Structured Summary

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The rapid expansion of wind energy as a key pillar of the energy transition has increased the demand for cost-effective and resource-efficient rotor blade technologies. Conventional glass-fibre reinforced polymer (GFRP) blades are structurally efficient but require energy-intensive manufacturing processes and pose challenges in terms of transport and installation. In parallel, the distributed wind sector and medium-sized turbines (up to 250 kW) are gaining importance for decentralised power supply; however, these systems remain highly cost-sensitive and face specific logistical constraints.

Against this background, the present thesis investigates a novel rotor blade concept based on a textile-covered load-carrying structure. The underlying hypothesis is that tensioned technical fabrics can provide a lightweight, modular, and potentially lower-cost alternative to conventional shell structures, while offering inherent aeroelastic flexibility that may be exploited for passive load alleviation.

The overarching aim of this work is to assess the technical feasibility and performance potential of a textile-covered rotor blade concept for medium-sized wind turbines. More specifically, the thesis pursues the following objectives:

- to develop a consistent conceptual and structural design framework for a PTFE-based textile-covered rotor blade and an equivalent hard-cover reference blade of comparable outer geometry;
- to experimentally characterise the aerodynamic and aeroelastic behaviour of both the textile-covered and hard-cover blades in a controlled wind-tunnel environment;
- to establish and assess numerical models coupling two-dimensional aerodynamic predictions with finite-element-based structural analyses;
- to compare the aerodynamic performance, deformation behaviour, and load trends of both blade concepts under representative operating conditions; and

- to discuss the implications of the textile-based concept with respect to manufacturability, scalability, and potential cost and load-reduction benefits.

The research combines conceptual design, wind-tunnel experimentation, and numerical simulation within an integrated framework. A baseline rotor blade geometry is adapted into two blade families: a conventional hard-cover (HC) reference blade manufactured from rigid shell elements, and a soft-cover (SC) blade employing a pre-stressed PTFE-based textile envelope supported by a simplified internal structure. Additional soft-cover variants, characterised by different pretension levels and effective stiffnesses, are introduced to investigate the sensitivity of the aerodynamic response to textile properties.

A wind-tunnel test campaign is conducted in the closed test-section wind tunnel of the University of Rostock. Aerodynamic forces are measured using a multi-component force balance across a range of inflow velocities and angles of attack. The deformation behaviour of the textile-covered blades is inferred indirectly from changes in the measured aerodynamic response.

Complementary numerical models are developed. Two-dimensional airfoil polars are generated using XFOIL over the Reynolds number range relevant to the experiments. These polars are employed to derive spanwise-distributed aerodynamic loads, which are subsequently mapped onto a static finite-element structural model to obtain the corresponding aeroelastic deformation response.

Finally, potential sources of systematic uncertainty are identified and discussed, and experimental findings are compared with numerical predictions. Results demonstrate the fundamental feasibility of textile-covered rotor blades as an alternative to conventional GFRP shell structures for medium-sized wind turbines. From an aerodynamic perspective, the textile concept maintains satisfactory performance, while structurally it introduces an additional degree of freedom through adaptive airfoil deformation. This behaviour indicates potential for passive load control and load alleviation.

The transferability of the findings to full-scale turbines and operation under turbulent atmospheric inflow conditions remains subject to further investigation and is identified as an important direction for future research.

Keywords

PTFE-covered rotor blade; wind-tunnel testing; aeroelastic deformation; passive load alleviation; Static structural analysis; medium-sized wind turbine