4a impetus (PART 1): Dynamic material characterization of plastics – development in the past 10 years

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

1 Introduction

In recent years plastics have been used more and more in automotive industry primarily
- for cost reasons in complex design,
- for safety reasons in the area of occupant and pedestrian safety application and
- for CO₂ reduction reasons in lightweight applications with regard to structural performance needs.
Therefore simulation of the application load cases is an indispensable must have in the product
development. Based on the successful usage of simulation tools in the metallic section, the standard
simulation methods and material models can’t represent the plastic material behavior. Many
developments and improvements in the crashcode LS-DYNA especially for plastics and composites
have been seen in the past 10 years, with the necessity to consider the deformation (viscoelasticity,
viscoplasticity, anisotropy) as well as damage and failure behavior in the material model.

2 Retrospect

New developments in the testing and material characterization have been going along with requirements
of these new models [1]. The classic testing methods ideally with mechanical understanding (tension,
compression and shear) with local strain measurements (for example by DIC) are one approach to deal
with this topic.

Another approach is to use the bending load case and its many advantages:
- this is the most frequently occurring load case in reality,
- the geometry of the test specimens can be very simple and
- tests can be performed very quickly and accurate using 4a impetus (see fig. 1).

Fig.1: Prototype of 4a impetus (2004 [2]), first commercial version (2006 [3]) and the current version
(2015 [4])

In the presentation we will give an exemplary overview of the development in the field of plastic materials
testing in the past 10 years
- starting with simple *MAT_024 and high-speed tensile tests compared to the easy 4a impetus
  bending approach,
- showing the reverse engineering process with LS-OPT and the normal and clamped bending as
  alternative to high speed tensile tests,
- considering different loading situations (e.g. *MAT_187), needed test specimens and methods to
  characterize the material,
- including temperature and moisture dependencies for thermoplastics and
- concluding with current developments in considering the process influence and in failure prediction.
3 State of the art

In the field of old school material characterization static and dynamic tensile tests are the base for a *MAT_024 material card generation. For plastics and composites there is no high-speed tensile testing standard method available. Considering complex yield surfaces (tension, shear, compression, ...) or anisotropy is often a known issue and well researched in several public founded projects, but cannot be seen as standard in automotive simulation applications.

4a impetus stands for the new solution, starting from measurement data handling up to an automatic material parameter identification process (MPIP) based on reverse engineering. The hardware and software products are used by automotive OEMs and their suppliers, material suppliers, research institutes and engineering service providers. Meanwhile 4a offers standards to generate simple material cards like *MAT_024, considering anisotropy *MAT_054/058/157, compression/tension behavior *MAT_124/187.

Fig.2: 4a impetus material characterization pyramid for plastics [5], [6],[7]

4 Summary & Outlook

Driven by the increasing requirements of the industry to predict not only the "average" deformation behavior, the simulation methods and the therefore needed material models as well as the testing methods have to be improved continuously. 4a impetus is the first approach, closing the gap between the simulation and testing fractions.

Due to lightweight applications and the mechanical structural relevance of plastic and composite materials especially damage and failure prediction as well as considering process induced inhomogeneity (e.g. short and long fiber reinforced materials, foamed plastics, ...) will be R&D topics in the next years.

5 Literature

4a impetus (PART 1):
Dynamic material characterization of plastics
development in the past 10 years

P. Reithofer, A. Fertschej, M. Rollant (4a engineering GmbH)

14th German LS-DYNA Conference
10th – 12th October 2016, Bamberg, Germany
4a technology group

4a technology-group: founded in 2002
Location: Traboch, Austria
Number of employees > 80
Field of operation: global
Certificates: ISO 9001
more than 2000 projects
more than 400 customers
polymer and materials science
numerical simulation methods
fiber reinforced plastics and composites
product development
method and software development
material characterization

strut bar:
LH$_2$ – tank mounting:

validated material cards for plastics, composites, metals, foams, ....
material variety

motivation

bending load case

original test curve tension  
scaling 1.25

test simulation

R. Luijkx - Kunststoffmaterialien in der Interieur Funktionsauslegung bei Audi AG, 4a Technologietag 2010
Dynamic material characterization of plastics first steps ....
Dynamic material characterization of plastics
5. LS-DYNA Forum 2006

4a impetus Hardware

4a impetus Software

4a impetus Hardware

4a impetus Software
Bilinear

Typical material card
*MAT_024

applicable
1-100 1/s

Interior / Exterior drop tests
Dynamic material characterization of plastics
7. LS-DYNA Forum 2008

4a impetus Hardware

Optical Sensor
impact velocity & detection

4a impetus Software

Parameter Identification
vs. Neuronal Net

4a impetus
Software

Optical Sensor
impact velocity & detection
Dynamic material characterization of plastics
7th European LS-DYNA Conference 2009

4a impetus Hardware

<table>
<thead>
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<th>applicable</th>
<th>0.001-100 1/s</th>
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<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5</td>
<td>40</td>
<td>510</td>
</tr>
<tr>
<td>1</td>
<td>60</td>
<td>1300</td>
</tr>
<tr>
<td>0.001</td>
<td>50</td>
<td></td>
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Bending setup

Tension loadcase

4a impetus Software

*MAT_PLASTICITY_COMPRESSION_TENSION

*MAT_SAMP-1

Drucker-Prager [Kolling2005]

Fixed bending

--- averaged test curves
--- result of simulation
Dynamic material characterization of plastics
Measurement update, 2009

4a impetus Hardware

0,01 mm

100.000 → 1.000.000 samples/s

4a impetus Software

Bending 1 m/s

New evaluation velocity, displacement

Compression 3.5 m/s
Dynamic material characterization of plastics
9. LS-DYNA Forum, 2010

4a impetus Hardware

Fixed bending

Component testing

4a impetus Software

Hardening Laws
Bilinear
\[ \sigma = \sigma_0 + E_T \cdot \varepsilon_p \]
G’sell Jonas
\[ \sigma = \sigma_0 + K \cdot (1 - e^{-w \cdot \varepsilon_p}) \cdot e^{h \cdot \varepsilon_p} \]
4a three parameter law
\[ \sigma = \sigma_0 + E \cdot \varepsilon_p \cdot \frac{1}{1 - \frac{E}{H} \cdot \varepsilon_p} \]

Reverse Engineering

Strain rate Laws
Cowper Symonds
\[ \sigma = \sigma_0(\varepsilon) \left[ 1 + \left( \frac{\dot{\varepsilon}}{D} \right)^p \right] \]
Johnson Cook
\[ \sigma = \sigma_0(\varepsilon) \left[ 1 + C \ln \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0} \right] \]
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<thead>
<tr>
<th>4a impetus Hardware</th>
<th>4a impetus Software</th>
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<td><img src="image2.png" alt="Image of Software" /></td>
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<td><strong>4a impetus Software</strong></td>
<td><strong>4a impetus Software</strong></td>
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<td><em>MAT_24</em> Dynamat</td>
<td><em>MAT_187</em> Dynamat</td>
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</tbody>
</table>
Dynamic material characterization of plastics
4a Technologietag, 2012

4a impetus Hardware

plugable acceleration sensor for pendulum

4a impetus Software

stress [MPa] at 10% strain

strain rate [s⁻¹]

plugable acceleration sensor for pendulum versus
Dynamic material characterization of plastics
11th LS-DYNA Forum, 2012

4a impetus Hardware

4a impetus Software

LS DYNA©

LS-OPT®

Reverse Engineering

MAT_054
MAT_058

[DYNAMore]
Dynamic material characterization of plastics
11th LS-DYNA Forum, 2012

P. Reithofer - Dynamische Materialcharakterisierung von Composites mit 4a impetus, 11. LS-DYNA FORUM, ULM

By courtesy of Magna Steyr Engineering Austria
4a impetus Measurement

**Supported data:**
- Zwick ASCII format
- Shimadzu ASCII format
- Plain text
- CSV
- Excel

4a impetus Software

**Import external Data**
(also DIC)

**First Damage models**

- *MAT_ADD_EROSION*
Dynamic material characterization of plastics

4a impetus Hardware

4a impetus Software

Temperature (-30°C & 80°C)

Statistical methods → failure

Puncture Test

Force [N]

Displacement [mm]

Simulation

Force [N]

Displacement [mm]

4a impetus Software

Validation

Failure Anisotropy
We have already tested a wide range of

- **thermoplastics** (ASA, ABS+PA; ABS+PC; PA6; PA6(6) GF30..50; PA66+P6; PBT GF30; PC; PE; PP; PP+ varnish; PP rubber modified; PP GF20..40; PP Impact modified; PP MX10; PP MX20; PP MX40; PP CF; PP+EPDM; MuCell-materials, …)
- foams (EPP30..80; PU RG 55, PU RG 65)
- **rubbers** (EPDM, silicone, TPS, …)
- **thermoset materials** (CFK, GFK with epoxy resin, …)
- **metals** (aluminum, DC04, …)
- others
  - fabric (interior, …)
  - glue (front hood, …)
  - wood (beech, multiplex, chipboards, MDF)
Dynamic material characterization of plastics

Summary

Workflows validated material card

ABS
Acrylnitril-Butadien-Styrol-Copolymer

NBR
Acrylnitril-Butadien-Copolymer

Component validation

\[ \alpha (0/45/90^\circ) \]
Thank you for your attention!

14th

23.- 24. March 2017
in Schladming, Austria

„Light weight applications & Composites”
More information: http://technologietag.4a.co.at/