approximately 50 pounds each of the white (polyester/spandex) and blue (cotton/polyester/spandex) fabrics were processed at Mill-Tex Fiber Processing Company, Millbury, Massachusetts. See Exhibit 4 for remnant characterizations.

Exhibit 4: Evaluation and Characterization of the Remnant Material

	Blue Outer Layer	White Lining Fabric
Fiber Content	43% cotton, 43% polyester, 14% Lycra spandex (1)	90% DuPont CoolMax polyester, 10% DuPont Lycra spandex (1)
Fabric Structure	Circular jersey knit: one feed cotton/polyester and one feed Lycra. Approximately 22 threads/cm in wales direction and 27 threads/cm in courses direction.	Circular jersey knit: one feed CoolMax polyester and one feed Lycra. Approximately 28 threads/cm in wales direction and 27 threads/cm in courses direction.
Fabric Weight	Approximately 256 grams/sq. meter	Approximately 194 grams/sq. meter

The white fabric was processed first. The materials were machine-cut into pieces of various shapes and sizes, with typical dimensions of 1 cm x 8 cm. The pieces were conveyed to a condenser and then to a three-process Laroche picking machine which pulled and tore at the material. The process ran well; the concern that the spandex would wrap around the cylinders proved to be unfounded. However the output, although shredded, was not yet in a purely fibrous state. So the material was run through the pickers a second time, with the tearing cylinders set with a closer gauge.

The blue fabrics were processed similarly. They were cut and then passed twice through the picking machines, with close settings for both passes.

The outputs of both the white and blue fabric runs were as follows:

- Unraveled fabric pieces typically measured 0.75 cm x 4 cm.
- Yarns pieces typically measured 1-2 cm in length.
- Fibers typically measured less than 1 cm.

Observations

- The processing was unexpectedly trouble free, especially since this was the first time this material had been processed through these machines. The throughput (pounds per hour) was low, but would likely increase with larger volumes of material and with more mill experience.
- The output material was not what was expected. Rather than the expected fibers, mostly small, unraveled fabric pieces were produced.

6.1.2 Laboratory Scale Processing of the Recycled Material: Carding, Drawing, Spinning, and Knitting

The author attended a Fiber Society conference in July 1999 at Asheville, North Carolina, where he discussed this project with Dr. Abdelfattah Seyan of the College of Textiles, North Carolina State University. Subsequently samples of the blue outer fabric and the white lining fabric were sent to Dr. Seyan for processing on the College's garnett machine. This machine consists of rotating main cylinders and worker rollers that reduce materials to a fibrous state. The College's laboratory manager and a technician evaluated the blue and white materials and, based on their experience, stated that the garnett machine would not separate the fibers.

The University of Massachusetts Dartmouth owns a Davis and Furber sample woolen carding machine. The machine also is known as a roller top card. The machine was re clothed by the Redman Company with aggressive metallic clothing. In other words, the drums and rollers in the machine were given new surfaces of metallic materials not unlike a continuous saw blade wrapped around the cylinders. The purpose of re clothing the machine was to simulate the garnetting/willowing processes. Because of the age of the card, Mr. Ravinder Singh Ginoira, a research assistant, constructed a safety cage around the machine to protect the people working on it.

The blue picked material (the output of the trial at Mill- Tex), which consisted of small fabric pieces, short yarns, and fibers, was processed through the re clothed carding machine. The machine ejected some of the material as soon as it entered the machine, at the first two opening rollers, called lickerins. This machine was designed to process long wool fibers, and since the material being fed was short and relatively heavy (yarn and

fabric pieces), ejection was inevitable. For every 40 grams of output material, between two and three grams were ejected. However this problem was minimized if the lickerins were bypassed by feeding the material directly to the worker rollers.

The card effectively broke down the yarn and fabric into fibers. However some very small pieces of yarn and fabric still were found among the fibers. Some of this material built up on the worker surfaces. It is not known whether the fabric would continue to build up or would reach equilibrium.

During the last run of this trial the ejected material and the buildup material on the workers were collected, mixed with the remaining feed material, and processed through the card. This output contained more small pieces and yarns than the previous runs. In other words, some small pieces would not reduce to a fibrous state.

The output fibers (along with the small pieces of yarn and fabric) were double carded with a flat top card, the type of machine used for cotton and other short fibers. The purpose was to further open the fibers and to produce a lap for subsequent processing into sliver and yarn. Just as before, material was ejected at the lickerin, and material was found to build up on the flats (these have the same function as workers on the other card). The fibers were processed on the machine a second time; this time 25% new acrylic fiber was added as a carrier. Even so, a coherent web was only possible with constant guiding of the material by hand.

The collected web was then processed on a drawing machine, which uses a series of smooth rollers to draft out the fibers. The residual small pieces of yarn and fabric caused the fibers to move as bundles, not as individual fibers. The result was frequent breaks in the sliver. After three drawing passes, the sliver was entered into a laboratory ring spinning machine. The material processed by this machine was so uneven that it was judged to be unspinnable.

The carded and drawn material was collected and blended with additional amounts of acrylic fiber so that the resultant blend was 80% new acrylic fiber and 20% recycled material (the blue outer fabric). This blend was carded, drawn, and spun without incident. The yarn was spun to a count of 36's (about the fineness of yarn in shirting material) with a twist of 19.5 turns per inch.

It was possible to knit, from the yarn, a small piece of fabric on a hand-driven circular knit machine. However it must be borne in mind that (1) the fabric contains many clumps of entangled fibers giving the fabric a poor appearance and (2) this is not yet an efficient process with at least 50% of the input material removed as waste by the carding process.

6.1.3 Chemical Treatment of the Samples

Two chemicals, sodium hydroxide (NaOH) and sodium hypochlorite (NaOCl), have been suggested as candidates for weakening the spandex. Destabilizing the spandex would reduce its tendency to coil around and lock onto the polyester and cotton fibers.

Treatment with NaOH

Samples of the unraveled fabric pieces weighing 0.2 grams (the same material as used throughout these experiments) were immersed and agitated in 10 ml of NaOH as shown in Exhibit 5. Although all samples became discolored by the treatment, only the 20% NaOH concentration resulted in an observable loss of strength.

Exhibit 5: Treatment of Samples with NaOH

Sample	NaOH Concentration	Temperature (° C)	Time (hours)
1	5%	Room	24.0
2	10%	Room	24.0
3	20%	Room	24.0

Treatment with NaOCl

Unraveled fabric samples weighing 0.2 grams were immersed and agitated in 10 ml of 5% NaOCl as shown in Exhibit 6. Although all of the samples became discolored by the treatment, none sustained any appreciable loss of strength.

Exhibit 6: Treatment of Samples with NaOCl

Sample	5% NaOCl Concentration	Temperature (° C)	Time (hours)
1	25%	Room	24.0
2	50%	Room	24.0
3	100%	Room	24.0

Followup treatments with NaOH

Additional experiments were run sequentially using NaOH at elevated temperatures at various concentrations and times as shown in Exhibit 7. The samples treated at 50 °C for four hours were microscopically examined. Only the sample processed with 20% NaOH showed any degradation. At 100 °C samples showed some loss of strength after 0.5 hours and more loss after one hour. This was more pronounced at a concentration of 10%.

Based on these experimental results, it was decided to process a larger (67 gram) sample with 10% NaOH at 100 °C for one hour, and then card and spin the fibers.

Exhibit 7: Followup Treatment of Samples with NaOH

Sample	NaOH Concentration	Temperature (°C)	Time (hours)
1	5%	50	4.0
2	10%	50	4.0
3	20%	50	4.0

Sample	NaOH Concentration	Temperature (°C)	Time (hours)
4	5%	100	0.5
5	10%	100	0.5
6	5%	100	1.0
7	10%	100	1.0

6.1.4 Mechanical Processing of the Chemically Treated Samples

Experiment 1

Fabric pieces weighing 67 grams were treated with 10% NaOH at 100 °C for one hour. Then the material was processed on the roller top card. The weight of the output material was 21.8 grams. At first glance, it would appear that the yield was only 32.5%. Most likely if additional amounts of material were processed, the fiber buildup on the carding surfaces would reach equilibrium, giving rise to a significantly higher yield. The output (the 21.8 grams of fiber) was mixed with 21.8 grams of virgin (new) acrylic fiber (1 inch in length/1.5 denier), for a total of 43.6 grams, and then carded twice using a sample flat top card, and drawn twice on a sample drawing frame.

During the first passage through the flat top card, the web broke several times. The brownish chemically treated fibers remained entangled in clusters, whereas the white, virgin fibers became straightened by the carding action. The second carding resulted in less entanglement and better distribution of the recycled and virgin fibers. Of the initial 43.6 grams fed, the output after the second carding in web form was 25.7 grams, a yield of 58.9%. Although waste was removed at several places in the card (flats, card cylinder loading, under card, feed roll to lickerin), 64.2% of the waste was entangled clumps of recycled fiber ejected under the card due to centrifugal force, since the entangled fibers have greater mass than individual fibers.

After carding, the fibers were drawn twice and then ring spun into yarn. The spinning process was difficult because the yarns frequently broke. Exhibit 8 compares these results with those obtained when spinning the 80% new acrylic/20% recycled blend (not chemically treated) described earlier.

Exhibit 8: Spinning Performance of Chemically Treated Materials Compared to Non-Treated

Run	Yarn: 80% New Acrylic/20% Recycled (Not Chemically Treated) Time Between Yarn Breaks (Sec.)	Yarn: 50% New Acrylic/ 50% Recycled (Treated with 10% NaOH, 100 degrees C, 10 min.) (Sec.)
1	---	9
2	---	1
3	---	8
4	---	7
5	---	6
6	---	17
7	---	20
8	---	30
9	---	6
10	---	60
11	---	30
12	---	3
13	---	4
14	Yarn did not break after 527 seconds	2

Based on these results it was decided not to proceed with additional chemical treatment experiments, but to concentrate on improving the separation of the fibers by mechanical means.

Experiment 2

This experiment is similar to the 80% new/20% recycled blend described above where the yarn continued to run even after 527 seconds. However this time the recycled fibers were double-carded on the roller top card for better opening. The yield was 69%, an indication of more efficient carding than with the chemically treated fiber. The percentage of new acrylic fiber added was reduced to 60% from 80%, an attempt to reduce material cost and increase recycled content.

During the spinning trial, these 60/40 fibers performed worse than the 80/20 blend. The yarn broke after running for intervals of 2, 107, 33, 80, 180, 18 and 17 seconds.

6.2 Producing Nonwoven Materials

Cotton fiber with a staple length of approximately one inch and a middling grade were processed on commercial opening, cleaning, and picking equipment to produce picker laps. The fibers then were carded with a Whittin card in the University of Massachusetts Dartmouth fiber processing laboratory.

Cotton sliver from this process was blended in a ratio of 33% cotton and 67% recycled CoolMax blue outer layer fibers. Additional quantities of fibers were obtained by passing the cut and shredded material through a Davis and Furber sample woolen card. The output of this process was hand-blended with the cotton sliver, lightly sprayed with a commercial anti-static agent, and double carded with a flat top card, using the same

procedure described earlier. In spite of the anti-static spray, during the first passage the card web tended to cling to metallic surfaces. The web had to be guided by hand onto the collecting drum to prevent breakage. This is the same condition experienced previously. It is believed that better control over the laboratory humidifier system would have improved performance.

As in previously described trials, the fibers were carded a second time with the flat top card, resulting in greatly improved performance, as the fibers became less entangled and more oriented each time they passed through the card. The card was thoroughly cleaned of fibers after this second carding. These waste fibers were collected and weighed with the following results in Exhibit 9.

Exhibit 9: Waste Fiber Characterization after Second Carding

Material Feed to Card	Waste (grams)/% of Material Fed	Composition of Waste	% Removed as Waste
20 grams fiber from CoolMax® + 10 grams cotton = 30 grams total	11 grams/37%	10 grams fiber from CoolMax® + 1 gram carded cotton = 11 grams	$10 \div 20 \times 100 = 50\%$ CoolMax $1 \div 10 \times 100 = 10\%$ cotton

Needlepunching the Webs

The card webs, after the second carding, were then placed on top of a paper-thin, spunbonded nonwoven fabric and secured with double-faced tape. This spunbonded material, carrying the card web, was fed into a James Hunter Fiber Locker, a needlepunch machine, with a needle density of 81 needles per square inch.

Several needled fabrics were produced in this manner:

1. Single density web: the web as it came off the card was used, ½ inch thickness after needling.
2. Double density web: the card web was folded, then needled, 1 inch thick after needling.

The experiment was repeated using 33% acrylic fiber as a carrier instead of cotton. The carding performance and composition and proportion of waste removed were the same as observed with the cotton blend, as were the needled fabrics produced.

In all cases the material processed without incident in the needlepunch machine. The resultant needled nonwovens had a satisfactory appearance with the double density

products looking the best. The main problem with this process is the high proportion of waste fiber generated during carding.

Observations on the Carding Waste

The fiber waste could be blended with new fiber and carded over and over again. Each passage would result in further straightening of the fibers, allowing some of the fibers to become part of the output card web. Some of the fibers again would be ejected as waste. The fibers which become part of the card web could be made into yarn and then into fabric, or could be converted into a nonwoven. But the economics suggest that the most likely use of the carding waste material would be as a stuffing.

One possible application is as stuffing in oil booms, or socks, used clean oil spills. The CoolMax waste is approximately 40% polyester, an oleophilic fiber (has an affinity for oil). Samples of waste fiber, 0.5 g, were compressed by hand into balls and immersed in 100 ml of mineral oil. The time for the balls to sink under the oil surface ranged from 29 to 30 seconds. The oil rapidly attaches to the fiber, making the waste fibers a good candidate for oil booms.

The waste also contains approximately 40% cotton which is hygroscopic (it absorbs water). Samples of waste fibers, as above, were placed in 100 ml of tap water plus a drop of surfactant. The time for the fibers to sink below the surface of the water ranged from 45 to 48 seconds. Thus the fibers are a candidate for a product that requires some ability to absorb water. Perhaps the fiber could be used in diapers if additional highly hygroscopic materials are added.

Other possible uses for the waste include stuffing for pillows or mattresses (the presence of spandex gives the material some spring) or the material could be chopped into flock.

6.3 Producing Flocking Materials

6.3.1 Flocking Study

Overview of Flocking Process

Flocking is the application of fine particles (flock fibers) to adhesive coated substrate surfaces. The majority of flocking done uses finely cut natural (cotton, wool, etc.) or manufactured fibers (nylon, polyester, rayon, acrylics, etc.)

Flock imparts a decorative and/or functional characteristic to the surface and can be used to create a variety of products:

- **Decorative and Visual Appeal/Apparel:** Wall coverings, greeting cards, jewelry display backings, toys and crafts, and numerous other applications.
- **Friction/Drag Modification:** Flocked finishes can be designed to either increase or decrease the frictional characteristics of the substrates.

- **Sound Dampening and Insulation:** Flocked wall coverings for music studios, flocked coatings for car ventilation units, flocked computer and printer housings
- **Heat Insulation and Thermal Stability:** Flocked blankets, comforters, and flocked upholstery products.
- **Transition-less Power Transmission:** Flocked clutch surfaces for electronic equipment.
- **Liquid Retention or Dispersal:** Paint /cosmetic applicator.
- **Buffing and Polishing:** Flocked buffing and polishing wheels for optical industry.
- **Cushioning and Protection:** Flocked packaging materials for sensitive instruments and jewelry products and scratch-proofing of surfaces.

Flocking can be accomplished using a number of methods:

- Mechanical (Beater-Bar) method
- Electrostatic method
- Electrostatic/Mechanical method
- Pneumatic/Electrostatic method
- Pneumatic/Turbo-Charging method

Target Products Using Flocked Fibers from Reclaimed Fabric Waste

Flock fibers from reclaimed fabric waste are chopped, ground, and sifted. They are mixed colors, typically gray, and the fiber dimensions depend on the sift mesh used. These fibers are best used with a product where the surface color is not critical and the pile height is about 1 mm or shorter. With these characteristics in mind, there are several potential target products for this material:

1. **Increasing surface area for evaporation and filtration.** Metal building anti-condensation flocked panels, machinery parts with reduced condensation, and oil spill management.
2. **Sound absorption and vibration isolation.** Flocked wall coverings for music studios, flocked coatings for car ventilation units, flocked computer and printer housings, acoustical absorption in metal buildings, and industrial ceiling treatments.
3. **Cushioning and shock isolation.** Flocked packaging materials for sensitive instruments and jewelry products and scratch-proofing of surfaces.

Experiments at Flocking Manufacturing Plant

Samples of cut and torn dyed fabric (43% cotton, 43% polyester and 14% Lycra spandex) and cut and torn white fabric (90% polyester and 10% Lycra spandex) were brought to Claremont Flock Corp., Leominster, Massachusetts, for conversion into flock. The material was processed on a flock grinding machine that tears at the material, producing flock of random lengths. The material processed in a very satisfactory manner, and it was

the opinion of the Claremont staff that there would be no problem processing large quantities of the material. A small quantity of fabric had been cut at Talbert Trading Company, but not torn. Fabric pieces typically measured 0.75 cm x 4 cm. These small pieces also were ground into flock. It was the opinion of the machine operator that this material was more easily ground than the fully cut and torn material. This suggests that the optimum commercial process would be a truncated version of the experimental process.

The surface conductivity of the resultant flock was measured to be zero. Thus the flock in its present condition would not be attracted to substrate fabric. A small quantity of finish was later sprayed onto the flock to make it conductive.

6.3.2 Products Employing Flock Fibers from Textile Waste Materials

Background

The purpose of this phase of the research was to evaluate practical uses of the textile wastes as various products made with the flocking process. Several questions were posed by this initial study:

1. Can textile wastes, which can be a mixture of various fibers, be cut, chopped, and/or ground into fibers that will be suitable for flocking?
2. Can these processed fibers be properly flocked?
3. If these fibers can be properly flocked, what are the product applications?

If textile fabric waste can be processed into a suitable flock fiber, several application areas will be evaluated. For example, flock coatings are presently being used for undercoating the interior of metal roof storage buildings. This is found to prevent ceiling moisture condensation from forming as well as decreasing the sound (by a vibration damping mechanism) of rain or hail. The flocking materials might also be used to create light absorbing/non-reflective surfaces. Another possible application would employ the frictional characteristics of flocked surfaces. Here, the use of flocked surfaces for electro-mechanical clutch face plates is a possibility. This would be especially applicable in miniature mechanical actuating devices employing fractional horsepower motors. The feasibility of using recycled flock fibers in some of these applications was investigated in this study.

Flocking Behavior of Textile Waste Generated Flock Fibers

The first part of this project involved converting the available knit fabric waste which consists of polyester, cotton, and Lycra mix (PCL) to a suitable flocking material. Fabric scraps from a local apparel manufacturing company were picked into short yarn segments and torn fabric pieces. This shredded waste fabric was sent to Claremont Flock Company, Leominster, Massachusetts, for conversion into flock material. Here, a conventional

chopping of the waste fabric was ruled out because of the Lycra elastomeric component in the waste. It was decided that grinding the waste with an abrasive wheel would be the process of choice. This process is frequently used in converting staple fibers or single fiber textile waste materials into flockable fiber fragments.

Examining the ground material in the Flock-In-Spec viewing device showed it to be diverse in length (0.05 to 0.5 mm). A photomicrograph of this ground product is shown in Exhibit 10. This ground material was found to be quite irregular. The fibers were fragmented and not straight. Irregular and curled fibers, as well as small fiber clumps believed to be the Lycra, characterized this converted experimental waste material.

Typical blade-chopped polyester flock fibers are shown in Exhibit 11 for comparison. Overall, the PCL textile waste materials were able to be processed into fine fiber elements suitable for flocking trials. Regardless of the observed differences between typical flock fibers and the converted (ground) textile waste, flockability testing of this experimental material was performed. Using a hand held DC flocking device at 70 kv, the PCL experimental flock was deposited on a vinyl-base adhesive (BFG-FL1059B) coated onto 1/16" thick aluminum sheet. Here a smooth, lightly speckled, gray, non-light reflecting flocked surface was successfully created. After these flocked aluminum sheet test samples were cured one hour at 80°C and vacuumed, they were ready for evaluation. Overall, the flocked surface was visually acceptable. Microscopic examination, however, showed irregularities in length of electrostatically flocked fibers. This is to be expected because of the variation of fiber length in the flock material from the ground waste fabric.

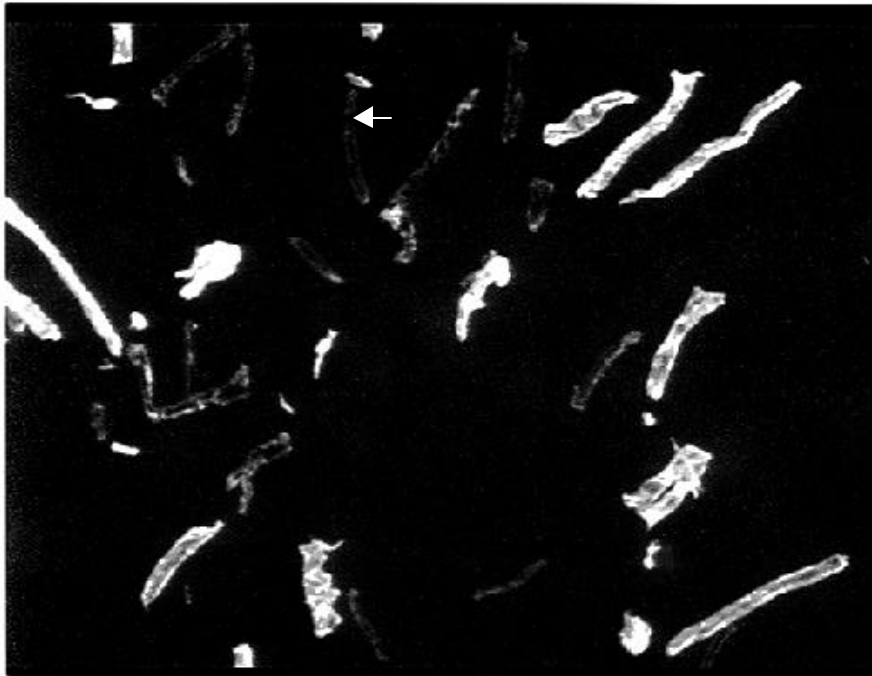


Exhibit 10: Photomicrograph of Ground Fibers (Flock) from Waste Fabrics

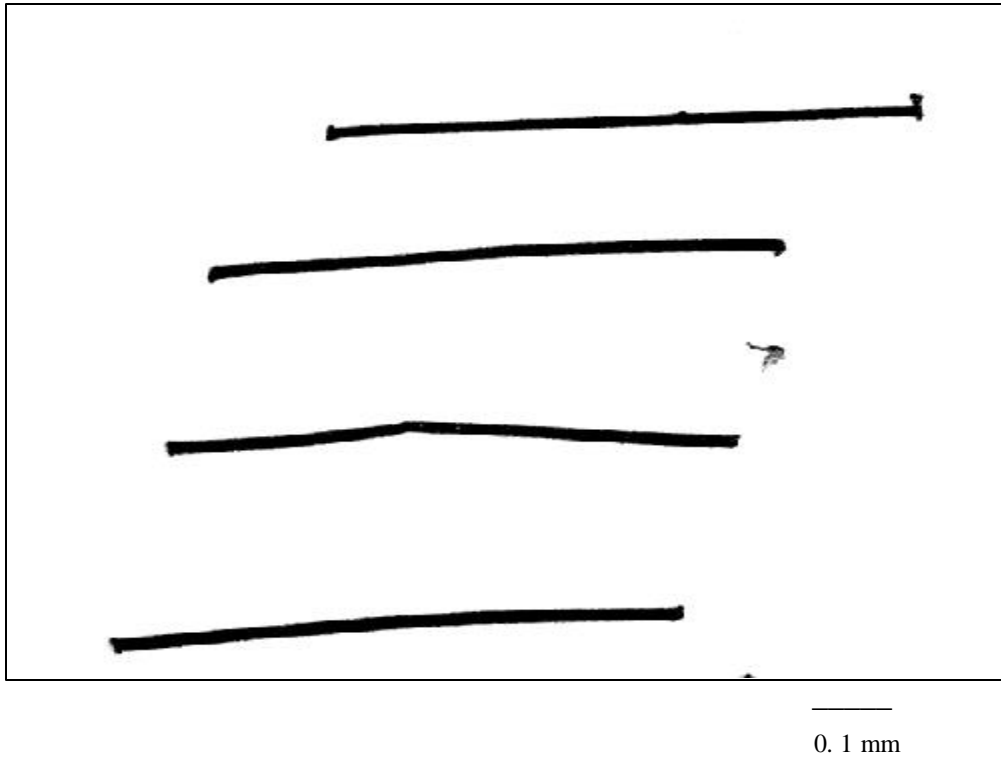


Exhibit 11: Photomicrograph of Typical Polyester Flock Fibers

All the ground waste fibers were found to be more or less electrostatically oriented by the flocking process. Further property evaluations of these PCL waste flocked surfaces were performed and are described below.

Energy Absorbing Properties of PCL Flock Fiber Surfaces

The PCL flocked aluminum sheet material was evaluated for its energy absorbing characteristics. The PCL flocked surface was observed to absorb visible light. The D65 light reflectance from the waste flock surface was 55% less than the bare aluminum (CIE $L^*a^*b^*$ values: Bare Aluminum – $L^* = 80.79$, PCL – $L^* = 36.31$). The flocked surface was qualitatively observed to absorb mechanical impact by creating less noise when impacted by a falling object (steel ball bearing). This behavior is similar to what is found when sheet metal is flocked with conventional flock fibers. Quantitative measurements of vibration damping and sound absorption characteristics of these PCL flocked aluminum sheets were not performed in this study.

Friction Properties of PCL Flocked Surfaces

The static coefficient of friction was measured on cured PCL flocked aluminum test samples using the inclined plane method. Starting from horizontal, the angle of the inclined plane slowly and steadily increased until the frictional surfaces began to slide

past each other. The angle of inclination at which sliding started, θ , is noted. The static coefficient of friction (μ_s) is then calculated from the following:

$$\mu_s = \tan (\theta)$$

Static coefficient of friction data of various contacting surfaces are presented in Exhibit 12. As shown, the static friction coefficients for the flocked surfaces against the solid metal surfaces, brass and aluminum, show classical behavior. Namely, friction coefficients are practically independent of normal loading force and are below 1.0 (below the limiting 45 degree slide angle). However, the data for the flock-to-flock sliding contact do not follow classical behavior. The sliding angles for these material surfaces are well above the 45 degree limiting angle in the lighter normal load ranges. This indicates strong adhesion or mechanical interlocking between the contacting flocked surfaces. This is not unexpected since mechanical interlocking of the face-to-face, perpendicular-oriented flock fibers can occur. More importantly, these data clearly show that this mechanical interlocking effect is less pronounced at the higher normal loads. This too is not unexpected, since at the higher normal loading forces, the perpendicularly oriented flock fibers would be more flattened out against each other. This leads to better interfiber parallel slippage. This is in contrast to the inter-fiber mechanical raking effect that occurs if the face-contacting flock fibers are more perpendicular to each other during the sliding action. This greater perpendicular orientation is the likely position of the flock fibers when lighter normal load forces are applied between the contacting flock fiber surfaces.

Exhibit 12: Sliding Angle and Static Coefficient Friction (SCOF) Between Various Surfaces Involving Flocked Waste Surfaces Conditioned at 60% RH.

CONTACTING SURFACES	NORMAL FORCE** (grams)	SLIDING ANGLE	SCOF
Aluminum to Aluminum	38.75	20.71± 1.38	0.38
	85.5	21.4 ± 1.95	0.39
	124.51	18.0 ± 0	0.32
	171.52	18.2 ± 0.45	0.33
	210.36	16.86 ± 0.9	0.30
	296.3	17 ± 0.58	0.31
Brass to Aluminum	500	17.4 ± 0.89	0.31
	1000	18 ± 0	0.32
Brass to Flocked Waste Surface (FWS)	500	15.8 ± 0.45	0.28
	1000	13.4 ± 0.55	0.24
Aluminum to FWS	38.75	19 ± 1.58	0.34
	85.5	22.2 ± 0.84	0.40
	124.51	17 ± 0	0.31
	171.52	21.6± 0.86	0.40
	210.36	17 ± 0	0.31
	296.3	16.7± 0.58	0.30
FWS to FWS	13.82	76.6 ±0.55	—*
	31.42	72 ± 1	—
	48.26	69.8 ± 0.45	—
	87.08	63 ± 0	—
	172.98	50.8 ± 0.45	—
	258.82	40 ± 1	0.84
	344.5	31.2 ± 0.45	0.61

* Sliding angles above 45° are meaningless in terms of friction coefficients.

**Represents the force on 5 cm x 5 cm (25 sq. cm) squares of the flocked aluminum surface.

In order to compare the friction properties of the PCL flocked surfaces, experiments were also conducted on aluminum surfaces flocked with some conventional flock fibers. These were 2 denier PET (0.69 mm length), 25 denier PET (2.5 mm length) and cotton fiber (0.25 mm length). Slide angle versus the normal load data for aluminum surfaces flocked with these fibers (flocked surface against flocked surface) and the textile waste fibers are presented in Exhibit 13. The comparison shows that all the flocked surfaces tested decreased in sliding angle (directly related to its frictional contact) as the normal load increased. However, at normal load forces above 100 grams, the PCL waste flocked surface showed an overall higher frictional contact effect. Furthermore the frictional

effect is more linear over the load force range tested. The reason for this is not known. It could be related to the nature of the PCL flock fiber mixture. Nevertheless, it appears that the PCL waste flock might be quite useful for fabricating mechanical energy transfer clutch plates.

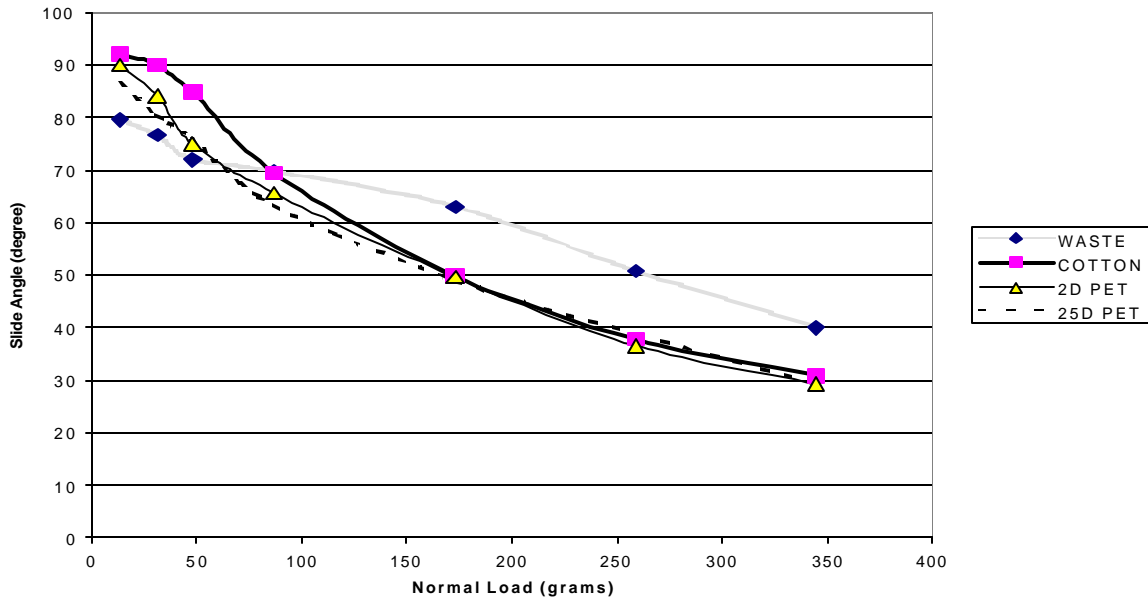


Exhibit 13: Slide Angle for Various Textile Flock to Textile Flock as a Function of Normal Load (60% RH)

Concluding Remarks on Flocking Study

This work shows that PCL apparel waste can be successfully converted into a flockable fibrous material. No special process conditions were needed. The PCL waste flocked aluminum sheet was found to absorb light and mechanical impact energy. The frictional properties of the PCL flocked aluminum surfaces were found to decrease as the normal load between the contacting surfaces increased. Compared to aluminum sheet surfaces flocked with conventional flock fiber, this decrease in friction effect for PCL was found to be more linear over the range of normal loads investigated. This suggests that the PCL flock may be useful for mechanical energy transfer clutch plates. Furthermore, the PCL flocked surfaces may be useful for special anti-skid frictional applications.

The course of this research project has uncovered some possible new applications for apparel waste material. Future work should be directed toward in-practice field trials.

6.4 Evaluation of the Oil Absorption Characteristics of Fiber Waste

A simple test was devised to measure the oil absorption capacity and oil absorption rate of various fibrous textile waste materials. This test was a modification of the INDA fluid absorption test [IST 10.1 (95)]. In the devised test, loose clumps of fibers are partly confined by wrapping or banding them with a knitted fabric sleeve. This enables the loose fragmented fibrous clumps to be held together while they are being manipulated during the test. The test was conducted by first banding 1.0 gram samples of the fibrous masses with a 5 centimeter length of 1.5 cm diameter knitted sock. The knitted sock was prepared using polypropylene (oleophilic) yarn. The rate of oil absorption into these samples was determined by measuring the time (in seconds) between dropping them into a beaker of oil and the time it takes for these banded fiber samples to become completely immersed in the oil.

The rate of oil absorption is calculated based on the total weight of the banded sample or:

$$\text{RATE OF OIL ABSORPTION} = \frac{\text{TIME FOR IMMERSION (sec.)}}{\text{MASS OF BANDED SAMPLE (gram)}}$$

The oil absorption capacity of these fibrous test samples was determined by measuring the mass (in grams) of the oil-soaked specimens. In each determination, the oil-soaked specimens were carefully removed from the oil beaker using forceps. After removing the specimens from the oil, ten seconds was taken to allow the samples to drip off any excess oil before weighing the samples. The absorption capacity was calculated by dividing the mass of the oil absorbed by the mass of fiber doing the absorbing, or:

$$\text{ABSORPTION CAPACITY} = \frac{\text{MASS OF OIL ABSORBED (gram)}}{\text{MASS OF FIBER DOING THE ABSORBING}}$$

Here the mass of oil was corrected for the mass of oil absorbed by the polypropylene knitted band. This was taken to be an averaged constant for the oils (hydraulic and diesel) studied. In addition, the mass of the fiber doing the absorbing was corrected for the dry weight of the knitted band material. Again, this correction was taken as an averaged constant for the length of knitted banding material used. These correction factors are as follows:

Dry Knitted Bands		0.22 +/- 0.03 grams
Oil Soaked Knitted Bands	Hydraulic oil	1.95 +/- 0.24 grams
	Diesel oil	1.21 +/- 0.04 grams

Oil absorption data on several fibrous materials are presented in Exhibit 14. The data for raw cotton (RC), melt blown (MBPP) and staple (SPP) polypropylene are included for comparison purposes. These fibers represent some of the fiber types used in commercial oil spill clean-up applications. The data show that compared to RC, MBPP and SPP, the shredded textile waste fibers are found to absorb oil at a much faster rate than in-practice traditional oil-spill clean-up fibers. This is further illustrated in Exhibit 15 which also shows that the oil absorption capacities of the textile waste products are found to be much lower than the slower-absorbing other fiber types (see Exhibit 16). Comparing these absorption properties with traditional oil clean-up fibers suggests that the observed rapid oil absorption capabilities of the studied textile waste is unique.

**Exhibit 14: Oil Spill Clean-Up Characteristics
of Various Fibrous Textile Materials ^(a)**

FIBROUS MATERIAL	ABSORPTION CAPACITY (grams oil/grams fiber)		ABSORPTION RATE (grams oil/second)	
	Hydraulic ^(d)	Diesel ^(d)	Hydraulic	Diesel
Black Textile Waste ^(b) (TWB)	6.1 +/- 0.3	6.2 +/- 0.3	0.40 +/- 0.04	8.5 +/- 1.1
White Textile Waste ^(c) (TWW)	6.6 +/- 0.3	7.3 +/- 0.8	0.42 +/- 0.03	7.8 +/- 0.5
Raw Cotton (RWC)	15.7 +/- 2.1	17.6 +/- 1.7	0.26 +/- 0.04	5.9 +/- 0.3
Staple Polypropylene (SPP)	12.4 +/- 1.7	12.2 +/- 1.4	0.25 +/- 0.03	5.2 +/- 0.5
Melt Blown Polypropylene (MBP)	9.1 +/- 0.6	9.3 +/- 0.4	0.17 +/- 0.03	3.4 +/- 0.4

- (a) Oil absorption tests made using the oil absorption test described in the text. All values are an average of five (5) replicate determinations.
- (b) Shredded mixture of 43% cotton, 43% polyester and 14% Lycra.® (DuPont polyurethane elastomeric fiber)
- (c) Shredded mixture of 90% polyester, 10% Lycra.®.
- (d) Brookfield viscosity (12 rpm, 24° C) of oils used: Hydraulic- 83.3 cp, Diesel- 3.3 cp.

To confirm the observation that the shredded textile waste material absorbed oil at a rapid rate, additional tests were carried out employing the Glass Tube Wicking (GTW) test. Here fibrous masses are uniformly packed into a length of 1.0 cm ID glass tube. One end of this fiber packed tube is immersed vertically into a reservoir of oil. The mass of oil absorbed by a vertical wicking mechanism into the fibrous material is measured in terms of a weight change as a function of time. GTW test results show that the textile waste materials absorb mineral oil at a much faster rate than the raw cotton.

Exhibit 15: Oil Absorption Rate of Various Fiber Assemblies

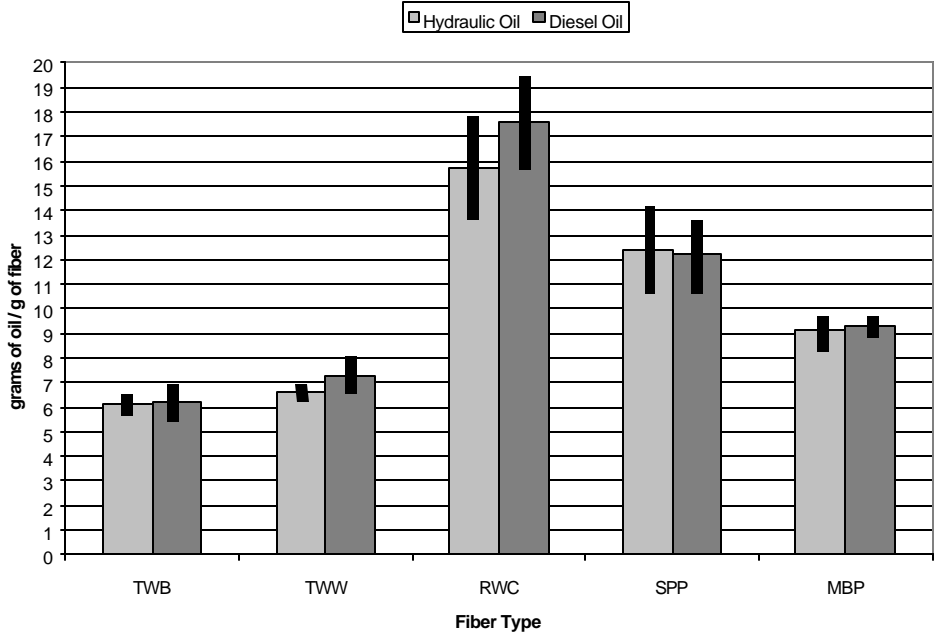
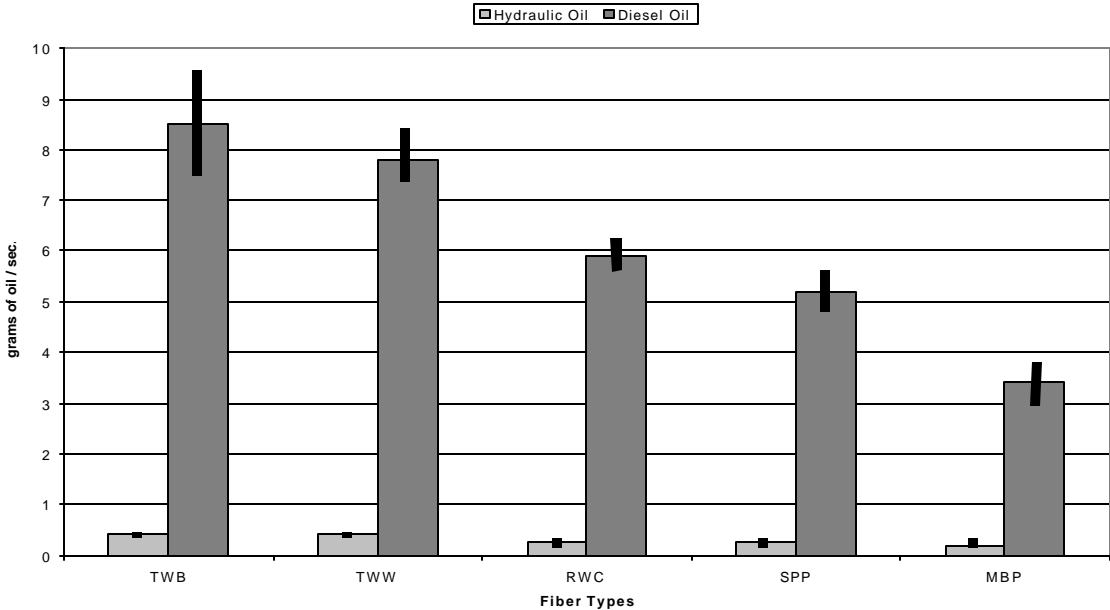


Exhibit 16: Absorption Capacity of Waste Fibers

Conclusions of Oil Absorption Study

From this work, the potential use of these textile wastes for oil spill clean-up applications can be justified. These fibrous waste materials should be used in oil spill emergencies where initial rapid rate cleanup of spilled oil is desired. Such conditions may occur in industrial, factory floor spills. In practice, these textile waste materials would be filled into a knitted sock boom configuration. Absorbent boom socks (sausage-shaped fiber containing tubes) and matted pads are the usual configurations used in factory fluid spill cleanup. It is suggested that some oil boom samples of these novel textile waste materials be prepared and tried in some controlled field testing. Furthermore, these shredded textile waste materials should be mixed with more traditional oil spill clean-up fibers to enhance the oil absorption capacity of these waste materials. The optimum mixture ratio of waste fibers to typical oil spill clean-up fibers should be evaluated.

7. LESSONS LEARNED

1. Contrary to conventional wisdom, fabrics containing 10-14% spandex can be recycled using conventional cutting and pulling machinery. The spandex did not wrap up in the machinery as feared.
2. The reclaimed material, however, consists of small pieces of yarn and fabric as well as individual fibers.
3. The reclaimed material can further be reduced to fibers with aggressively clothed cards but the fiber to fiber separation is not perfect and each process produces high waste levels. This is because the spandex fibers lock the other fibers in place.
4. The reclaimed material can be spun into yarn when it is blended with sufficient quantities of new fiber. But the yarn and fabric produced from it have a poor appearance.
5. The experiment with chemical treatments to reduce the influence of the spandex resulted in entangled bundles of fibers, some of which were removed as waste in carding. The entangled bundles that survived into spinning resulted in frequently broken yarns.
6. The experiment with more intense (double) roller carding followed by a reduction in the amount of new acrylic fiber did not improve spinning performance. It appears that successful spinning is accomplished only with high levels of new fiber to act as carriers for the entangled bundles of fiber.
7. There is a very large and growing market for nonwoven fabrics. In particular the application of needlepunched fabrics from recycled materials is quite wide and varied. We were able to make needled fabrics from the recycled materials. Waste in processing was high, but there are applications for this waste as a stuffing material.

8. A possible application that avoids making additional waste is flocking. The recycled material was readily converted into flock. Materials covered with this flock had high frictional properties, indicating that there is a possible end-use in mechanical energy transfer clutch plates.
9. An application of the picked material, which avoids the problem of having to further break down the material, is in oil-spill cleanup. The picked material could be stuffed into knitted sock booms or pads. The product would have a higher absorption rate than typical materials such as raw cotton or polypropylene. It should be inexpensive to manufacture, and it should result in what could be a high value-added product.

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