Title: Experimental and Simulation Approach for the Description of Heating Effects in Millimeter-Wave Processed CFRP Composites

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Text:

High interest exists in industrial use of carbon fiber reinforced composite materials (CFRP) due to their unique combination of characteristic mechanical features. The main obstacle for widespread applications are high manufacturing costs and one cause for them are curing temperatures between 100 and 200°C. To reach them by conventional processing in electro-thermal or gas furnaces is an energy consuming procedure.

This paper presents a heating approach employing millimeter-waves. For these very good coupling occurs due to the dielectric properties of CFRP which enables heating of large workpieces directly and homogeneously. The processing is therefore significantly less energy-consuming and faster.

Modifications of the differential pressure resin transfer molding (DP-RTM) were established to adapt this technique to the requirements of millimeter-wave heating and produce sample plates with multi-axial carbon weave of comparative quality to conventional processing. Experiments were successfully conducted in 28 and 30 GHz gyrotron systems.

To allow a better understanding of the production of these cured samples, heating experiments were made with cured CFRP samples and stacked CFRP single-layers. Samples with roughly the same geometry as in the curing experiments and multi-layered multi- or unidirectionally oriented fibers were millimeter-wave heated up to 100°C. The temperature distribution was measured with thermocouples and IR imaging. The distributions of these two sample types differed strongly after the same heating process. In the experiments with multi-directional samples a strong temperature gradient between hot edges and a cooler center could be observed. In the case of the unidirectional samples, the temperature gradient was overall lower but inverted.

These processes were also simulated with the THESIS 3D simulation tool. It allows the numerical solution of the nonlinear heat conduction equation under the influence of the electromagnetic heating field. In the case of multi-directional material the results of isotropic calculations were in accordance with the experiments if averaging of the anisotropic dielectric and thermodynamic properties over the layers was assumed. This method cannot be used for the unidirectional samples where the anisotropic properties of the material dominate.

Currently this issue is addressed with an adapted model especially for the interaction with the electromagnetic field to obtain a simulation code for unidirectional samples. With this simulation tool in combination with thermodynamic modeling of the exothermic curing of the resin insights in the material processing and an enhancement of the complete process will be obtained.