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Deformation and Damage Mechanisms in Thin Ductile Polymer Films

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Deformation and Damage Mechanisms
in
Thin Ductile Polymer Films

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1 Introduction and Background

The mechanical material behavior of highly extensible or ductile polymer films used in the packaging industry has been studied in this work [1]. The polymer material, consisting of different variants of polyethylene grades, is used as several components in the packaging material structure at Tetra Pak®. Experimental tensile tests were used to quantify the mechanical behavior and to be able to calibrate numerical constitutive material models. The studied polymer materials were able to withstand large deformations before breaking, involving both necking in the width and thickness direction of the specimen. During deformation re-orientation of polymer chains and substantial strain-hardening were also occurring. The latter effect was accounted for in the presented material modeling approach. The numerical simulations were solved in the general finite element software Abaqus version 6.13. In this work a continuum damage modeling (CDM) approach was used. CDM which are attractive in macro scale applications, thus solving our engineering problems, was chosen in this study due to the computational efficiency. A damage model consisting of two functionalities; initiation of damage and evolution of damage was suitable for modeling the ductile fracture behavior. During the numerical analysis it has been assumed that the polymer materials are isotropic, homogenous through the thickness, independent of strain rate and independent of temperature to ease the material parameters identification.

2 Experimental and virtual testing

An experimental test complemented with the photoelastic effect was compared to the difference of the principal stresses in the virtual tensile test solved in Abaqus, shown in Fig. 1. The upper edge is displaced a distance of 0 mm, 5 mm, 17 mm and 47 mm. The figure shows similar deformation pattern in both the experimental and virtual test. Material model parameters were identified with the inverse modelling approach. Accounting for a significant strain hardening is important for this type of highly extensible thin polymer films. An accurate continuum material model is important and the basis when involving fracture mechanical behavior in the material model and the numerical analysis procedures.

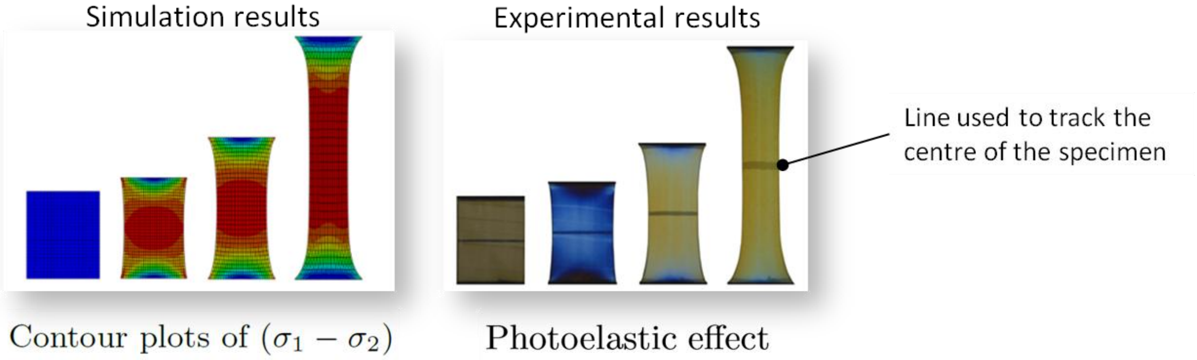

Fig. 1
Simulation and experimental test results

The large deformations involved when ductile polymers are modelled is typical hard to handle in a reliable way with a lagrangian element formulation. In this work we utilized four node shell elements with reduced integration that is efficient and easy to use. To our current understanding this element selection is not the most suitable for this kind of applications with highly extensible materials. An Arbitrary Lagrangian Eulerian (ALE) approach or a re-meshing technology complemented with triangular elements that not suffer that much when exerted to large deformation would maybe more reliable and appropriate. The quadratic element shape that was used suffers from increased aspect ratio, as shown in Fig. 1, continuously when you stretch the specimen during the tensile test. It was possible to get an acceptable correlation between the experimental fracture mechanical testing and the corresponding virtual test but some areas are identified that can be improved to create a better virtual prediction.

3 Findings and Conclusions

A result graph from an experimental test, as presented in Fig. 2, is a combination of geometrical effects, deformation mechanisms, micro-mechanical mechanism and continuum material behaviour. It is very important to be aware of this mixture of effects and hence try to extract the “real” material behavior from the specific experimental test-setup that has been performed. The material model used in the finite element software should typically not include the geometrical effects and during the inverse modelling phase should this be accounted for. A video recording or even better a Digital Image Correlation (DIC) should be used when solving the inverse problem. Otherwise the risk is large of finding a non-unique solution that is not the most accurate one. The benefit of using a video that capture the deformation sequence is also to be able to understand the involved mechanism during the experimental tensile test.

The final calibrated numerical continuum material model used in the virtual tensile test replicating the experimental tensile test is presented in Fig. 2. A very good fit was possible to obtain when strain-hardening was included in the two different material models due to micro-mechanical effects happening in the molecular morphology. Most often the material model is later on used in a much more complicated stress state, for instance including a cyclic behavior with a combined loading/un-loading scenario. This calls for more sophisticated and engineering feasible material models more realistically predicting polymer behavior including anisotropy, temperature and time dependency and different response when loaded in tension and compression.

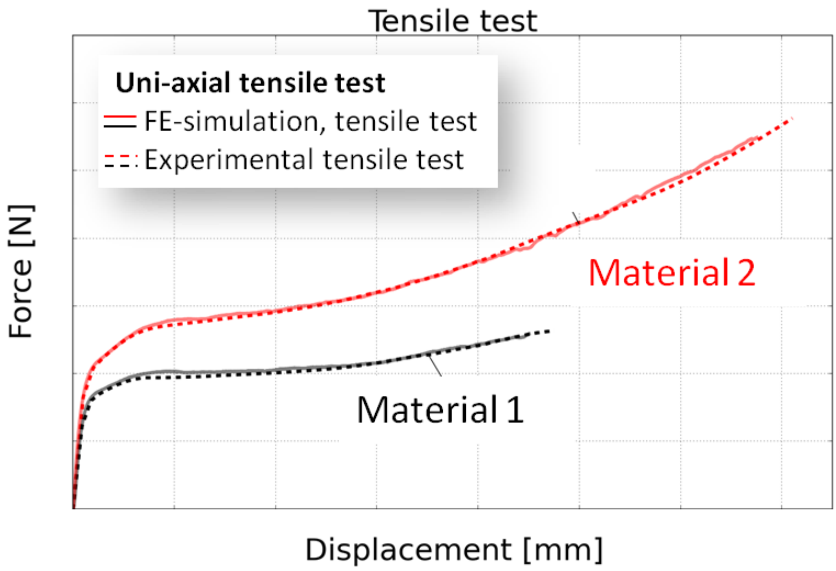

Fig. 2
Calibrated material models verified in a virtual tensile test

4 References

[1] Jönsson J., Sandgren M.: “Deformation and Damage Mechanisms in thin ductile polymer films - Experimental tests in combination with numerical simulations”, Master Thesis, Division of Solid Mechanics, Lund University, ISRN LUTFD2/TFHF-13/5174-SE(1-56), 2013