Taking into Account Glass Fibre Reinforcement in Polymer Materials: the Non Linear Description of Anisotropic Composites via the DIGIMAT to LS-DYNA Interface

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Summary:

In the context of light weight construction the replacement of metal parts with substitutes made from plastic plays a major role. These devices commonly are manufactured through injection moulding and reinforced by different amounts of glass fibres to enhance the strength of the material. In everyday application this poses a challenge to the engineer as due to this processing the local orientation of the reinforcements is varied on a broad scale leading to pronounced different material properties. Finally this can influence the overall stability of the part which is especially true for regions where welding lines occur.
In the early stages of the virtual development of such plastic parts it is therefore significant to the take into account the material microstructure while carrying out macroscopic simulations. For explicit calculations non linear material properties, strain rate dependency and the failure of material play an important role in this context.

The DIGIMAT to LS-DYNA interface allows to couple microstructure information coming from injection moulding simulations to be integrated in the structural mechanics calculation. Within this approach DIGIMAT is implemented as LS-DYNA user material and offers an independent description of the local composite in each element. The interface uses homogenization schemes which take constitutive laws for fillers and matrix, the percentage of fillers and the filler shape as an input and calculate the average macroscopic stiffness of the material based on the local microstructure.

In the standard workflow of a coupled analysis several steps have to be carried out. Within DIGIMAT the constitutional laws are described by mathematical functions. These functions are fitted to the experimental measurements of the material. Usually these experiments are already carried out for fibre reinforced samples leading to the necessity that within DIGIMAT the full composite has to be reverse engineered for the fixed microstructure of the samples.
The result is a set of material parameters which can then be taken for a coupled analysis connecting the injection moulding with the structural simulation for the full part under multiaxial load. As both types of simulation usually bear vastly different meshes a preparing step is required in which the local fibre orientations is mapped from the injection moulding mesh to the mesh used in the structural simulation.

DIGIMAT offers all tools necessary to carry out the above described steps. In the presentation the workflow of a coupled DIGIMAT to LS-DYNA is demonstrated. Within the virtual material laboratory DIGIMAT-MF the composite is reverse engineered. The resulting parameter set is compared to coupled MOLDFLOW/LS-DYNA calculations on tensile bars under uniaxial strain as well as three point bending. For the application in explicit calculations also failure indicators can be defined within the coupling scheme. As at each step of an analysis DIGIMAT automatically offers all information about the microstructure failure criteria can be derived from the matrix phase or fibre phase separately and used for element deletion within the explicit calculation.

All necessary descriptions for composites in explicit simulations can be defined within DIGIMAT, from nonlinear materials over strain rate dependency to failure. On that base the results of a coupled analysis show convincingly better results for an impact through an injection moulded plate than with the conservative approach with isotropic material.

Keywords:

DIGIMAT, composite material interface, fibre reinforced polymers, micro / macro coupling

1 DIGIMAT as a material interface to injection moulding simulation

DIGIMAT offers the user a complete set of tools that allows the coupling between injection moulding simulation and the structural analysis of the so produced plastic parts. Expressed in another way, via its material description DIGIMAT takes into account the locally different microscopic glass fibre orientations in the part. These differences are caused by the viscous flow of the plastic part during processing of the part leading to a variation of the microstructure over the part which is frozen into the polymer matrix upon cooling down to room temperature. Through these locally oriented fibres the material becomes anisotropic in its behaviour, so in principle for each element in the structural analysis an individual material description has to be used.

Through a combined application of the DIGIMAT modules such a material description can be used in practical application. The base module is called DIGIMAT-MF. MF stands for *mean field homogenization theory*, the approach that allows the quick calculation of material properties based on the constitutional description of the material matrix and the glass fibres as well as information about the shape and amount of fibres and finally the fibre orientation. A speciality of DIGIMAT is that besides purely linear elastic behaviour also nonlinear laws and strain rate dependent materials are implemented. The DIGIMAT-MF material can be used in arbitrary FEM solvers featuring user material subroutines, e.g. in ANSYS or LS-DYNA. This interface functionality is then called DIGIMAT to CAE. It also extends to including injection moulding results as a base for the fibre orientation, namely the orientation tensor as given by the software packages Moldflow, Moldex3D or Sigmasoft. In these software types the output is given as a physical property per element for the injection moulding mesh. However, the meshes used in structural FEM are usually vastly different from those used in injection moulding. This gap is overcome by the use of the MAP module within DIGIMAT which offers a comfortable way of transferring properties from one mesh to another including several meshing algorithms as well as way of globally or locally testing the quality of the meshing procedure.

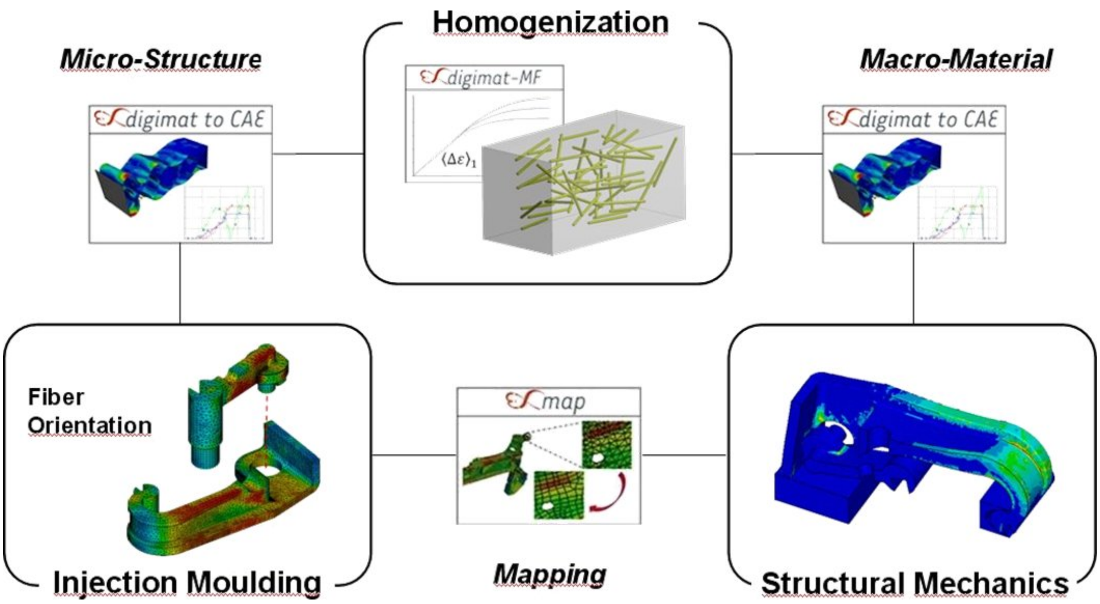

Figure 1: DIGIMAT offers a complete set of tools for the coupling of injection moulding simulations with structural mechanics.

2 Workflow of a coupled DIGIMAT analysis

The standard workflow of an integrated DIGIMAT analysis commonly starts with the reverse engineering of material properties within DIGIMAT-MF. In DIGIMAT-MF, the constitutional behaviour of the matrix and the filler phase is defined separately through a set of parameters for predefined mathematical functions. These parameters are derived from the experimental stress strain curves for the respective material. Often only measurements for the complete composite material are at hand. In these cases the average microstructure of the test specimen is taken as a set value and the composite material parameters can be reverse engineered by the use of DIGIMAT-MF (see figure 2).

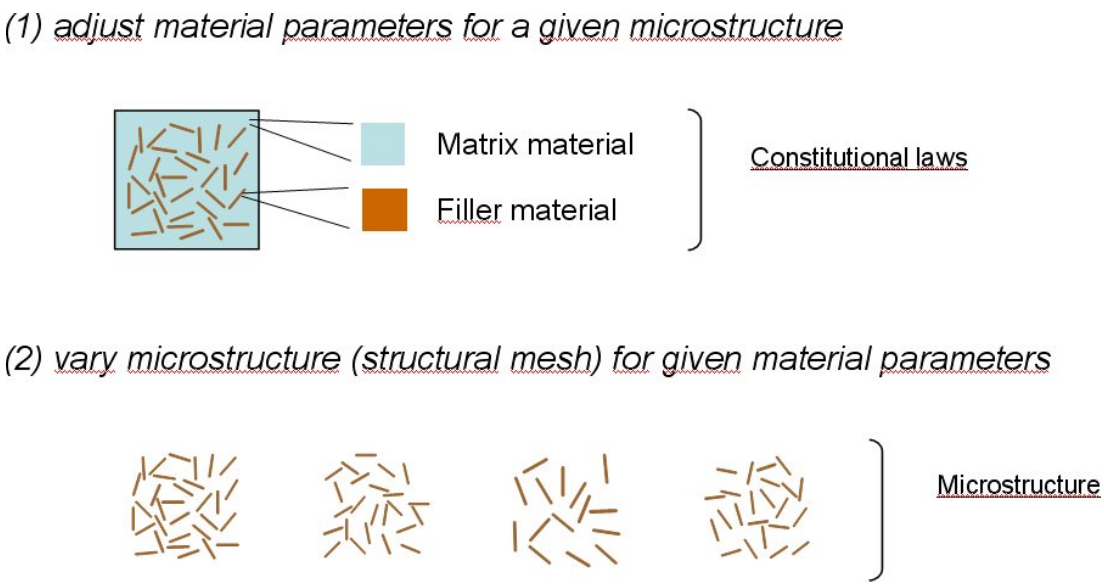

Figure 2: Systematic workflow of a coupled DIGIMAT to LS-DYNA analysis

Once the parameters are known they are kept fixed and the influence of the microstructure on the material behaviour can be investigated (see figure 3). It is this sensitivity towards a change in the microscopic fibre orientation which is taken into account by setting up a coupled analysis with results from injection moulding simulations.

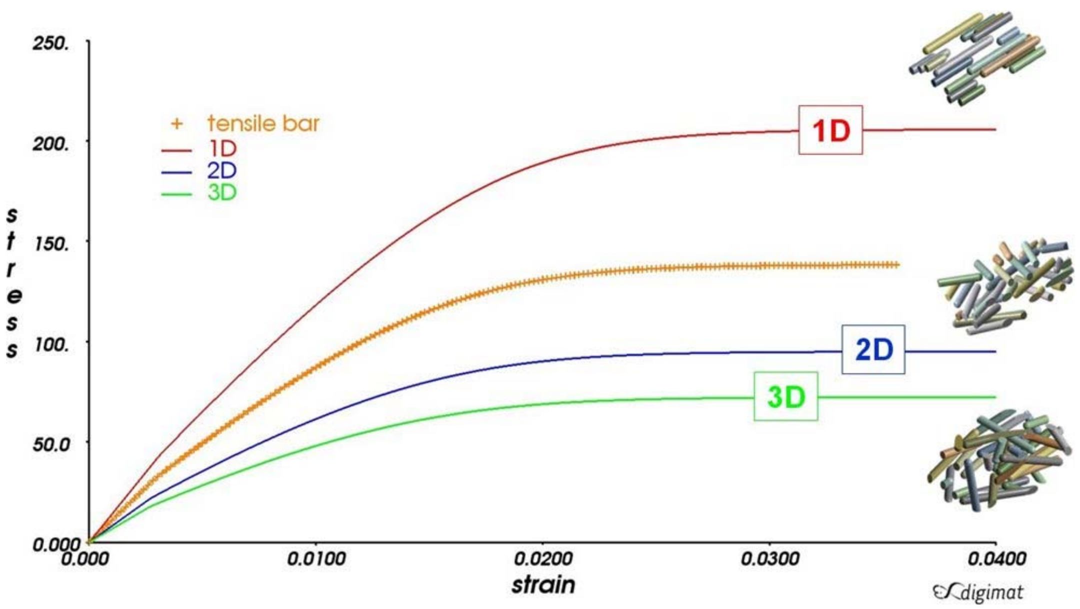

Figure 3: Through the implementation of homogenization theory within DIGIMAT the sensitivity of composite materials towards their microstructure is taken into account in the material behaviour.

Before doing so for a full part under the complicated state of multiaxial stress it is recommended to test the DIGMAT material for some easier state such as uniaxial load or, more complicated, for a three-point bending test with some specimen featuring a simple geometry (see figure 4). This step is already carried out as a coupled analysis based on injection moulding results. The sample investigated can be directly a moulded tensile bar or some cut out specimens from a moulded plate. The latter gives the opportunity to use well known fibre orientations and systematically investigate the behaviour of the sample for cut outs along the length of the fibres and perpendicular to them.

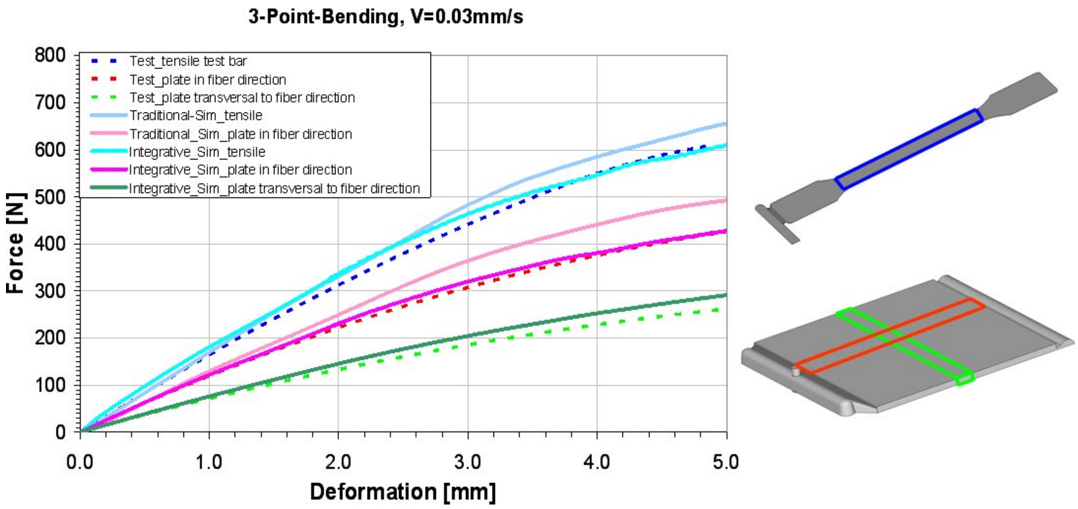

Figure 4: Check of material parameters in a coupled analysis of a 3-point-bending test.

Once these tests successfully reproduced the experimental behaviour further improvements can be made. The material model can be enhanced by specifying failure indicators within DIGIMAT. The great advantage here is that within the homogenization approach the average stresses and strains in the matrix and filler phases are given separately for each step of the analysis. Thus it is possible to define failure directly as strain failure from the polymer material matrix or based on a maximum principle stress in the filler phase. Also more complicated failure modes can be chosen up to fully strain rate dependent indicators.

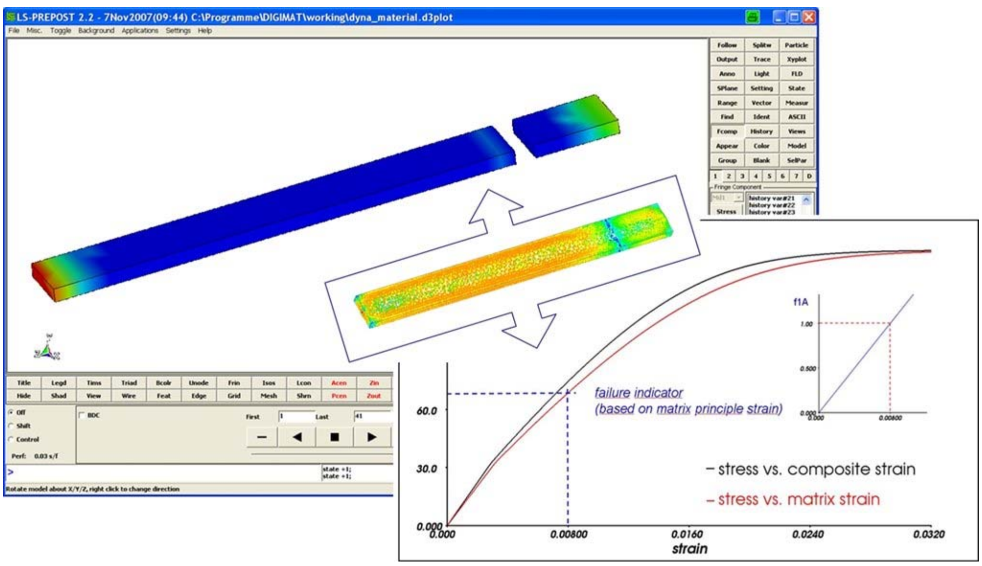

Figure 5: Element deletion at a welding line based on failure indicators defined in DIGIMAT.

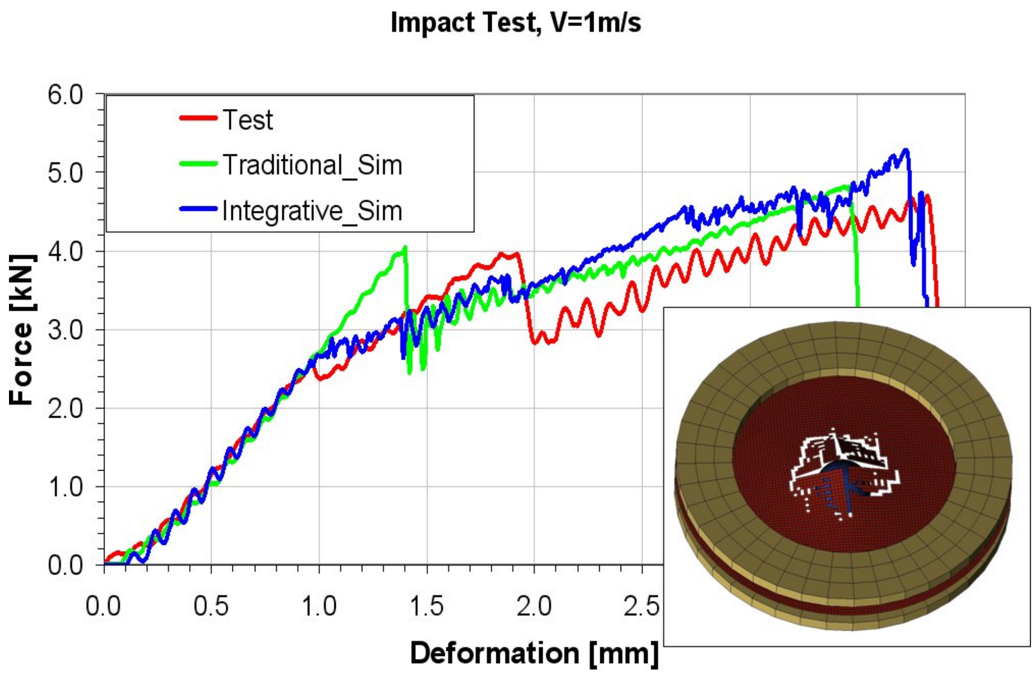

Figure 6: Check of material parameters in a coupled analysis of a 3-point-bending test.

Once the DIGIMAT material is defined and confirmed in the above described way it can be used in a coupled analysis of complex systems under multiaxial strain. Figure 6 shows a comparison of an impact test carried out for a specimen first injection moulded in a Moldflow Midplane analysis which was then coupled to LS-DYNA in an integrated DIGIMAT simulation. Whereas with the classical approach of isotropic LS-DYNA material the force characteristic is only reproduced in a qualitative way the integrative DIGIMAT solution gives much better results.