Using an Optical Measuring System for Identification of Material Parameters for Finite Element Analysis

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1 Introduction

Finite element simulations in passive safety applications for the automotive industry have reached the status of a major development tool. Therefore, the prediction, gained by simulation, has reached high levels of quality.

Load paths, loads and energy absorption have to be detected correctly by simulation to reach the necessary level of real life prediction. The modeling of a finite element simulation has to be done carefully. Modeling may be divided into 4 areas, the modeling of geometry, of material behavior, of connecting techniques and of numerical parameters.

In this paper, material characterization and modeling of plastics are described. Deformation and failure behavior of the plastic material have to be modeled correctly to calculate load paths and energy absorption. Stress-strain and failure mechanisms of materials need to be known for the modeling of the material behavior. Those values depend on strain, strain rate and temperature.

The material characterization, the description of the behavior under given loads, is the base for the choice of an appropriate material model. Experimental data is used for the material characterization and the determination of the necessary parameters within a material model.

The Accredited Test Center 'ATC' of EDAG in Fulda, which is accredited according to ISO 9000, is performing such experiments for some years. The introduction of an optical measuring system to evaluate the stress-strain behavior is described in this paper.

2 Test Device

The test facility for dynamic tests includes a high speed testing machine of type Zwick 1852 and the optical measuring system Aramis developed and provided by the "Gesellschaft für Optische Messtechnik" (GOM, 2006), figure 1. The high-speed camera system Photron Sa1.1, a two-camera system that allows the detection of 3-dimensional movements, can be seen. These cameras are part of the optical measuring system Aramis.

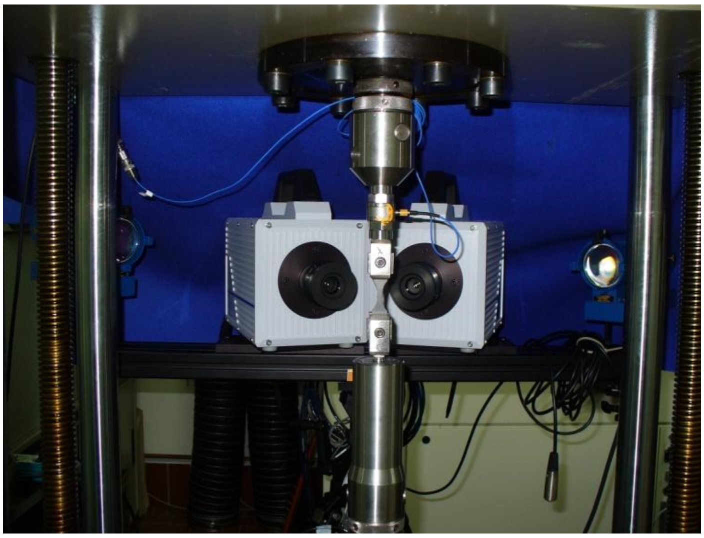

Fig. 1: Setup of the tension test

All dynamic tests are performed on that hydraulic system. Different clamping systems are used to allow a wide range of experiments. Today, tension, bending and shear tests, figure 2, at different speeds and temperatures are done. The maximum speed is 11 m/s and the maximal load force is 20 kN.
The 1-dimensional tension tests specimen have a geometry according to ISO 527. Usually, the length of the specimen is reduced to 5 mm especially for materials with high strains. The range of test speed is between 1 mm/s and 7000 mm/s.

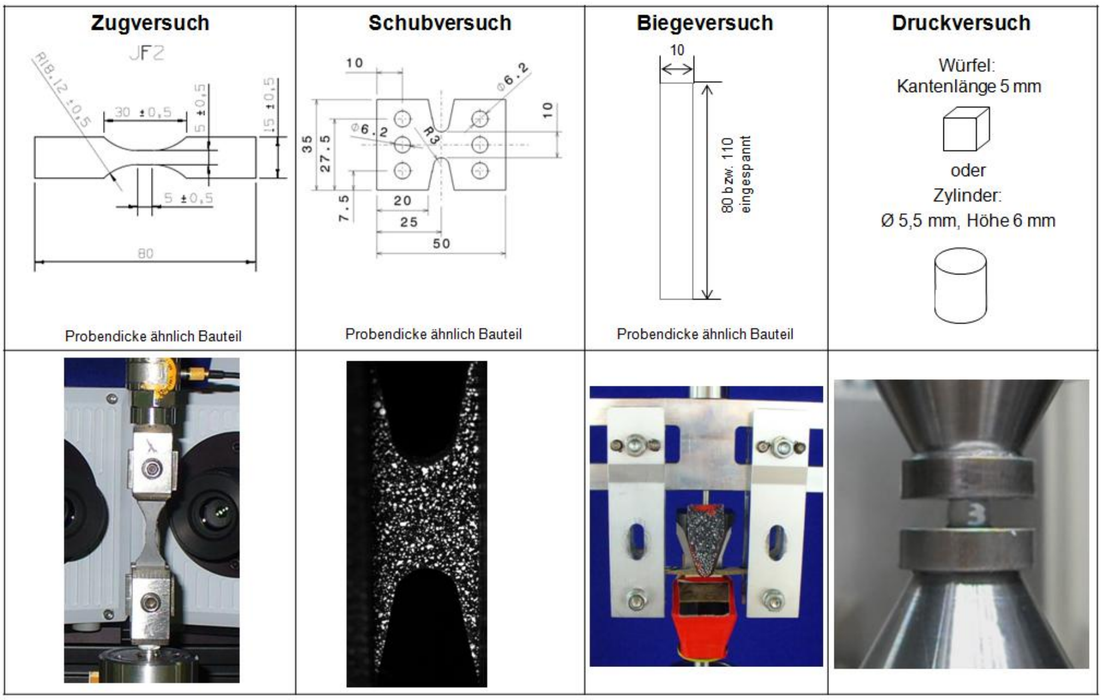

Fig. 2: Dynamic Tests – specimen and test configuration

The three-point bending tests are done according to ISO 179. The system is designed for different bending and boundary conditions. Support distances as well as tool radii can be changed. The specimen might be clamped at its ends in order to change stress conditions.
The specimen for the shear tests are designed according to the ones suggested by Iosipescu (Grellmann, 2007). Finite element simulations have been used to define a geometry with optimized stress conditions within the specimen during testing.

3 Procedure of optical strain measurement

The procedure for the strain measurement using the optical measuring system is explained for tension tests. The procedure is similar for all tests.

The procedure includes the following steps
- Sawing and milling of specimen out of plates according to ISO 294
- Priming of the specimen with black or white lacquer coat
- Applying a pattern using a spray can, varying the size by the distance to the specimen
- Choosing the resolution and the pictures frequency
- Starting the recording of force, time and pictures
- Doing the test
- Post processing of the data.

The size of the pattern is chosen depending on the distance between camera and specimen, the chosen frequency of pictures, the resolution of the camera and the measured area.
The measured load data of the test device and the pictures, are the main data used for processing the experimental data. The data processing has been automated as far as possible. The Aramis program allows writing scripts in Python (Python 2011). The optical measuring system delivers correct determination of two-dimensional strains on the surface of the specimen. Because of the two-camera system, the determination will be correct even when the specimen moves normal to that surface. Because of the position of the cameras one side and both edges of the specimen can be observed as well, which has been used to detect failure beginning on the backside of the specimen. Calculating the stresses is based on the assumption that the material has a constant volume during deformation and that the measured force is acting homogenously over the cross section. With Aramis, stress and strain might be calculated in different ways, using mean values of a rectangular window including some facets, using the value of just one facet or by calculating the strains of a line.

The following results are calculated and reported for tension tests, figure 3. Calculation of
- true stress and strain for a rectangular window of about 3 x 5 mm² in height and width, here the mean stress-strain curve is divided into a part until first failure is observed and a part from first to final failure
- true stress and strain of an single facet which can be defined after a first preview of the result
- the mean strain rate for the window.

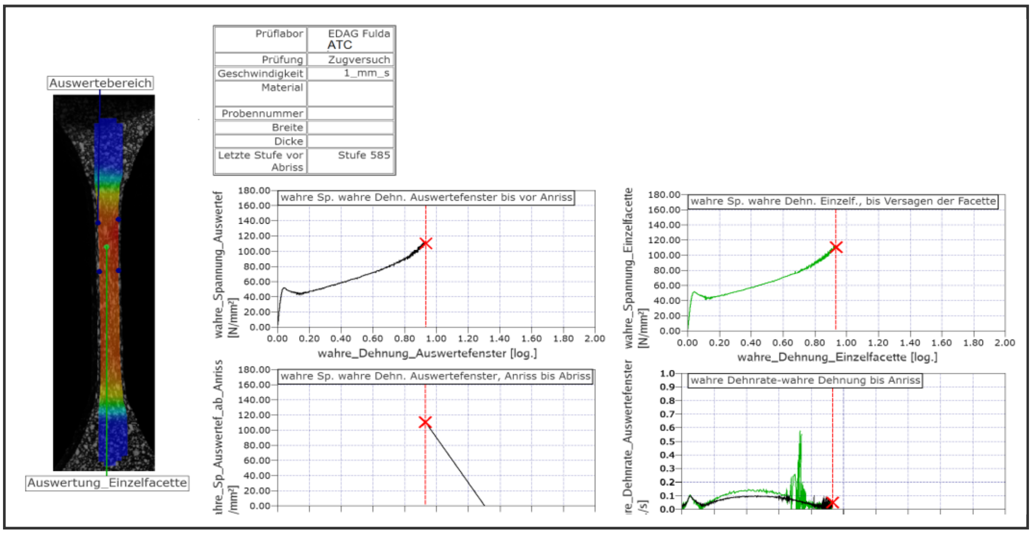

Fig. 3: Standard evaluation of the optical strain measurement for the tension test

Those data are provided for the determination of the parameters for material models in finite element simulation.

4 Definition of parameters for material models

Based on a material characterization, a material model can be chosen. The parameters for such a material model will be defined and validated on experimental data.
Here, a von Mises material model will be used. Tension tests at different speeds are taken for the definition of the parameters and bending tests for the parameters' validation. Here, all tests are performed at room temperature and always until the specimen fails.
From the above shown standard data processing, the stress-strain curves of the window are used. For each speed usually five tests are done. Using those data a mean stress-strain curve is calculated, figure 5. The mean stress-strain curves for testing speeds of 1 mm/s up to 3000 mm/s are calculated, which show a strain rate dependency. Those curves are used for the determination of failure strain depending on strain rate as well. The given curves of the strain rates show the same behavior for different testing speeds. To define the mean strain rate a procedure similar to the one in (Böhme, 2008) is used. Here minimal values are about 1 1/s and maximum values of about 250 1/s. The Young's modulus is defined using the test-data with the lowest strain rate. Here a value of 1200 N/mm^2 is calculated. The plastic range starts at a strain of about 0.004. The modulus is compared to the data at higher speeds and if necessary corrected.

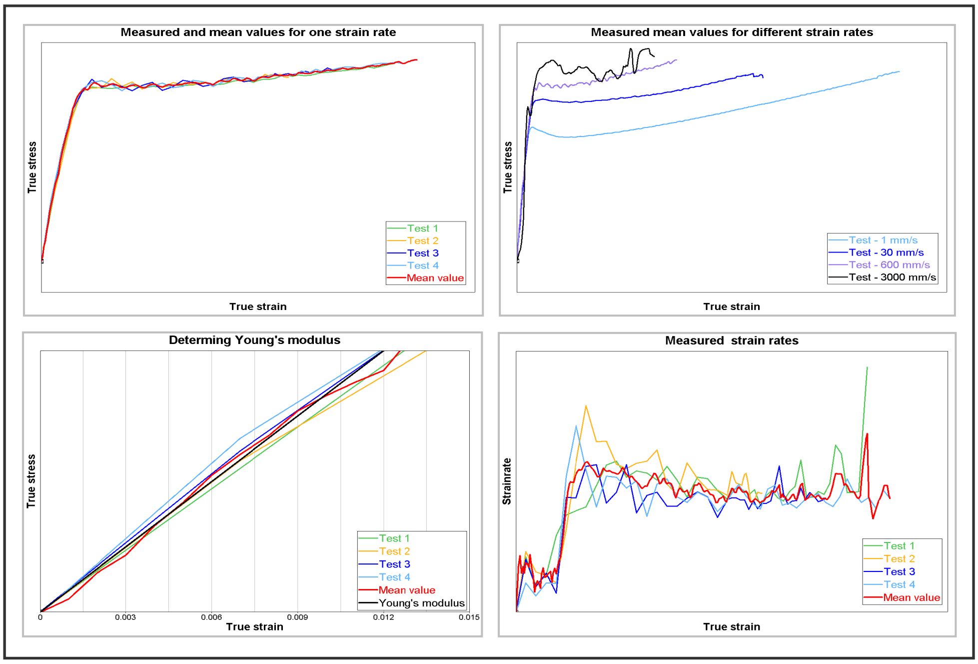

Fig. 5: Preparing data for parameter evaluation

Tests with a speed of 7000 mm/s are performed without an optical measurement. Caused by the given boundary of the testing device the measured force oscillates heavily. These effects have been observed by (Bruch, 2009) as well and are known by the supplier of the test device. These tests are used to define upper limit for the stress-strain behavior and lower limit for the failure.
When Young's modulus, strain rates and failure strains depending on strain rates are defined, stress-strain curves have to be defined. Therefore the mean experimental data of figure 5 are used. Here the definition is done for material model MAT89 (MAT_PLASTICITY_POLYMER), so one stress-strain curve has to be created which is then scaled in stress direction for strain rate dependency. As shown in figure 6 this curve has to be adapted to define curves valuable for finite element simulations. Depending on material, those changes might be significant in different areas of strain and stress. The stress-strain curves will be adapted to plastic stress-strain curves according to (LS-DYNA, 2012).

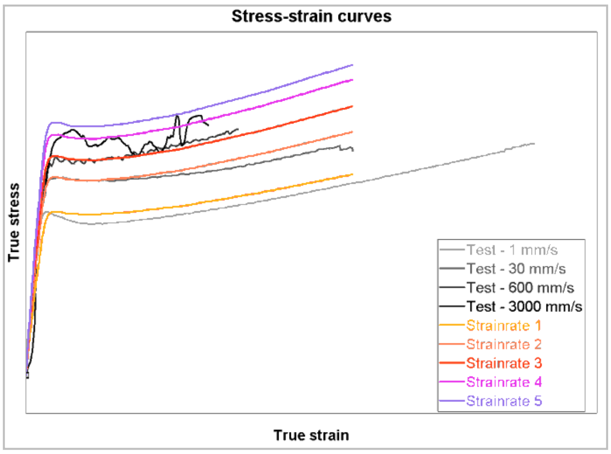

Fig. 6: Stress-strain curves for the calculation

5 Validation

Here, the parameters for the chosen von Mises material model will be validated using the experimental results by comparing the force-deflection behavior in dynamic tension and bending tests. In the bending load case two different bearings have been tested, a loose and fixed one.

The one dimensional tension test is simulated using models with different element lengths as shown in figure 7. Here deflection is measured between the marked points in test and simulation. The comparison between experimental and numerical force-deflection behavior shows similar results for elastic and plastic characteristics, but not for the failure. By using small element lengths failure appears earlier, while a tall element length causes late failure, figure 7. The failure strain is here optimized for an element length of 2,5 mm. With this discretization also a good correlation of failure is achieved.

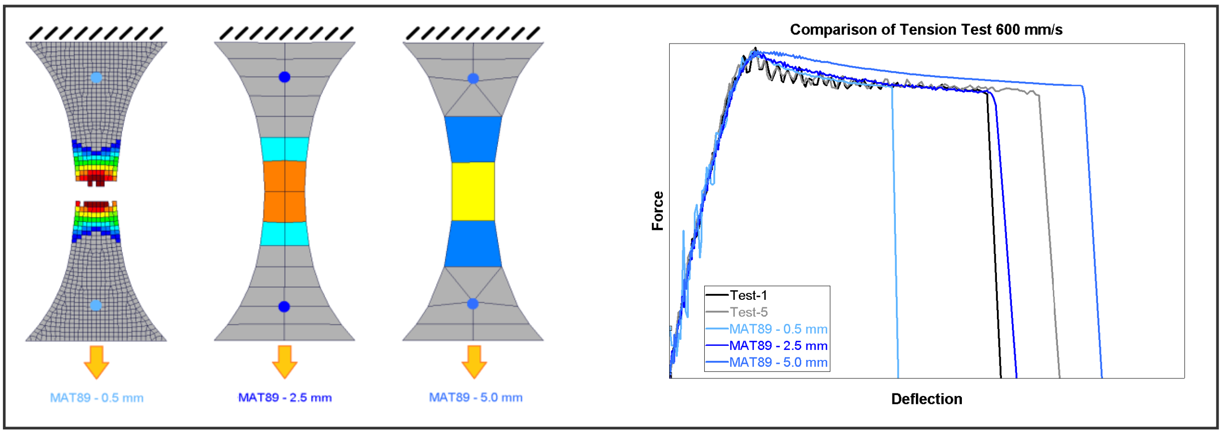

Figure 7: Tension test comparison with MAT89

For the simulation of the bending test, the element length is changed as well. In bending with loose bearing the comparison of test and simulation shows similar results, also for different element lengths. With the reviewed ductile material the loose specimen glides through the bearings and no material failure occurs, so an influence of element length on failure can not be checked, figure 8. Friction is used in that simulation with LS-DYNA to stabilize the rigid body movement of the specimen.

For adjustment of failure the bending test with fixed bearing is used. As already identified in the simulations of tension test, the element length shows dependency on failure as well. Nearly good correlation is achieved with an element length of 2,4mm, which is near to the optimal element length. But using a taller discretization, failure appears much too late, figure 8.

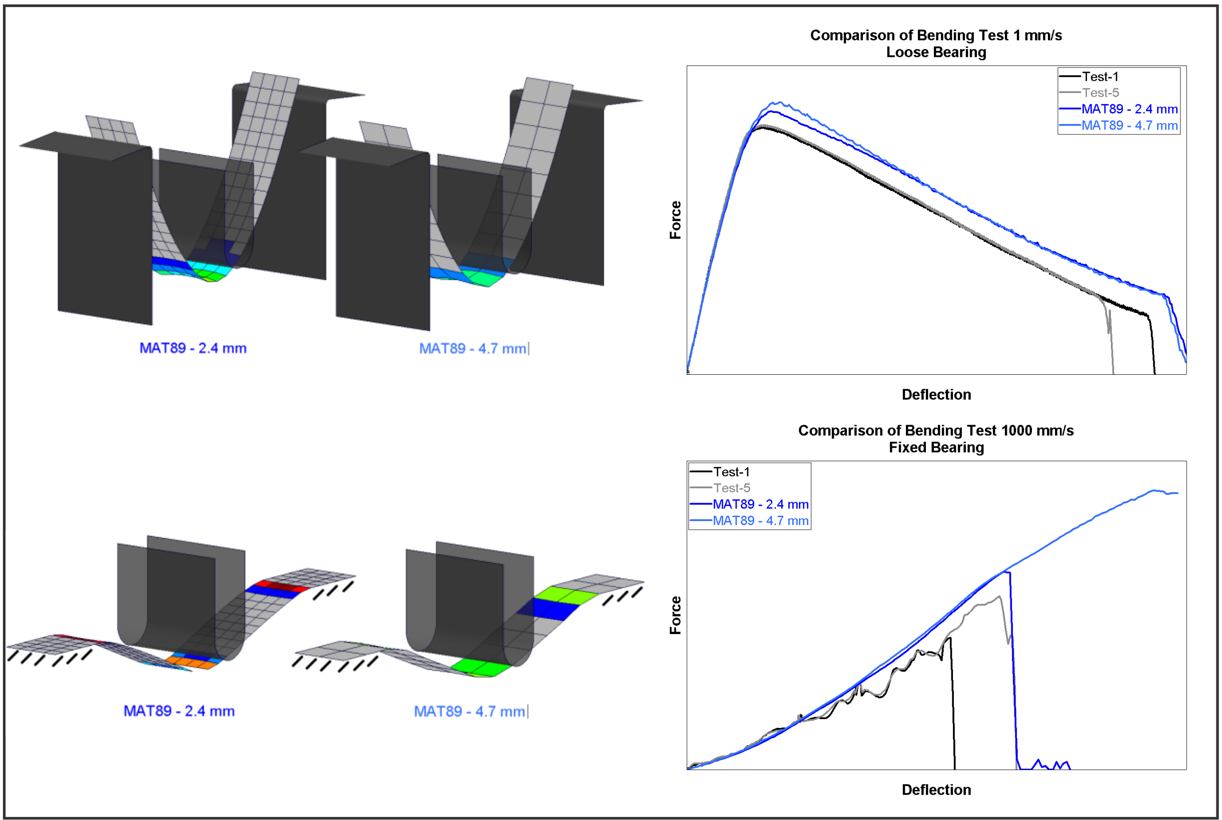

Figure 8: Bending test comparison with MAT89

By linking a GISSMO damage model to the defined material model MAT89, a regularization of element size dependency on failure is possible. As an reference element length 2,5 mm is chosen, because for this size the failure in MAT89 is validated. For all other element sizes, the equivalent plastic strain to failure gets scaled. The scale factors are iteratively determined in validations of tension tests, so that the different meshed specimens fail at nearly the same deflection as shown in figure 9.
The analyzed material shows a very early softening and the stress at this point does not differ very much from the failure stress, which is not so ideally represented using GISSMO damage definitions. So the material softening gets represented in the stress-strain curves of MAT89 and a damage in GISSMO gets defined on the verge of material rupture.
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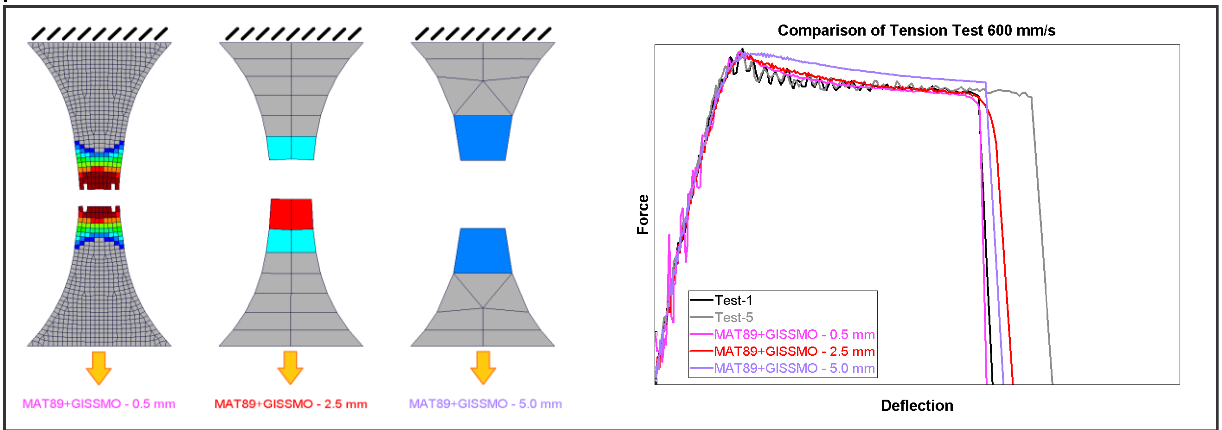

Figure 9: Tension test comparison with MAT89+GISSMO

Similar to the tension test the comparison of the bending test does not show any difference of elastic and plastic behavior between MAT89 and MAT89 with GISSMO until the point of damage initiation.

Comparing material failure at different element sizes MAT89 with GISSMO offers a much better correlation. Still the simulation of the bending test with a tall element size does not correlate optimally with the experimental data. However the reason for this difference is not the quality of the material model, but the fact that a bending line is geometrically not well described with tall element sizes, figure 10.

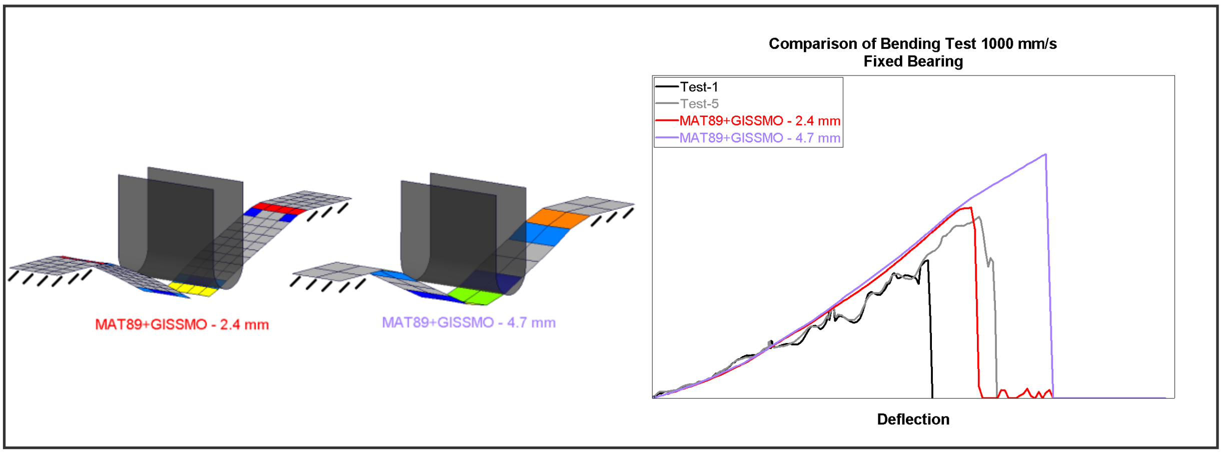

Figure 10: Bending test comparison with MAT89+GISSMO

6 Measuring of Polymeric Foams

Polymeric foams are often used for energy absorption in automobiles. Usually, those foams undergo a compressive load. Crushable foams under dynamic loads are usually simulated by using a short time inelastic approach. Here, the behavior under compression, for analyzing the transverse deformation, and under bending, for analyzing the tension failure, has been examined. For the optical measuring, a different preparation has been necessary. The surface has been covered with an elastic material before the pattern could be added.

Different types of strain measurements have been examined. Strains in x and y have been measured by lines and by two rectangular windows of different size, figure 11. The yellow line is used for measuring the y-strain, the green line for measuring the x-strain. The two windows, the smaller window is represented by the blue dots and the bigger one by the red dots, are used for measuring the x- and y-strains. All strains are logarithmic strains.

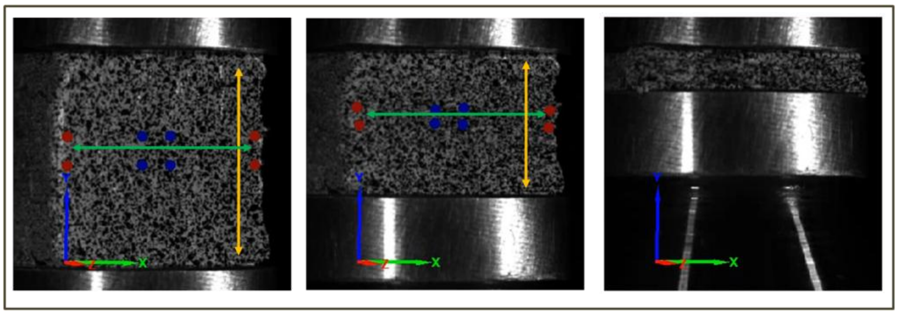

Fig. 11: Compression test of polymeric foam

The different strain measures in x-direction show lowest values for the small window, higher for the line and highest for the bigger window, see the top diagram in figure 12. In y-direction the two windows show similar results which are higher than the strain of the line, see central diagram. All those values indicate that the deformation is inhomogeneous. The optical measuring fails when more than half of the compression is done, compared to the force-time curve at the bottom.

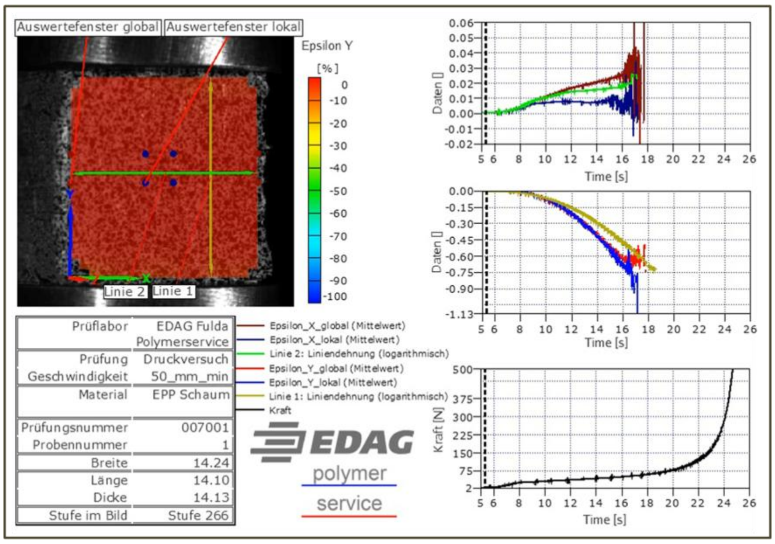

Fig. 12: Compression test of polymeric foam – strain measures

The compression test results show that the deformation seems to be inhomogeneous. The measured transverse strain supports the usual assumption that polymeric foam is highly compressible.
The bending test shows pure bending conditions just in the beginning of the test. Then the foam starts to be compressed in the areas of the punch and dies, figure 13. The very inhomogeneous deformation result in a localization of stresses and strains. The foam starts to fail in areas of high stresses and strains.

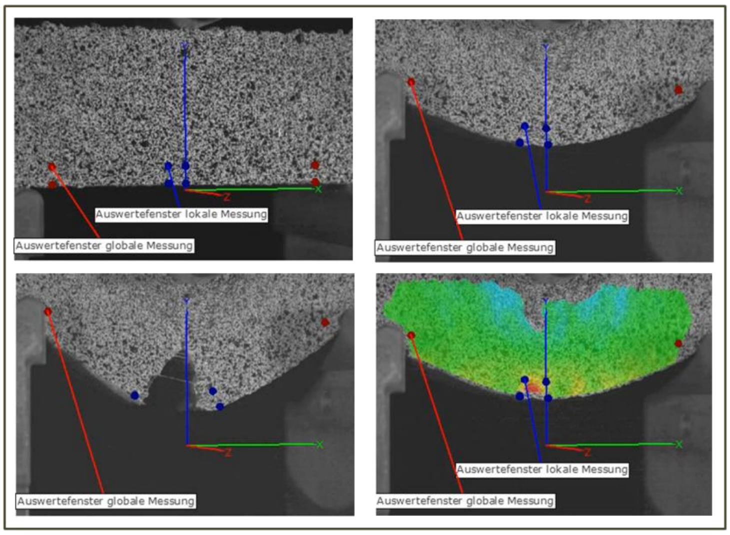

Fig. 13: Dynamic bending test of polymeric foam

Using the optical measuring system for analyzing the behavior of polymeric foams lead to some new information regarding the material characterization which should be used for improved determination of material model parameters.

7 Summary

The optical measuring system for different experiments has been successfully established at EDAG in a very short period of time. Today, dynamic tension, shear and bending tests at room temperature as well as low and high temperatures for different materials like plastics, polymeric foams and reinforced materials can be done. Using the optical measuring for compression tests has been introduced for polymeric foams.

Using the optical measuring system allows an easier and better determination of two-dimensional strains and strain rates on the surface of the specimen. The calculation of strains is done after a review of the results. So that effects like localization and failure could be taken into account.
The usage of the optical measuring improves the quality of data for the finite element simulation.
Using the damage model GISSO in combination with MAT89 a regularization of element size dependency on failure can be implemented and allows better forecasts of component failure in simulations.

8 Literature

(LS-Dyna, 2012) LS-DYNA Keyword User´s Manual
Version 971 R6.1.0, August 2012
Livermore Software Technology Corporation, Livermore, California, USA

(Böhme, 2008) Böhme, W.
FAT-Richtlinie: “Dynamische Werkstoffkennwerte für die Crashsimulation”
MP materials testing 50 (2008), No.4, pp.199-205, ISSN: 0025-5300

(Bruch, 2009) Bruch, O.
“Materialbeschreibungen für die Crash-Berechnung von Kunststoffbauteilen”
Shaker Verlag, Aachen, 2009, ISBN 978-3-8322-8211-0

(GOM, 2006) Gesellschaft für Optische Messtechnik
Aramis Benutzerinformation
Version 6, Braunschweig, 2006

(Grellmann, 2007) Grellmann, W., and S. Seidler
“Polymer Testing”
Carl Hanser Verlag, München, 2007

(Python, 2011) Python 2, Python 3
Python Software Foundation, Wolfeboro Falls, USA
www.python.org