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New Recycling Technology for Thermoplastic Structure-Winding Components Made from Continuous Fibers

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Abstract

Hybrid yarns can be used in structure-winding components, consisting of a thermoplastic reinforcement component made of continuous fiber and a lower-melting-point thermoplastic matrix component [1]. These yarns can be produced, for example, by a covering process and subsequently converted into a structure-winding component by a structure-winding process followed by thermal consolidation.

The presented novel recycling technology allows the low-melting matrix component of such structural wound lightweight components to be separated from the reinforcement component by means of a tailored temperature control process and the application of kinetic energy. The reinforcement component can then be directly reprocessed as a continuous fiber without the need for complex preparation processes. The matrix component is collected and can also be recycled as a single-material product, for example, by being re-spun into filament yarn.

Keywords: Structure winding; Hybrid yarn; Recycling of thermoplastic fiber composite components; Fiber composite components; Structure-wound components; Recycling of structural wound components

Introduction

The recycling of fiber-reinforced composite components still represents a major challenge. In existing recycling processes, fiber composites are, for example, ground or shredded, which results in shortened fibers and thus leads to downcycling [2,3]. A large proportion of the waste is currently landfilled, thermally recovered, or used as a raw material in cement and blast furnace processes [4].

Structure-winding components represent a subgroup within fiber-reinforced composite components. Such a component can be manufactured from a single continuous filament yarn. The reinforcing component contained therein has the potential to be reused directly as a continuous filament yarn in recycling, while the matrix component can be fed back into the melt-spinning process

used for filament yarn production. Thus, part of the structure-winding components can be directly reused for the manufacture of new structure-winding components without generating waste streams, while the remaining part can be returned to the process via material recycling.

The DITF Denkendorf, in cooperation with JBF Maschinen GmbH, have developed a new recycling technology to enable the recycling of continuous fiber-reinforced thermoplastic structure-winding components.

This closes a previously existing technological gap, as no recycling method had been known to date that enables the complete recovery and reuse of thermoplastic continuous fibers from fiber-

reinforced composite structures. This newly developed recycling technology allows the separation of the thermoplastic matrix from the thermoplastic reinforcing fibers and the reuse of the continuous fibers in their original, uncut length.

Structure-winding technology offers an economical way to manufacture components made of fiber-reinforced plastics. It allows various requirements to be met, such as variable cross-sections—which, as is typical for winding processes, may be circular but also non-circular—different dimensions, and different yarn constructions, with a focus on lightweight design. In addition, the yarn placement can be adjusted very precisely, enabling the

production of customized components [5-7]. In this process, the yarn is deposited in a defined manner onto a rotating sleeve or mandrel. The yarn guide traverses back and forth while the sleeve rotates. By varying the speed ratios between the traversing motion and the rotational motion—via the so-called winding ratio—different structural patterns can be achieved. For example, open rib structures and closed surfaces are possible. An example of an open rib structure is shown on the left in Figure 1. A closed wound surface is shown on the right as a structural implementation. Both structures were manufactured from a single purely thermoplastic hybrid yarn.

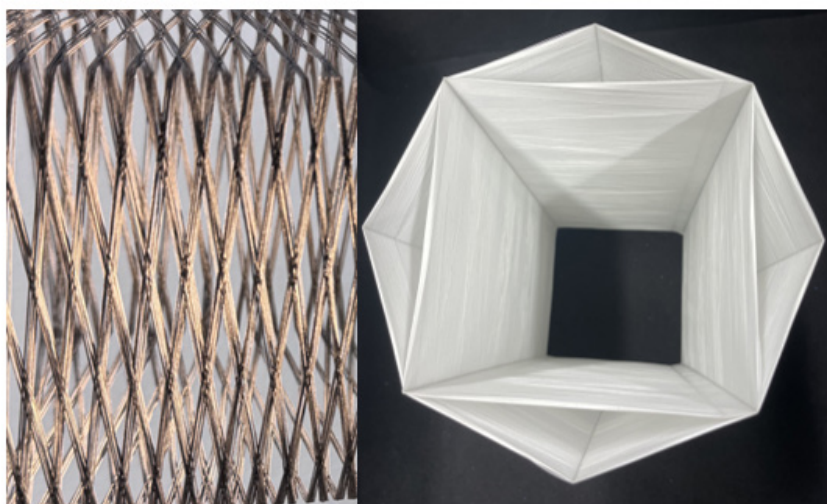


Figure 1: Left: structurally wound open rib structure; right: structurally wound closed surface with a non-circular shape.

In principle, other materials can also be used in structure-winding technology, such as paper yarns in combination with natural adhesives, which then result in recyclable structures [8,9].

The manufacturing technology for thermoplastic fiber-reinforced plastics using structure-winding technology is a dry winding process. This means that hybrid yarns are used, which already contain a reinforcing component and a matrix component. These two components are twisted together or are placed in a covered yarn structure. In a covered yarn, the reinforcing component lies straight in the core, while the covered component is helically wound around it. Unlike yarn spools, which are unwound in a subsequent process after a conventional winding process, the yarn coil is consolidated so that the resulting structure, which is placed on the core, can be removed. During consolidation, the thermoplastic matrix component with the lower melting temperature is heated into its melting range. It liquefies and, after solidification, forms the closed matrix around the reinforcement component. Depending on the shrinkage behavior of the continuous reinforcement fibers used, the core should generally be collapsible during thermal loading in the consolidation process. Precision winding machines are essential for the formation of so-called rib structures, as they ensure a consistent winding ratio. Figure 2 shows such a precision

winding machine with a collapsible core system. The dimensions are adapted to those of the recycling plant.

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The new recycling technology enables the recycling of thermoplastic structure-winding components, in particular those in which both the reinforcement yarn and the matrix yarn are thermoplastics. The recycling loop is illustrated in Figure 3.

The recycling system consists of a rotation unit, on whose mandrel the structure-winding component to be recycled is mounted, and a heating unit. By means of a controlled temperature profile and the targeted introduction of kinetic energy, the low-melting thermoplastic matrix component can be separated from the reinforcement component. For this purpose, the rotation unit is inserted into the heating system. The rotating unit performs the rotational movement according to the defined parameters. It allows for both clockwise and counterclockwise rotation. This is necessary because the direction of rotation, determined by the winding direction, can vary depending on the component. The rotating unit can rotate continuously up to 2600 rpm.

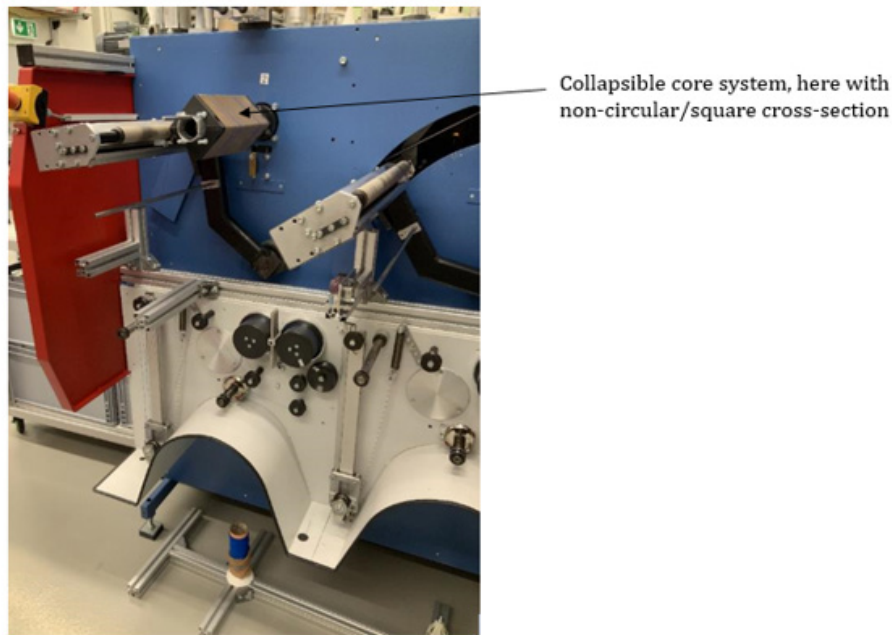


Figure 2: Precision winding machine for the production of structure-winding components, here: for the production of a non-circular component with a square cross-section.

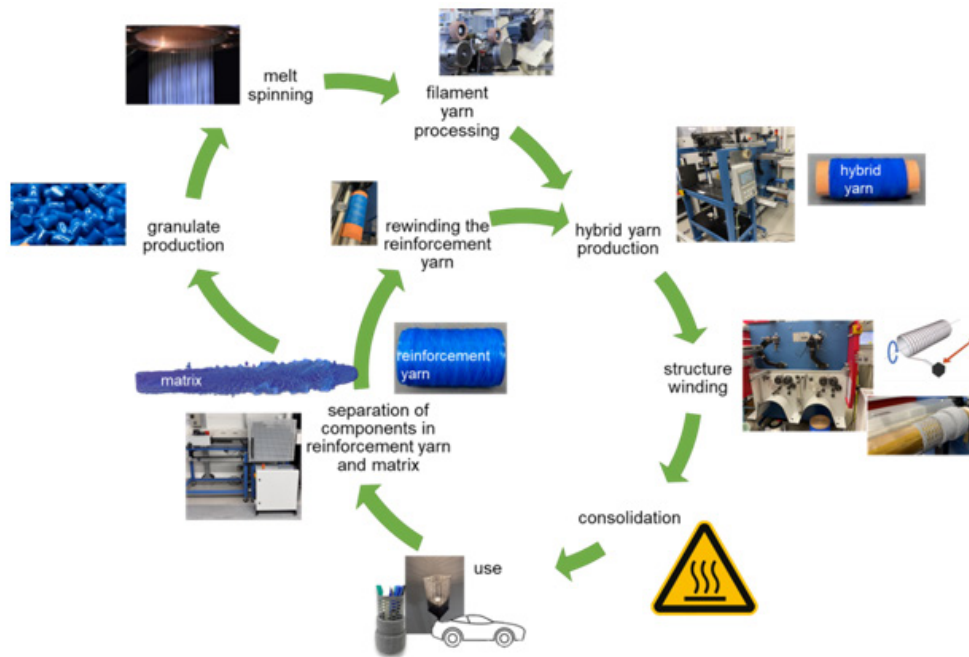


Figure 3: Recycling loop of thermoplastic structure-winding components.

The separated matrix is collected, while the reinforcement fiber remains. Due to minimal residual amounts of the matrix polymer, the wound reinforcement fiber structure is preserved to an extent that ensures sufficient stability, allowing it to be tangentially withdrawn without difficulty and subsequently rewound in an orderly manner

on a winding machine. Alternatively, the reinforcement fiber can be withdrawn directly within the recycling system. This approach is particularly advantageous when the matrix exhibits strong adhesion to the reinforcement fiber.

Results

In initial experimental series, various hybrid yarns were manufactured, consisting of a thermoplastic mono- or multifilament reinforcement fiber and a thermoplastic matrix with a lower melting temperature. These hybrid yarns were processed into structure-winding components, subsequently recycled using the newly developed recycling technology, and the yarn properties before and after the recycling process were compared.

Figure 4 presents an example of a thermoplastic reinforcement yarn, here in the form of a PES monofilament, as well as the hybrid yarn produced from it with a blue polypropylene matrix yarn. The blue coloration was selected to facilitate evaluation of the recycling process and to improve visual assessment of the reinforcement yarn after separation of the hybrid yarn constituents. Figure 5 shows the separated thermoplastic matrix within the recycling system.

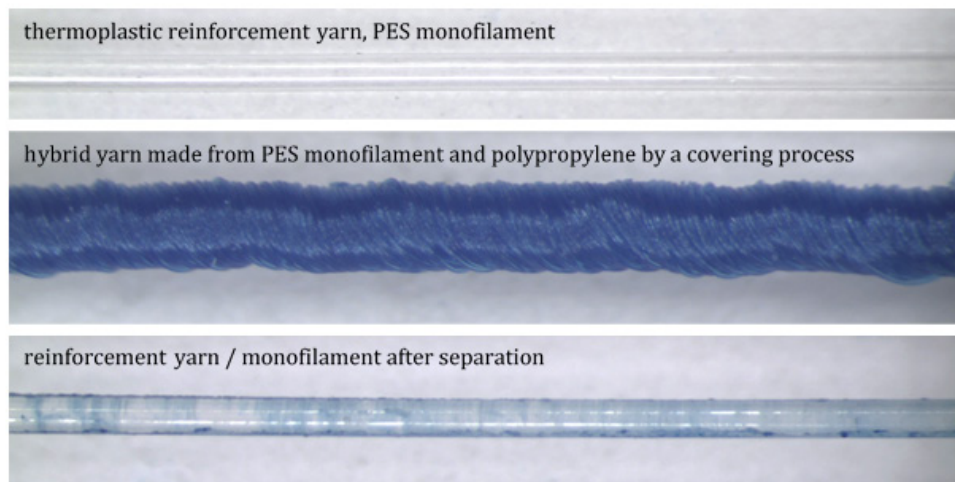


Figure 4: Example of an original reinforcement yarn (here: PES monofilament), the hybrid yarn produced from it (here: reinforcement yarn covered with blue polypropylene), and the reinforcement yarn after the recycling process, i.e., after separation.

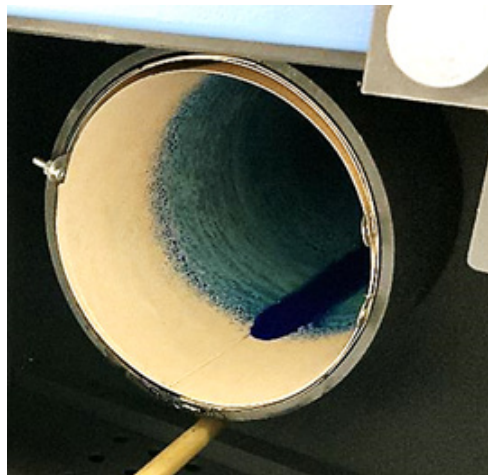


Figure 5: Separated thermoplastic matrix (blue).

Recycling was carried out under temperature-adjusted process conditions in order to maintain the mechanical properties of the recycled reinforcement yarn at a process-neutral level compared to the original reinforcement yarn. For polypropylene matrices, a process temperature of 182 °C proved to be particularly suitable. Under these conditions, the polypropylene matrix could be effectively separated from the reinforcement yarn in the form of a

PES monofilament. The separation efficiency, which quantifies the fraction of matrix removed during the recycling process, averaged 97.6 % in experiments using polypropylene as the matrix and a polyester monofilament as the reinforcement fiber. The recycled monofilament yarn exhibited an average deviation in elongation at break of -4.58 % relative to the original monofilament. The maximum tensile force showed a mean deviation of -13.03 %.

When a PES multifilament yarn was used as the reinforcement component instead of a PES monofilament yarn, an average separation efficiency of 92.4 % was achieved. Compared to the original material, the recycled multifilament yarn showed an average deviation in elongation at break of +5.99 %, while the maximum tensile force exhibited a mean deviation of -2.37 %.

Conclusion

The newly developed recycling technology allows recovery of continuous reinforcement fibers from a thermoplastic structure-winding component through controlled temperature profiles and defined kinematic energy inputs, preserving process-neutral yarn properties. The separated thermoplastic matrix can be reintegrated into melt-spinning for filament production, while the recycled fibers are immediately ready for reuse in the manufacturing cycle.

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Conflict of Interest

No conflict of interest.

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