Derivation of Materials Energy Absorption Requirements from Crash Situations

Johann E. Siebels
Materials Research
Volkswagen AG, Wolfsburg

Abstract

Requirements on energy absorption given by the different crash tests (Government regulations, consumer organisations)/2/ generally cannot be directly converted into the desired materials properties. To enable appropriate laboratory testing with materials capable of energy absorption by permanent deformation without elastic rebound specific values like compression strengths have to be defined and evaluated. This is valid for occupants protection as well as deformation elements for the car body.

A simple procedure to deduce and estimate materials requirements from crash situations is shown and discussed with respect to occupants protection in the case of side crash. Some experimental results of laboratory tests of various materials resp. materials structures are compared with results obtained from Aluminium foams. Some low density foams show applicability for energy absorbing car panels. The effects of impactor shapes are discussed theoretically and verified by experiments.

Influences of design characteristics like surfaces of various kinds (natural or additional layers) are shown, closing the loop from laboratory investigations and results to the application in a car component .

Finally some examples for effects of foam inserts in structural components are given.

1 Introduction

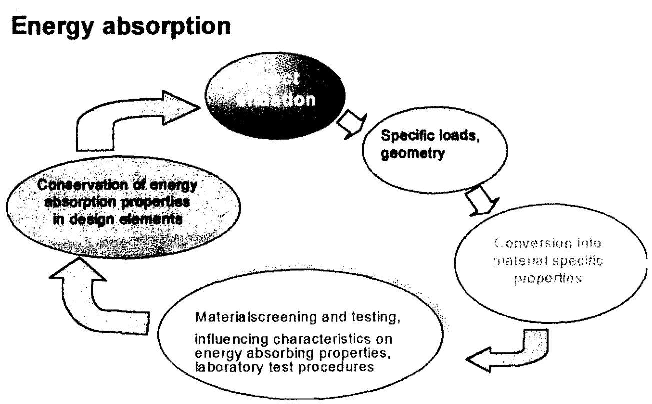

Figure 1: Schematic procedure of evaluating materials properties for occupants protection

Requirements on energy absorption given by the different crash tests generally cannot be directly converted into desired materials properties. To enable appropriate laboratory testing with materials capable of energy absorption by permanent deformation without elastic rebound specific values like compression strengths have to be defined and evaluated.

For side collisions the available distance until the impact of the passenger is very short – there are aspects of improvement of occupants protection by adequate materials selection and development. Also in the case of multiple collisions, when the airbag is no longer efficient, occupants protection has to be guaranteed by selected panel materials and intelligent design.

2 Crash situations

Figure 2 illustrates the evaluation of collision types according to subsequent injury costs. It is obvious, that side collisions earn particular attention. In comparison with frontal collision where time to panel impact is comparatively long and retainer systems are very effective selected materials might be very helpful in side panels (i.e. doors) to improve safety.

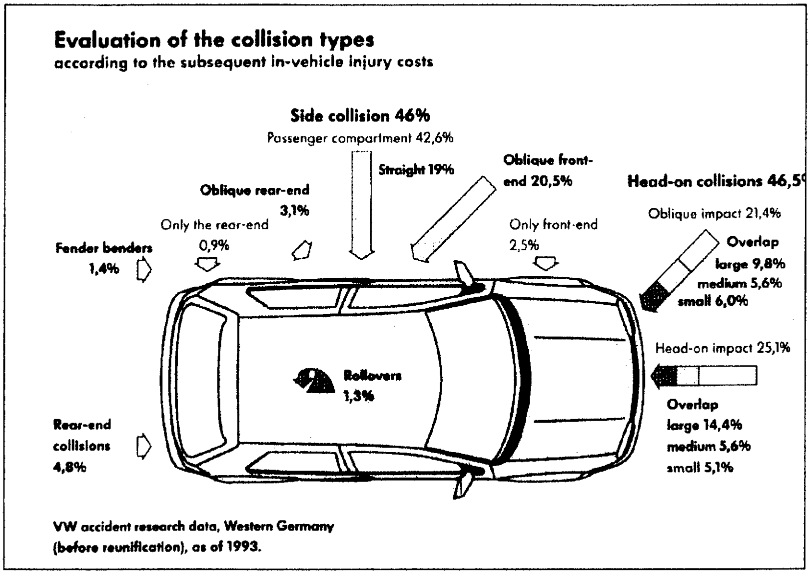

Figure 2: Evaluation of collision types

The relevant impact velocities range from 32 km/h up to 56 km/h.

3 Energy absorption by deformation

Figure 3 shows the principle of energy absorption valid for all cases in which impact energy has to be converted into deformation work. The force level A is specified by the permissible load (e.g. of a part of the human body; the passenger compartment) and must never be exceeded. The compressive densification range B of a material, resulting in an extreme increase in force should be as short as possible (optimum material thickness utilisation)./1/

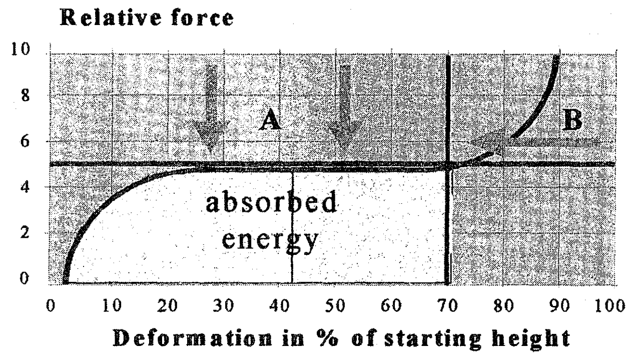

Figure 3: Energy absorption by deformation

4 Estimation of necessary materials properties /3,4/

The example of a padding for a side impact shall show, how, for example, the required compression strength for door areas can be estimated. Basically energy absorption by deformation work is described by the equation

$$mv^2/2 = m\ a\ s$$

where the allowed acceleration **a** for example for a part of the human body (m = mass) and the related cross section yield the maximum specific load. **s** is the deformation length required for a complete energy conversion. Figure 4 illustrates the effective impact area for two examples at a dummy simulation of a side impact.

In the hip (pelvic) area this results in a compression strength of about

$$Rc = 0.5\ N/mm^2,$$

for the thorax impact area materials have to be found not exceeding the compression strength range of

$$Rc = 0.1....0.15\ N/mm^2.$$

Also values beneath this level are not wanted, because they need thicker padding for the same energy absorption amounts. This generally leads to limitations of the occupants compartment size.

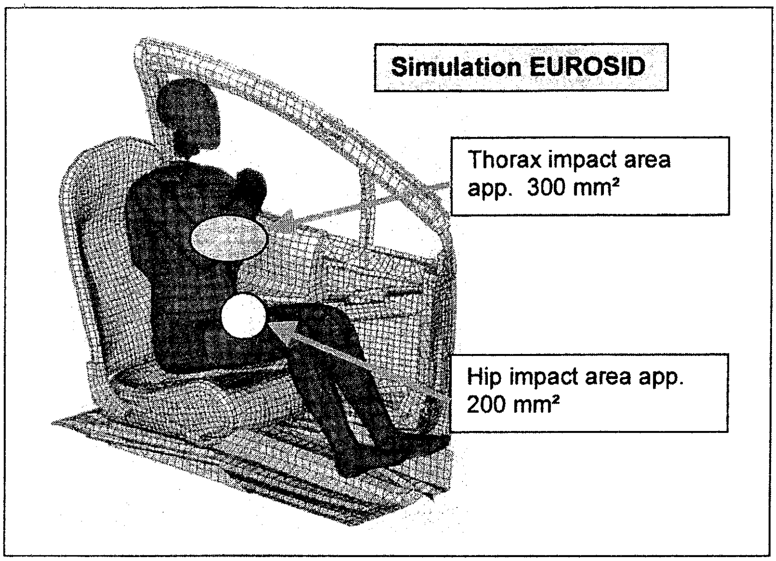

Figure 4: Illustration of effective impact areas at an EUROSID

These crushing strength values require Aluminium foams of low density and good homogeneity.

5 Applicability of Aluminium foams

Al-foams of all production methods and particularly PM – foams have the problem, that their crushing strength is rather high for low impact force applications like occupants and pedestrian protection. Figure 5 shows, that it is possible to manufacture low density foams (here melting route) with good reproducibility. The progressive slope of the crushing curve has to be compensated by design.

Figure 6 illustrates the correlation between foam density and crushing strength of a PM-foam.

As a characterising criterion predefined grades of compression (permanent) proved to be useful as long as no reliable definition of the "block length" is found. Regression analysis delivers a correlation between strength **R** and density **D** following the function

$$\mathbf{R} = \mathbf{D}^2/\mathbf{C}\ (\text{mat})\,.$$

Particularly PM-materials follow very good a quadratic function. Foams with stabilising particles deliver a slightly higher exponent (melt foams). Also PM-foams made from alloys of a less plastic deformation behaviour show exponents greater than exactly 2. The exponent seems to be dependent on the "brittleness" of a foam.

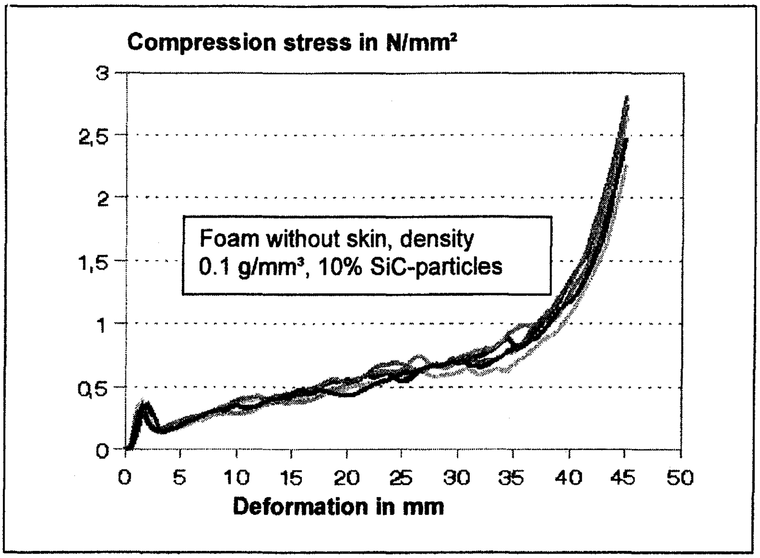

Figure 5 : Example of an Aluminium foam of low density applicable for occupants protection

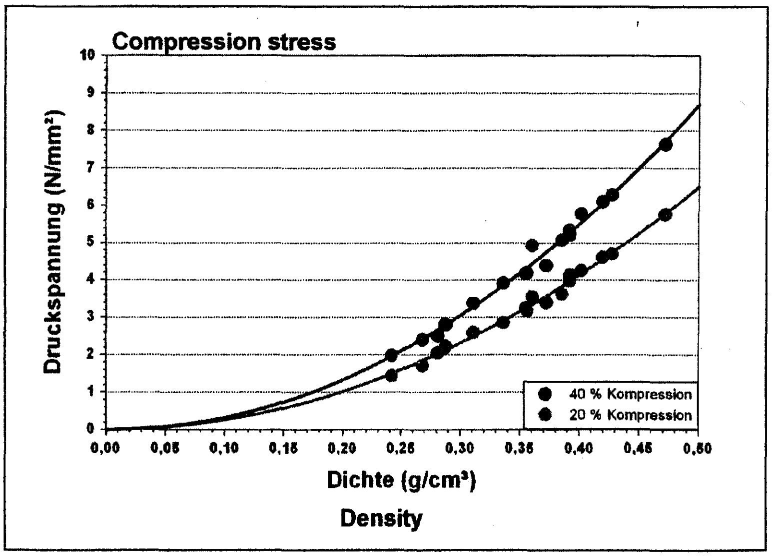

Figure 6 : Correlation between crushing stress and foam density (example: PM-Al-foam)

6 Comparison with competitive materials

The figure 7 shows the comparison of crushing curves (static compression) of materials applicable for hip protection.

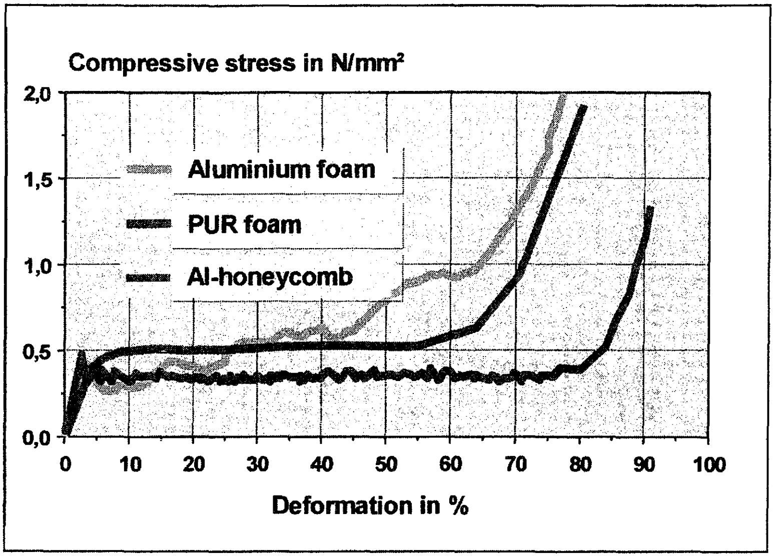

Figure 7: Comparison of materials capable for hip protection

The non-isotropic Al-honeycomb yields best performance at the lowest weight. The shown PUR-foam example is also very promising. Al-foam of low density shows also a potential for low impact force padding with the advantage of more isotropic behaviour compared to the honeycomb and less environmental sensitivity over the plastic foam. The "progressive" slope of the crushing curve can be smoothed by a more uniform pore structure.

7 Alignment of crushing by design prevention

Laboratory determination of materials properties assumes standardised random conditions. In reality an impact on an energy absorbing element occurs by bodies of various shapes, for which the material specific "rectangular" crushing curve is no more strictly valid.

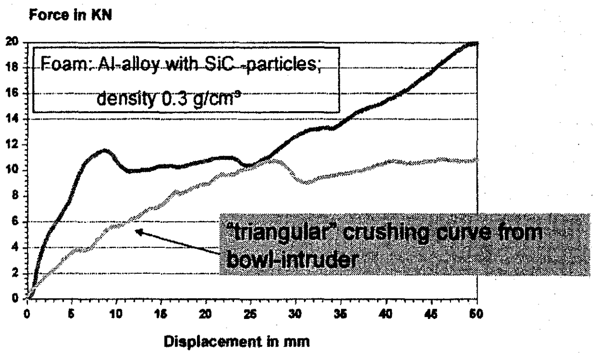

Figure 8: Al-foam crushing at bowl impact

For example the intrusion of a bowl into a foam with nearly ideal crushing properties (rectangular crushing curve in laboratory test) would lead to a "triangular" curve with an efficiency drop of 50% of energy absorption (see Figure 8).

An adequate surface design compensates this disadvantage and is able to improve the absorption as shown in Figure 9.

Laboratory simulation (experimentally) of impact situation can be done with a variety of idealised test shapes. Thus standard tests (preferably static) help to convert materials properties into component properties and deliver the basic knowledge for calculation and simulation of vehicle tests.

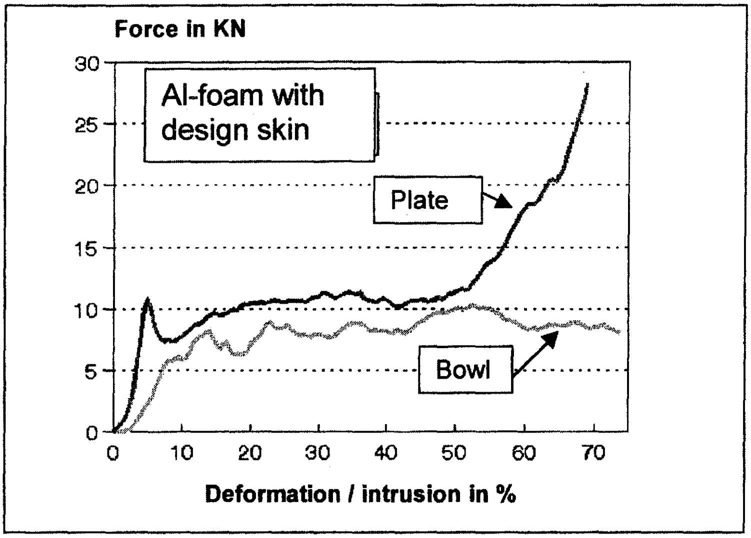

Figure 9: Effects of skin design on Al-foam crushing

8 Aluminium foams in structural deformation elements

Aluminium foams are also in discussion for applications in structure elements of car bodies. Besides reinforcing effects against buckling i.e. in pillars also energy absorbing properties in beams are considered.

Figure 10 shows a few examples of Aluminium tubes after axial load simulating energy absorption by different folding patterns.

Figure 11 shows the principal disadvantage of Aluminium foam filled tube beams as far as energy absorption is concerned. If prevention against buckling is the reason for foam filling design has to compensate the danger of excessive force levels and the reduced deformation length to keep the required energy absorption efficiency.

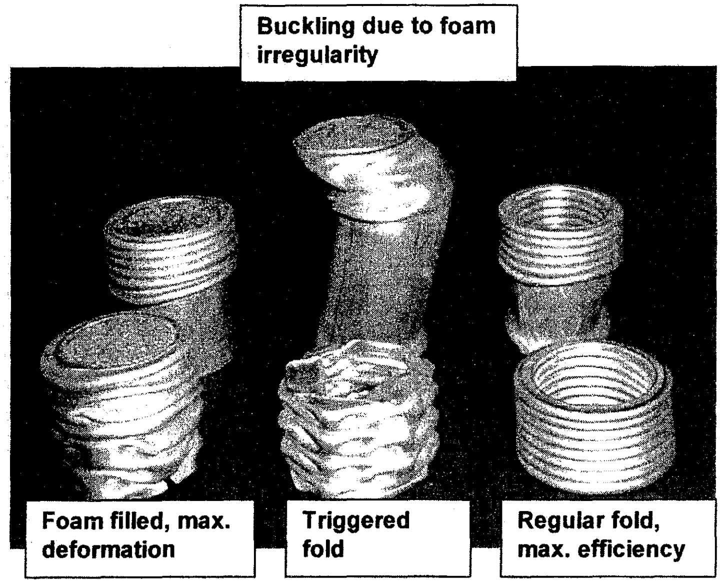

Figure 10: Various states of deformation of Aluminium tubes with and without Aluminium-foam cores

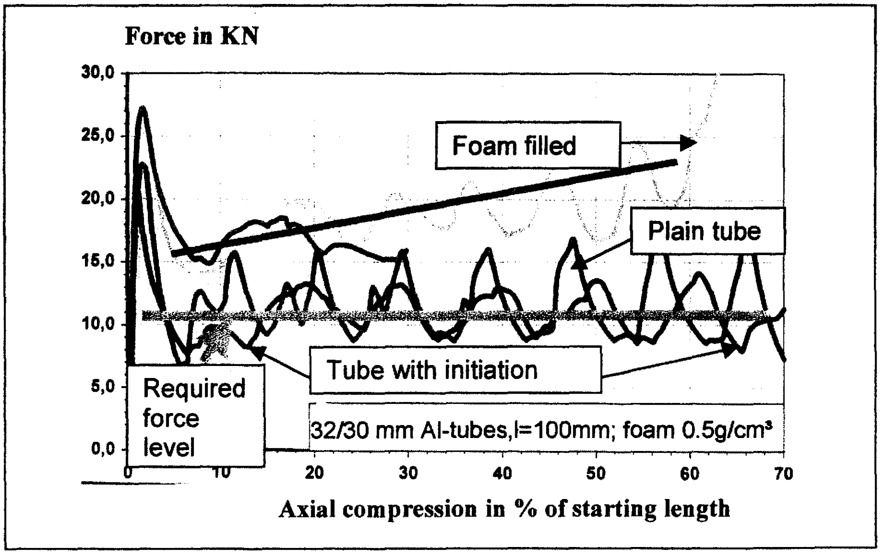

Figure 11: Axial compression curves of Aluminium tubes prepared without and with Al-foam insert

Deformation Element	Mass (g)	efficient length (%)
Al-tube without trigger notches	30	75
Al-tube with trigger notches	30	75
Al-foam beam	42	70
Al-foam beam	49	70
Al-tube with foam insert (without trigger)	65	70
Al-tube with foam insert (without trigger)	75	35
Al-tube with foam insert (with trigger)	60	60
Al-tube with foam insert (with trigger)	80	45

Table 1: Mass and efficient deformation length of tube elements

A disadvantageous experience with foam filled beams is that additionally to the changes of the crushing curve the weight is increased and the usable or effective deformation length is decreased. This stands against light weight design ambitions. Table 2 gives a rough idea on the dependencies between mass and effective deformation length.

9 Outlook

Aluminium foams for energy absorption application, particularly for low impact forces are in an early state of development. In automotive applications like occupants protection in cases of collisions an improved uniformity of properties, i. e. crushing strength level, has to be achieved.

Metallic foams show advantages where environmental influences like temperature and/or moisture would change the properties of plastic foams and structures. Aluminium foam here would be a less expensive solution compared to Aluminium-honeycombs.

Some drawbacks might come from the poor machinability of low density foams mostly from melts with stabilising ceramic particles. Shaping of 3-dimensional components is decisive for future application in cars.

Principle investigations, also reported in this paper, show that there is a good chance to have Aluminium foam components in the future after solving the shown problems and processes are so far stable to make reliable cost estimations.

10 References

/1/ Energy-absorbing materials, Volkswagen AG,1999

/2/ Vehicle Safety – The Basics, Volkswagen AG, 1999

/3/ Siebels, J. Aspekte zur Umsetzung von Energieabsorbtionsanforderungen in Materialeigenschaften (passive PKW-Sicherheit, Haus der Technik ,Essen, Tagung Metallschäume,1999

/4/ Siebels, J. Umsetzung passiver PKW-Sicherheit in Materialeigenschaften, IVW-Kolloquium '98, 1998