Bicomponent Fibers for Thermoplastic Composites:
Towards a New Intermediate Material for Rapid Stamp Forming

Coating individual glass filaments with a thermoplastic sheath is proposed as an alternative concept to existing hybrid intermediate materials to facilitate the high volume production of thermoplastic composites. The intimate contact between fiber and matrix in bicomponent fibers provides full wet-out of the fibers while retaining the draping possibilities of the unconsolidated rovings. To manufacture such bicomponent fibers, we propose a dip-coating process incorporated in-line with glass fiber spinning facilities. Here, an experimental proof of concept for dip-coating single filaments in dilute polymer solutions and an analytical feasibility study are given.

Christoph Schneeberger, Joanna C. H. Wong, and Paolo Ermanni
Laboratory of Composite Materials and Adaptive Structures,
Institute of Design, Materials and Fabrication, ETH Zurich.
Email: cschneeb@ethz.ch, Web Page: http://www.structures.ethz.ch

ETH zürich CMASLab

Introduction

With European legislation continusously reducing the emission limits for vehicles, the automotive industry faces the challenge of producing more energy efficient vehicles through strategies such as lightweighting. The use of fiber-reinforced composites is broadly considered as a viable, but labor intensive alternative and is thus seldom chosen for high volume production schemes. Let's change that!

We are developing a new hybrid intermediate material for thermoplastic composites which is assumed to significantly shorten cycle times in rapid stamp forming processes. The idea is to eliminate time-consuming impregnation phenomena during preform consolidation by providing individually hybridized filaments, hereafter described as bicomponent fibers.

The Concept of Bicomponent Fibers

Sheath-core bicomponent fibers (Fig. 1) eliminate the problem of impregnation, in that all fibers are already fully wetted and flow lengths smaller than the diameter of a single filament are needed for complete consolidation, while keeping the flexibility of dry yarns. For a continuous high-volume production of bicomponent fibers, we propose to integrate the coating process in-line with glass fiber spinning (Fig. 2), exploiting the separated arrangement of the fibers between the spinneret and the gathering shoe.

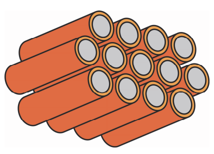

Fig. 1. Schematic of the morphology of bicomponent fibers [1].

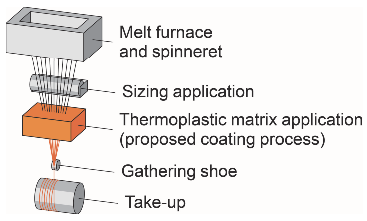

Fig. 2. Schematic of glass spinning with in-line coating [1].

Materials

Single glass fibers with a 1 wt% 3-aminopropyltriethoxy silane sizing were dip-coated in different solutions of poly(ester-amide) (PEA, Fig. 3) in chloroform.

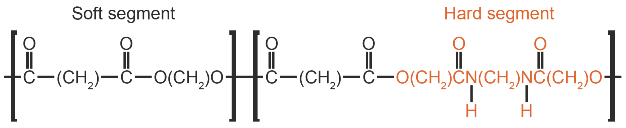

Fig. 3. Structural formula of segmented block poly(ester-amide). *Source: Dow Europe GmbH.*

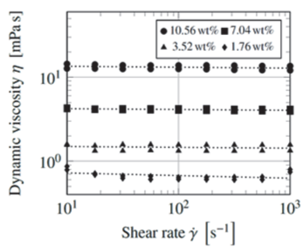

Fig. 4. Dynamic viscosity of the PEA-chloroform solutions. Dotted lines represent power-law fits.

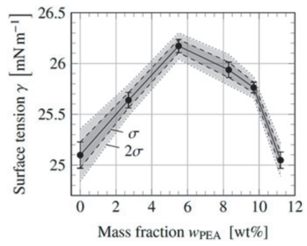

Fig. 5. Surface tension of the PEA-chloroform solutions [2]. σ denotes the standard deviation.

Experimental Proof of Concept

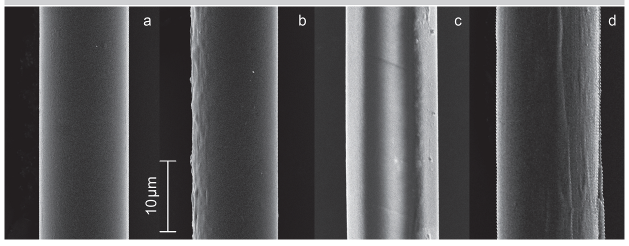

Fig. 6. Surface morphologies of polymer sheaths fabricated from different coating solutions. a: 6.9 wt%. b: 10.5 wt%. c: 12.3 wt%. d: 14.2 wt%.

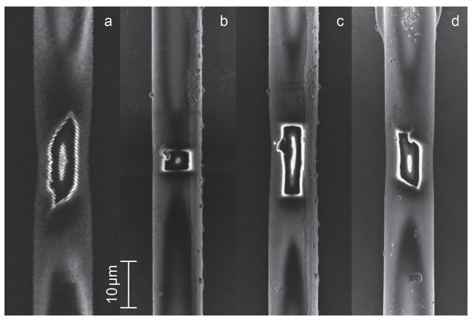

Fig. 7. Bicomponent fibers with etched off polymer sheath revealing their glass core. a: 10.5 wt%. b,c: 12.3 wt%, coated at 0.20 m/s. d: 12.3 wt%, coated at 0.23 m/s.

Analytical Feasibility Study

We identified an overlap in processing conditions:

Glass Fiber Spinning: Equalizing the volumetric flows of glass at take-up (bulk velocity) and the spinneret (Hagen-Poiseuille flow) allows to calculate the take-up velocity for a target fiber diameter $2r$ [3].

Dip-Coating of Cylinders: The normalized coating thickness h/r is largely dependent on the capillary number Ca of the flow. Tallmadge [4] proposed an advanced model for dip-coating from non-Newtonian fluids, which was employed to describe coating with a PEA-chloroform solution (Fig. 8).

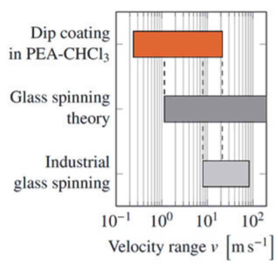

Fig. 8. Comparison of processing windows of industrial glass spining and glass spinning in theory with dip-coating in PEA-chloroform solutions.

Conclusion and Expected Impact

We have proven that the fabrication of bicomponent fibers for structural composites is possible through dip-coating of glass fibers in dilute polymer solutions. Theory suggests that this process can be implemented in-line with melt spinning, leading to an economically and ecologically viable high-volume production of this novel intermediate material.

The use of bicomponent fibers in rapid stamp forming of thermoplastic composites is expected to reduce cycle times as well as overall production costs, rendering composites more attractive for the automotive sector and more accessible for the medium- to low-budget markets. Successful industrialization of the presented technology could lead to a significant increase in advanced lightweighting of vehicular structures.

References

[1] C. Schneeberger, J. C. H. Wong, and P. Ermanni. Bicomponent Polymer/Glass Fibres for Stamp Forming. *SAMPE Europe Conference 16*, Liège, Belgium, 13-15th September 2016.
[2] C. Schneeberger, J. C. H. Wong, and P. Ermanni. Manufacturing of Bicomponent Fibers for Thermoplastic Composites: A Feasibility Study. *ECCM17*, Munich, Germany, 26-30th June 2016.
[3] K. L. Loewenstein. *The manufacturing technology of continuous glass fibers*. Elsevier, 2nd ed., 1983.
[4] John A. Tallmadge. *AIChE Journal*, 14(5):837-838, 1968 and 15(6):941-942, 1969.

Partners

Swiss National Science Foundation
(Project № 200021_165994)
FNSNF Swiss National Science Foundation

Dow Europe GmbH
DOW

Leibniz Institute of Polymer Research Dresden
Leibniz-Institut für Polymerforschung Dresden e.V.