Concept study, design and experimental investigation of integral fiber reinforced hinges for the application to shape adaptive wing structures

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Fiber composites have been in use in aviation industry for quite some time in order to save weight and fuel. CFRP structural parts in these applications usually contain a thermoset or a thermoplastic matrix. But besides the structural mass, the aerodynamic grade affects the efficiency of an aircraft, too. Flow separation and tip vortex effects on flaps lead to high drag forces. For a long time, it has been a professed goal in aviation industry to reduce these drag forces by shape adaptive structures (morphing structures) for as many flight phases as possible.

This thesis focuses on concept study, numerical design and experimental investigation of a shape adaptive gap cover for the aileron of an A320 by using a hybrid-matrix fiber composite approach. Instead of using a homogenous matrix material for the whole part, the “hard”, brittle thermoset matrix is locally replaced on the whole or partially by a matrix with a significantly lower Young’s modulus (elastomer). In combination with the fiber reinforcement a distinct anisotropy is built up and in this way local, extra flexible regions within a part are feasible.

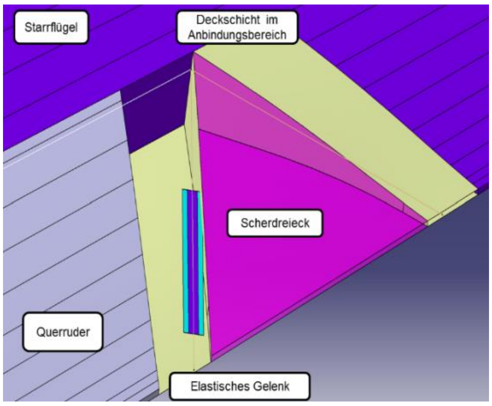

fig. 1: surface model of the gap cover

In the course of a geometric preliminary dimensioning, the available space of the gap cover is investigated in a parametrized, macro-controlled CAD model (see fig. 1) and optimized by a genetic algorithm (minimization of cover sheet strains) in MATLAB. The calculations give important insight in dependencies on aileron flap angle, hinge angle and cover sheet strains.

By means of the hybrid-matrix fiber composite concept, integral hinges can be implemented in composite structures. In order to avoid stress concentrations during bending deformation, it is important to ensure a soft rising, stiffness gradient through the cross section. To achieve this, layers with heterogenic matrix as well as fiber orientation are staggered in a way, so that a homogenous stiffness decline evolves towards the middle of the integral hinge. The elastomer EPDM is used as matrix in the flexible regions and conventional epoxy is used in the stiff regions.

By using EPDM as matrix, the main challenge lies in the complete saturation (micro as well as macro flow) of the fibers. In its uncured state, EPDM is a high-viscous, tacky mass and the short-time viscosity decline during the vulcanization in an autoclave is not enough to saturate woven fabrics, for example. Therefore a new production route had to be developed. The viscosity of unvulcanized EPDM can be decreased by adding a solvent. In experiments with wet-layup vacuum compaction, an appropriate mixture ratio was found. It provides both a low enough viscosity and a high enough EPDM fraction after the solvent has evaporated. The EPDM-prepreg is stacked together with the epoxy-prepreg, vulcanized and cured in an autoclave respectively. Due to the co-curing an optimal adhesive bonding is built up on the matrix interface. A micrograph of the hybrid-matrix laminate is shown in fig. 2.

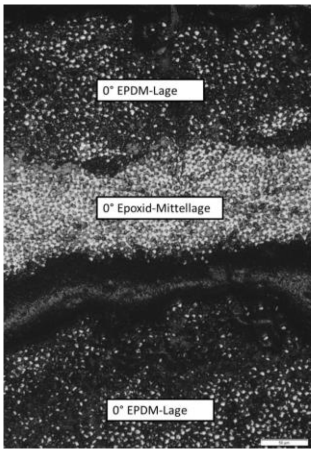

fig. 2: micrograph of the EPDM-epoxy composite after processing in an autoclave

On the basis of two-dimensional integral hinge specimens, the mechanical behavior was characterized in tension and special hinge bending experiments according to Colin [1]. Fatigue tests (~10^4 hinge deflections) revealed a reduction of the Young’s Modulus of 16%. However, the tensile strength did not alter significantly, because it depends in the chosen lay-up mainly from the middle layer, which is near the neutral axis. Therefore it is not gravely damaged by bending loads.

The new hybrid composite enables a large variety of innovative applications, like improving the crash resistance of brittle CFRP structures. Furthermore the EPDM matrix is very promising for the aerospace industry, because of its high temperature, chemical and radiation resistance.

The investigations were made within the framework of the FlexMat project (Flexible Materialien und Strukturen für formvariable Komponenten in industrieller Fertigung) which was funded by the BMWi and took place in cooperation with the Invent GmbH and the DLR Braunschweig.

[1] D. Colin, Bending Characterization of Hybrid-Matrix Fiber Reinforced Hinges with a Developed Testing Device, Garching: Technische Universität München, Lehrstuhl für Carbon Composites, 2015.