Innovative Methods for Secondary Material Development in Mechanical Textile Recycling

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The textile and apparel industry currently follows a linear model of take-make-waste (Schumacher & Forster, 2022) where garments are worn less than 10 times before being thrown out (Morgan & Birtwistle, 2009). In the US in 2018, 17 million tons of textile waste were generated with only 14.7% recycled (EPA, 2023). While an estimated USD 500 billion in value is lost each year due to clothing underutilization and the lack of textile recycling (EMF, 2017) current technologies are not scalable enough to make recycling cost effective at the commercial level (Echeverria et al., 2018). Currently, mechanical recycling initiatives often result in downcycled products (Leal Filho et al., 2019). The industry lacks formal standard guidelines and procedures to operationalize the use of textile and material waste in apparel product development. Technological and methodological advances for textile-to-fiber recycling initiatives are critical drivers toward circular change (Sandwick and Stubbs, 2019). The purpose of this research was to develop yarns and nonwoven fabrics from textile-to-fiber mechanically recycled fibers (Respool fibers) and evaluate durability and comfort properties of the yarns and fabrics. The researchers collected end-of-use 100% denim cotton and 100% polyester fabrics and shredded them to "Respool" fibers using a proprietary shredder (Teixeira Franca Alves, 2024). The ReSpool shredded fibers were then carded on a Strauch Drum Carding Machine (Hickory, NC, USA). Pure Respool polyester fibers could be carded to create a 100% recycled batts, but pure Respool cotton fibers could not be carded by itself so new cotton or wool fibers were added. Two recycled fiber to new fiber ratios (65% recycled to 35% new and 85% recycled to 15% new) were tested to determine the optimal ratio for textile development. Respool shredded polyester fibers were also carded with new polyester fibers (ratios: 65% recycled to 35% new and 85% recycled to 15% new) for comparison. When blending recycled fibers with new fibers, the new fibers were carded first, and then the recycled fibers were carded on top of the new fibers, creating a two-layered batt. The batt was removed from the machine and carded two more times. After carding, the batts are spun into 2-ply yarn on an Electric Eel Wheel Spinner or needle punched on a Feltloom (Model Lexi, Feltloom, Sharpsburg, KY) creating a nonwoven fabric. For nonwoven fabric development, a batt was cut into four equal squares. The squares were laid on top of each other alternating fiber orientations to create a multidirectional fiber layup. The batts were then felted eight times. For the yarn samples, the researchers tested durability properties (tex, tensile strength and elongation). The weight of eighteen inches of yarn was measured (with three replications) and the tex (g/km) and denier (g/9 km) data were calculated. Tensile strength and elongation were measured in accordance with ASTM D2256 (Standard Test Method for Tensile Properties of Yarns by the Single Strand Method) using a H5KT Benchtop Materials Tester (Tinius Olsen, Horsham, PA, USA) with three replications.

Tenacity data were calculated by tensile strength and tex or denier data (gf/denier). For the nonwoven fabric samples, the researchers tested comfort and mobility properties (thickness, and air permeability). Thickness was tested using a portable gauge with ten replications. Air permeability was measured by an Automatic Air Permeability Tester (Aveno Technology Co., China) following ASTM D737 standard with ten replications. There were two independent variables, i.e., Fiber Type (3 levels: Respool polyester/new polyester, Respool cotton/new cotton, Respool cotton/new wool) and % Recycled Material (2 levels: 65% Respool fibers and 85% Respool fibers). Dependent variables were textile property testing results. Data were analyzed using 2-way ANOVA tests. Since 100% Respool polyester yarns and nonwoven fabrics were developed, 100% Respool polyester Fiber Type was added in the post-hoc data analysis.

Table 1: Yarn and Fabric Testing Results

Recycled Fiber Ratio and Type	**Air Permeability (mm/s)** Mean ± SD	**Thickness (mm)** Mean ± SD	**Tex** Mean ± SD	**Breaking Force (kgf)** Mean ± SD	**Tenacity (gf/denier)** Mean ± SD	**Elongation (%)** Mean ± SD
65% Respool polyester/35% new polyester	1641.46 ± 130.9	4.60 ± .29	1333.48 ± 146.5	1.83 ± .42	.15 ± .03	23.1 ± 8.2
65% Respool cotton/35% new cotton	997.46 ± 179.24	3.50 ± .33	3388.01 ± 148.33	2.96 ± .77	.1 ± .03	25 ± 1.85
65% Respool cotton/35% new wool	1076.2 ± 107.40	4.24 ± .24	2450.42 ± 352.63	3.39 ± .97	.16 ± .07	23.1 ± 2.8
85% Respool polyester/15% new polyester	2319.94 ± 448.39	3.31 ± .44	922.28 ± 121.43	0.96 ± .17	.11 ± .01	16.8 ± 3.1
85% Respool cotton/15% new cotton	1292.94 ± 234.16	3.65 ± .39	3187.52 ± 323.46	2.14 ± .52	.07 ± .01	23.4 ± 3.9
85% Respool cotton/ 15% new wool	1368.52 ± 221.69	3.85 ± .3	2824.44 ± 425.55	2.37 ± .51	.1 ± .03	21.1 ± 2.6
100% Polyester	2798.56 ± 454.21	3.49 ± .48	1899.97 ± 264.81	1.72 ± .88	.1 ± .04	17.6 ± 8.2

Testing results are in Table 1. For yarn tenacity, there was no significant interaction between "Fiber Type" and "% Recycled Materials" ($p = .603$). The main effect of fiber type was not significant ($p = .084$) but the main effect of % recycled material was significant ($p = .032$) indicating that yarns with 65% recycled fibers ($M = .137$) have higher tenacity than yarns with 85% recycled fibers ($M = .095$). When comparing 100%, 85%, and 65% recycled polyester, there was no significant difference amongst the yarns ($p = .163$). For Respooled cotton/new cotton, there was no significant difference between 85% and 65% Recycled Materials ($p = .455$). For Respooled cotton/new wool, there was a significant difference with 65% Respooled cotton having a higher tenacity than 85% Respooled cotton ($p = .049$).

For Air Permeability, there existed significant interaction between Fiber Type and % Recycled Materials ($p = .023$), and the main effects of fiber type and % recycled material were both significant ($p < .001$). Post hoc comparisons showed that for polyester, air permeability scores for 100% recycled material were significantly higher than 85% recycled material ($p = .025$), which was significantly higher than 65% recycled material ($p = .001$). For Respooled cotton/new cotton and Respooled cotton/new wool, the 85% recycled material nonwoven fabric had

significantly greater air permeability than 65% recycled material (p = .010, .011).
In conclusion, the researchers successfully created yarns and nonwoven fabrics using a high percentage of mechanically recycled polyester and cotton fibers. For recycled polyester, the yarn tenacity is the same for 65%, 85% and 100% recycled fiber content. For recycled cotton/new cotton blend, the yarn tenacity is the same for 65% and 85% recycled fiber content. This indicates that this method can be used to create yarns with 85% or higher recycled fibers without sacrificing strength. However for nonwoven fabric development, the higher the percentage of recycled material, the larger the air permeability indicating the higher % recycled nonwoven fabrics are more breathable.

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