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

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When performing material testing usually global measurements are used for the calculation of material strains. Especially, when high strain rates of more than 100 1/s are examined those data are often unreliable. Within this paper the recently at EDAG introduced optical measuring system is presented and the identification of material parameters is explained. The comparison of experimental and numerical component test data of an automotive door trim demonstrates the advantages of such a system.

Keywords:Automotive, Material Modeling, Testing, Plastics, Crashworthiness

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.

Load paths, loads and energy absorption have to be detected correctly by simulation to reach the necessary level of real life prediction. The modeling for e.g. the simulation of a side crash impact, a head impact according to FMVSS 201u or the impact of head or leg impactors for the pedestrian protection must be done carefully. Modeling may be divided into 4 areas, the modeling of geometry, of material behavior, of connecting techniques and the modeling by the right usage of numerical parameters. The geometry of the involved components must be discretized correctly as well as the connecting techniques. A good description of the material behavior is as necessary as the right usage of numerical methods, which also includes the definition of external loads.

This paper deals with the material modeling of plastics. To simulate the loads on a car passenger it is necessary to simulate the behavior of plastic components involved in the load path. Loads, like forces and moments, have to be calculated which again depend on the deformation and failure behavior of the plastic material. 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. Bumper, pillar and door trims are some components made by unreinforced and reinforced plastics.

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.

The test laboratory ‘Polymerservice’ 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, a company for optical measuring techniques, (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.

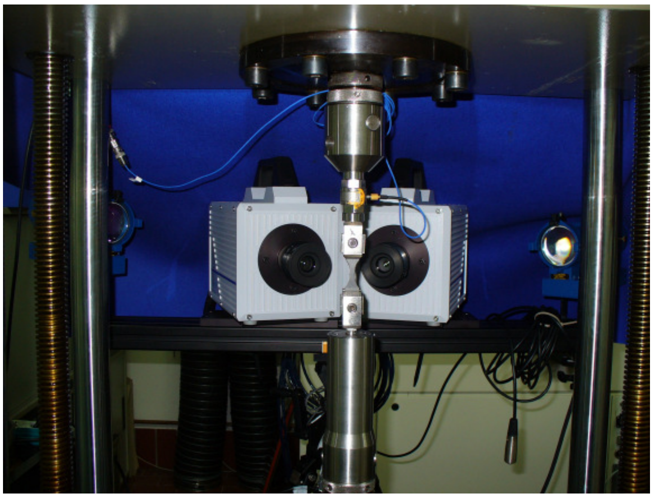

Figure 1. Setup of the tension test

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 1, 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.

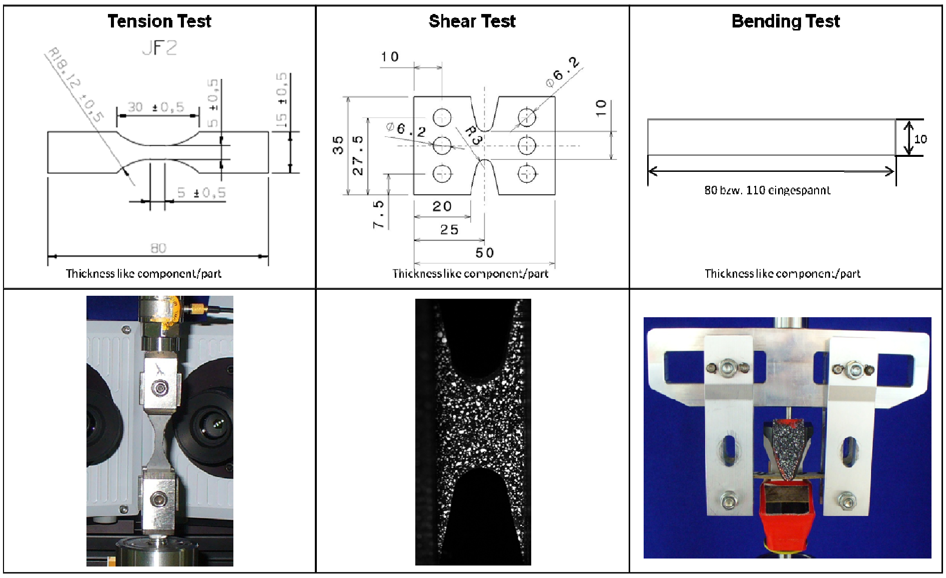

Figure 2: Dynamic Tests – specimen and test configuration

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. Usually stripes of a length between 80 and 110 mm and of a width of 10 mm are used.

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
- Doing the 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, a PNG format, 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.

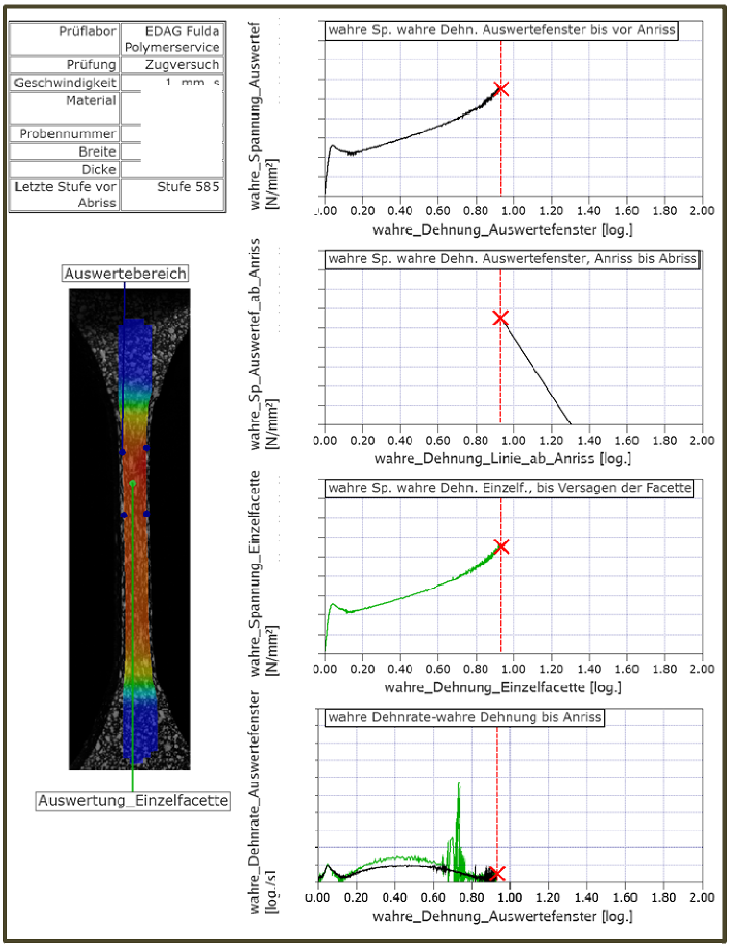

Figure 3. Standard evaluation of the optical strain measurement for the tension test

The following results are calculated and reported for shear tests, figure 4. Calculation of

- shear angle and shear strain for 1 facet in the middle of the specimen
- effective strain, shear stress and effective stress.

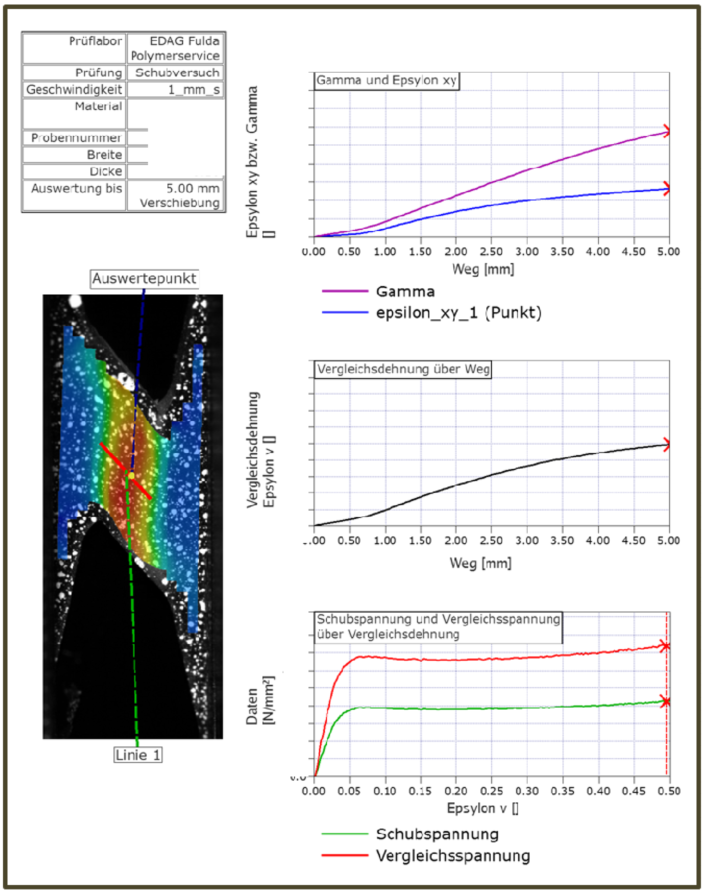

Figure 4: Standard evaluation of the optical strain measurement for the shear test

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

4. Definition of parameters for material models

Experimental data under test conditions similar to real life loads of the material are used to describe the material behavior for finite element simulations. Based on this 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 minmal 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/mm2 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.

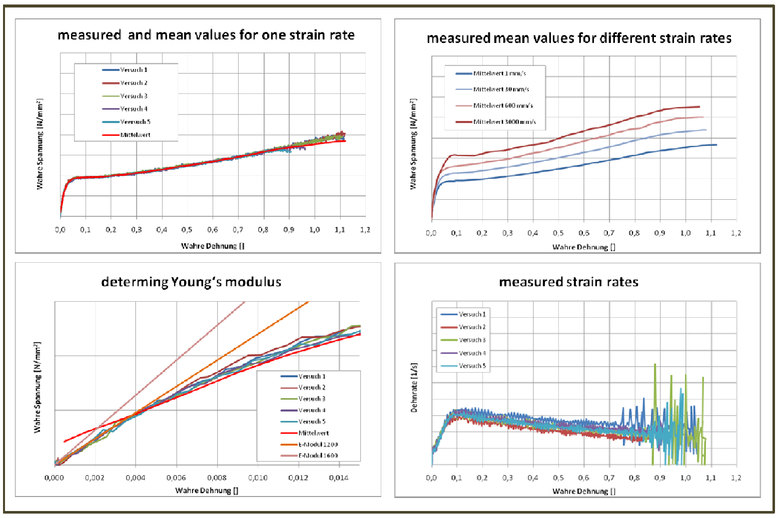

Figure 5. Preparing data for parameter evaluation

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. Finite elements simulations of the device explain the behavior (internal report). 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. The mean experimental data of figure 5 are used. As shown in figure 6 those curves have 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 (Abaqus, 2010).

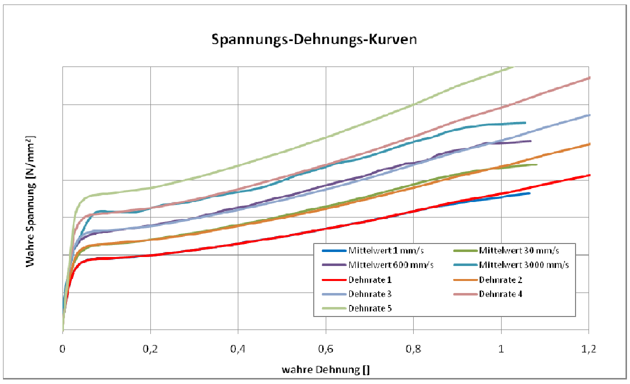

Figure 6. Stress-strain curves for the calculation

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.

The one dimensional tension test is simulated using the model in figure 7. Variations of element length and boundary conditions are used to examine their influence. The comparison between experimental and numerical force-deflection behavior show similar results, even for the failure.

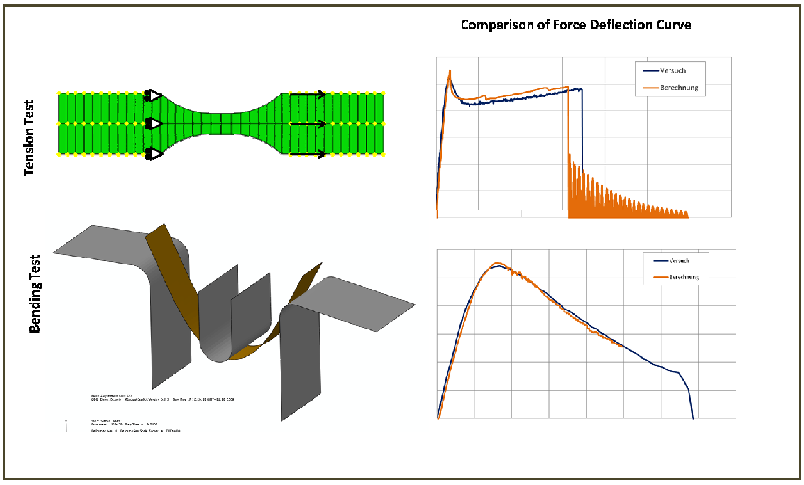

Figure 7. Model for tension test simulation

For the simulation of the bending test, the element length is changed as well. Again, usually there is no major difference when using an element length of 1 mm or of 4 mm. Friction is used in that simulation with Abaqus/Explicit to stabilize the rigid body movement of the specimen, figure 7. Again, the load deflection curve for experimental and numerical data shows a good correlation. It has to be taken care for the scatter of the experimental data, which is significant for some materials at a speed of 3000 mm/s.

Usually, the comparison of experimental and numerical data shows a good correlation for the load deflection behavior in tension and bending tests. Only for reinforced plastics or chromed specimen a calibration of the parameters might be needed for validation

6. Small Strain Measurement of Plastics

Static tension tests with just small elongations have been done and analyzed by using the optical measuring. The purpose of those tests has been the determination of the beginning of the plastic range of deformation and to determine a static Young’s modulus. An unreinforced plastic material with the above described specimen has been used here. Different elongations of 0.1 to 0.7 mm and of 2.0 mm have been examined.

With the given testing device, none of those tests showed an ideal elastic behavior. Even for the smallest elongation, leading to a tension strain of about 0.002, the unloading happened at lower stresses and resulted in some residual strains, figure 8. The given testing device or the used displacement control might cause this. Elongating the specimen to 2.0 mm resulted in a usual elastic-plastic stress strain curve of plastic material.

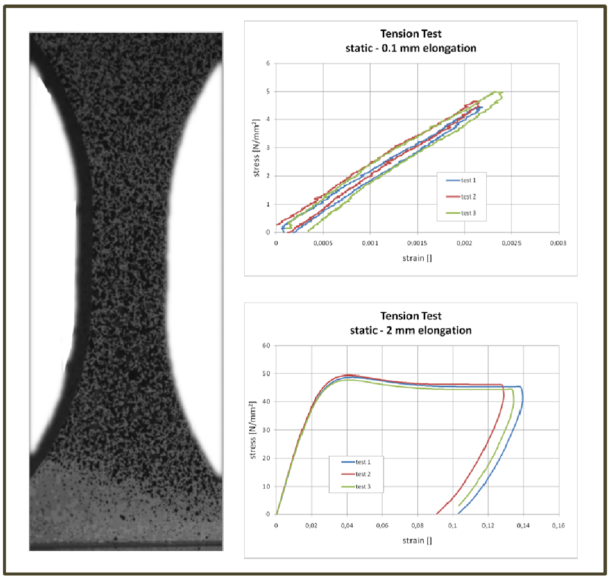

Figure 8: Static tension test with different elongations

All elongations between 0.1 and 0.7 mm resulted in a similar behavior, figure 9. The elastic stress strain curve of an elastic behavior with a Young's modulus of 2170.0 N/mm^2 has been added. Using this curve a different behavior could be observed for an elongation of 0.7 mm. This effect might be used to determine the beginning of the plastic range to a strain of about 0.01.

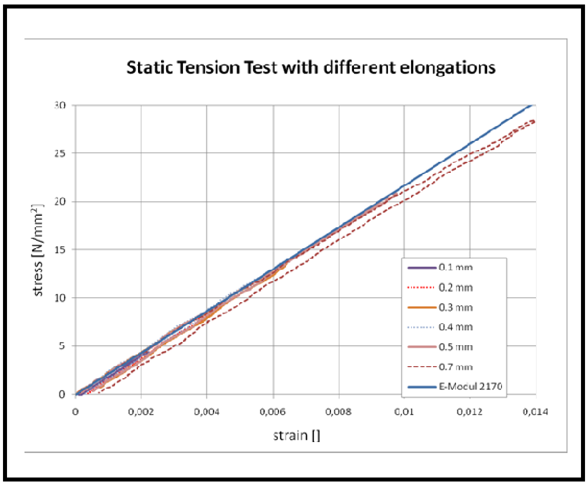

Figure 9: Stress strain curves for different elongations

Analyzing static tension tests with the optical measuring system resulted in a determination of a static Young's modulus, which is very close to the one determined in dynamic tests. Using the Young's modulus and the qualitative behavior of the measured stress strain curves a beginning of the plastic deformation range could be determined. Here the plastic range starts at a tensions strain of 0.01 that is much higher than the values found in literature, (Grellmann 2007).

7. Measuring of Polymeric Foams

Polymeric foams are often used for energy absorption in automobiles. Usually those foams undergo a compressive load. Those crushable foams are usually simulated by using a short time inelastic approach, e.g. crushable foam model in (Abaqus 2010). 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 10. 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.

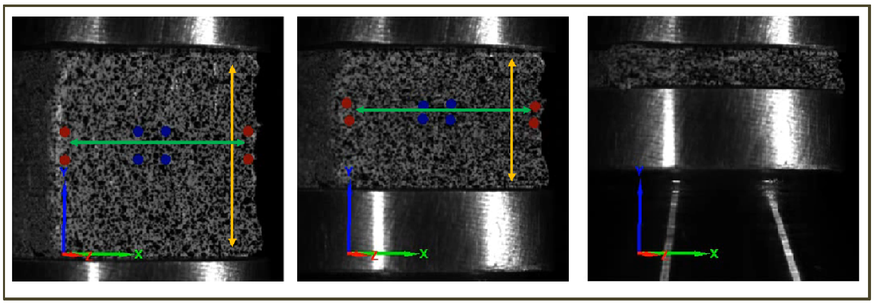

Figure 10: Compression test of polymeric foam

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 11. 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.

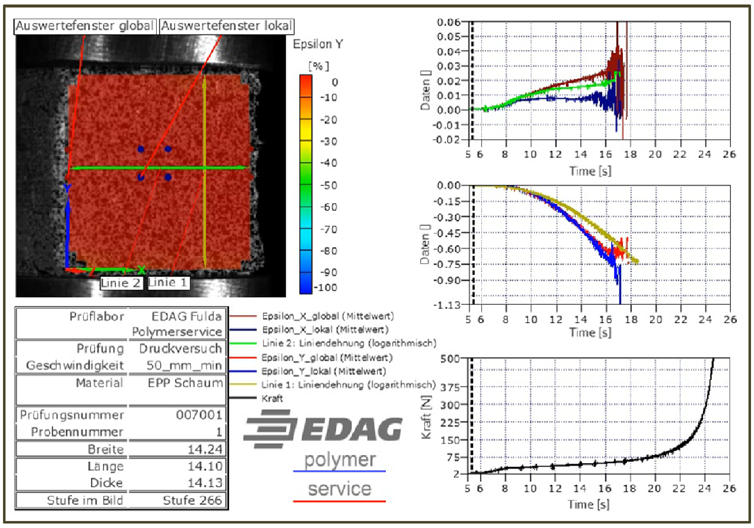

Figure 11: Compression test of polymeric foam – strain measures

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 12. The very inhomogeneous deformation result in a localization of stresses and strains. The foam starts to fail in areas of high stresses and strains.

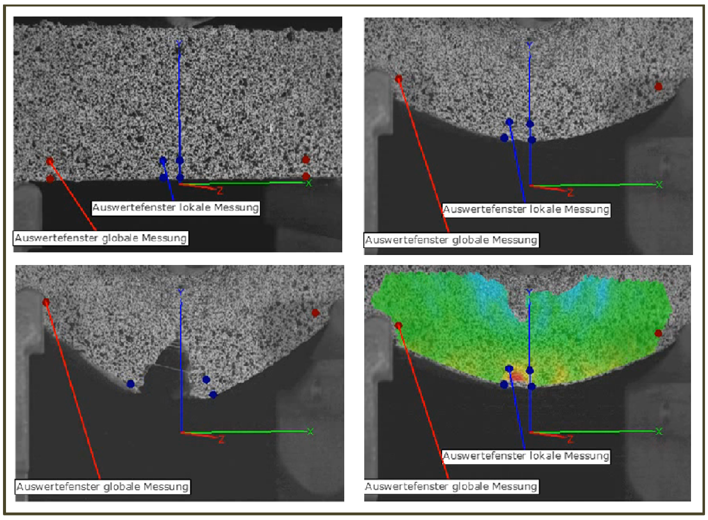

Figure 12: Dynamic bending test of polymeric foam

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.

8. Door Trim Example

The aim of introducing the optical measuring system is to optimize the parameters of material models in finite element simulations. The example of the testing of a door trim, originally published in (Emrich, 2010) has been used for that aim.

Usually all crash testing is done for room temperature. Low and high temperature situation should be considered as well. Some plastic materials do behave very brittle when impacted at low temperature. Within this project (Emrich 2010) material data for a PP/EPDM plastic material should be defined by using the optical measuring system at low temperature and should be validated by an impact test of a door trim.

In figure 13, the set up for the optical measuring system is shown on the left. The testing set up had to be adapted, especially the illumination. The dynamic component testing with a half sphere impactor and the mounted door trim are shown on the right. The impactor hits the door trim on an edge.

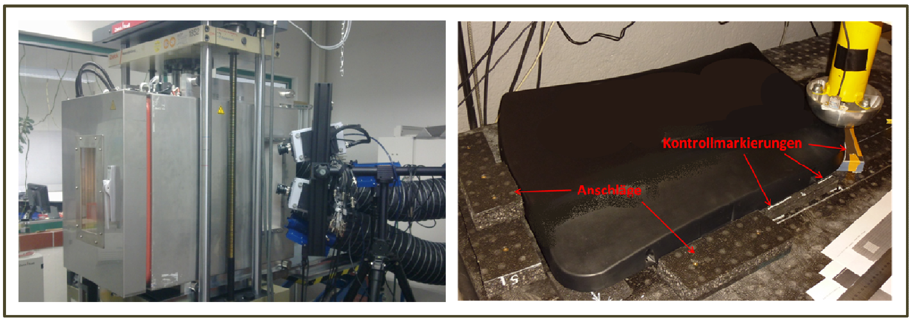

Figure 13: Tension testing device and door trim testing (Emrich, 2010)

Brittle failure occurs when the impactor hits the door trim at low temperature. Using the optimized material parameters the failure could be observed in the simulation as well, figure 14.

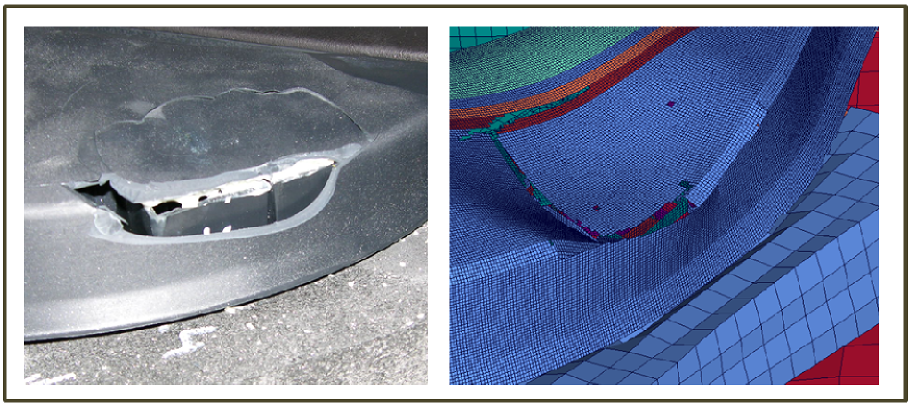

Figure 14: Brittle failure in testing and simulation (Emrich 2010)

The door trim example demonstrates that using the optical measuring the parameters of material models could be optimized so that a predictive simulation is available even for low temperature behavior.

9. Conclusion

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 and polymeric foams can be done. Using the optical measuring for compression tests has been introduced for polymeric foams.

Using the optical measuring system allows for 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.

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