TEMPERATURE DEPENDENCY OF DYNAMICALLY LOADED POLYURETHANE FOAM

Eva Kasparek(*), Robert Scheidemann, Mike Weber, Holger Völzke
Federal Institute for Materials Testing and Research, Germany, Berlin
(*)Email: eva-maria.kasparek@bam.de

ABSTRACT
Polyurethane foam used as impact limiter material undergoes high plastic deformations, whereat the resulting stress-strain relations strongly depend on loading speed and temperature. This paper discusses the efforts necessary to develop a reliable numerical foam simulation model focussing on generation and implementation of temperature-dependent yield curves.

Keywords: polyurethane foam, finite element model, strain rate, temperature dependency, impact limiter.

INTRODUCTION
Polyurethane foams are used for impact limiters protecting casks for radioactive waste in case of accidental incidents during transport or handling operations in nuclear facilities. Since the qualification of such packages is increasingly based on numerical safety assessments, enhanced material formulations are needed in order to reliably estimate the energy dissipation potential of their shock absorbers. Implementation and adaption of respective finite element models presuppose an appropriate experimental data base. Even though extensive impact tests had been conducted at e.g. Sandia National Laboratory (Sandia, 1995) and Savannah River National Laboratory (Savannah, 2009), not all relevant factors were taken into account so far. Thus, BAM being in charge of the mechanical evaluation of such casks and their components, has had carried out a government funded research project from 2009 to 2013 on different impact limiting materials including two polyurethane foams with different densities: FR3718 having 280 kg/m³ and FR3730 with 488 kg/m³. The associated experimental program consisted of more than 1300 individual tests covering different loading speeds, support conditions as well as specimen sizes and temperatures. The results were used to select and refine adequate material formulations and adapt their parameter sets or to develop new concepts, when necessary. In case of foam, the crushable foam model from Deshpande and Fleck (Deshpande, 2000), provided by Abaqus code, yielded good agreements with experimental values and reproduced all relevant characteristics.

RESULTS AND CONCLUSIONS
The crushable foam model requires uniaxial flow curves as well as information about the ratio of uniaxial to hydrostatic compressive strength. For room temperature (RT), these curves were generated from quasi-static uniaxial tests and all parameters were validated by means of quasi-static tests with confined specimens. In generally, the graph is characterized by a short, almost linear zone and a long plastic deformation region followed by blocking for
compression higher than ~70%. The behaviour is similar even for different loading speeds as shown in Fig. 1. As strain rate increases, the strength increases, whereby these dependency can be approximated by a logarithmic function. The related dynamic factor varies along the strain range, but on the average a value of up to 1.5 is gained for high loading speed. Eventually, by covering strain rate hardening by the Cowper Symonds power law, all experiments could be simulated with sufficient accuracy (Kasparek, 2011).

![Stress-strain relations for strain rates](image)

**Fig. 1 – Stress – strain relations for strain rates from** $10^{-4}$ s$^{-1}$ (D1) up to 30 s$^{-1}$ (D3), RT

Quasi-static tests on tempered specimens are rather difficult to realize, as loading of a cubic sample with 10 cm edge runs for about 60 minutes. Nevertheless, in order to avoid tempering the whole test set up, experimental and numerical investigations had been conducted to quantify the thermal balancing behavior of the sample. Finally, a minimum strain rate of $5^{-3}$ s$^{-1}$ in combination with overcooling/overheating the sample by 10 K was applied. The impact of temperature on the resulting stress-strain relations is presented in Fig. 2.

Since the influence varies strongly over the strain range, temperature specific flow curves are required rather than simple scaling factors. The lack of an effective quasi-static reference curve, made it necessary to develop a multi-step parameter identification procedure. It was based on the assumption of similar strain rate hardening of RT and tempered specimens at least for low loading speeds. Finally, good numerical solutions were obtained for samples at RT as well as at -40° C and +90° C.
ACKNOWLEDGMENTS

The authors gratefully acknowledge the funding by German Federal Ministry of Education and Research under grants 02S8588.

REFERENCES

[1]-Sandia National Laboratories. Impact Limiter Tests of Four Commonly Used Materials and Establishment of an Impact Limiter Data Base. SAND95-0375C, Albuquerque, New Mexico
