Dynamic Material Characterization Using 4a impetus

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Abstract. The demand for shorter product development times and the consequence of increased usage of simulation programs has lead to a rise of the importance of gaining quickly material data. For this the testing device 4a impetus was developed by 4a engineering GmbH. The system allows performing many test methods (bending, clamped bending, pressure tests, puncture tests, component tests), managing of the tests and simulations by a database, and is linked to optimization algorithms to identify the material parameters by reverse engineering. The material data is evaluated from bending tests which are near to reality load cases, high strain rates can be achieved and the test specimens can be taken directly from parts. Generating more complex material cards (general yield surface, failure) is possible by regarding additional tests (e.g. clamped bending, puncture test). So 4a impetus is a system to gain very easy, quick and cost efficient validated material cards.

CHARACTERIZING PLASTICS USING 4A IMPETUS

In recent years plastics are substituting other materials mostly to reduce the weight of the part. As they are also carrying the applied loads 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. Due to DIC (digital image correlation) this test is 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).

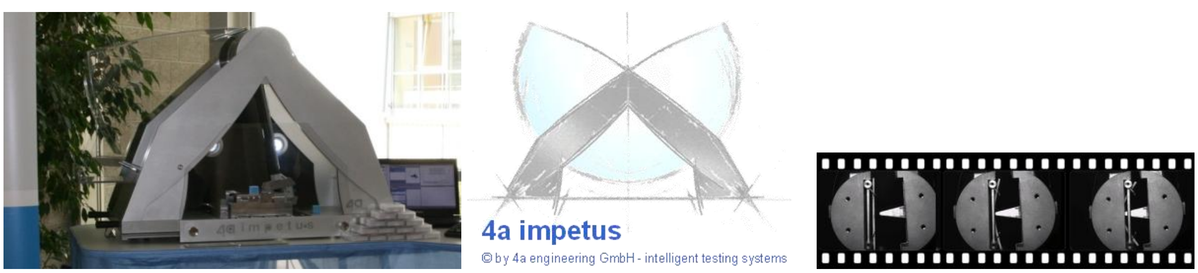


FIGURE 1. Testing system 4a impetus; bending test on 4a impetus using the double pendulum option [1]

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.

MATERIAL MODELING BY REVERSE ENGINEERING

The material characterization is done by reverse engineering using the 4a impetus process (Fig. 2). The material parameters are adapted iteratively until simulation and test fit with a minimum of deviation by using the software LS-Opt.

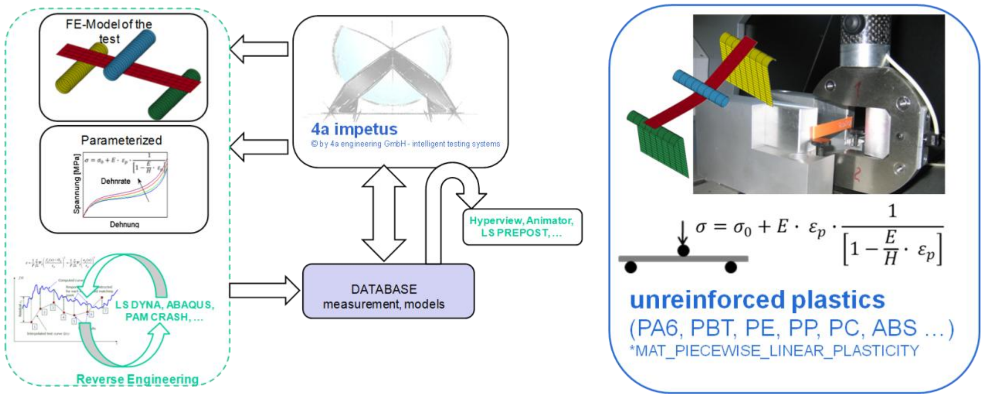


FIGURE 2. Material characterization by reverse engineering using the 4a impetus process [2]

Parameter identification can be solved using mathematical optimization. In most cases the objective is to minimize the mismatch between two curves, typically a two-dimensional experimental target curve, e.g. a stress-strain curve or a force-displacement curve, and the corresponding computed curve extracted from a simulation. The computed curve depends on system parameters that can be varied, e.g. material constants.

To solve parameter identification problems, "Sequential Response Surface Method with domain reduction" (Fig. 3) is usually used [3]. Figure 4 shows a result of characterizing the yield behavior based on a three point bending test for a polypropylene. By each iteration the simulation curve fits the test curve better and the design space is becoming smaller [3].

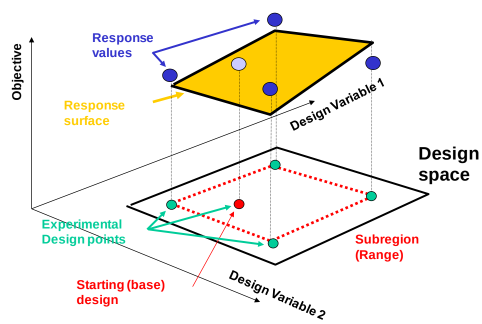
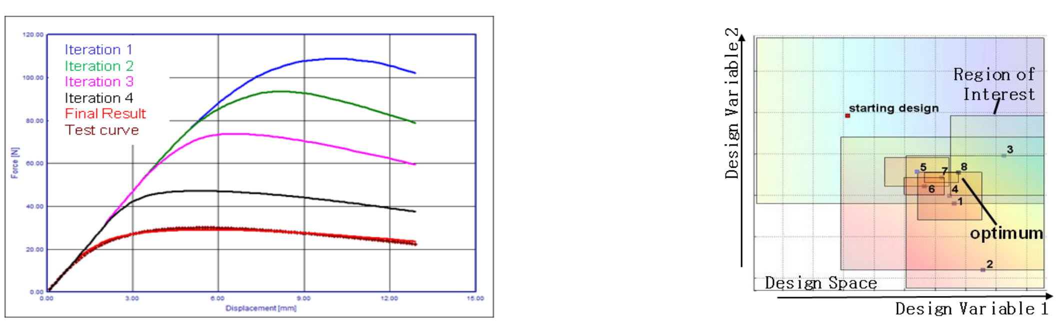


FIGURE 3. Sequential Response Surface Method [3]



(a) (b)

FIGURE 4. Fitting of the simulation curve to the test curve (yield behavior of a PP Hostacom; three point bending; (a)) and reduction of the design space iteratively (b) by reverse engineering [3]

FORMULATION OF THE MATERIAL "PARAMETER" LAW

Typical material cards in commercial solvers for elastic viscoplastic material behavior are defined by true stress - true strain curves for different strain rates. Internally the commercial solvers are using a table lookup algorithm to have the current material state during an implicit or explicit simulation.

To use reverse engineering for material characterization, the stress-strain curves in dependence of the strain rate have to be described by a parameterized material law. Before simulating each loadcase the material card has to be created by a script using the design parameter submitted by the optimizer.

Well known material laws for describing the yield behavior can be found in Table 1 left, those describing the strain rate behavior in Table 1 right. All these material laws are included in the 4a impetus software.

TABLE 1. Some well known material laws for yield curves (left) and for strain rate dependence (right)

Bi-Linear	$\sigma = \sigma_0 + E_T \cdot \varepsilon_p$	PowerLaw	$\sigma = \sigma_0(\varepsilon)\, \dot{\varepsilon}^n$
Ludwik	$\sigma = A + B\varepsilon_p^n$	Cowper Symonds	$\sigma = \sigma_0(\varepsilon)\left[1 + (\frac{\dot{\varepsilon}}{D})^{\frac{1}{p}}\right]$
Bergström	$\sigma = A + k\sqrt{1 - \exp(-0.5\,\varepsilon_p)}$	Johnson Cook	$\sigma = \sigma_0(\varepsilon)\left[1 + C\,\ln\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right]$
G'Sell Jonas	$\sigma = \sigma_0 + K \cdot (1 - e^{-w \cdot \varepsilon_p}) \cdot e^{h \cdot \varepsilon_p^n}$	Kang	$\sigma = \sigma_0(\varepsilon)\left[1 + C_1\,\ln\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0} + C_2\,(\ln\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0})^2\right]$
Johnson Cook	$\sigma = \left[A + B \cdot (\varepsilon_p)^n\right] \cdot \left[1 - (T^*)^m\right]$		
Swift	$\sigma = A \cdot (B + \varepsilon_p)^C$		
Voce	$\sigma = A + (B - A) \cdot e^{-C*\varepsilon}$		
4a three parameter	$\sigma = \sigma_0 + E \cdot \varepsilon_p \cdot \frac{1}{\left[1 - \frac{E}{H} \cdot \varepsilon_p\right]}$		

Figure 5 shows the comparison of the simulation curves to the test curves for the optimized material model. The results are very good and show the successful usage of the reverse engineering process [3].

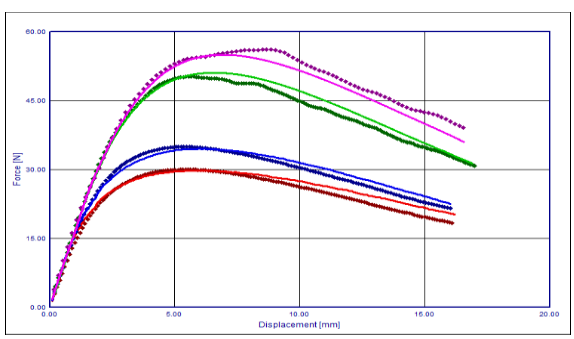


FIGURE 5. Final validation of the optimized material model for PP Hostacom for different test velocities [3]

FURTHER EXAMPLES USING 4A IMPETUS

In a project together with Magna the front hood for BMW M3 CRT made of fiber composites was characterized. The fronthood outer layer consist of glasfiber plies, the core was a honeycomb as inner layer. Both materials were characterized using 4a impetus by 3-point-bending and compression tests. Figure 6 shows the final validation of an impact onto the fronthood. The simulation curve matches the test curve very good [4].

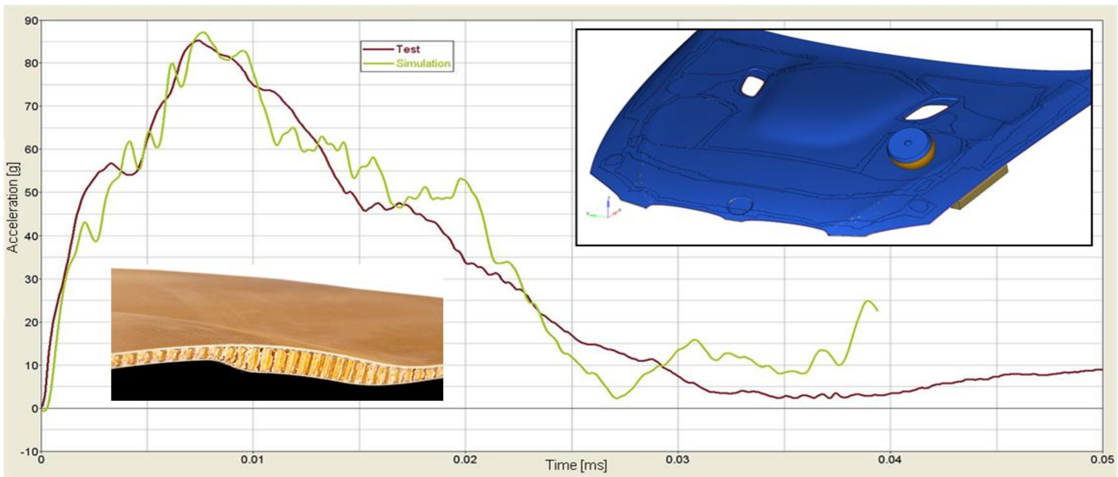


FIGURE 6. Final validation of the fronthood by an impact test [4]

Another example was the simulation model simplification and characterization of a wire harness for the automotive industry (Fig. 7). 3-point-bending tests as well as compression tests were performed and the material parameters were determined by reverse engineering. Figure 7 shows the results for the compression tests at two different velocities. The comparison of both test and simulation curve shows a very accurate correlation [5].

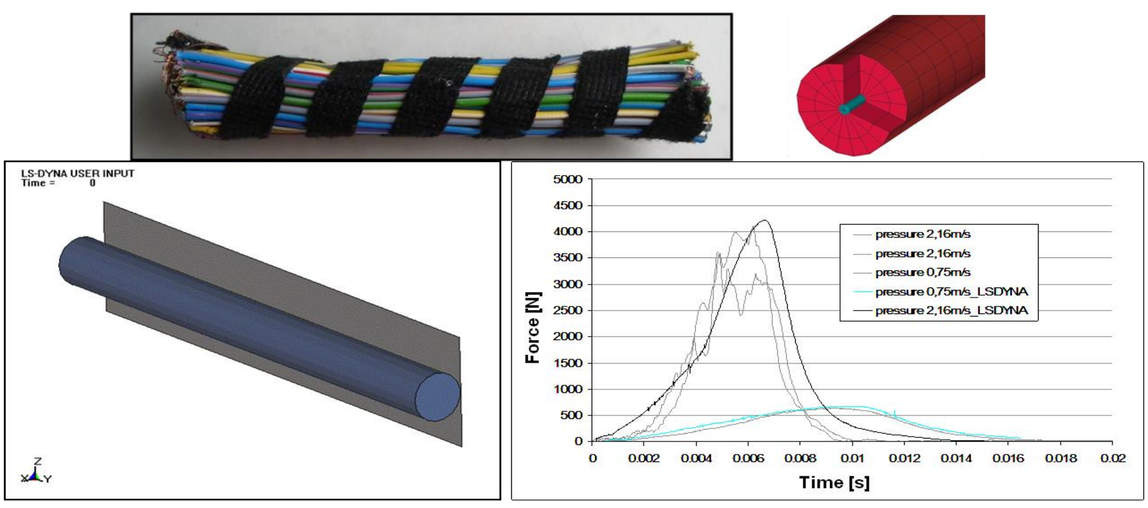


FIGURE 7. Characterization of a wire harness, top left: wire harness; top right: model of the wire harness; bottom left: schema of the compression test; bottom right: comparison of results [5]

A further example for a reinforced material (PBT GF20) is the casestudy of the so called "Nutini box" which is shown in Fig. 8. In addition to the material testing using 4a impetus the fiber orientation was mapped on the LS-DYNA simulation model by using the software 4a fibermap. The material model used was an averaged *MAT_157 (orthotropic material model with visco plasticity), the simulation results including the consideration of failure were quite accurate [6].

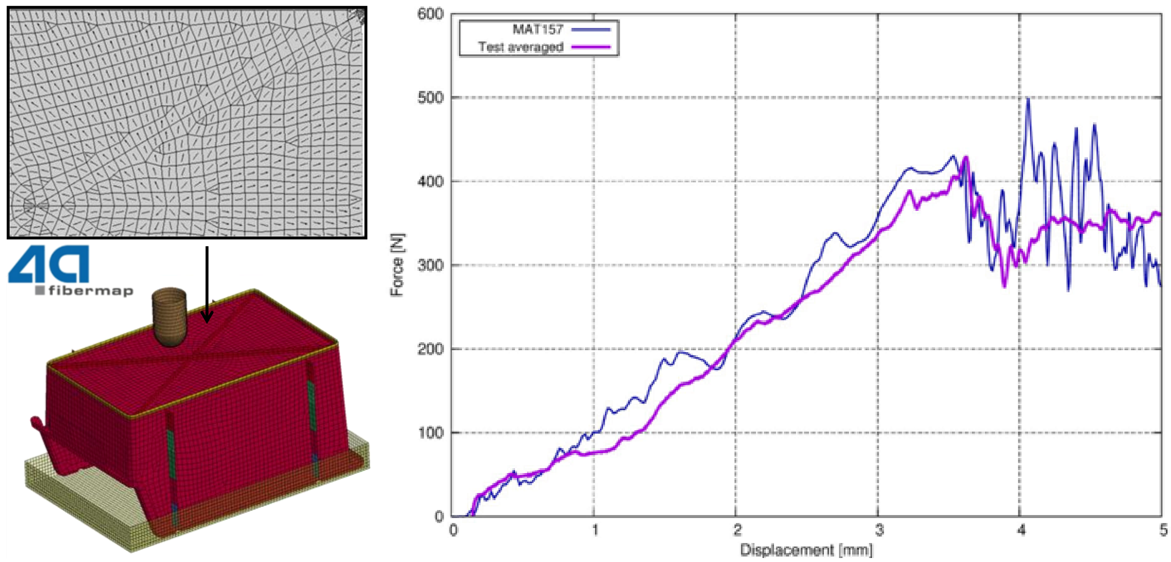


FIGURE 8. Crash of the Nutini box; results were achieved using the 4a impetus process [6]

SUMMARY

The testing device 4a impetus was developed to allow a very quick and reproducible generation of material cards. The base load case is the bending test which is near to reality, high strain rates can be achieved and the test specimens can be taken directly from parts. The material parameter identification is based on the method of reverse engineering. The validation of the 4a impetus workflow is proved on many examples.

REFERENCES

1. http://impetus.4a.co.at/en/
2. P. Reithofer, M. Rollant, „Dynamische Materialcharakterisierung mit 4a impetus”, 4a Technologietag Schladming, 2012.
3. https://www.carhs.de/en/companion-poster/product/caecompanion-pdf.html, pp. 50-52.
4. P. Reithofer, M. Rollant, W. Dietz, H. Kassegger, „Anwendungsnahe Materialcharakterisierung mit 4a impetus am Beispiel einer Verbundwerkstoff-Motorhaube“, crashMAT, Freiburg, 24. April 2012.
5. M. Fritz, P. Reithofer, S. Neumair, U. Franz, „Kunststoffcharakterisierung mit Impetus II - Der effiziente Weg zu validierten dynamischen Materialdaten“, 6. LS-DYNA Forum Frankenthal, 2007.
6. R. Jennrich, M. Roth, S. Kolling, C. Liebold, G. Weber, „Experimentelle und numerische Untersuchung eines kurzglasfaserverstärkten Kunststoffes“, 13. LS-DYNA Forum Bamberg, 2014.