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As-built FE simulation of advanced fibre placement structures based on manufacturing data

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ABSTRACT

To manufacture advanced fibre placement (AFP) structures according to the results of conceptual design and optimisation, several manufacturing constraints must be considered. As a result, the computationally optimised solution often cannot be perfectly achieved within the manufacturing process. Instead, a producible fibre alignment is realised, which may include local fibre particularities and, hence, locally raised material efforts. To properly account for the real fibre path, the As-built Feedback Method has been developed. It transforms manufacturing data of AFP structures to as-built FE-models by suitably considering the realised fibre orientations as well as special fibre features like tight fibre curves. In the present paper, the Feedback Method is exemplarily applied to an AFP tension strap. By investigating failure analysis results, significant discrepancies have been identified between as-built and as-design. Thus, the application of the Feedback Method is particularly advantageous, if the effect of irregular fibre alignments is important.

1. Introduction

Advanced or Tailored Fibre Placement (AFP, TFP) is a textile process for the production of optimised fibre reinforced structures. AFP follows the examples in nature, where an adapted, perfect design provides an optimal survive [1]. Accordingly, the carbon fibre tows or rovings in AFP structures may be placed in almost any desired orientation, thus deploying calculated optimum fibre quantities and orientations for optimal performance [2]. However, the AFP manufacturing process also affects the material properties [3]. Specific material properties and appropriate material models of the textile fibre composites are of critical importance for a successful application [4].

The present work is a contribution to close the gap in the development chain of AFP structures that still exists between design, manufacturing and certification. Fig. 1 shows the development chain of a horizontal tailplane connection beam: Following the topology optimisation, the sizing optimisation includes determination of dimensions, thicknesses, materials, lay-ups, etc. For AFP structures, the fibre alignment is one of the design variables. It can be optimised, e.g. by the TFP design tool TACO, developed at DLR [5–7]. Subsequently, fibre placement manager (FPM) data and/or computer aided design (CAD) geometry models are developed, which build a first basis for the manufacturing process. For certification of the manufactured structure, the corresponding strength analysis must correctly represent the behaviour of the actual manufactured structure by a detailed, high-fidelity "as-built" FE model. For this purpose, the As-built Feedback Method is developed, which suitably transforms manufacturing data stored in vector files of the fibre path (FIB) into high-fidelity computer aided engineering (CAE) models. It generates as-built FE models by considering manufactured fibre lay-ups, fibre orientations as well as special fibre features like tight fibre curves. The resulting as-built FE models may significantly differ from the original FE model used for design.

In the present paper, the methodology (Section 2) and an application of the Feedback Method are presented. The method consists of two main parts: An upstream Multiscale Analysis (Section 3) evaluates significant local material discontinuities and computes effective global material properties. Within the subsequent As-Design → As-Built Data Transformation (Section 4), the effective material properties are considered and fibre alignment data are automatically transformed into as-built CAE input files to be readable by FE software. In Section 5, the Feedback Method is applied, and differences between failure analysis results of as-built and as-design FE models are demonstrated by using the example of an AFP tension strap.

2. Methodological concept of the Feedback Method

To suitably consider manufacturing features in a high-fidelity FE model, the following two aspects are important: Firstly, local

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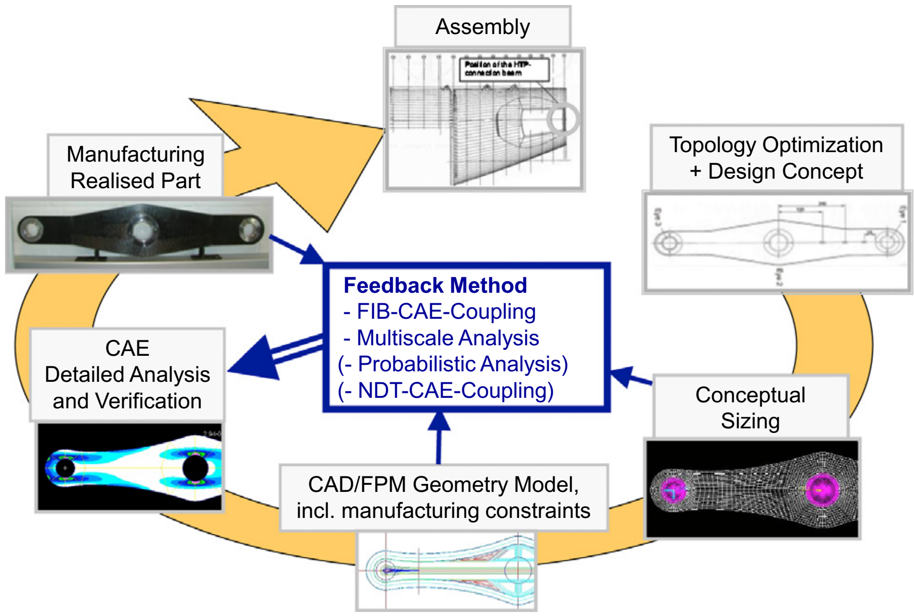

Fig. 1. Development chain, using the example of a horizontal tailplane connection beam.

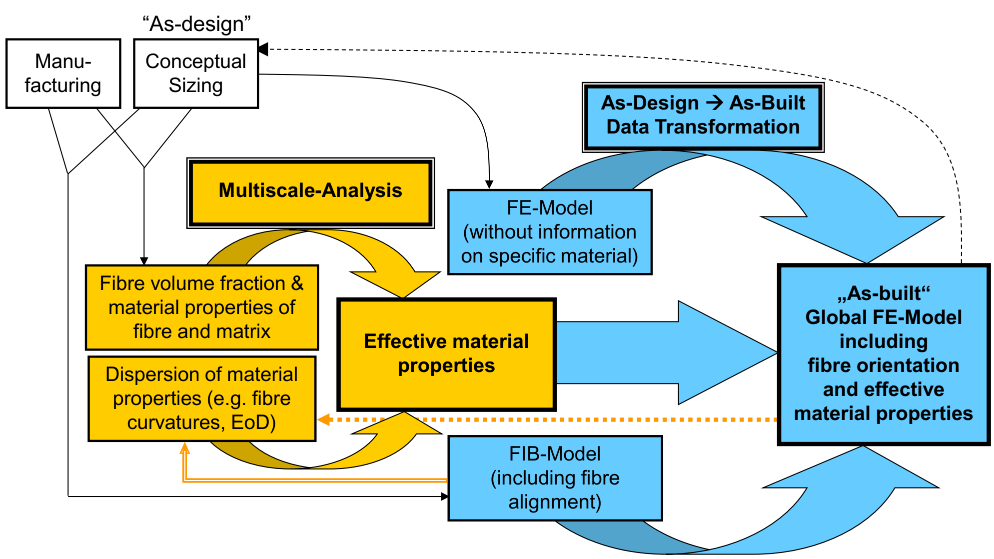

Fig. 2. Sub-tasks of the Feedback Method and their interaction.

particularities like tight fibre turns need to be suitably modelled by effective global material properties. Secondly, an automatic transformation is needed from the manufactured fibre path stored in a vector file (a universal format of this fibre path file has been generated in this work and has been called FIB) into an adjusted CAE input file, which is readable by FE software. Consequently, the Feedback Method, which shall provide a suitable transformation of manufacturing details, consists of the following two main parts:

– Multiscale Analysis: coupling of analysis methods at different scales to include local material discontinuities and to establish a suitable macroscopic resolution of certain material particularities (fibre turns, sharp fibre kinks).
– As-Design to As-Built Data Transformation: automatic coupling between fibre path and CAE models, i.e. automatic transformation of FIB data to CAE input files readable by FE software.

The concept of the Feedback Method with interaction of multiscale analysis and as-design to as-built transformation is illustrated in Fig. 2. The required input for both parts multiscale analysis and as-design to as-built data transformation comes from manufacturing and from the results of the design process ("As design" conceptual sizing). In the multiscale analysis the effective macroscopic material properties are computed by using the local material properties and the local dispersion of material properties. During the as-design to as-built data transformation, the as-design FE-model of the optimisation process is enhanced by the results of the multiscale analysis and by the actual, manufactured fibre alignment. It finally results in the global as-built FE-model. In addition to the arrows in Fig. 2 which go from as-design to as-built, there is also a dashed black arrow which goes back from as-built to as-design, which indicates the communication between analysis and design which is important to develop improved guidelines for design and for manufacturing.