Movable and adjustable injection of air through concentrated sources of mass and momentum for the pneumatic atomization of polyurethane and the modeling of droplet-fiber-interaction for the manufacturing process of polyurethane-fiber-reinforced composites

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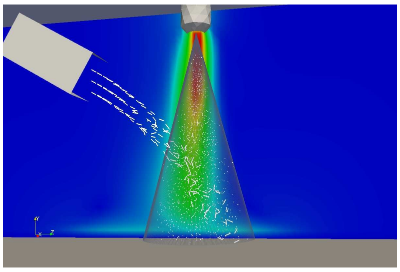

Figure 1: Spray-fiber-injection simulation

The polyurethane spray molding process is a manufacturing technology applied to produce composites by spraying the initially liquid polyurethane (PUR) matrix together with reinforcing fibers in a tool form or on a substrate. The fibers are laterally injected in the polyurethane-air spray cone for wetting before the entire composite is spread on the substrate, where it starts curing. In Fig. 1 a PUR mixing head nozzle is shown together with the inclined fiber glass chopper on the left side. A reliable prediction of the properties of the final composite is only possible if the average orientation and density distribution of the fibers in the matrix are known and translated into material properties. It is additionally of interest for the manufacturer to quantify the influence of some process parameters (e.g., fiber injection angle, fiber mass flow, polyurethane and air mass flow) on the orientation and density distribution of fibers for optimization purposes of the spray process itself. Therefore, the different interaction processes of the three phases (air, fibers and polyurethane droplets) within the spray jet are modeled and simulated in this project and their impact on the fiber distribution on the substrate are compared with experimental data from the facilities of our industrial partner (see Fig. 2).

The modeling of the two fluid phases, continuous air flow and particulate PUR droplets, including a four-way coupling (fluid-particle, particle-fluid and particle-particle-collision) is performed with a commercial CFD code (*ANSYS Fluent*) by using a RANS Euler-Lagrange approach with the built-in discrete model to represent the PUR droplets (discrete phase). A new approach has been developed for the air injection where a source term in the continuity equation (for the air mass) and in each of the momentum equations (for the regulation of the jet angle and velocity at the outlet) are applied to a definite number of adjacent cells of the computational domain. Those cells represent the nozzle outlet and can be activated and deactivated as the virtual injector moves through the domain. This method allows the implantation of an axial symmetrical air flow and avoids the modelling of a nozzle and the remeshing of domain after each motion of the nozzle. The impact of this new approach on the spray pattern will be compared with experimental data from the literature.

For the computation of the fiber dynamics, i.e., the one-way-interaction of the fibers influenced by the air and the one-way-interaction of the fibers affected by the PUR-droplets, the code *FIDYST* developed by the *Fraunhofer-Institute for Industrial Mathematics ITWM* (Kaiserslautern, Germany) is used. The fiber modeling in this tool is based on the Kirchhoff-Love-theory for large, non-linear deformations by making use of the Bernoulli-Euler material law and considering a fiber as a one-dimensional elastic rod, which depends on length and time. The fiber-droplet coupling is modeled using two approaches:

- Semi-Homogenization: an algorithm, which averages the time dependent dynamic data (mass, momentum) of discrete PUR-droplets present in a finite-volume cell over the cell volume to compute the effective droplet force acting on the fibers in that cell. This effective force is considered in *FIDYST* either as an independent drag force which together with the force from the air jet act on the fibers. in a straightforward manner by adjusting some specific flow field functions already used for the interaction of the fibers with the continuous air phase.
- Homogenization: an algorithm, which alternatively computes mixed/hybrid dynamic data out of the PUR-droplets and air present in a finite-volume cell. Thus a fictive ("homogenized") fluid is created and those data are used within the *FIDYST*-environment to compute the drag force acting on fibers.

Both methods are tested and compared to each other. The paper will present the entire methodology and results of the multiply coupled simulations.

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