# Failure of Thermoplastics - Part 1 Characterization, Testing

A. Fertschej, P. Reithofer, M. Rollant

4a engineering GmbH, Austria

## 1 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 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 (figure 1). 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. Using 4a impetus one gets a complete system from the test to the validated material card.

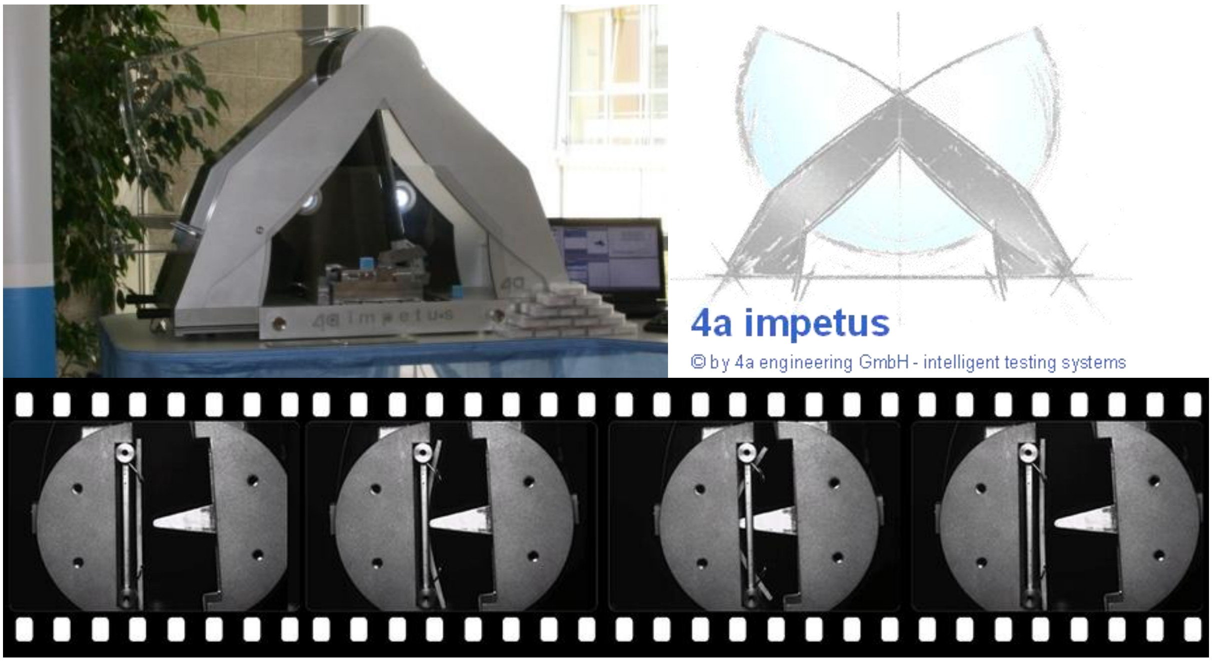


*Fig.1: Testing system 4a impetus; bending test on 4a impetus using the double pendulum option [1]*

## 2 Characterizing failure

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

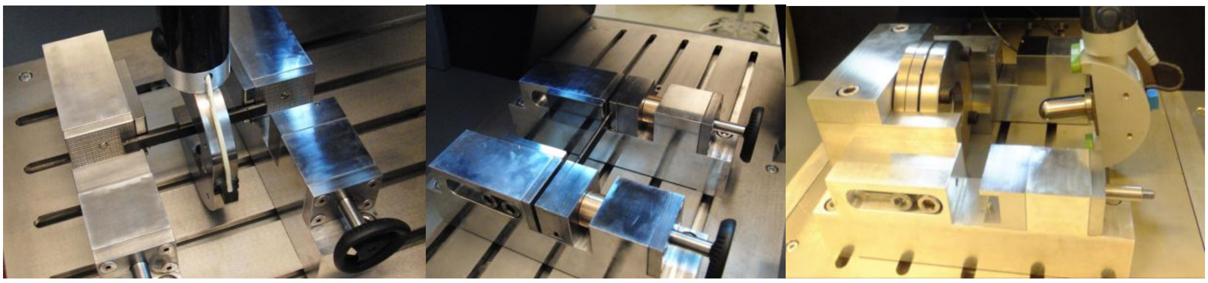

*Fig.2: Dynamic bending test (left) [2]; dynamic clamped bending test (middle) [2]; dynamic puncture test (right).*

Figure 3 shows a comparison of the achievable triaxialities using 4a impetus (bending, clamped bending and puncture tests) and the classical approach (tensile, compression and shear tests).

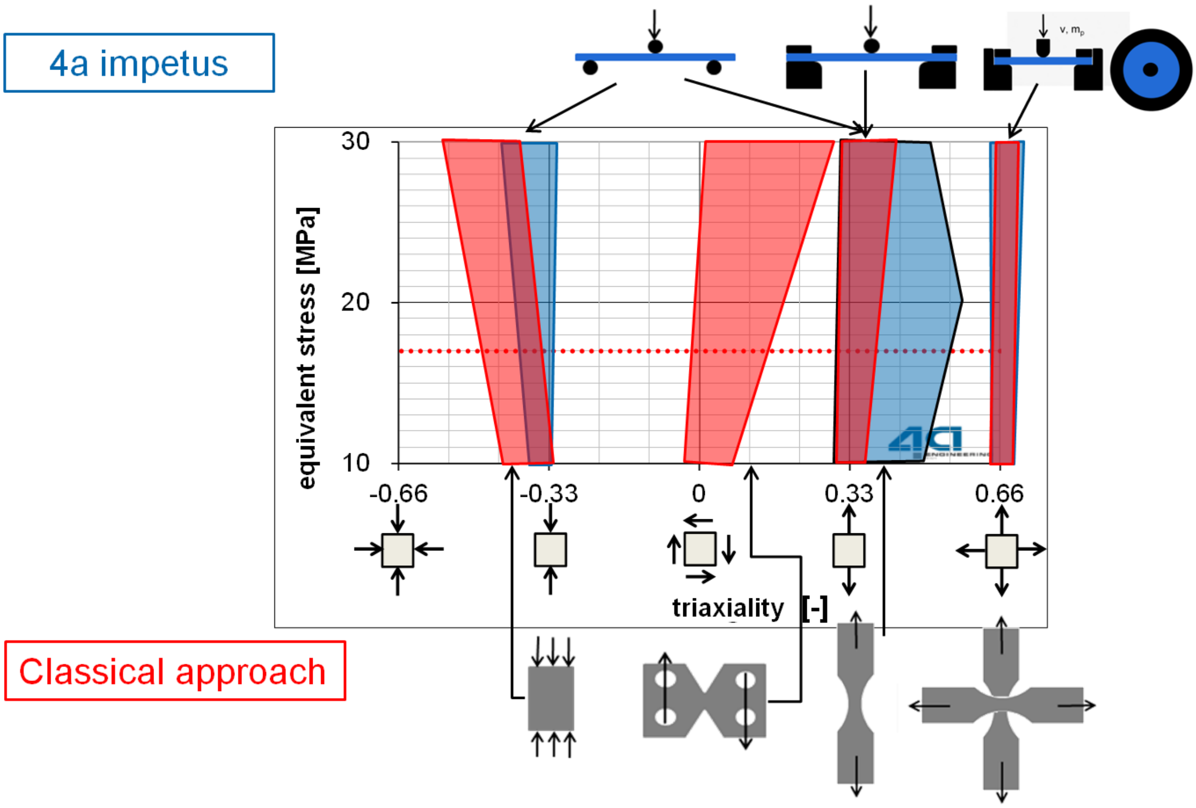


*Fig.3: Achievable triaxialities using 4a impetus (bending, clamped bending and puncture tests) and the classical approach (tensile, compression and shear tests) [3].*

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 (e.g. talc reinforced PP, see figure 4) 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 or are recovered (figure 5).

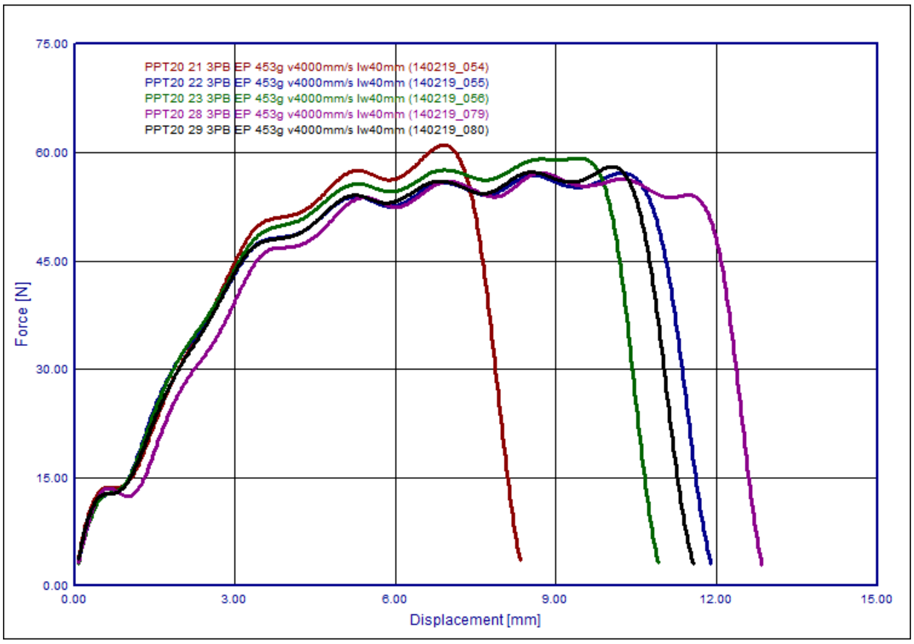


*Fig.4: Force-displacement curves for 3-point-bending at a speed of 4 mps; material: PP T20 (brittle) [4].*

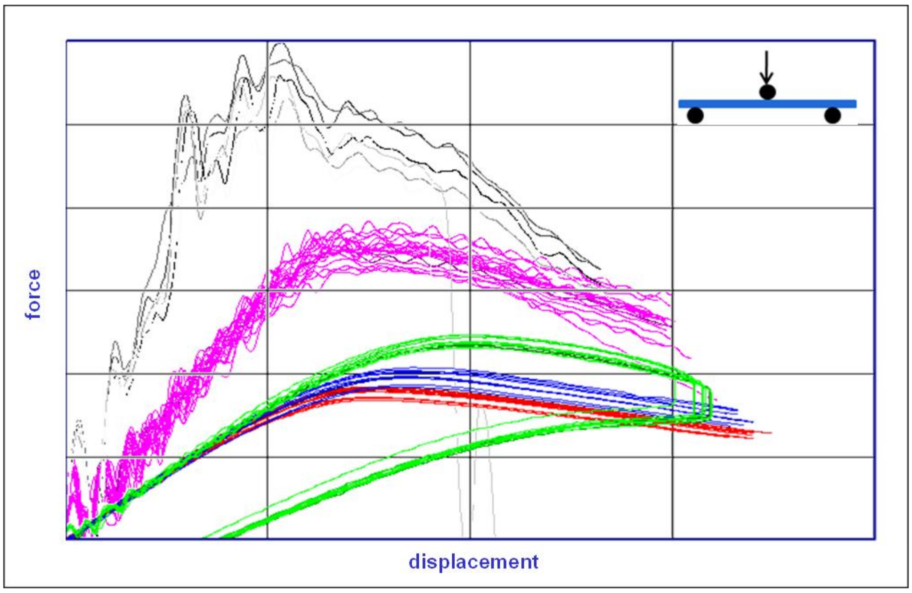


*Fig.5: Force-displacement curves for 3-point-bending for a ductile material at different testing velocities; failure occurs just for 2 test specimens at the highest speed, all the other test specimens were pulled through the support or were recovered.*

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 (figure 6 and figure 7).

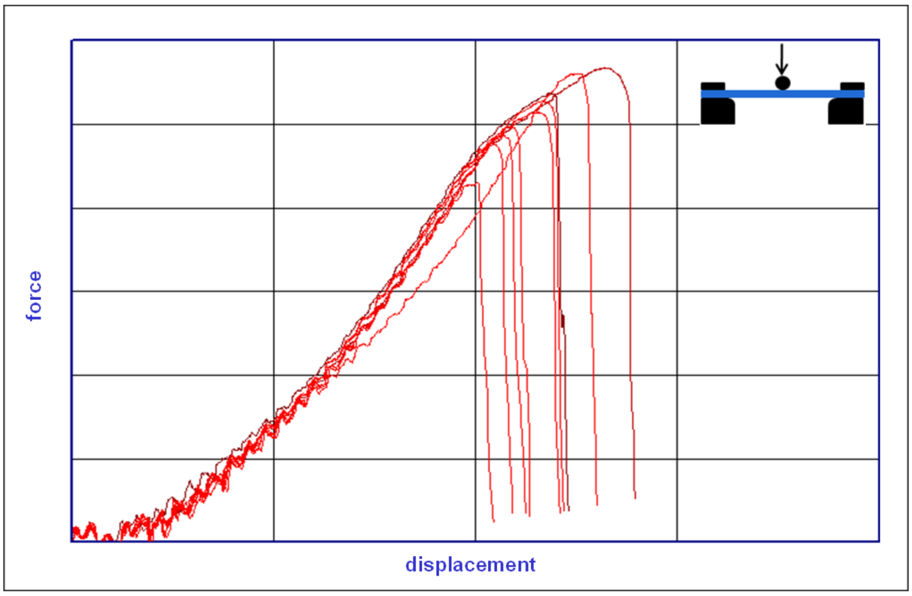


*Fig.6: Force-displacement curves for clamped 3-point-bending for a ductile material; failure occurs for all test specimens.*

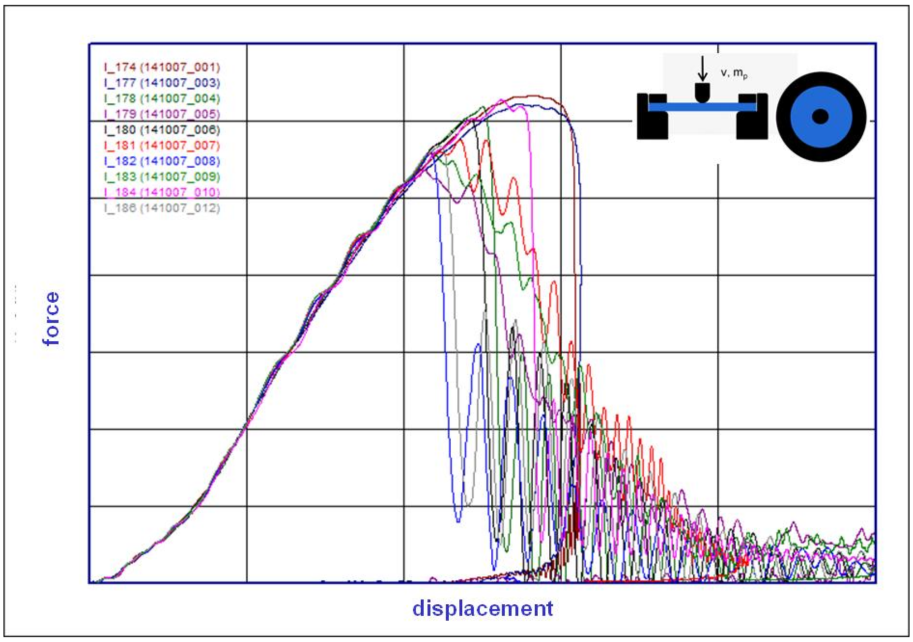


*Fig.7: Force-displacement curves for a dynamic puncture test for a ductile material; failure occurs for all test specimens.*

As an alternative measurement results from other testing machines (ASCII or Excel data format standard) can be imported into the 4a impetus software, evaluated and used for the process of creating material cards. As an example static and dynamic tensile tests including optical strain measurement can be used for the material mapping process.
In addition to the influence of the strain rate and triaxiality to the failure also imperfections in the parts are essential. These lead to different failure times (figure 8) and can be integrated in the simulation using appropriate probability considerations.

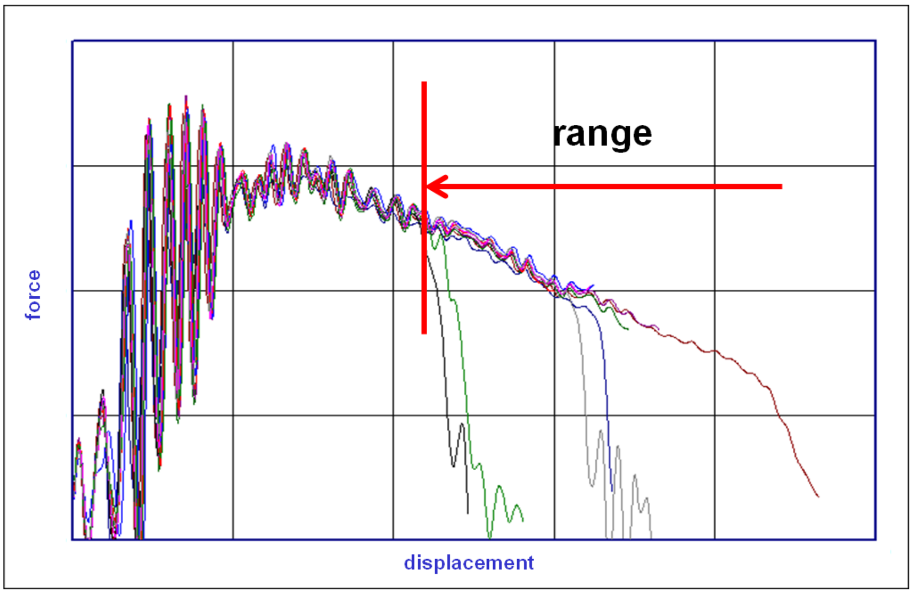


*Fig.8: Force-displacement curves for dynamic 3-point-bending tests; failure occurs in a wide range; the support distance was decreased so that the test specimens failed.*

As the test specimen geometry is simple and the tests are easy to perform the higher amount of tests needed for statistical reasons can be considered cost efficiently. Attention regarding the failure time has to be paid for the preparation of the raw data (filtering and evaluation), so that failure time and behavior are not falsified (see figure 9).

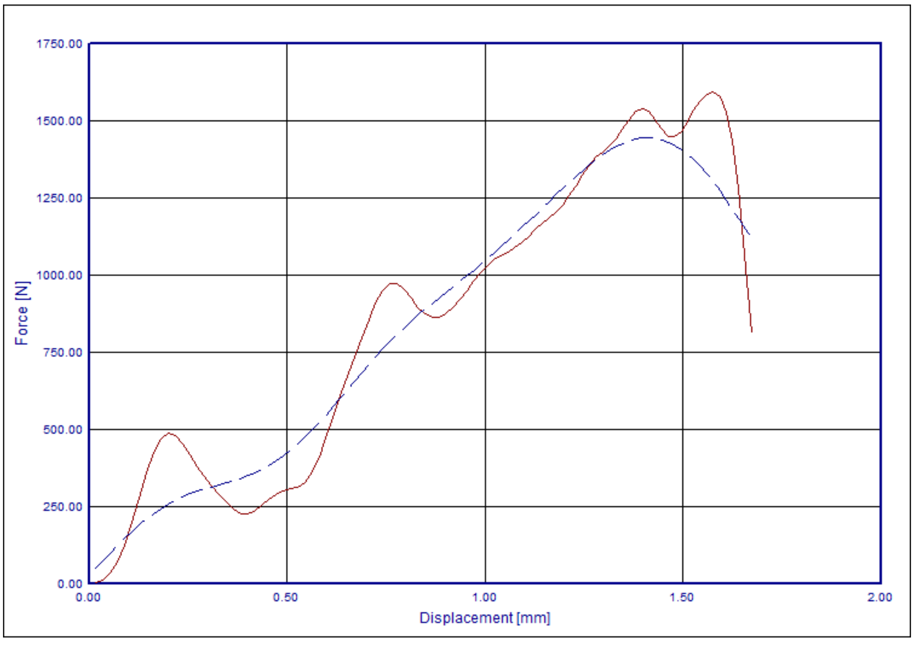


*Fig.9: Force-displacement curves for a puncture test at a speed of 4 mps; solid line (red): unfiltered curve, dashed line (blue): filtered curve.*

Using the aforementioned tests a material modeling near to reality including failure can be performed. For example the material properties of *MAT187 (*MAT_SAMP-1) can be determined based on these tests.

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. This aspect is shown more detailed in the second part (Failure of Thermoplastics - Part 2 - Material Modeling and Simulation).

## 3 Summary

4a impetus offers a variety of test methods to fulfill the requirements for measuring strain rate dependencies and failure for different materials (thermoplastics, composites, aluminum, ...).
The bending load case is the base of the testing system which is easy and quick to perform.
To research on failure clamped 3-point-bending and puncture test are possible test methods, which can be performed on a 4a impetus device. These tests offer a cheap and easy capability for a statistical evaluation of the necessary information for failure modeling.
In contrast to that the classical test methods (tensile, compression or shear tests) often provide insufficient information for modeling failure vs. triaxiality or need a much higher effort in performance.

## 4 Literature


[1] http://impetus.4a.co.at/en/

[2] P. Reithofer, M. Rollant, M. Fritz (4a engineering GmbH); A. Haufe, V. Effinger (DYNAmore GmbH) - Validation and Material Modeling of Plastics; Europäisches Dynaforum 2011, Straßburg

[3] A. Fertschej, P. Reithofer, M. Rollant (4a engineering GmbH) - Dynamische Kunststoffcharakterisierung (Thermoplaste, Schäume, Composites); NAFEMS 2014; Bamberg

[4] A. Fertschej, P. Reithofer, M. Rollant (4a engineering GmbH) - Materialmodelle für Kunststoffe, Komplexe Fließflächen und Versagen; 4a Technologietag 2014, Schladming