Failure models for thermoplastics in LSDYNA

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Abstract. In recent years the demand on safety relevant plastic parts in the automotive industry has led to a strong interest for describing failure behavior of non- and fiber-reinforced thermoplastic materials. Currently material and failure modeling in crash simulations typically deal with simple von Mises visco-plasticity and mean strain failure criteria, which cannot describe the complex material behavior of plastics. Past developments have focused in the yield behavior under different load situations (tension, shear, compression). 4a engineering began generating material cards of dynamic bending tests to consider the typical tension-compression asymmetry of plastics. This led to better descriptions in the yielding, but further tests are required to determine the complex failure behavior. Developments in the last 10 years in simulation software tools provide the possibility to describe the failure and energy absorption by damage initiation and evolution models. The influence of triaxality and strain-rate on strain criteria are the base of these damage models. A huge amount of tests have to be carried out, to determine the material parameters and additionally to represent the thermoplastic characteristics in crashworthiness simulations. So an efficient and reliable process, starting with realistic tests and final validation of these tests via simulation is required. Recent developments of new test methods for 4a impetus satisfy the needs of complex material models. The novel 4a impetus workflow as well as results for material modeling including failure are shown.

CHARACTERIZING PLASTICS USING 4A IMPETUS

In recent years the light weight construction 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).

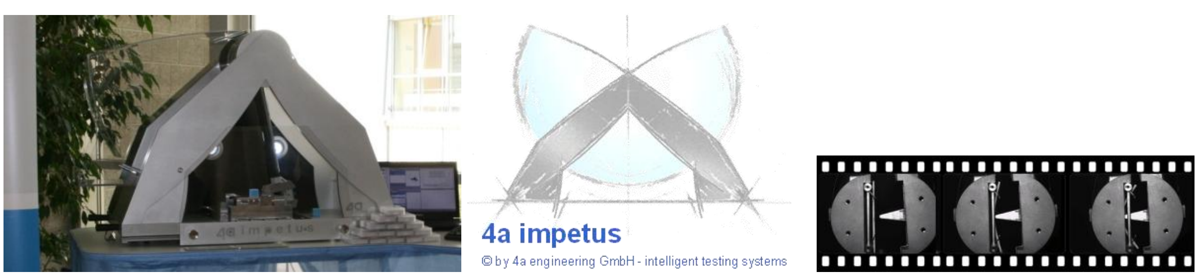


FIGURE 1. Testing system 4a impetus; bending test on 4a impetus using the double pendulum option

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.

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.

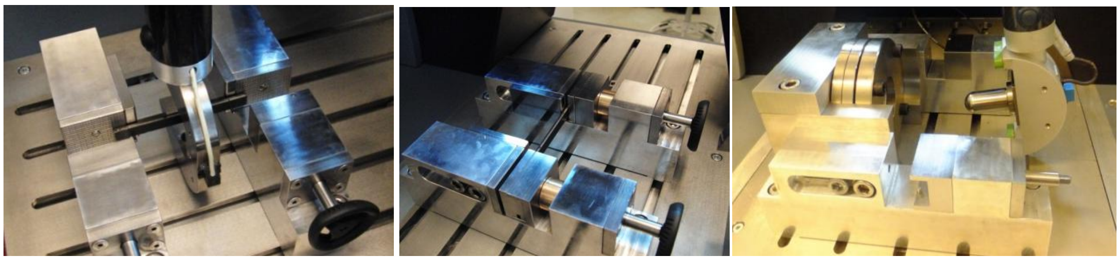
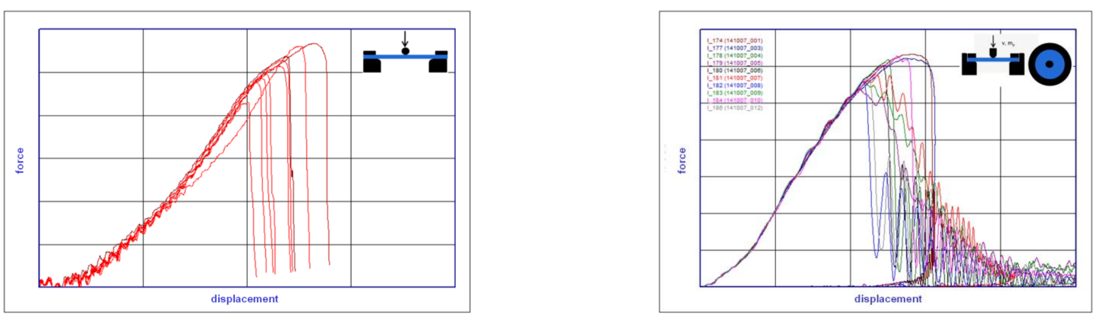


FIGURE 2. Dynamic bending test (left); dynamic clamped bending test (middle); dynamic puncture test (right) [1]

The bending test is the 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, the test specimens are pulled through the support.

The clamped bending test 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].



(a) (b)

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

MATERIAL MODELING

Using the aforementioned tests a material modeling near to reality including failure can be performed. The material characterization is done by reverse engineering using the 4a impetus process (Fig. 4). The material parameters are adapted iteratively until simulation and test fit with a minimum of deviation. Detailed information can be found in [3].

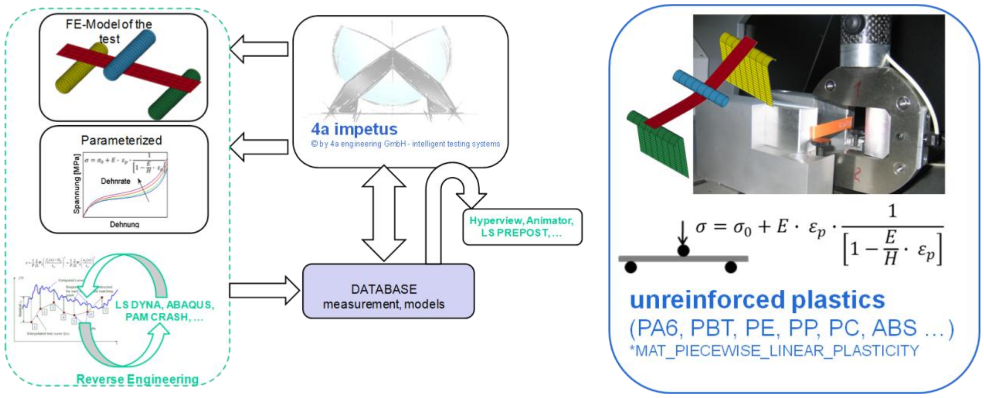
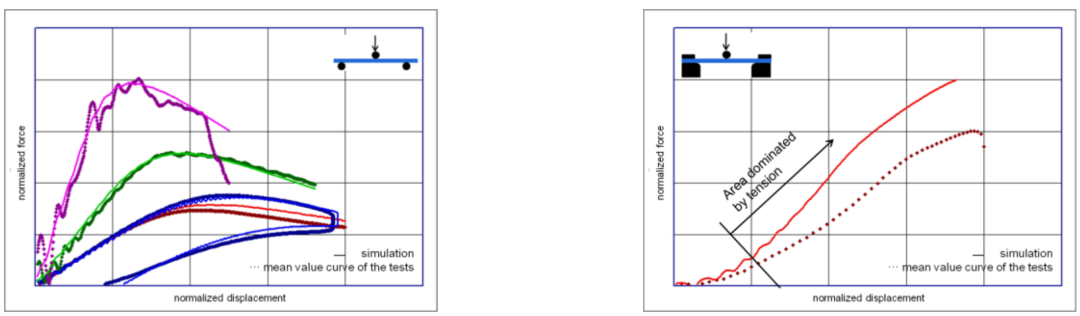


FIGURE 4. Material characterization by reverse engineering using the 4a impetus process [4]

Using a simple material model like *MAT24 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. 5a) a *MAT24 could be derived on a compression/tension average, which would cover most common applications in engineer's daily work. Nevertheless this approach can't describe the mechanical behavior of a tension dominated load cases (Fig. 5b), which cannot be considered in the well known von Mises plasticity used in *MAT24 [5].



(a) (b)

FIGURE 5. (a) - Describing the material behavior using *MAT24 for bending tests at different velocities; test and simulation curves match very well. (b) - Describing the material behavior using *MAT24 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 [5]

So a more complex material model has to be used, e.g. *MAT187 (*MAT_SAMP-1), which considers such yield surface. As mentioned before this is also essential for a correct determination of failure criteria.

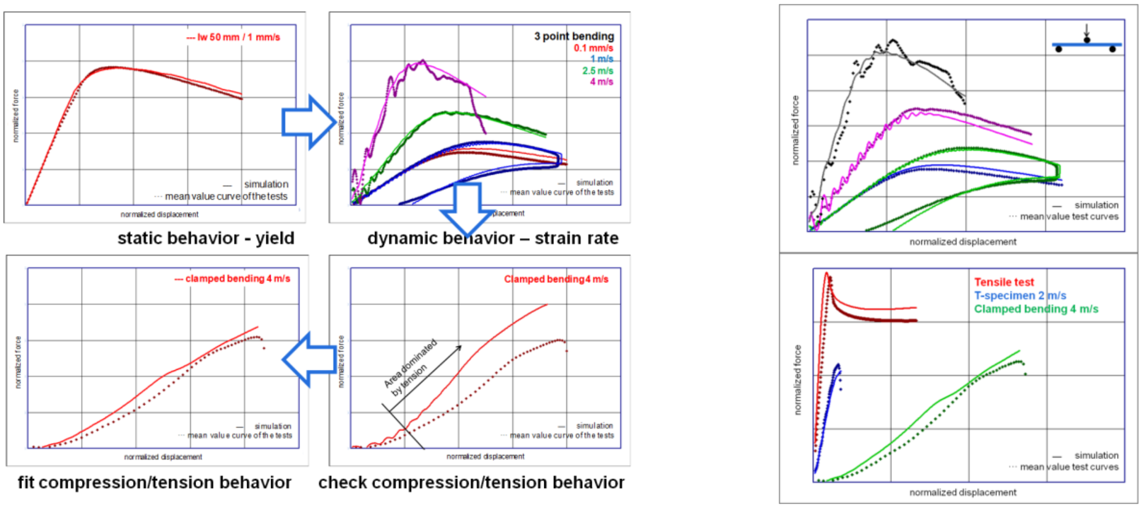
Classically the material characterization [6][7][8][9] would be performed on static tensile, shear and compression tests together with dynamic tensile tests. Nevertheless many steps have to be conducted to evaluate, transform and fit the test data to extract strain rate independent yield functions for 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 6a shows this process in material modeling [5]:

- 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. 6b).



(a) (b)

FIGURE 6. Improved workflow in 4a impetus to determine a complex yield surface (a) and comparison of 3-point bending test curves at different velocities and further test curves with simulation curves using *MAT187 (b) [5]

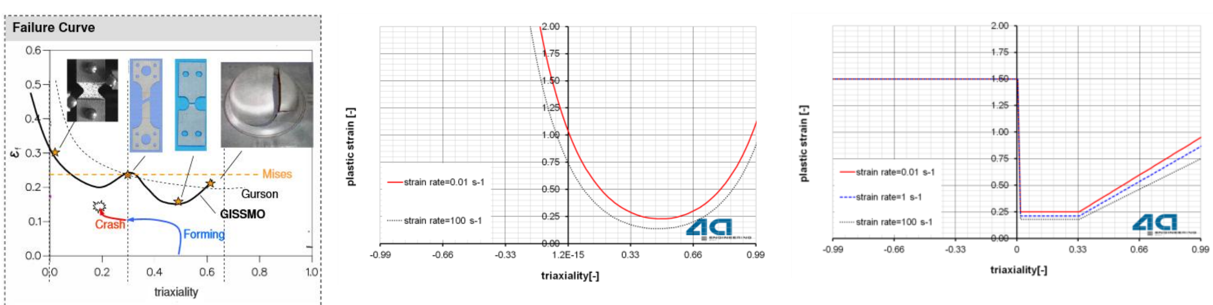
FAILURE MODELING

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, *MAT24)
- over comprehensive damage/failure models (e.g. plastic failure strain with damage, *MAT81)
- up to highly complex damage/failure models (e.g. failure in dependence of strain rate and triaxiality, *MAT_ADD_EROSION, Fig. 7c)

With the exception of *MAT187, which was developed especially for plastics, all these material resp. damage models were derived from the metals section. 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), so failure criteria can be modeled especially for the triaxiality above 0.33. For failure lower than 0.33 just assumptions can be made [10]. The Gurson and GISSMO model derived from metal models consider this fact also by assuming a high plastic failure strain at negative triaxialities [11]. Abaqus offers also a ductile criterion for damage in their material model ABQ_MOLDED_PLASTIC, developed for aluminum [12] used for plastics materials. The criterion is described using a hyperbolic sine function [13].



(a) (b) (c)

FIGURE 7. Example of failure curves in dependence of triaxiality and strain rate – (a) GISSMO and Gurson [11]; (b) using ABQ_MOLDED_PLASTIC [13]; (c) using *MAT_ADD_EROSION

To model damage/failure the Keyword *MAT_ADD_EROSION with the Damage Initiation and Evolution Model DIEM [14] 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 9 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 calculation results this was also considered in the material modeling process.

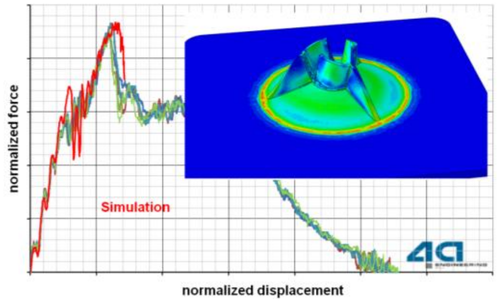


FIGURE 9. Comparison of test and calculation results for a part characterized by a complex material model [5]

SUMMARY

Using static and dynamic 3-point-bending tests simple material cards (*MAT_24) 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. 4a impetus has been and is upgraded by including failure modeling using various failure models to meet these requirements for an accurate material modeling.

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