The Respool Fiber Research (RFR) model: A protocol for the evaluation of mechanically recycled materials towards "second life" product applications.

Kendall Ludwig, Michelle Yatvitskiy, Kelly Cobb, Huantian Cao
The University of Delaware, Newark, DE. USA

According to the U.S. Environmental Protection Agency (2023), about 17 million tons of textile waste was generated in 2018. Of that, only 14.7% was recycled, 18.9% was combusted for energy recovery, and 66.4% was landfilled. Textile recycling promotes a circular economy (CE), a system seeking to minimize waste and maximize the value of textiles by reusing them (NIST, 2022). Currently, mechanical recycling produces short, weak fibers that diminish the value of the textiles, resulting in downcycled products such as insulation (Thompson, 2017). An estimated USD 500 billion in value is lost each year due to clothing underutilization and the lack of textile recycling (EMF 2017). Recognizing the pressing need for increased textile recycling infrastructure, researchers are working collaboratively across academia, government, industry, and nonprofits to create a regional ecosystem for transforming post-consumer fashion waste into innovative new products. This study provides a protocol for the evaluation of mechanically recycled materials towards "second life" applications for textiles and products. The purpose of this model is to assist product developers to determine potential product pathways that can add value back to the textiles for reuse and restoration of functionality of materials over multiple use-cycles (Niinimaki 2018).

Figure 1. Application of RFR model.

The Respool Fiber Research (RFR) model was developed from an examination of current practices, relevant literature, and experimentation. It builds upon the Bye and Griffin (2015) Wearable Product Materials Research (WPMR) model, using laboratory testing in addition to sensory evaluations. Demonstrating the capabilities of mechanically recycled textiles in material development, the RFR model is intended for educators, research and development laboratories, product developers, designers, etc. The model leads the user to the development of a yarn or non-woven prototype, depending on the chosen recycled fiber. The RFR model ventures beyond current models of textile recycling through its fiber-oriented approach to material development. Multiple recycled fibers, which were obtained from research collaborators, are tested in this study to demonstrate the

application of the RFR model as part of the development process. Figure 1 illustrates recycled 100% cotton denim and 100% wool fibers as examples of the model application.

The first step of the model is to determine the inherent qualities of the recycled fiber through visual, tactile, and sensory evaluation. The 100% recycled cotton denim fiber was predominately long yarns and short fibers, leading the researchers into the second step. To increase the fibrous consistency of the cotton denim, the fiber must be mixed with new fibers in the carding process. In this study the researchers decided to keep prototypes mono-material due to a lack of research in mechanically recycled blends. Therefore, the recycled cotton denim should be carded with natural fibers like itself, namely new cotton fibers. If new cotton fiber is not available, the recycled cotton denim can be carded with any natural cellulosic or protein fibers to ensure the end prototype can be mechanically recycled again or biodegraded to promote circularity. For the 100% recycled wool test, the wool is much more fibrous and fluffy, with long fibers allowing for the wool to be carded by itself without adding any new fibers.
The third step of the model prioritizes yarn development in the making of a prototype because its end-uses allow for more upcycling opportunities than a nonwoven prototype. However, if yarn cannot be produced, a nonwoven prototype is also a viable option. Both the recycled cotton denim fiber and the wool fiber can be spun into yarn and needle punched into a nonwoven. To determine which prototype is most appropriate for its application, textile testing such as tensile strength and elongation tests should be conducted in the fourth step. An unsupported nonwoven would be most appropriate if the yarns' tensile strength is too low, while yarns and subsequent knit and woven textile development is appropriate if the yarns' tensile strength is high. Figure 2 provides an overview of the steps of the RFR model.

The RFR model is valuable for selecting which recycled fibers are appropriate for different types of products: yarns or nonwoven fabrics. Future developments include textile property tests of prototypes, including developing knits and wovens from the yarn prototype, and application of the model in a larger scale, industry setting.

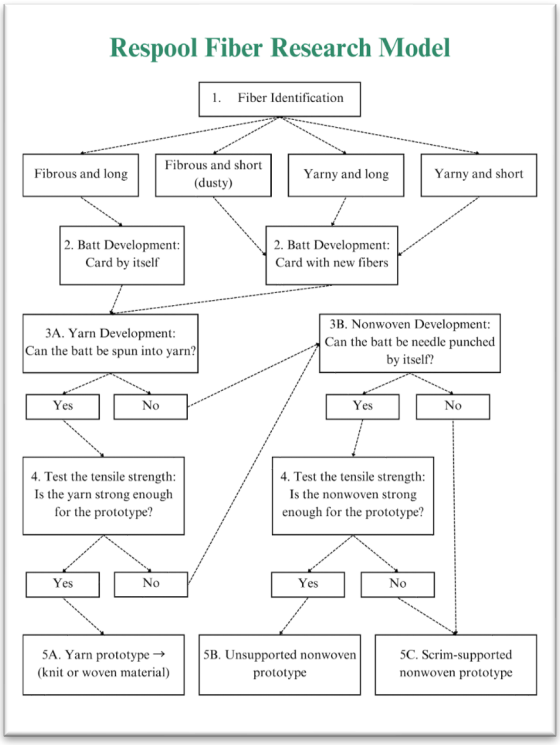

Figure 2: Steps to apply RFR model in Product Development.

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