Tailored Fiber Placement for Complex Tubular Connector Structures – Design, Manufacturing and Validation

Jan Georg Kreutzer*[1], Cameron Welker[1], Tales De Vargas Lisboa[1], Axel Spickenheuer[1,2], and Markus Stommel[1,3]

[1]Leibniz-Institut für Polymerforschung Dresden e.V. – Germany
[2]Hochschule für Technik und Wirtschaft [Dresden] = HTWD University of Applied Sciences – Germany
[3]Technische Universität Dresden = Dresden University of Technology – Germany

Abstract

This work presents the design, manufacturing and experimental validation of a tubular connector with a variable-axial fiber architecture. The head-tube node of a hardtail bicycle frame was selected as an industry-relevant demonstrator with well-documented boundary conditions. Its dynamic impact loads were converted into equivalent static loads.
Tubular components are widely used in lightweight load-bearing structures, with their connecting nodes playing a critical role in load transfer. Fiber-reinforced polymer (FRP) tubular connectors are typically manufactured by braiding, filament winding or 3D weaving, restricting their design to conventional uni- or multiaxial fiber architectures. Tailored Fiber Placement (TFP), by contrast, enables fibers to be aligned with local stress directions but has not yet been applied to three-dimensional tubular nodes.

The design process started with a volume topology optimization, which was transformed into a closed surface model, re-optimized as a shell and abstracted into discrete, straight struts. To account for the planar manufacturing of TFP preforms, the resulting structure was designed to be developable. The shell geometry was derived from the principal stress trajectories of a bending-loaded plate, allowing both the struts and fiber paths to follow a largely shear-free stress state. FE analysis confirmed predominantly tensile and compressive loading without critical shear-loaded areas. The resulting three-layer preform was supplemented by separate bearing and connection preforms.

An FDM-3D-printing-based rapid-tooling approach was developed for manufacturing of this complex tubular shape. The porous printed tool was vacuum-infiltrated from the inside with epoxy resin, making it pressure-tight and suitable for internal pressurization during processing.
The manufactured demonstrator was experimentally tested using digital image correlation, and its performance was compared with an isotropic numerical reference part. The results demonstrate the feasibility of manufacturing complex tubular connectors with variable-axial fiber architectures.

Keywords: Tailored, Fiber, Placement, variable, stiffness, rapid, prototyping, 3D, printing

*Speaker