Finite Element Simulations of Pulsed Thermography Applied to Porous Carbon Fibre Reinforced Polymers

G. Mayr[1], B. Plank[1], J. Suchan[1], G. Hendorfer[1]

[1]University of Applied Sciences, Wels, Austria

Abstract

Porosity in carbon fiber reinforced polymers (CFRP) as shown in figure 1 degrades the engineering performance, especially the interlaminar shear strength [1]. In the aviation industry a porosity level of 2.5 % has become the maximum level of acceptance. The presence of air-filled voids (pores) has strong effects on the thermal diffusivity. Pulsed thermography offers a rapid, non-destructive testing method, which can be used to determine the effective thermal diffusivity based on the transient temperature field. A flash lamp is used the heat up the surface of a sample, while an infrared camera records the surface temperature. S. Torquato [2] has developed theoretical models to predict the thermal conductivity and the diffusivity of a 2-phase material with inclusions of ellipsoids. The aim of this work is to validate this effective medium model by means of 3D-Xray computed tomography (3D-XCT) and a 2D numerical simulation using the finite element method (FEM).

To simulate the 2D steady state and transient temperature field in porous CFRP the application mode of heat transfer through conduction with heat flux and convective boundary conditions is chosen. The geometry for the FE-simulation is derived from 3D-XCT. The parameters for the boundary conditions on the upper (3rd kind: heat flux and convection) and lower surface (2nd kind: convection) of the specimen are deduced from pulsed thermography measurements. By the application of the LiveLink™ to MATLAB® module a graphical user interface is build up to solve the numerical model with subsequent pre- and post-processing the data in a user-friendly way.

The porosity prediction procedure using steady state FE-simulation results is shown in figure 2. The same procedure (Step 1-4) can also be applied on transient FE-simulations if the thermal wavelength is much larger than the characteristic length (typ. pore distance) of the microstructure. In the first step an image segmentation process is applied to the 3D-XCT data to distinguish the pores from the matrix. Using this segmented image a FE-model is generated to simulate the temperature field. The transverse component of the thermal conductivity is determined by applying both a reflection (y=0) [3] and transmission measurement technique (y = L) [4]. These measured thermal conductivities decrease with porosity Φ in a similar way. Furthermore the effective medium model agrees very well with the results of the simulation. Step 4 in figure 2 shows the model based porosity evaluation. By rearranging the effective medium equation in Step 3 an explicit description of the porosity can be derived. The graph compares the 3D-XCT porosity values with the predicted values based on FE-simulations. It may be seen that the

predicted values and the measured values match one another quite well.

Reference

1. M. L. Costa et al., The influence of porosity on the interlaminar shear strength of carbon/epoxy and carbon/bismaleimide fabric laminates. Composite Science & Technology, 61, 2101-2108 (2001)

2. S. Torquato, Random Heterogeneous Materials. Microstructure and Macroscopic Properties, Springer (2002)

3. D. L. Balageas, Thickness or diffusivity measurements from front-face flash experiments using the TSR (thermographic signal reconstruction) approach, Proceedings of 10th Quantitative InfraRed Thermography conference, paper QIRT2010-011 Québec (Canada), (2010)

4. G. Mayr et al., Active thermography as a quantitative method for non-destructive evaluation of porous carbon fiber reinforced polymers, NDT&E International, 44, 537-543 (2011).

Figures used in the abstract

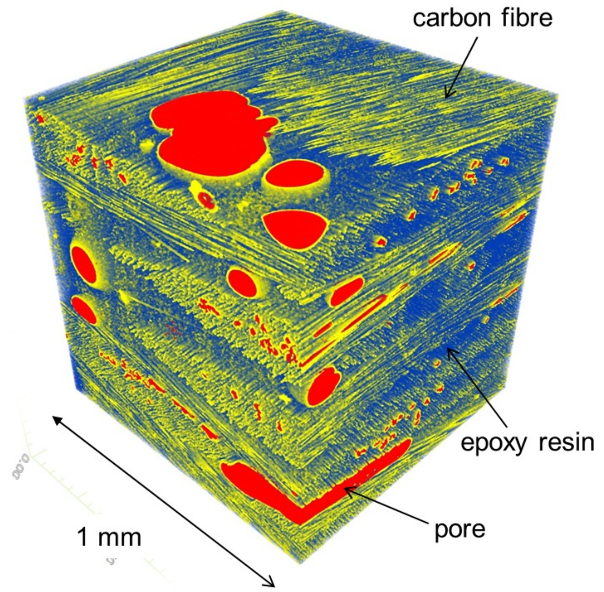

Figure 1: A 3D-XCT image of a representative elementary volume (REV) of a porous CFRP test panel.

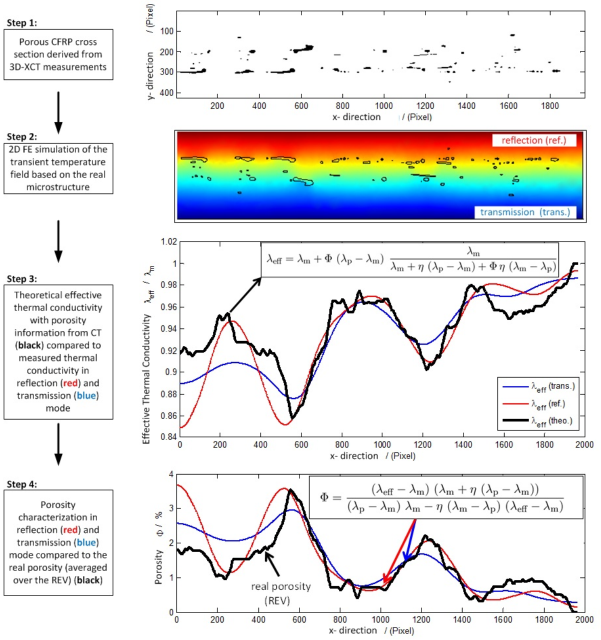

Figure 2: Results of the 2D FE-simulation of the steady-state heat conduction to determine the porosity.