Failure models of plastics - material characterization for *MAT_ADD_EROSION (DIEM)

A. Fertschej, B. Hirschmann, P. Reithofer, M. Rollant
4a engineering GmbH

1 Introduction - Characterizing plastics using 4a impetus

In recent years the light weight design has become more and more important due to the rising demand of energy savings. Coming along with that reason plastics substitute other materials and they are also carrying the applied loads. Therefore it is necessary to consider the deformation behavior (plasticity) as well as damage and failure in the material model. The correct deformation behavior is also needed to describe failure criteria like plastic strains, that are used in damage initiation and evolution models.
The tensile test is a standard testing method for many different materials to determine elasticity, plasticity and failure. Compression and shear tests have a rather scientific character, they can be used to determine elastic and plastic properties, but failure never occurs in the favored triaxiality. Due to DIC (digital image correlation) all these tests are time consuming and in the case of dynamic testing also cost intensive. To characterize the dynamic deformation behavior dynamic bending tests on 4a impetus are a cost-efficient alternative (Fig. 1).

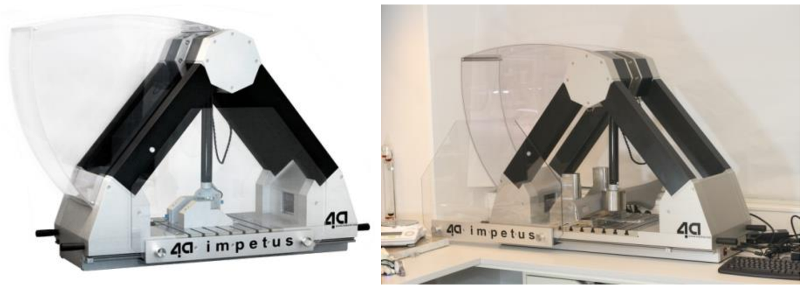

Fig.1: The actual version of 4a impetus (left); component testing in 4a impetus (right)

The bending case is also the most frequently occurring load case in reality. As a result of the processing plastics have different mechanical properties at the outer surface compared to the inner core. So the bending properties (stiffness, failure behavior …) are accordingly higher and near to reality because of the higher loading of the outer fiber compared to the tension properties.

2 Characterizing failure

In the last years further test methods for 4a impetus were developed to characterize failure (Fig. 2). These test methods are easy and fast to perform and failure at different triaxialities can be specifically investigated.

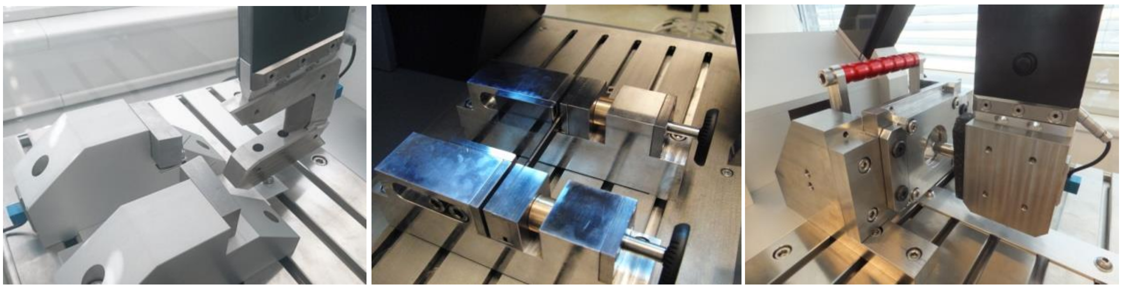

Fig.2: Dynamic bending test (left); dynamic clamped bending test (middle); dynamic puncture test (right) [1]

The bending test is a standard test method in 4a impetus; the strain rate dependency can be determined quite well by changing the test velocity and/or the support distance.

Testing brittle materials failure can be achieved in the bending tests. For more ductile materials (e.g. unreinforced thermoplastics) failure mostly doesn't occur. In typical bending cases strains up to 30% can be observed. Afterwards the test specimens will be pulled through the support, if the sample doesn't fail.

The clamped bending test overcomes this problem, furthermore it has a significant area where tension dominates, so the tension/compression asymmetry of the material can be determined. The puncture test provides information on the mechanical behavior under biaxial tensile load. Having ductile plastics these two test methods have to be performed on 4a impetus to characterize the test specimens concerning failure at dynamic loading (Fig. 3) [2].

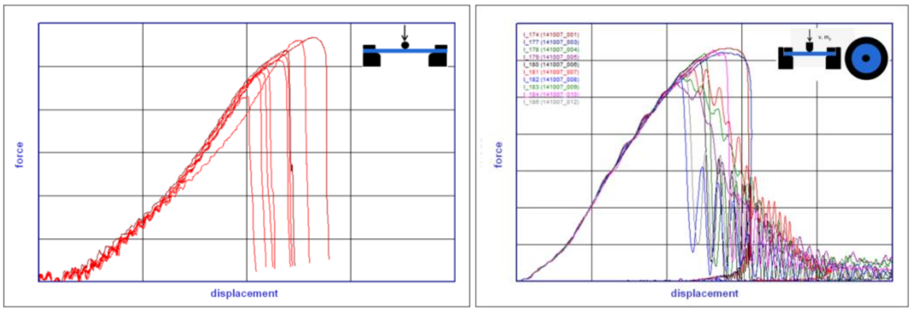

Fig.3: Force-displacement curves for clamped 3-point-bending (left) and dynamic puncture test (right) for a ductile material; failure occurs for all test specimens [2]

Also a high-speed-camera (newest accessory kit) can be implemented in 4a impetus. This allows the visualization of dynamic behavior of the material during test (crack initiation and propagation in detail, see Fig. 4).

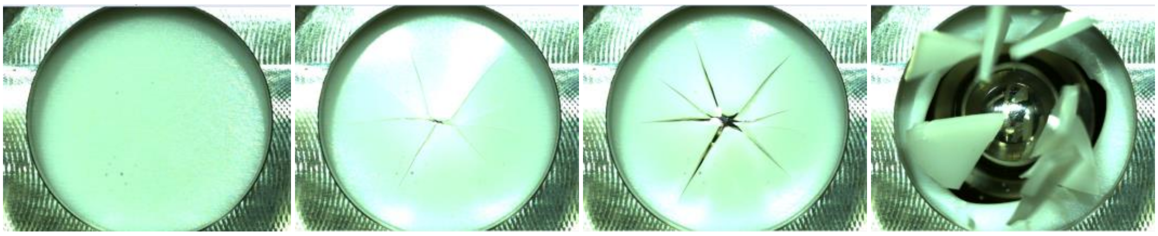

Fig.4: High speed pictures of the dynamic puncture test of a POM at different time steps [3]

3 Material card creation

Using the aforementioned tests the material failure behavior can be determined and used to generate a material card that reflects the real material answer. The material characterization is done by reverse engineering using the 4a impetus process (Fig. 5). The material parameters are adapted iteratively until simulation and test fit with a minimum of deviation. Detailed information can be found in [4].

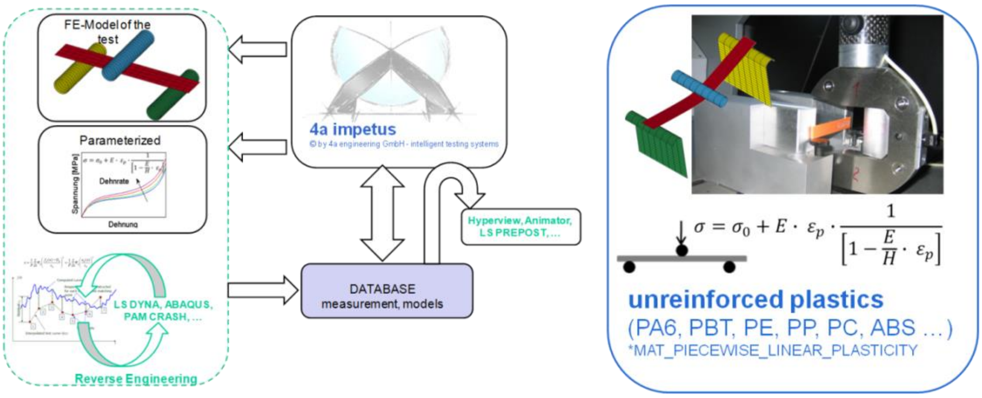

Fig.5: Material characterization by reverse engineering using the 4a impetus process [5]

Using a simple material model like ***MAT_024** in LS-DYNA (elastic visco-plastic) the material behavior can be described very well for one triaxiality (typically tension is used). By using 3-point-bending tests (Fig. 6a) a ***MAT_024** could be derived on a compression/tension average, which would cover most common applications in engineer's daily work. Nevertheless by using this well known vonMises plasticity of ***MAT_024** the mechanical behavior of a tension dominated load case (Fig. 6, right) can't be described by a bending load case or vice versa [6].

So a more complex material model has to be used, e.g. ***MAT_187** (***MAT_SAMP-1**), which considers a yield surface that distinguishes between tension and compression. As mentioned before this is also essential for a correct determination of failure criteria.

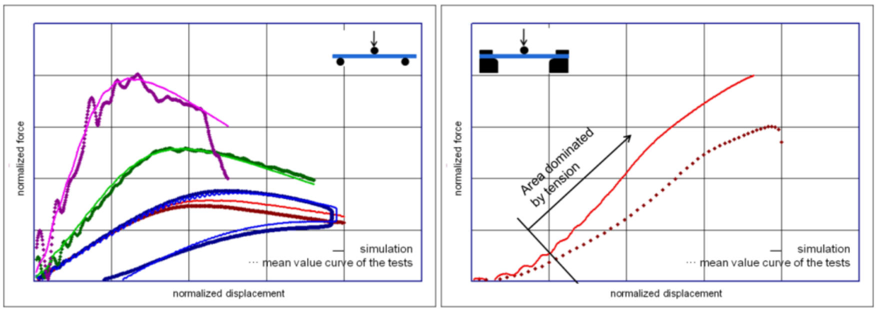

Fig.6: left - Describing the material behavior using ***MAT_024** *for bending tests at different velocities; test and simulation curves match very well.*
right - Describing the material behavior using ***MAT_024** *for the dynamic clamped bending test; test and simulation curve don't match because of the tension/compression asymmetry of the material which cannot be considered in the material model [6]*

Classically the material characterization [7][8][9][10] would be performed on static tensile, shear and compression tests together with dynamic tensile tests. Many steps have to be conducted to evaluate, transform and fit (also a reverse engineering together with the solver of your choice is needed) the test data to extract strain rate independent yield functions for different triaxialities.

An alternative easy to use process as an improvement can be
- the usage of static bending tests instead of compression tests and
- the usage of dynamic bending tests instead of dynamic tensile tests

Figure 7 (left) shows this process in material card generation [6]:
- starting with static bending tests to get the yield function,
- deriving the strain rate dependency from dynamic bending tests,
- proving/reverse engineering the compression/tension asymmetry on clamped bending tests,
- and finally validating further tests (Fig. 8).

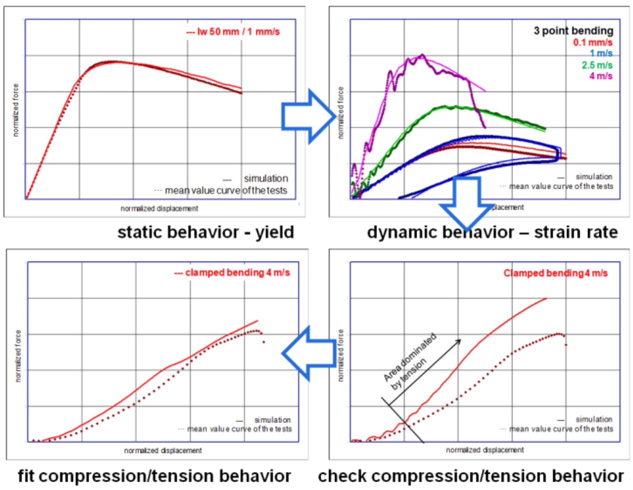

Fig.7: Improved workflow in 4a impetus to determine a complex yield surface [6]

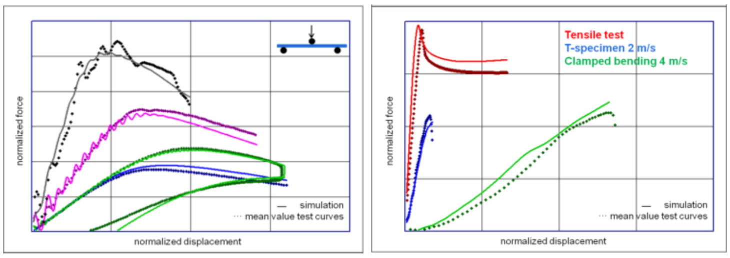

Fig.8: Result of the reverse engineering process for 3-point bending test curves at different velocities (left) and validation of the material card for further load cases (tensile test, clamped 3-point bending test and T-specimen test) using ****MAT_187*** *[6]*

4 Failure modeling

LS-Dyna offers many material models for plastics that have an implemented damage/failure modeling. This modeling goes from

- simple failure models (e.g. plastic strain, ****MAT_024***)
- over comprehensive damage/failure models (e.g. plastic failure strain with damage, ****MAT_081***)
- up to highly complex damage/failure models (e.g. failure in dependence of strain rate and triaxiality, ****MAT_ADD_EROSION***, Fig. 9, right)

With the exception of ****MAT_187***, which was developed especially for plastics, all these material resp. damage models were derived from the metal material needs. Anyway these models allow a good and technical suitable approximation to the reality of plastics. Just visco-elasticity and temperature dependency are neglected due to missing material models. Damage and failure can be included e. g. defined generally piecewise linear over triaxiality. **Of course approaches describing the basic behavior of unreinforced plastics are still missing.**
Thermoplastics mostly have a ductile failure behavior (no failure under compression and shear has be observed [11]), so failure criteria can be modeled especially for the triaxiality above 0.33. For failure lower than the triaxiality of 0.33 just assumptions can be made [11]. The Gurson and GISSMO model derived from metal models consider this fact also by assuming a high plastic failure strain at negative triaxialities [12], figure 9 left. Abaqus offers also a ductile criterion for damage in its material model ***ABQ_MOLDED_PLASTIC***, developed for aluminum [13] and used for plastics materials. The criterion is described using a hyperbolic sine function [14], figure 9 (middle).

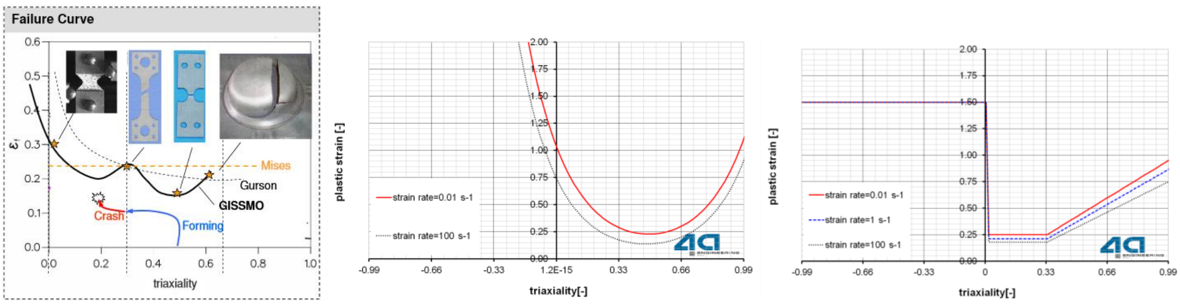

Fig.9: Example of failure curves in dependence of triaxiality and strain rate – left: GISSMO and Gurson [12]; middle: using ABQ_MOLDED_PLASTIC [14]; right: using ****MAT_ADD_EROSION*** *[6]*

To model damage/failure the keyword ****MAT_ADD_EROSION*** with the Damage Initiation and Evolution Model DIEM [15] was used and adapted to the test curves. A final validation of this damage/failure material was performed for a dynamic puncture test on 4a impetus. Figure 10 shows the good conformity of simulation and test curves [6]. As the used idealization (shell vs. solid), element type and element size have a significant influence on the simulation results, this has to be considered in the material modeling process.

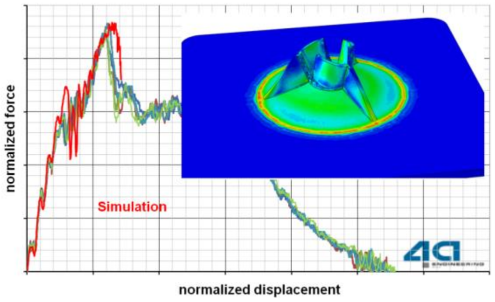

Fig.10: Comparison of test and simulation results for a part characterized by a complex material model [6]

To support the user in failure modeling most commonly used failure models are implemented in 4a impetus. This includes simple ("constant" plastic failure strain) up to highly complex models (plastic failure strain in dependency of strain rate and triaxiality) with access to different failure models (e.g. Johnson Cook, Xue-Wierzbicki, Mohr-Coloumb), see Fig. 11, left. The significant inputs for the chosen failure model are accessible over the design variables (Fig. 11 right). So an easy determination of failure model parameters is available in the 4a impetus software solution.

5 Summary

Using static and dynamic 3-point-bending tests simple material cards (***MAT_024**) are generated reasonable and quickly for simulation. If the material shows a tension/compression asymmetry the simple material model is limited, so more complex material models (e.g. ***MAT_SAMP-1**) are needed. A novel workflow based on standard 4a impetus test methods has been shown to generate complex material cards like ***MAT_SAMP-1**. It was shown that ***MAT_ADD_EROSION** offers all needed possibilities to describe the failure behavior of unreinforced thermoplastics close to reality. The latest software release of 4a impetus includes failure modeling using various failure models to meet these requirements for an accurate material modeling.

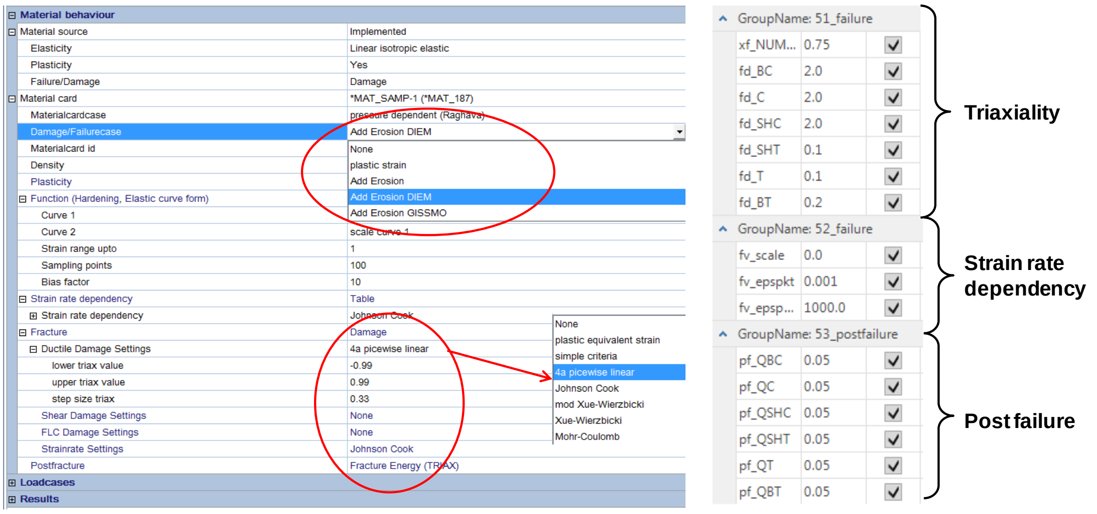

Fig.11: Modeling failure in 4a impetus (left); according design variables for the chosen failure model (right) [3]

6 Literature

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