

Using the local fiber orientation and fiber to volume fraction in μ CT data to improve the simulated failure location and strain at break of Long Fiber Thermoplastic (LFT) parts.

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Abstract

Taking a fiber orientation and a volume fraction of the fibers of LFT parts in account to predict the failure location and strain at break is standard in today's simulation software. Nevertheless the main question is how to get the real fiber orientation and fiber to volume fraction as a basis for the simulation and if the knowledge of the local microstructure of the real part would improve the results of a stress simulation. In this project the local fiber orientation and fiber to volume fraction of a μ CT scan (DITF) of a LFT test specimen was analysed using VGSTUDIO MAX (Volume Graphics) on a microstructure level. This microstructure material data was directly coupled to the simulation software Digimat (MSC Software) to improve the predicted failure location as well as the strain at break in a virtual tensile test. To validate the results the tensile test was also done in a real test setup at Brose. The comparison of the experimental and the simulated results clearly show, that using this coupled analysis Digimat was able to predict both, failure location and strain at break in good correlation with the experiment. It could also be shown that the simulation results are more accurate when the local information on microstructure level from the μ CT scan was used as input data for the simulation. This research was done in a joined project between Brose, MSC Software, DITF and Volume Graphics.

Keywords: Computer Tomography, Modeling and Simulation, Strain simulation, Fiber orientation, Radiographic Testing (RT), Other Methods

1 The Workflow

The basis of the whole project was a tensile specimen (150mmx10mmx1.8mm) which was scanned, simulated and destroyed in a tensile test. In this study a real world test specimen was cut out from a bigger long fiber enforced thermoplastic part used in the automotive industry. This test specimen was scanned at Brose and at the DITF with different resolutions. How these scans were performed in detail is described in chapter 2. For the study only the scans with the highest resolution were analysed in VGSTUDIO MAX. The analysis delivered the local fiber orientation and the fiber content of the test specimens, see chapter 3. The results were exported into a simulation mesh generated out of a CAD model generated for the test specimen. This mesh filled with the local material properties had been imported into Digimat software. Digimat used this local information to build a material model of the test specimen. This material model was used as a basis for a simulated tensile test within Digimat. The



simulated strain at break and the failure location were compared to the real values generated by a real tensile test done at Brose, see chapter5.

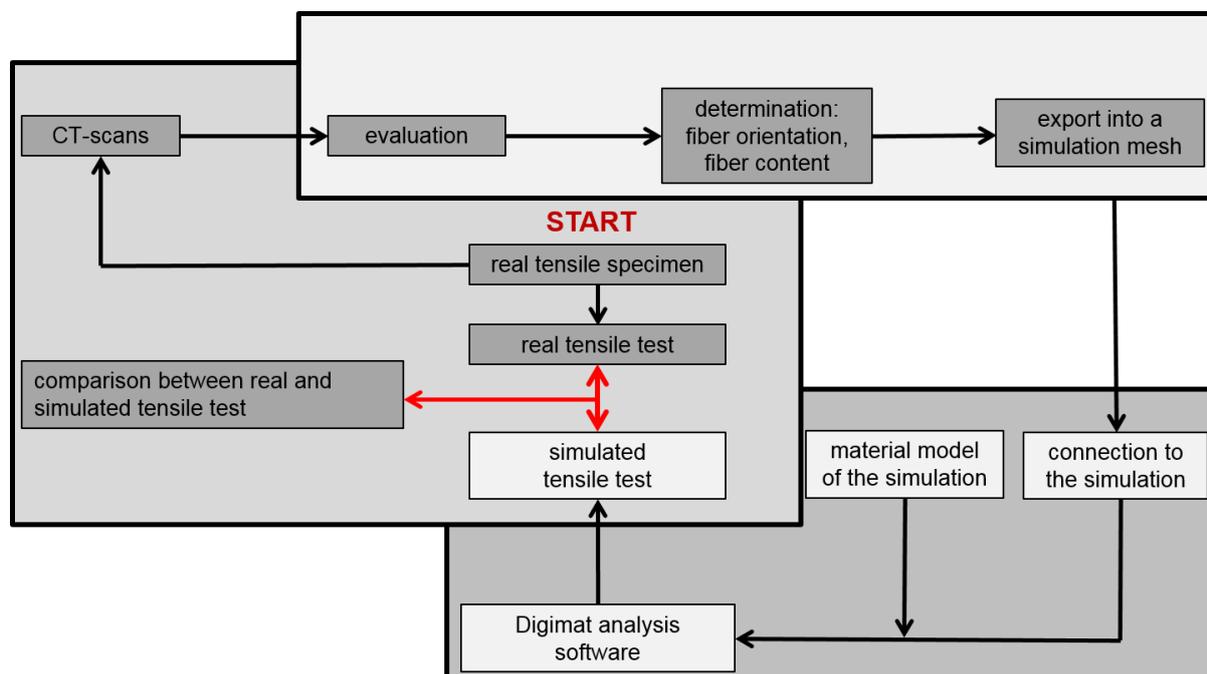


Figure 1: This is an overview of the whole Workflow. The work in the top right box was done by Volume Graphics, the CT Scans and the tensile tests were done by Brose, the high resolution scans were done by the DITF. The whole simulation part and modelling was done by MSC software (bottom box).

2 The CT Scans

Three scans had been performed for this study. Two scans were done at Brose and one scan was done at the DITF. In a first attempt the specimen was scanned with a voxel resolution of 50 μ m in order to get the best resolution out of the used CT system the final scan data had been assembled from seven sub scans. Using this technique the whole sample can be scanned with the maximum resolution the scanner is capable of. The second scan was also done using seven sub scans but here the voxel size was 12.5 μ m. The total scanning time for all scans together had been 30 hours. Due to this long scanning time the instability of the x-Ray tube lead to a low quality of the scan.

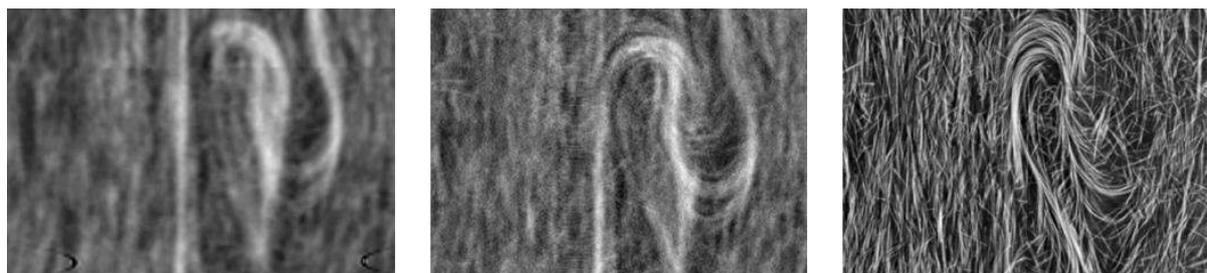


Figure 2 is showing 3 different CT scans from the same location in the tested part. The left scan has a voxel size of 50 μ m, the middle and the right scan 12.5 μ m. Even having the same resolution the different quality levels of the scans are clearly visible.

The results from this first two scans could be used to extract the fiber orientation in VGSTUDIO MAX, but in order to get the best possible results it was decided to have the specimen scanned at the DITF on a μ CT system designed for the analysis of fiber composite materials. The final scan data from this system consists of 4 sub scans with a voxel size of 12.5 μ m each. The total scanning time were 8 hours. In figure 2 you can see a slice from the same position in the part from all performed scans. It is clearly visible that the third scan has the best quality (geometric and contrast resolution). Only the third scan was used to generate the following results.

2.1 Preparing the data

In order to achieve a compatibility between two high end software packages (VGSTUDIO MAX and Digimat) the scan data has to be prepared before the analysis of the fiber orientation can be started and easily transferred. The first step of the preparation was to merge the 4 sub scans into one single volume this can be done easily in VGSTUDIO MAX. For a precise transfer of the analysis results (fiber orientation and content) a common coordinate system has to be defined the easiest way of doing is to register the specimen against a CAD model generated from this part.

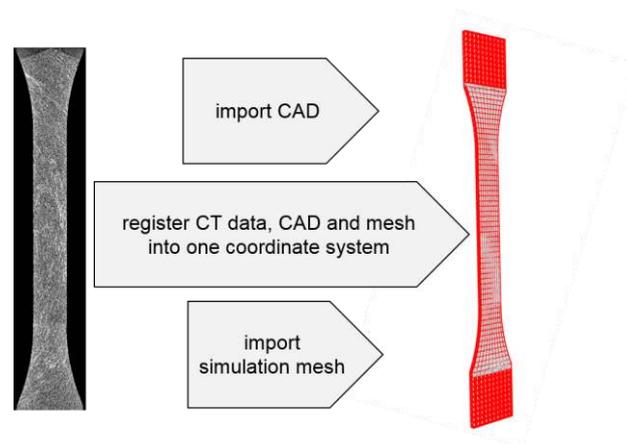


Figure 3 gives an overview of the data preparation in order to ensure a precise data transfer

Next to a coordinate system the transfer of the orientation data and the fiber to volume fraction has to be taken in account. In this case the three dimensional mesh which will be used for the mechanical simulation was also imported in VGSTUDIO MAX in Patran format. The voxel volume was now registered against the CAD model, which also leads to a registered mesh because the mesh was generated using the CAD model. This procedure ensures a precise data transfer between the used software packages. The result of the aligned CAD, mesh and voxel data is shown in Figure 3.

3 Analysing the data in VGSTUDIO MAX

After the preparation of the data the analysis of the real fiber orientation and content was performed in VGSTUDIO MAX. An analysis based on the grey values of the voxel data set delivers an orientation tensor for every voxel in the scan. This leads to an enormous amount of data this granularity of the results cannot be handled by any simulation software but it ensures to get information about the fiber orientation on a real microstructure level. To overcome this problem the already mentioned simulation mesh was used. VGSTUDIO MAX is capable of averaging the analysis results for every mesh cell within this mesh independent of their shape or size. So we ended up with an average fiber orientation and content for every single mesh cell of the simulation mesh. All of these results can be plotted as graphs, histograms or exported as .csv files. In this case the possibility to export the simulation mesh filled with local material properties as .csv was used. A visualization of the resulting fiber orientation and content can be seen in figure 4.

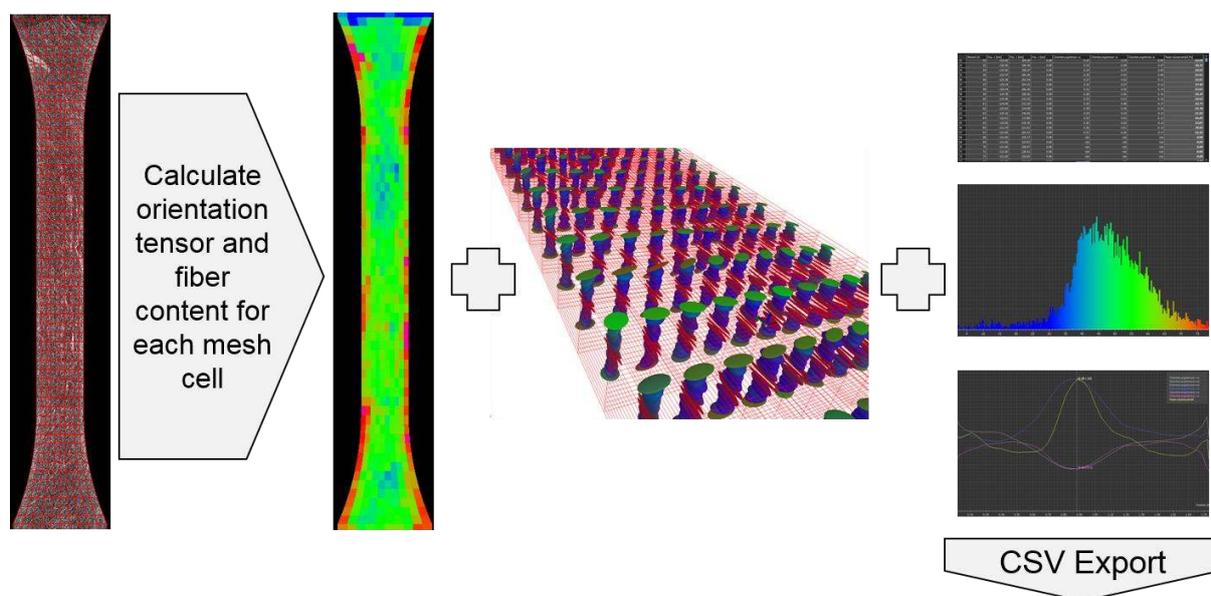


Figure 4 is showing the analysis results from VGSTUDIO MAX and the aligned simulation mesh on the left side. In the second picture the fiber content is colour coded, the next picture is showing the local fiber orientation tensors in a 3D visualization within the used mesh. On the right side further visualization possibilities of the analysis results are shown.

4 Simulation

To simulate the tensile test the analysis data was read into Digimat-MAP. In Digimat MAP a material model was generated using the local material properties from the analysed CT scan. The improvement of the material model by using the local material properties leads to an improvement of the simulation results. In order to get the best possible simulation results the data exported from VGSTUDIO MAX were mapped into a structural mesh which consists of 13 layers and the local analysis results were averaged over 11 voxels. In Figure 5 the mesh filled with the local fiber orientations is shown. Furthermore the highly aligned fiber structure (red colour code) in area indicated with an arrow can also be found in the original CT data. This area of aligned fibers is where the tensile will break in the real test.

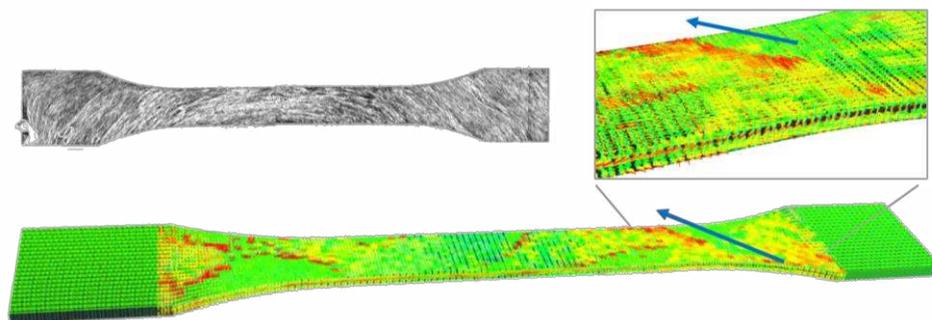


Figure 5: On the top a slice out of the CT data is shown, the fiber structure is clearly visible. In the bottom picture of the tensile the mesh filled with the local fiber orientations is shown. In the magnified area around the arrow the highly aligned fiber structure (red colour code) can be seen.

Next to the local fiber orientation the analysis also delivers the local fiber to volume fraction. As described above the local fiber density is extracted out of a grey scale analysis. The analysis delivered a mean value of 55% fibers in the volume in the fiber distribution of the whole part. This value has to be handled carefully due to the fact that this value is based on grey values and the areas where the fibers are very close to each other are also “seen” as “fibers”, so in this case this value is overestimated by CT. This value has to be corrected to get good simulation results. It was decided to shift the mean value for the fiber to volume fraction distribution function to 13% which accords to a mass fraction of 30% fibers which corresponds with the used material. The relative fiber to volume distribution over the whole part did not change by the shift of the mean value of the fiber distribution function. In Figure 6 the influence of the fiber to volume fraction of the simulation results are visualized. Here again the area where the actual break took place is indicated, especially here the information about the local fiber to volume fraction is changing the simulation results but the prediction of the failure location becomes much better. Because in the left picture the failure arises from the mid plane after taking the fiber content into account this changed and the failure arises in the simulation from the area the part broke in the real tensile test.

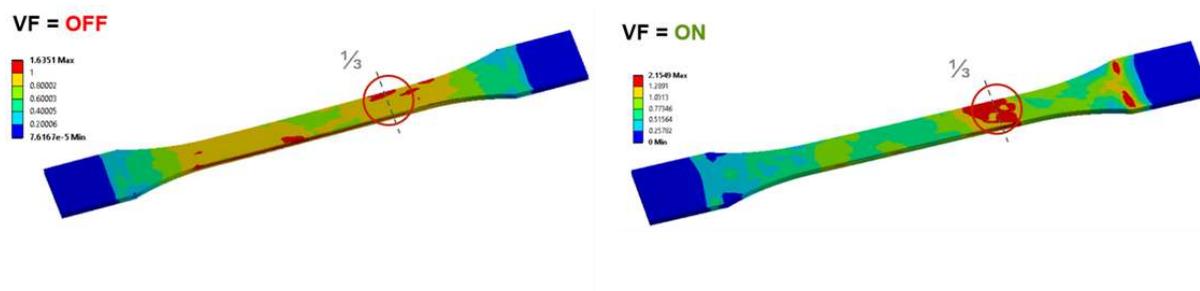


Figure 6 is showing the analysis results of the simulation. In the left picture the information of the fiber content is not used, in the right picture the real fiber to volume fraction distribution was taken into account for the simulation.

5 Optical Strain Measurement

To verify the simulation results an optical strain measurement was performed at Brose. The used setup and the result can be seen in Figure 7. In principle the 3D deformation of the part is measured by a video analysis following the movement of markers. The procedure is a contactless and material independent measurement. It is clearly shown that the results correspond with the simulation, the areas with the highest strain are the areas predicted clearly by the simulation when the fiber orientation and the fiber content from the real part had been taken into account.

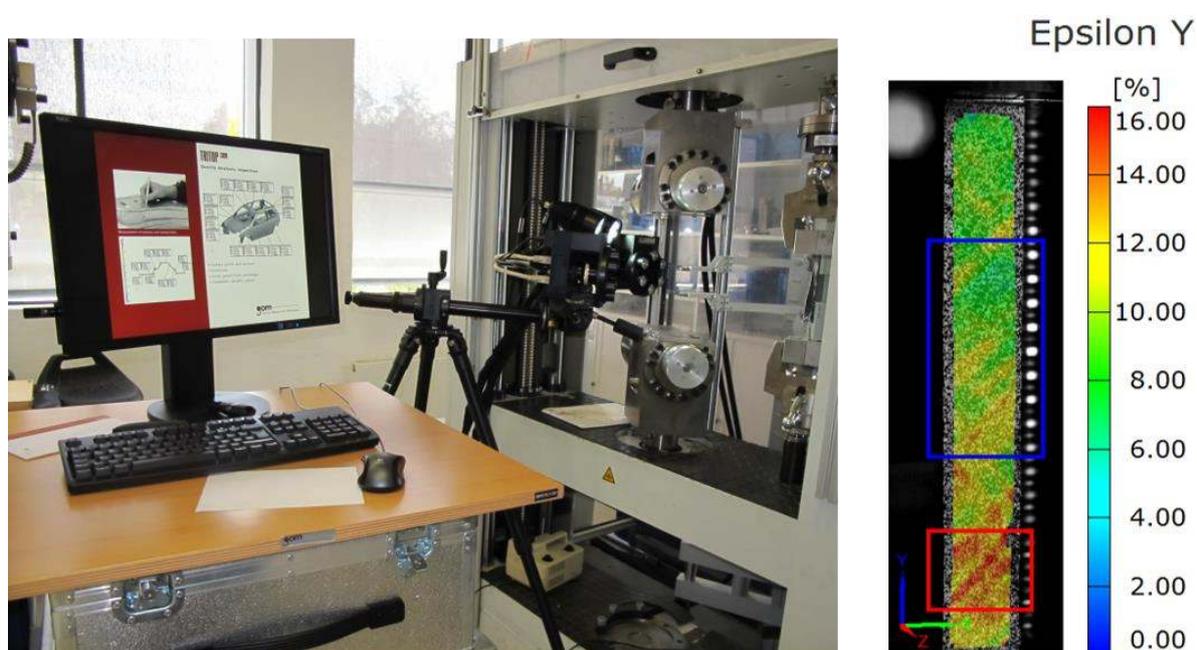


Figure 7 is showing the setup for the optical strain measurement at Brose.

On the right side the result is visualized.

6. Bringing it all together

In Figure 8 the results of the optical strain measurement and the simulation results are shown. Using the local fiber orientation and the (corrected) fiber content enables the simulation to predict the measured strain at break very precisely. The experimental result of the strain at break was $\sim 2.5\%$ - 3.5% for the testes part. The simulation predicted $\sim 2.8\%$ - 2.9% . Next to the strain at break also the area of failure could be predicted very well for the tested part.

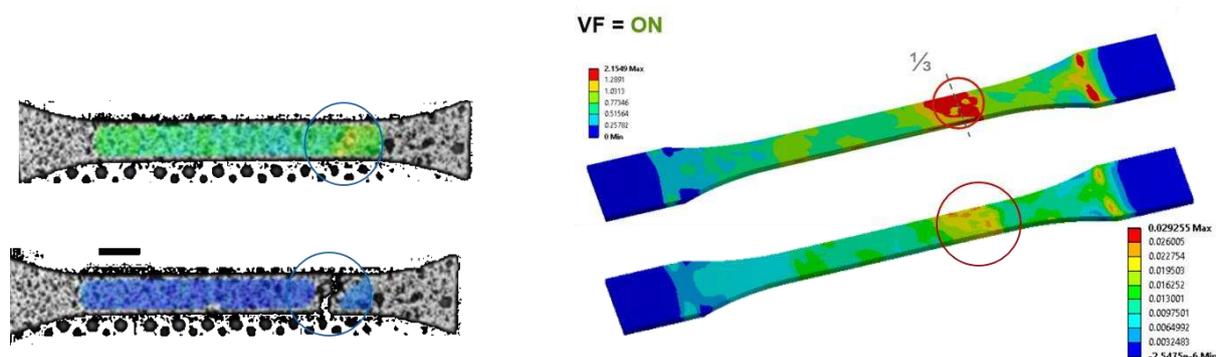


Figure 8 the two picture on the right side are showing the areas where the part broke in the real tensile test. The two picture on the right side are showing the simulation results.

8. Summary

For the simulation of failure based on the analysis of CT data a high resolution scan with a good signal to noise ratio and no artefacts is helpful. It was shown, that the measured fiber orientation and fiber content could be exported from the analysis software to the simulation software in order to build precise material models out of this data. This procedure using this new material models leads to much more accurate simulation results. It was shown that the use of the fiber orientation and the fiber content data enables the simulation to predict the area of failure precisely for a real world LFT part with a complex internal fiber structure. Next to the failure location also the strain at break could be predicted precisely. The study shows that in general the use of microstructure data from CT scans is improving the simulation results. If in future the data transfer between the measurement software and the simulation software will be standardized the use of CT data to get the real microstructure material information for the usage within simulations will become standard.

Acknowledgements

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