DESIGN OPTIMIZATION OF INTERLAMINAR STRESSED COMPOSITE AEROSPACE COMPONENTS

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ABSTRACT

In this paper aspects of a study to investigate the potential for a novel composite fan annulus filler for a gas turbine aero-engine will be discussed. The annulus filler is a shell-like structure optimised for weight and mounted from the fan rotating system. It has to ensure optimal air-flow into the fan blades whilst interfacing with surrounding components. Besides the aerodynamic requirements, the filler has to resist impact loads and the high centrifugal forces due to the fan rotation. The geometry of the filler is constrained by the surrounding parts, thus requiring the integration of key features. This in turn leads to interlaminar stresses in the composite elements. A channel section and a T-joint have been modeled using finite element analysis software and the same geometries have been tested experimentally. The results show a good agreement between the FEA and tests and also reveal a strong dependency of interlaminar properties on the laminate porosity.

INTRODUCTION

Large scale jet engines use annulus fillers (Figure 1 – metal design) to close the gap between the individual fan blades and to guarantee an appropriate aeroline. The filler is normally mounted directly onto the fan disk using an engagement feature, as it is inserted on the disk after the mounting of the blades. During operation, centrifugal forces cause high loads in several sections of the filler, particularly in the engagement feature (U-channel) and the T-joint where web and lid (the aerodynamic surface) meet for a composite suitable design. Because of certain load requirements, a quasi-isotropic fibre structure is preferred for various regions of the structure; thus optimisation potential using anisotropic fibre orientation is limited.


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Figure 1: Typical metallic annulus filler

For a better estimation of the stresses in the U-channel and the T-joint, symmetrical sub-models of these features are generated and evaluated with both tests and Finite Element Software.

To benchmark the Finite Element Analysis Software (Ansys 13, Ansys Composite PrePost 13), experimental data and corresponding simulation are compared. Material data available from the manufacturer for a representative carbon/epoxy material system for Resin Transfer Moulding (RTM) in dry/room temperature conditions are used. However, the filler structure will be dimensioned for hot/wet conditions later. Of particular interest is the prediction of the failure mode, as this will ensure an appropriate modeling and analysis of the significantly more complex filler structure. Based on the load cases and the geometry of the sub-components, it is expected that interlaminar shear stresses (ILSS) and through thickness tensile stresses (TTT) will have a significant influence on the failure of the component.

THEORETICAL

Both geometries are modeled using the latest version of Ansys ACP, which is capable of extracting normal stresses for curved surfaces using a shell model (ref. 1). Additionally, a simplified 2D cross section model in MARC/MENTAT is considered to confirm the stress values calculated in Ansys. Quad4 elements are used for all simulations.

The U-channel is modeled as layered shells with 8 plies of biaxial material system. An aluminium pad is bonded in the lower section for load introduction. The upper ends are clamped (zero displacement), whereas a force of 17kN is applied on a fraction of the (perfectly bonded) pad (Figure 2).

The T-section consists of several converging preforms. Thus, a resin rich area would form, if the box section is not filled with an additional wedge (Figure 3). In the experiments, an aramid cord is used as wedge.

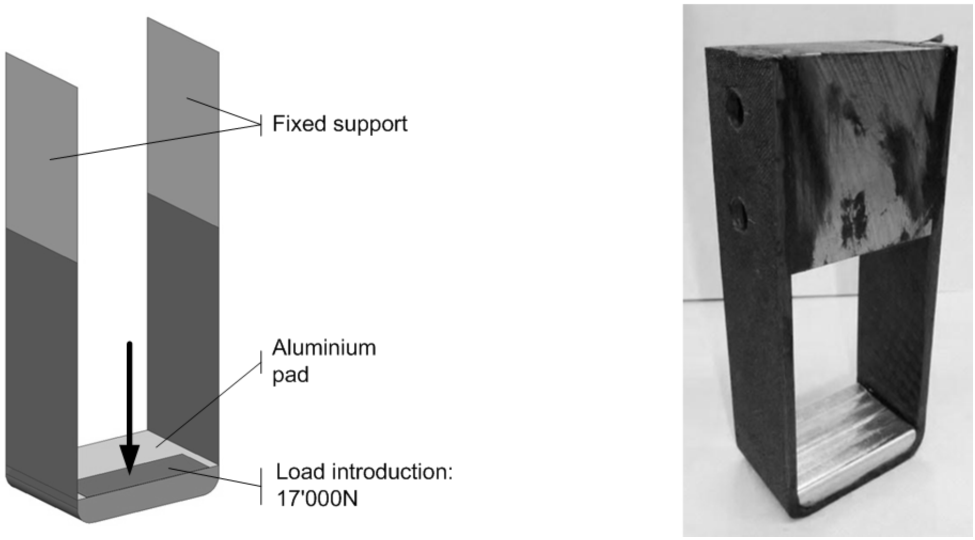

Figure 2: U-channel model and test specimen

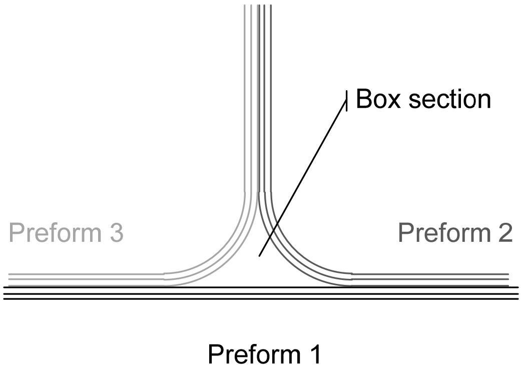

Figure 3: Cross-section view of the T-section with individual preforms

The T-section is also modeled as 8 plies layered shell, a force of 2kN is introduced at the top and 2 lines of the lid are fixed in vertical direction (Figure 4). The wedge is neglected, which represents a “worst case” scenario.

EXPERIMENTAL

Whereas the future fan filler will be produced in a RTM process, the test specimens are manufactured in hand lamination (T-sections) or resin infusion processes (U-channel) due to tooling limitations. This influences fibre volume fraction (approx.. 55% for the final filler, 44% for the U-channel test specimens, <40% for the T-sections) and air entrapments, especially for the hand laminated samples. Thus, mechanical data provided by the material manufacturer are not directly applicable when considering the specimens.

The U-channels are mounted between the hydraulic clamps by inserting a steel block, which is bonded using 3M ScotchWeld DP 490 adhesive and additionally fixed by screws. The load is applied with a steel hook that partially engages on the horizontal pad surface of the specimen (Figure 5).

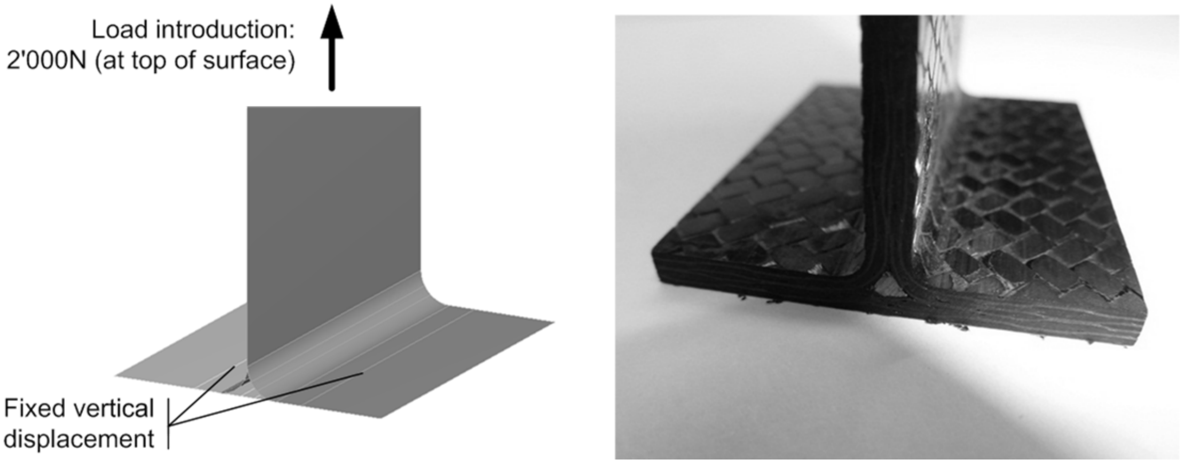

Figure 4: T-section model and test specimen

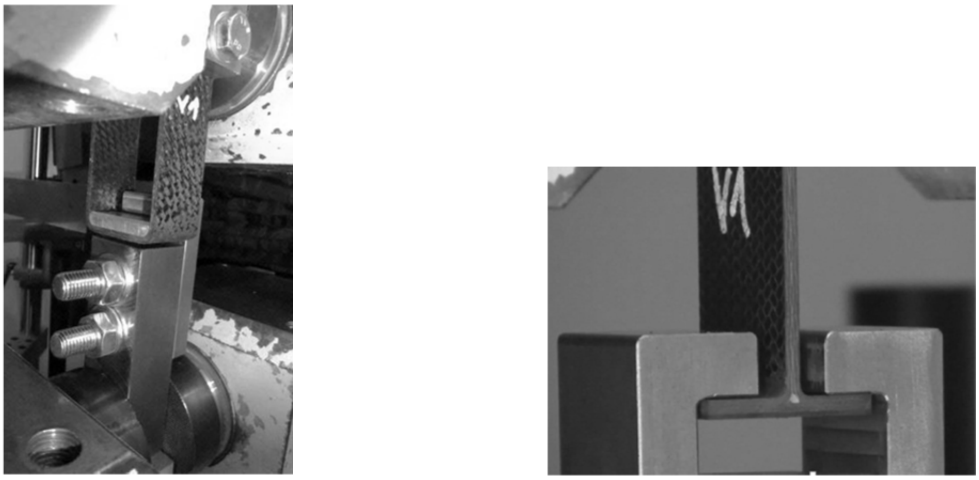

Figure 5: U-channel (left) and T-section (right) in testing machine

The T-sections are clamped directly without any metal doubler. On the lower side, 2 steel hooks fix the lid (Figure 5). For both U-channel and T-section, displacement and force are recorded and the experiments are video monitored.

RESULTS

The laminate quality of the T-section specimens manufactured by hand lamination turned out to be very poor. This leads to a low force level which is not representative for the parts manufactured by RTM. A comparison illustrates the content of air entrapments in the hand-laminated samples, whereas the specimens produced by infusion only show some resin rich areas (Figure 6).

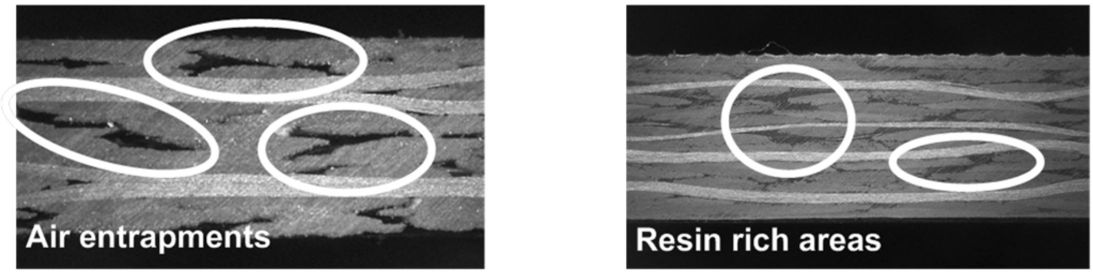

Figure 6: Comparison of hand-laminated and infused samples

Generally, simulation and experiment are in very good agreement. The analysis of the TTT and ILS stresses in the critical area of the U-channel reveals a lower stress level than expected (Figure 7) and through thickness compression instead of tension. However, fibre fracture is observed in the experiments and also predicted by the simulation (Figure 8).

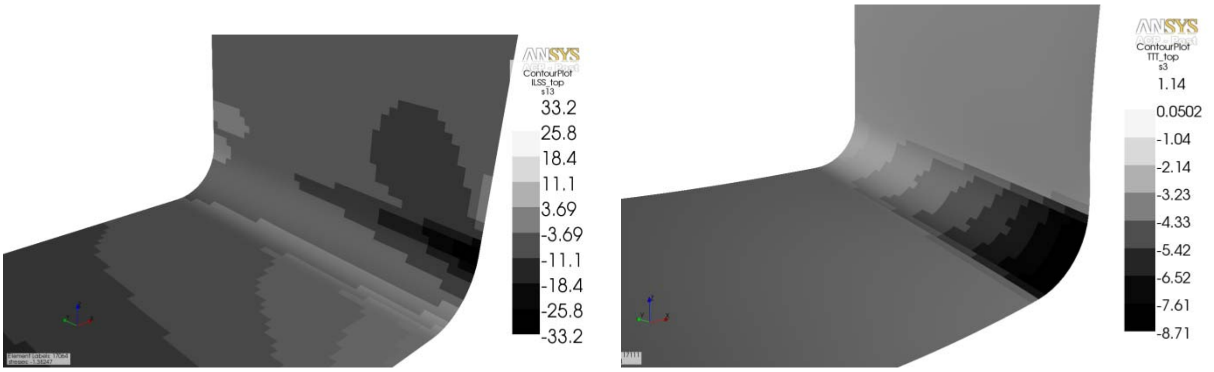

Figure 7: ILS (left, max. 33MPa) and through thickness (right, max. 9MPa compression) stresses for the U-channel

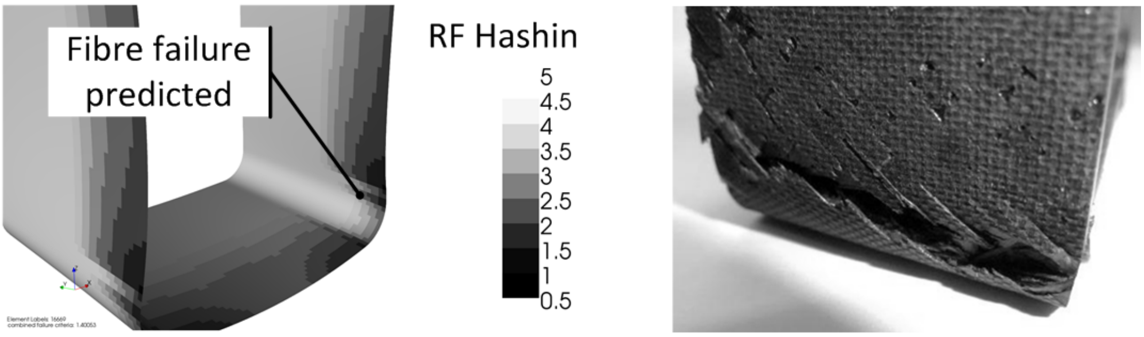

Figure 8: Comparison of FEA failure prediction and specimen fracture pattern

For the T-section, peeling forces separating the vertical preforms are observed. The FEA predicts considerable TTT and ILS stresses in these areas, which confirms the expected failure mode. Design optimization should therefore concentrate on the minimisation of TTT stresses within the T-section. The poor laminate quality caused by the air entrapments significantly reduces the stress limits (ref. 2); therefore even a low level of TTT stresses leads to a separation of the preforms.

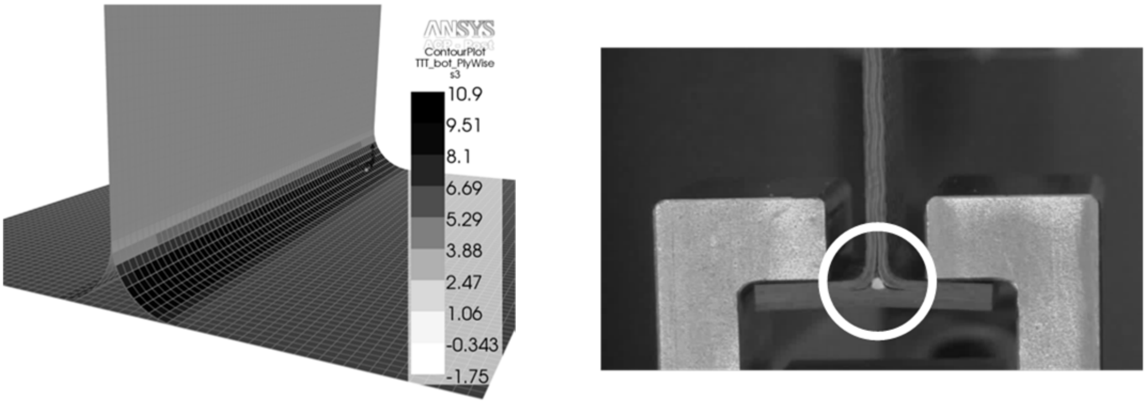

Figure 9: TTT stresses (max. 10MPa) in T-joint and preform separation in experiment

Based on the centrifugal load, a force level threshold is defined. It is expected, that the specimens meet at least these requirements. Based on the fact that the specimen's laminate quality is inferior compared to the intended RTM process, safety margins seem more than adequate. For the T-sections (with a high amount of air entrapments), the threshold force level is exceeded by a factor 2, for the U-channel nearly by a factor 4 (Figure 10).

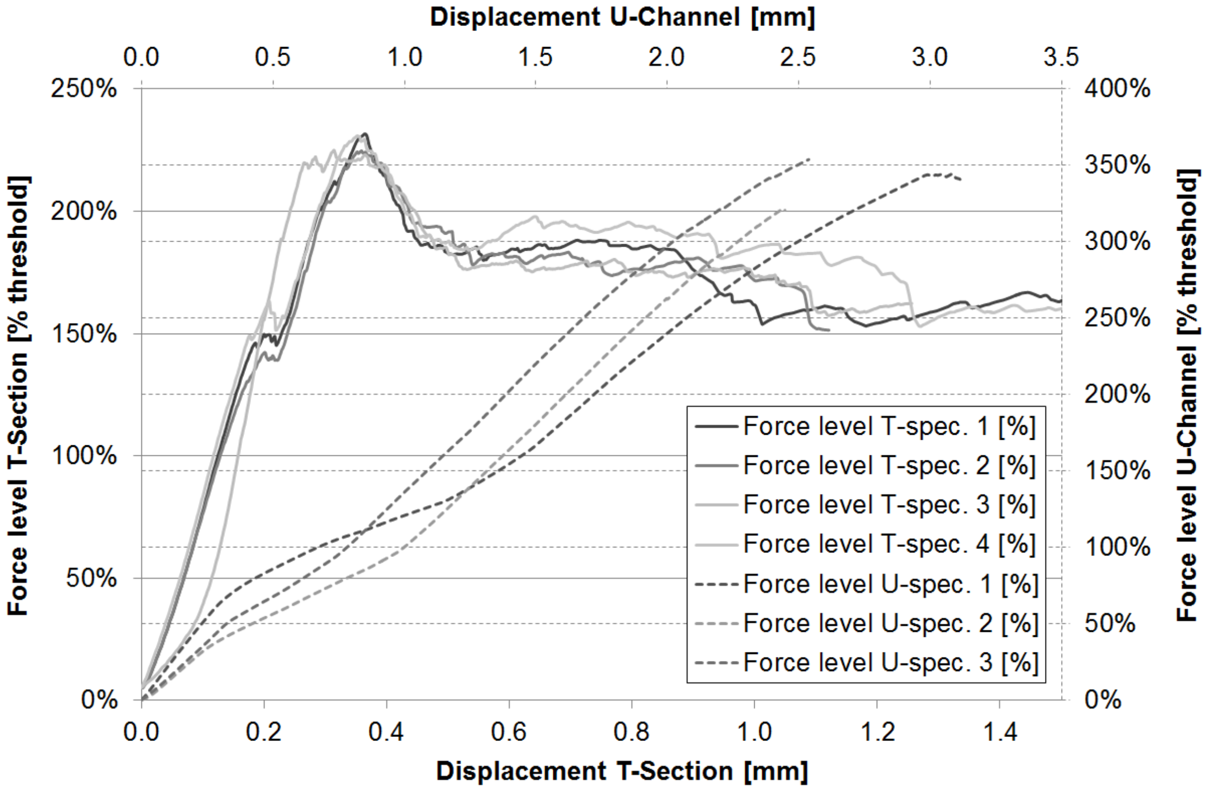

Figure 10: Experimental results for T-section (solid lines) and U-channel (dashed lines)

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