# EXPERIMENTAL AND SIMULATION STUDY ON THE PERFORMANCE OF FIBER PATCH PLACEMENT (FPP)

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## Abstract

The presented work shows a study on the performance of patch-based composites compared to composites with classical quasi-isotropic (QI) laminate. Usually, loading of industrial products results in curvilinear paths. Therefore open-hole specimens with curved contours were subjected to tensile loading. The chosen geometrical shape of the specimen prevents straight load transmission between the load application resulting in curvilinear load paths. A FE-based modeling technique for predicting the stiffness behavior will be investigated. Additionally, an approach for an automated patch-based modeling process will be presented. Experimental results including a digital image correlation will be used to evaluate the simulation results.

## 1. Introduction

In recent years, we have observed an increasing trend towards energy and material efficiency becoming the focus in development and manufacturing of technical products. New lightweight technologies for processing carbon fiber are being used increasingly in various industries, such as medical technology, sports and leisure, automotive or mechanical engineering. However, laminates made of conventional multiaxial non-crimp fabrics are not fully utilizing the high material properties. Furthermore, CFRP production chains have modern technologies and processes (e.g. Fiber Patch Placement (FPP) [1], Tailored Fiber Placement (TFP) [2], Fiberforge [3], Multi-step preforming [4]) but the preforms require an additional forming process for a net-shape production. Consequently, current developments in industrial application of CFRP products primarily aim for a reduction of process costs through automation, reduction of material waste and an increase of material utilization. Additionally, a technology-specific software is also a key factor to exploit the material properties and to ensure an efficient product development. In the following, FPP is shortly introduced, followed by a performance demonstration on a specimen level.

## 2. Fiber Patch Placement (FPP) Technology

A significant potential to overcome the above addressed manufacturing challenges is provided by the innovative FPP technology. It is predestinated for manufacturing of complex-shaped medium-sized structures and curvilinear fiber architectures. The principle of the FPP process is shown in Fig. 1 representing the following steps: 1. Feed dry, bindered carbon tape & inspect quality >>> 2. Cut carbon tape into fiber patches >>> 3. Inspect fiber patch quality >>> 4. Pick up patches, check patch position >>> 5. Position patch on 3D preforming tool. This enables a load-oriented fiber orientation on a complex-shaped surface which results in high mechanical properties at low weight. Additionally,

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FPP reduces material scrap by up to 50%, and decreases cycle times through net shape 3D preforming. Industrial automation based on multiple camera controls guarantees highest preforming quality and documentation. This is a fully automated preforming process that is suitable for scalable serial production.

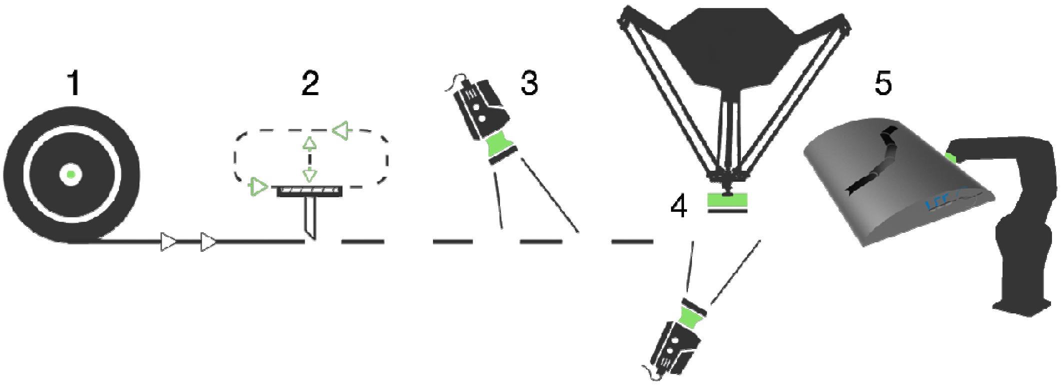

**Figure 1**. Principle of Fiber Patch Placement

## 3. Ply-based modeling technique and patch-based modeling automation

The FE-based modeling of specimens was performed with the *Ply-Based Laminate Modeling Concept* which is provided by the commercial software HyperMesh. The main characteristic of this technique is based on modeling the structure with a single layer of shell elements. Multiple plies can be defined representing the composite laminate property, which includes the fiber orientation, ply shapes, thickness, orthotropic material model and stacking sequence. The latest version of the OptiStruct solver (version 14.0) using this modeling technique supports a free size optimization with manufacturing constraints based on Automated Tape Laying (ATL) and Automated Fiber Placement (*AFP*). The optimization process starts with a ply stack with predefined fiber orientations which remain constant during the free size optimization.
For this study OptiStruct version 13.0 was used to perform a free size optimization with a subsequent translation into FPP-based machine data for manufacturing (see Fig. 2). This resulted in devations from the optimized results.

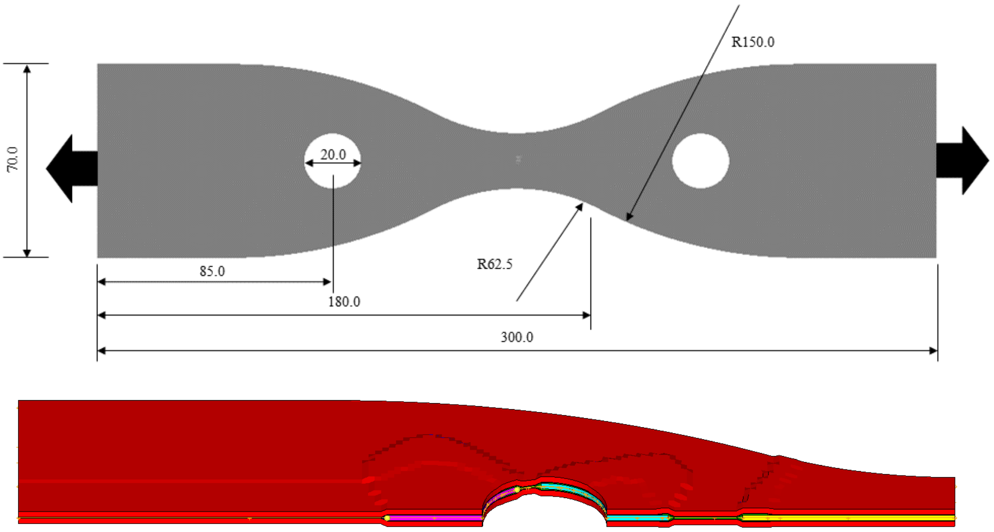

**Figure 2.** Geometry and loading condition of specimen (dimensions in mm) (top)
Free size optimization result (bottom)

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Therefore a new model was built based on the machine data (see Fig. 3). For this purpose a TCL script was developed for an automated patch-based modeling in HyperMesh. The machine data and the structural mesh served as basis input for definition of rectangular patches with their corresponding material properties and fiber orientations.

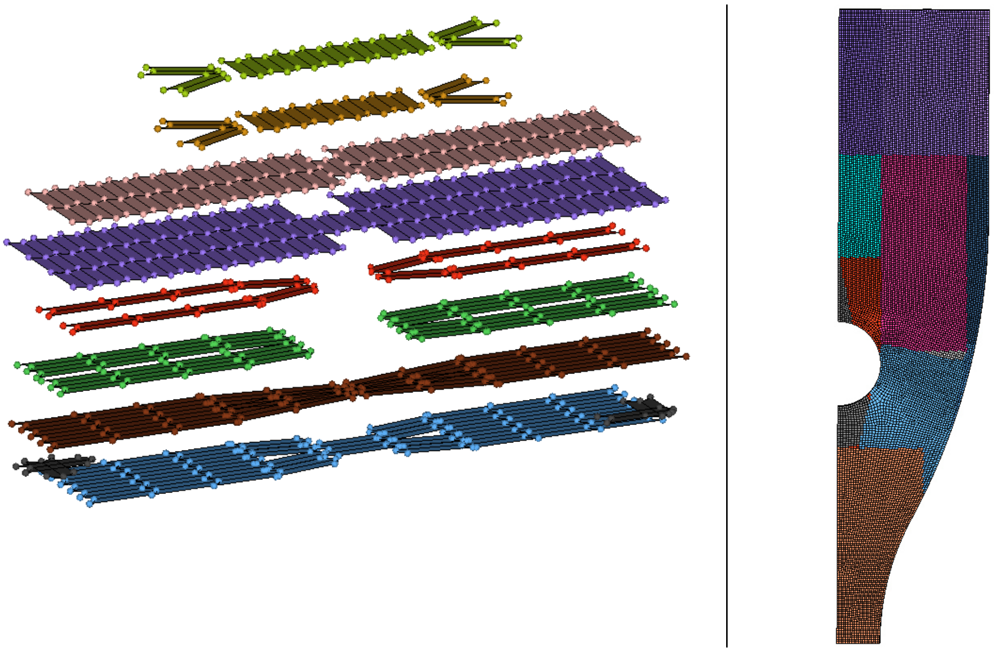

**Figure 3.** Representative extraction of the FPP laminate
transferred from the optimization result to a FPP-based lay-up (left)
Result of the automated modeling process using FPP-based machine data (right)

## 4. Material and experimental set-up

The material used in this study was carbon fiber of type HTS45 (biaxial layers for QI) combined with resin RIM135 in a vacuum-assisted process. The fiber volume fraction achieved 56%. Fig. 4 (left) shows the QI and FPP specimen with the test system (right) for a quasi-static loading.

QI (top) and FPP specimen (bottom) Test machine

**Figure 4.** Manufactured specimens (left) and test set-up including a digital image correlation (right)

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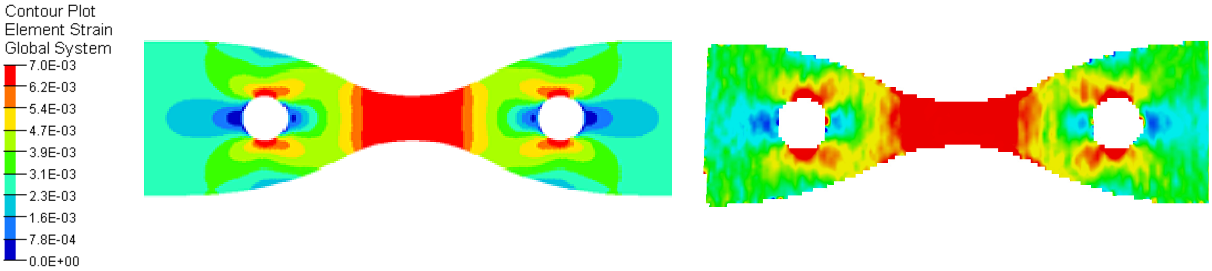
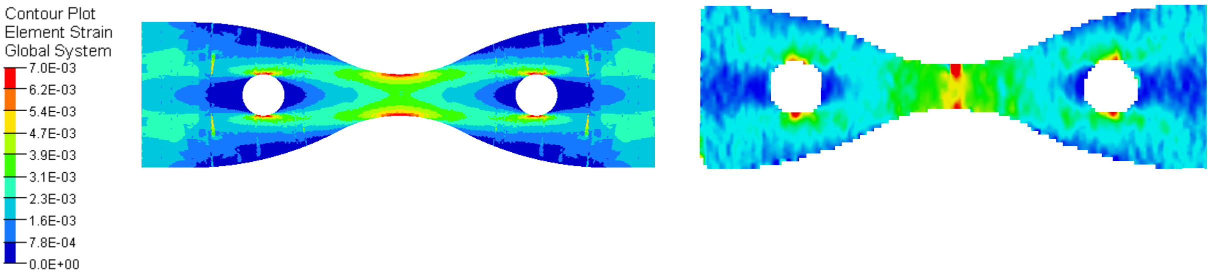
## 5. Results and discussion

Fig. 5 and 6 represent the strain distribution of the QI and FPP specimens for both simulation and experiment. The comparison of simulation and experimental results shows a good correlation (see Fig. 7).



simulation experiment

**Figure 5.** QI-specimen with strain distribution in loading direction (F=20kN)



simulation experiment

**Figure 6.** FPP-specimen with strain distribution in loading direction (F=20kN)

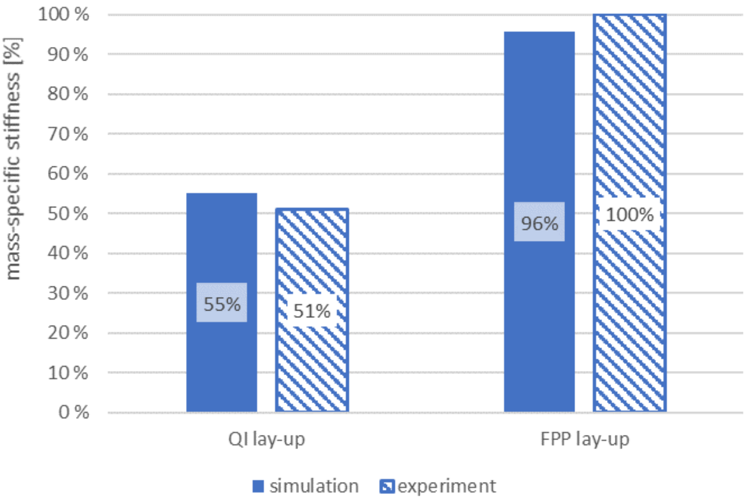


**Figure 7**. Mass-specific stiffness (normalized representation) - Comparison between experimental and simulation results

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The application of FE-based software in combination with the freedom for fiber orientation increases the mass-specific stiffness of FPP specimen by a factor of two compared to the QI design. As a result of that, the FPP based strain distribution is smoother than the QI one.

## 6. Conclusion and outlook

This paper investigated the performance of FPP-based composites compared to a classical quasi-isotropic (QI) laminate demonstrated on a specimen with curvilinear load paths. It can be stated that the applied ply-based modeling concept can be used for the prediction of the stiffness behavior. This can be achieved with a sufficient patch overlap.

In the future, the strength behavior has to be investigated, starting from the ply-based modeling concept with an increase in the modeling complexity.

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