Numerical Simulation of 9 Meter Drop of a Transport and Storage Cask with Aluminium Impact Limiter

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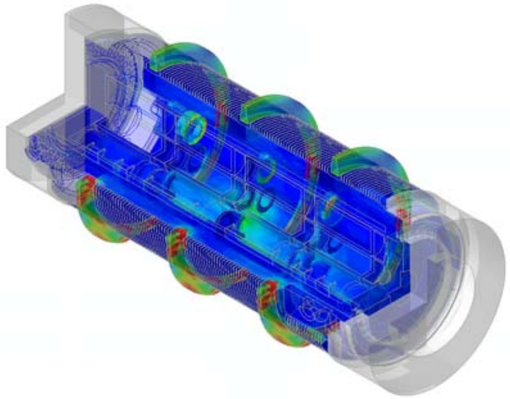
1. Introduction
2. Drop tests of cask with aluminium impact limiter
3. Finite element model
4. Material description of aluminium
5. Simulation strategy
6. Simulation of material testing
7. Simulation of drop tests
8. Conclusions



- For transport and storage of vitrified High Level Waste from reprocessing, a new cask design was developed from the German company GNS Gesellschaft für Nuklear-Service mbH, Essen.
- BAM as part of the competent authority system was responsible for mechanical safety assessment within the complete evaluation of the Safety Analysis Report.
- An extensive drop test program with an instrumented half-scale model was carried out.
- **Some details are missing because of GNS copyright, only methodical questions are discussed.**

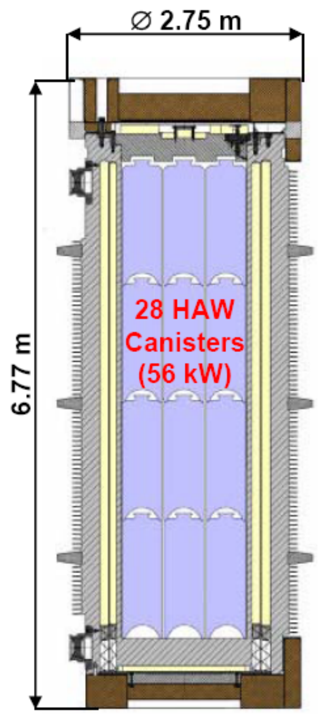


Figure and data:
GNS Gesellschaft für Nuklear-Service mbH

- Among other assessment goals the horizontal drop tests P01 (0.3m drop, 20°C) and P04 (9m drop, -40°C) were performed for verification of the appropriate and allowable aluminium impact limiter behaviour.

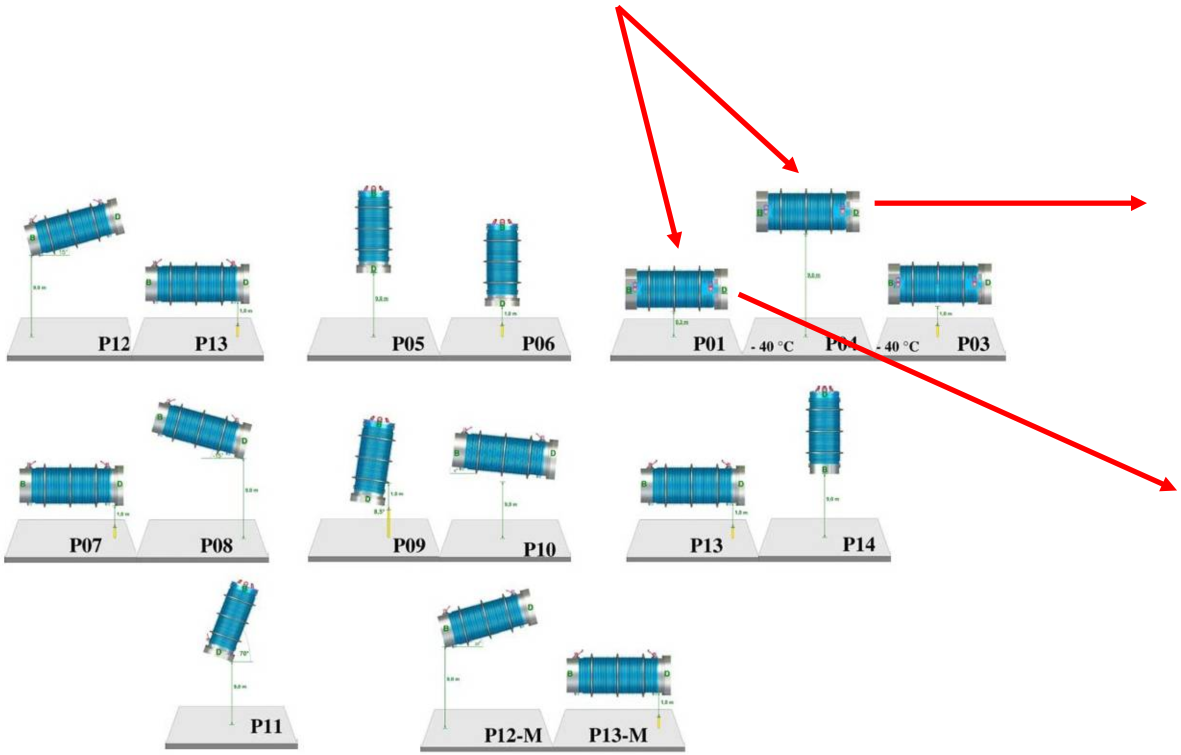
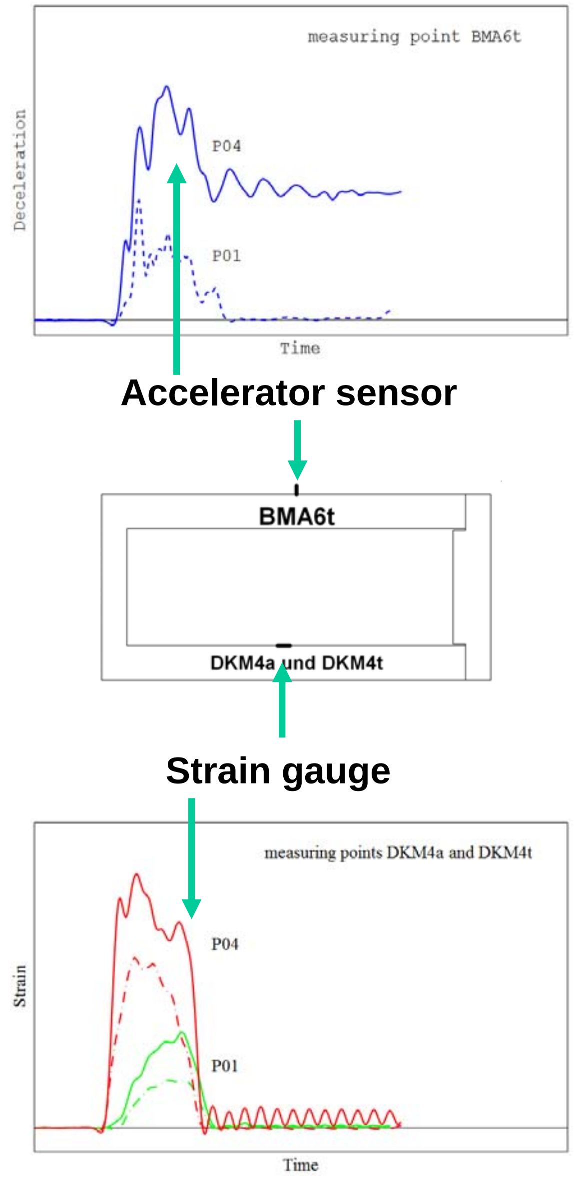


Figure and data:
GNS Gesellschaft für Nuklear-Service mbH

9 m drop (P04)

0,3 m drop (P01)

- Data of the horizontal drop test:
  - Cask mass: 14.5 Mg
  - Drop height: 0.3m and 9 m
  - Cask temperature: 20°C and -40°C
- Measuring strains and accelerations on cask body



Detailed description of test program:

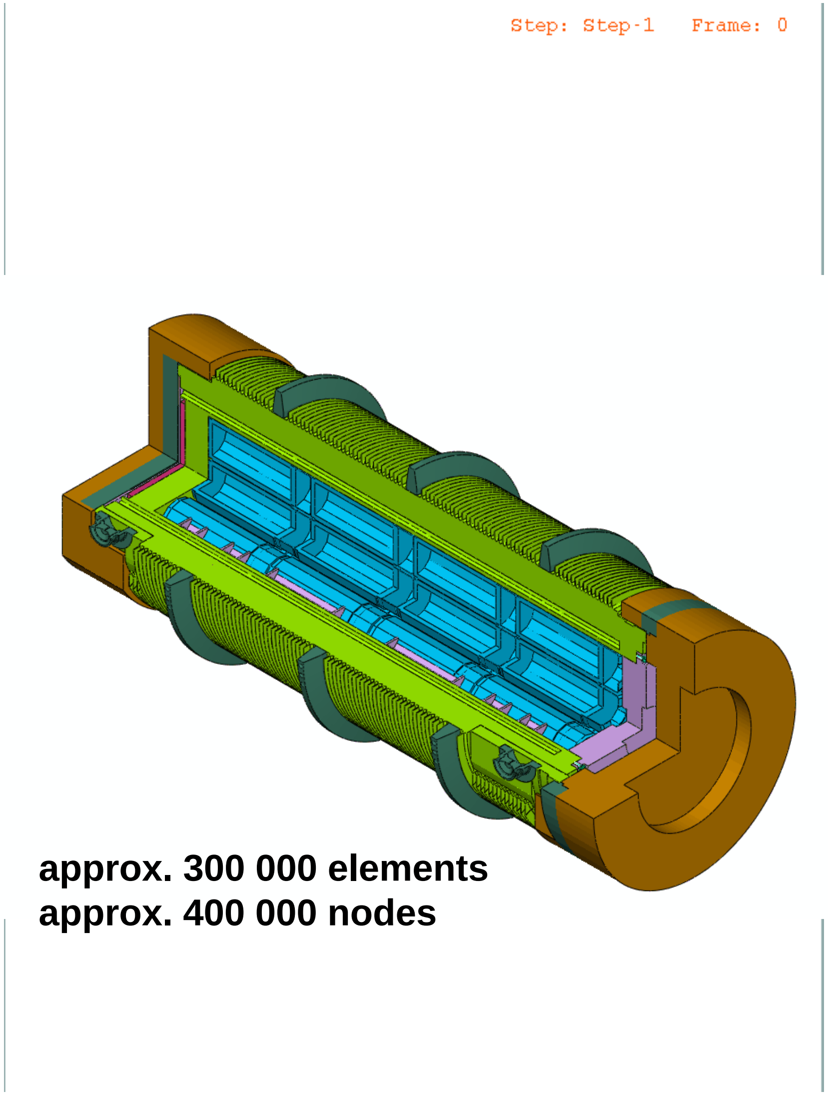
- A. Musolff, et al: "Drop test program with the half-scale model CASTOR HAW/TB2", 16th Int. Symposium on the Packaging and Transportation of Radioactive Materials (PATRAM 2010), London, UK., 3rd-8th October, 2010.

Independent calculation of BAM

- own developed FE model and
- different FE code as applicant

BAM Model of the 1:2-test casks

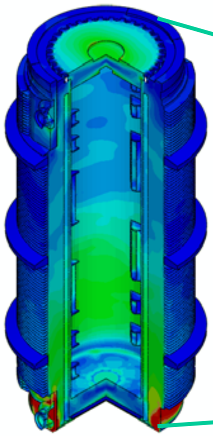
- Cask body with moderator borehole,
- model canisters,
- model graphite columns,
- primary lid and lid screws,
- trunnions,
- moderator plate on the cask bottom,
- closing plate on the cask bottom,
- bottom and lid impact limiter made of wood with aluminium shell and
- belt impact limiter made of aluminium.

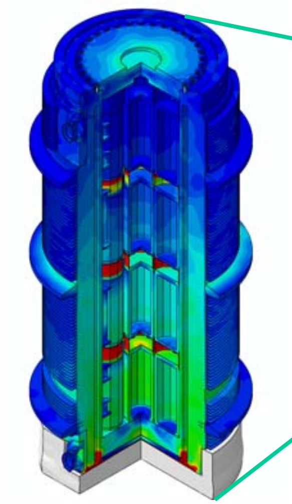


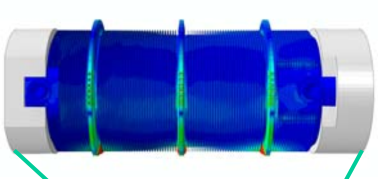
approx. 300 000 elements
approx. 400 000 nodes

3. Finite Element Model (continued)

- The FE model was at first verified with a test without impact limiter.
- After that impact limiter are formed for other tests.
- Belt impact limiter and their connection to cask body are modelled in detail for horizontal drop test.





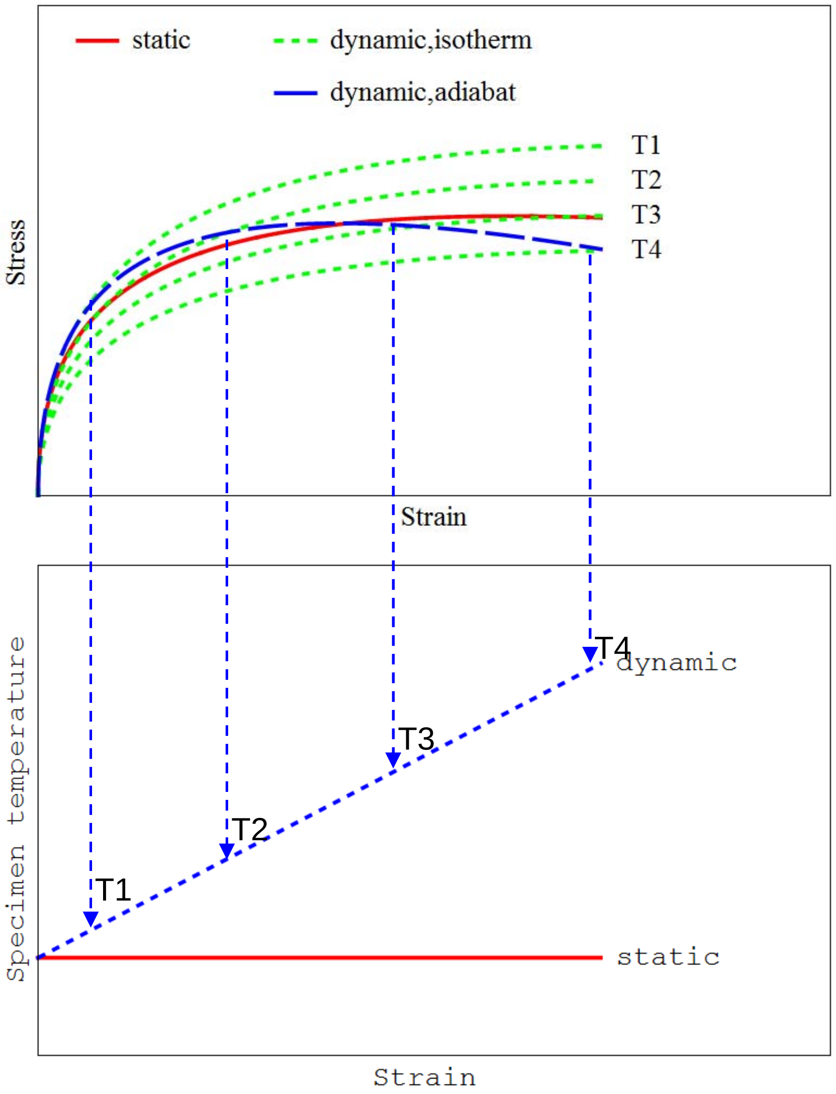


Schematic presentation of stress-strain relation of Aluminium

- The stress-strain curves of the aluminium impact limiter used in the simulation are based on experimental investigations.

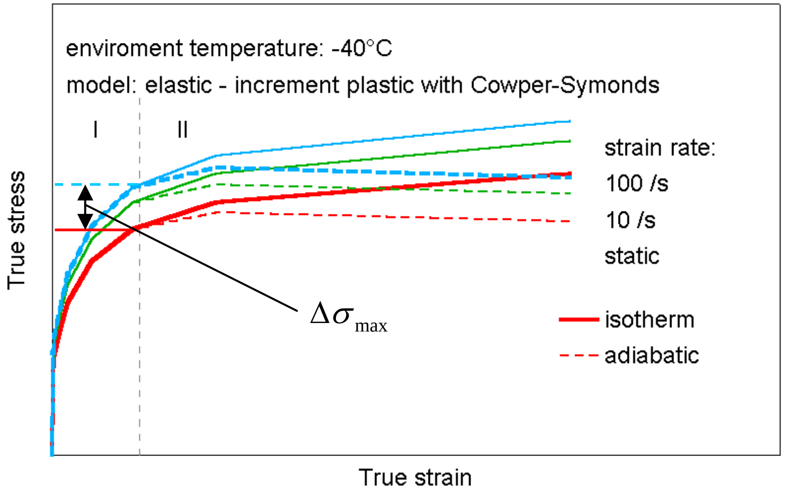
- The measuring of isotherm stress-strain curves is difficult due to the significant temperature rising during great deformation going along with high loading speed.

- The specimen behaves only during low strain rate (quasi-static) isothermally, otherwise even under laboratory conditions with high loading speed adiabatically.



Derivation strategy for stress-strain relation of aluminium under dynamic conditions

- The picture illustrates the derived isotherm and adiabatic stress-strain curves from measuring data.



BAM fitted dynamic flow curve based on the measuring data from GNS Gesellschaft für Nuklear-Service mbH

- In area I there is no difference between isothermal and adiabatic behaviour, thus the Cowper-Symonds parameters are adapted.

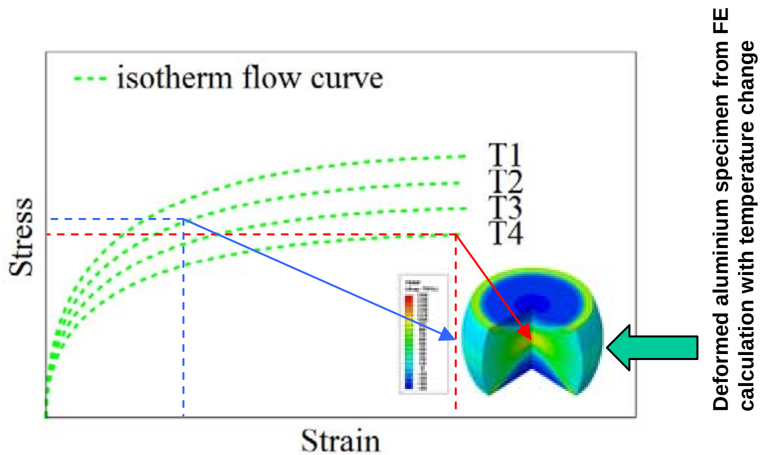
- In area II the isothermal dynamic curves are calculated from the isothermal static stress-strain curve with the dynamic hardening parameter from area I.

- The adiabatic dynamic curves are calculated from the stress-strain curve measured at the highest strain rate and the Cowper-Symonds parameters from area I.

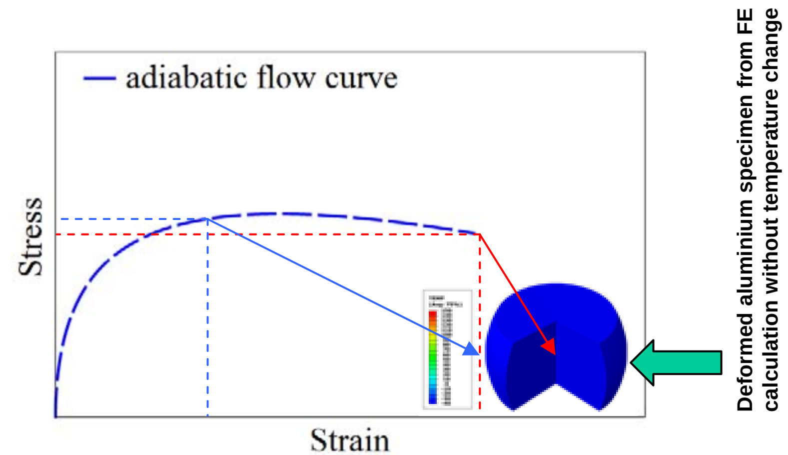
Two different strategies for the calculation:

1. Thermo-mechanical coupled calculation with isothermal flow curves of aluminium under consideration of temperature change because of an adiabatic heating process.

2. Calculation under constant temperature but with adiabatic flow curves of aluminium.

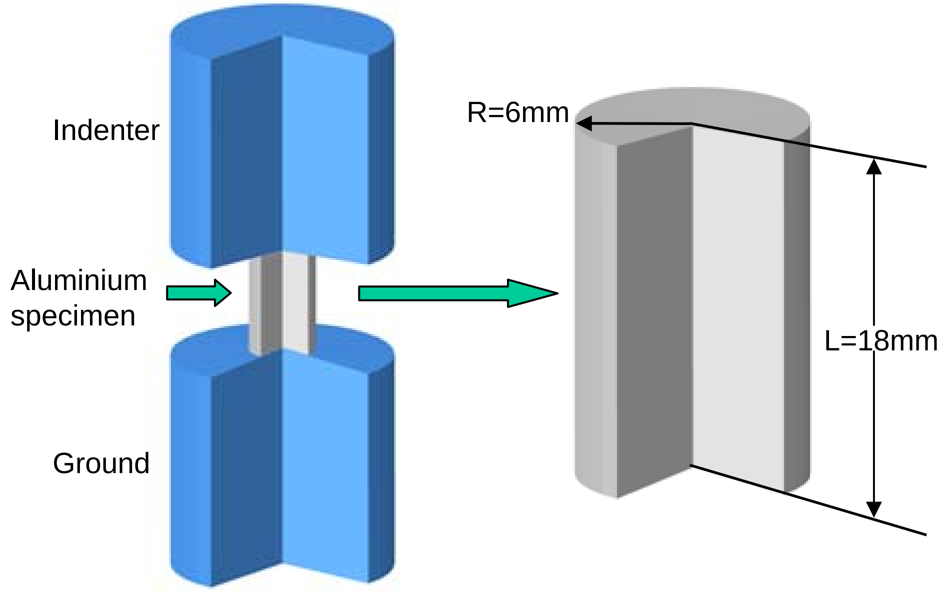


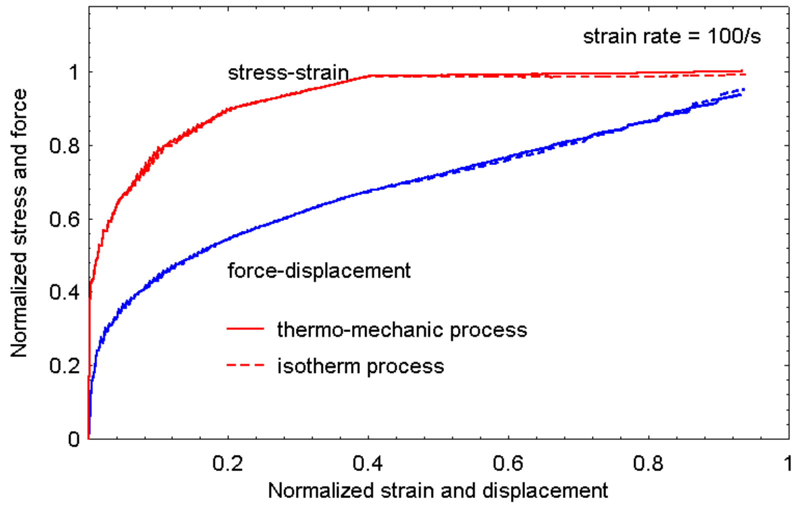
Thermo-mechanical coupled calculation: temperature change is considered, isothermal flow curves depending on temperature must be defined.

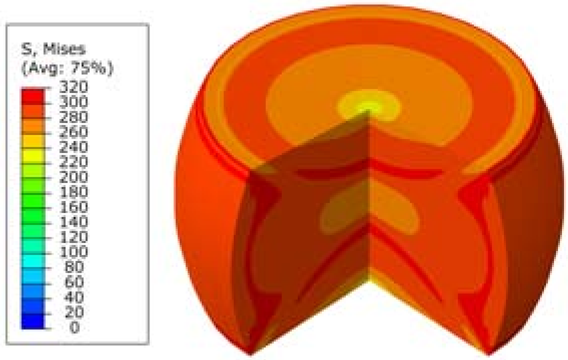


Calculation under constant temperature: adiabatic flow curve must be used to consider the influence of temperature change.

For purpose of verification of material parameters described in prior section, different compression tests of material specimen were simulated with finite element method. Figure shows the geometry of the compression test without confining pressure. Hereby the indenter is controlled with different loading velocity for quasi-static and dynamic tests.

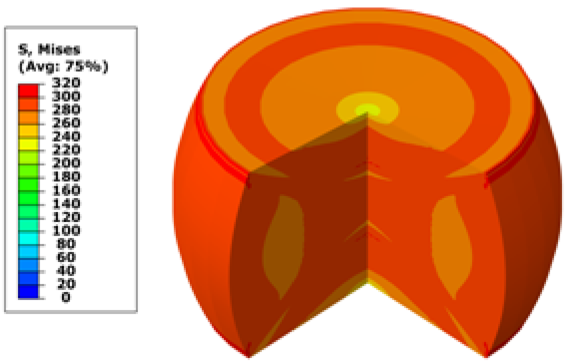






v. Mises stress from thermo-mechanical coupled calculation

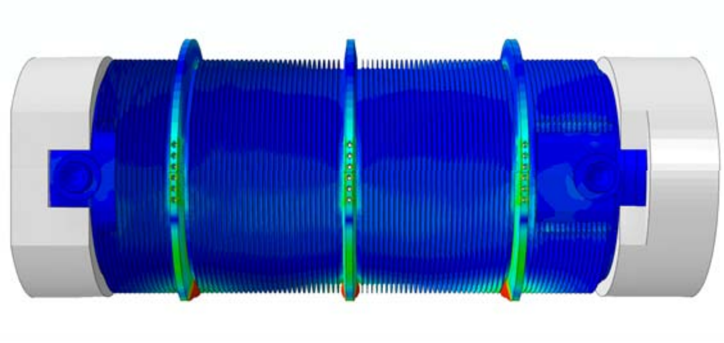
Figure shows the results of simulation with global force-displacement curve from indenter and local stress-strain curve from centre of the specimen at strain rate 100/s. Two different strategies (thermo-mechanic process and isothermal process) show hardly any differences at high strain rate.



Stress from calculation under constant temperature

Altogether 6 Simulations for 0,3 m (P01) and 9 m (P04):

- **isothermal stress-strain curves without consideration of the temperature change (Iso),**
- **isothermal stress-strain curves with consideration of the temperature change (Therm),**
- **adiabatic stress-strain curves without consideration of the temperature change (Adia).**

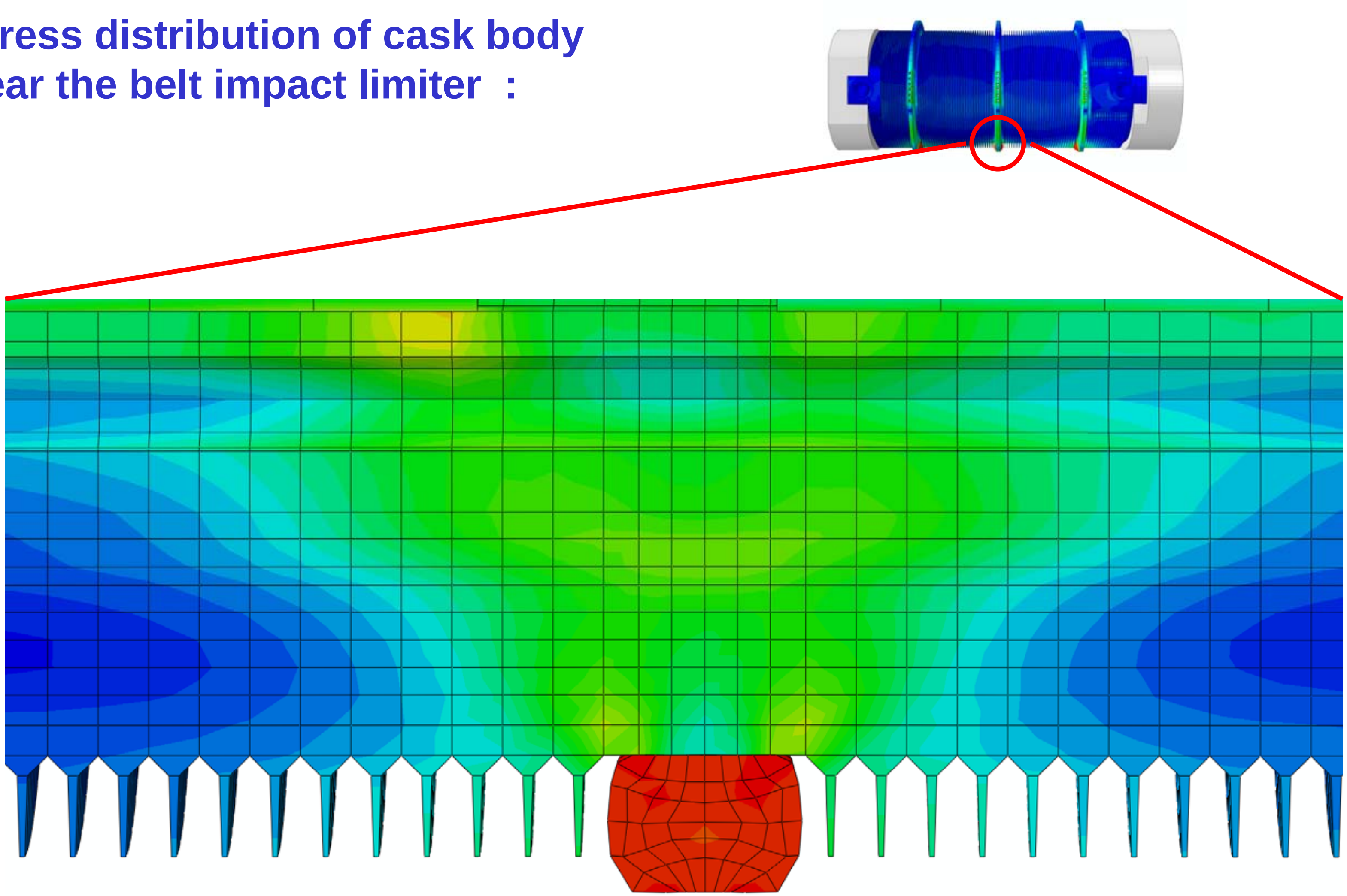


Assumption:
The impact process of drop test takes only in ms region. In this short time, the deformed zone of belt impact limiter is in an adiabatic thermo-mechanical process.

Model verification without impact limiter:

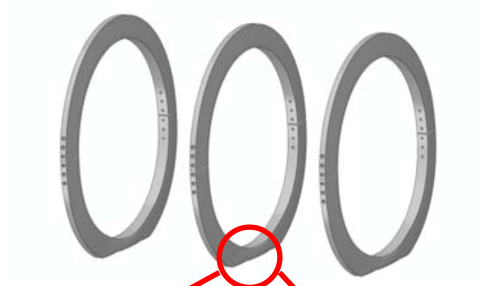
L. Qiao, U. Zencker, G. Wieser and H. Völzke: „Numerical Safety Assessment of a Transport and Storage Cask for Radioactive Materials without Impact Limiters by the 0.3m Drop test onto an Unyielding Target", 9th International Conference on Computational Structures Technology, Athens, Greece, 2008.

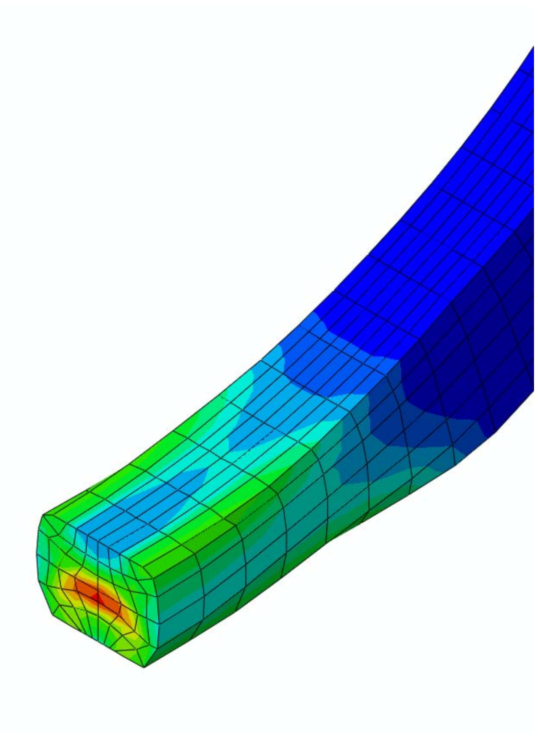
Stress distribution of cask body near the belt impact limiter :



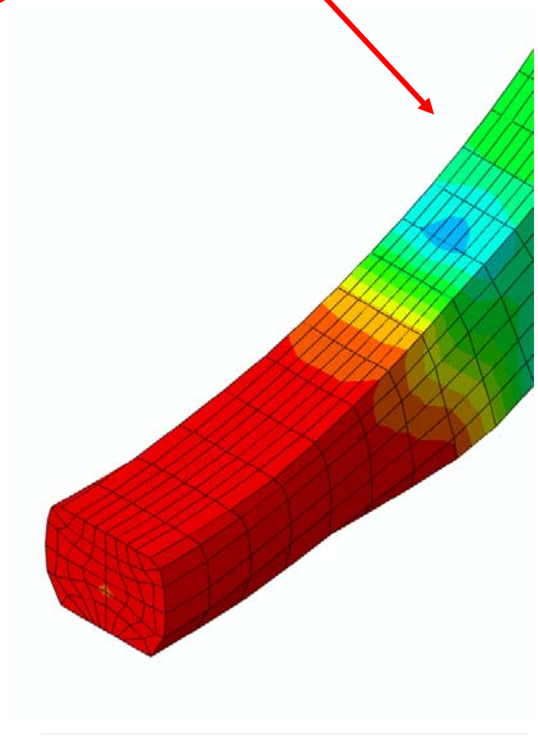
7. Simulation of drop tests (continued)

Temperature and stress distribution of belt impact limiter:



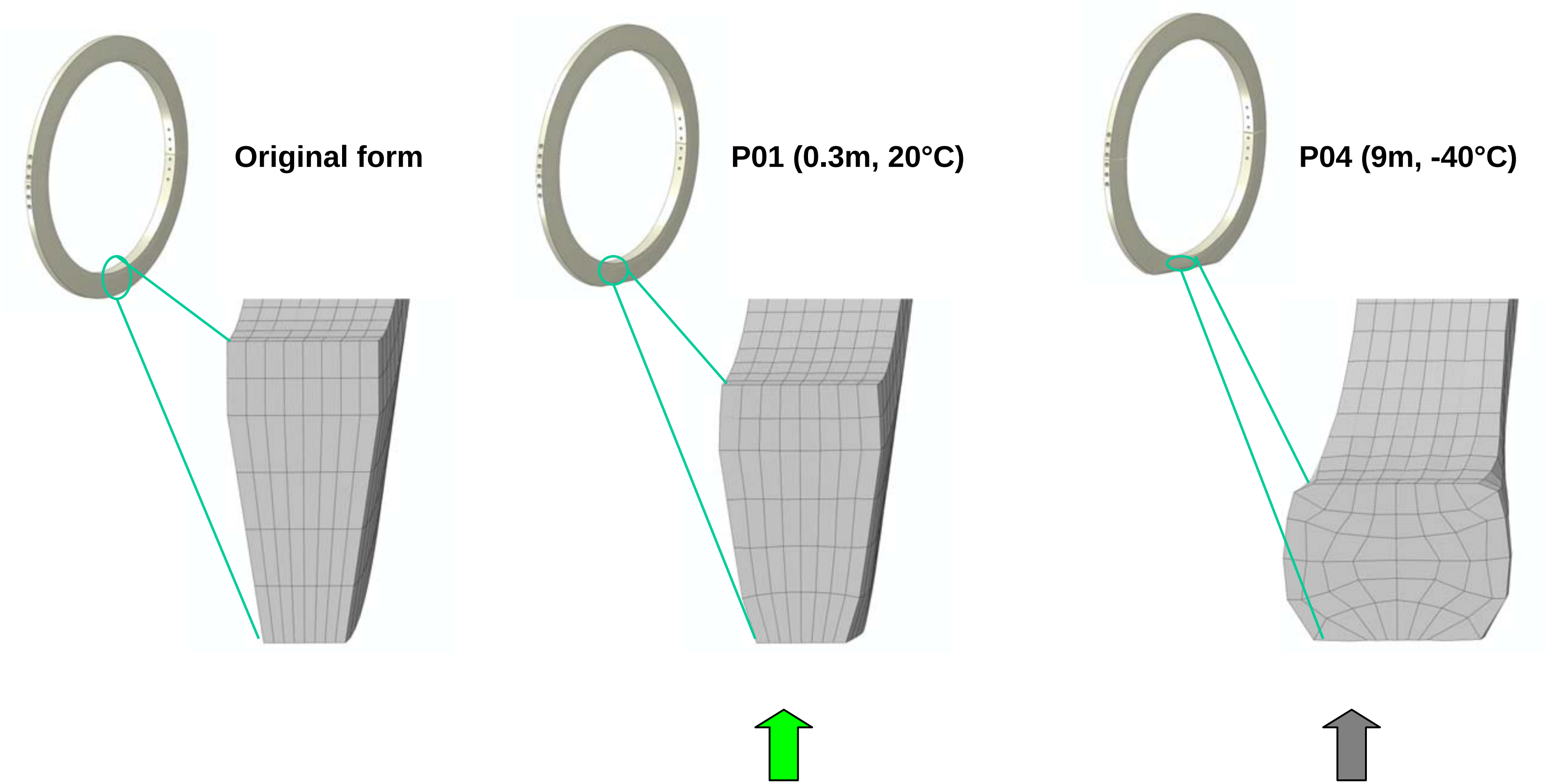


Temperature



von Mises equivalent stress

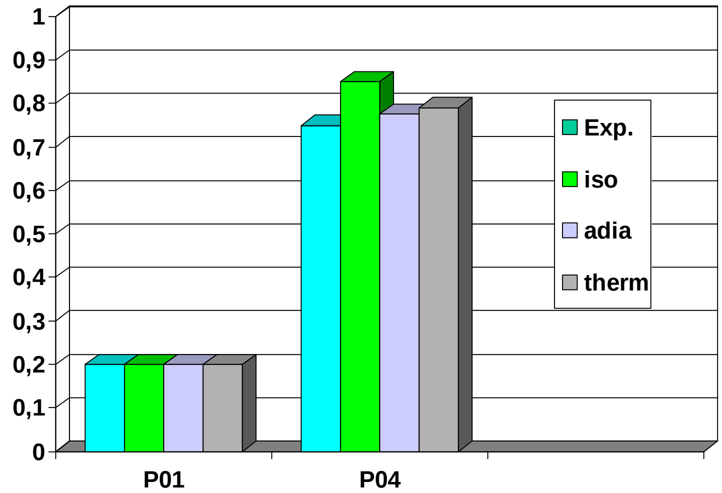
Deformation of belt impact limiter



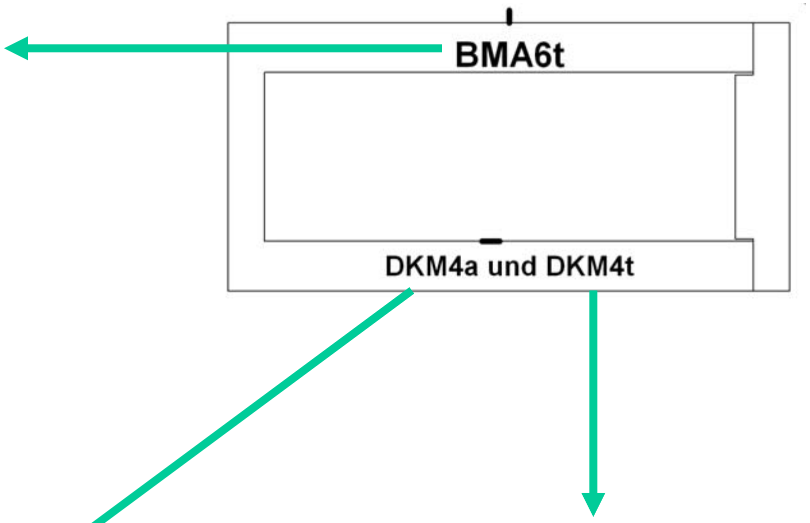
P01:
Small deformation acc. to isothermal stress-strain relation, since the temperature change of belt impact limiter is negligible low.

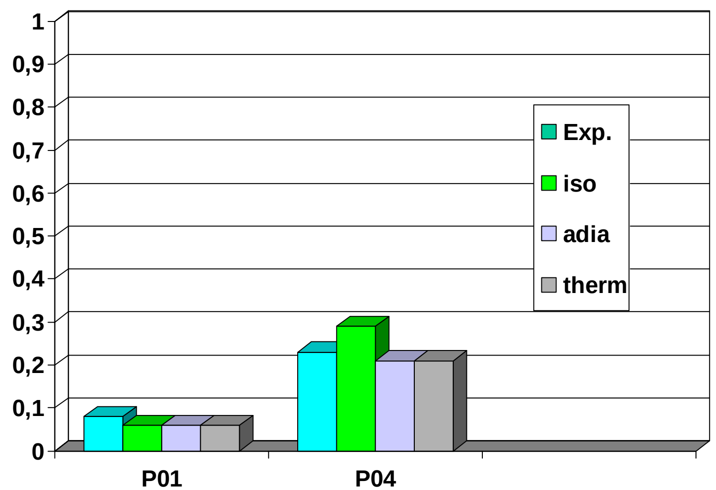
P04:
Large deformation acc. to adiabatic stress-strain relation, since the temperature change of belt impact limiter must be considered.

7. Simulation of drop tests (continued)

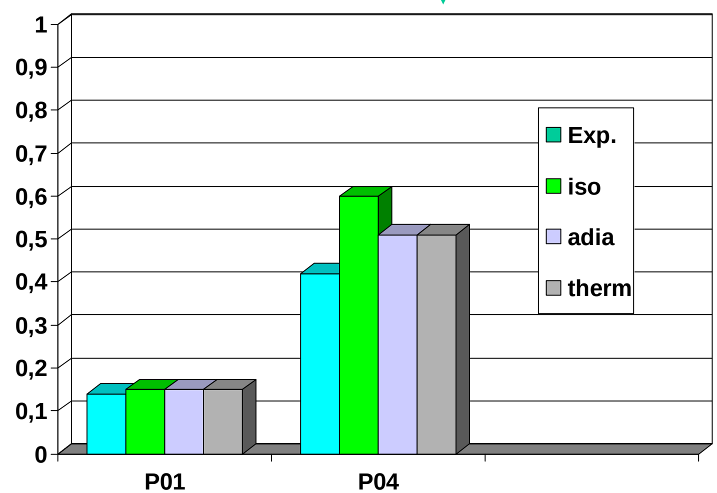


norm. maximal deceleration at BMA6t





norm. maximal strain at DKM4a



norm. maximal strain at DKM4t

8. Conclusions

- Two drop tests (0.3 m and 9 m) performed within an extensive drop test programme with a half-scale model with belt impact limiter made of aluminium are calculated with finite element method.
- A detailed 3D finite element model was developed and verified by a drop test performed without impact limiters. After that the aluminium impact limiter and its connection to the cask body were taken into account.
- A fitting strategy was suggested with focus on how isothermal and adiabatic stress-strain curves of aluminium depending on temperature and strain rate can be derived from experimental investigations on small specimens under constant ambient temperature.
- For the simulations of the drop tests, the material law was considered at first with isothermal stress-strain curves under consideration of thermo-mechanical coupling for more exact results. In a second step a calculation was performed under consideration of adiabatic stress-strain curves but without thermo-mechanical coupling.
- The comparison of the calculation results shows that for the drop tests precisely studied here, both computational approaches lead to comparable results.

Thank you very much for your attention.

(http://www.tts.bam.de)