THE FENOSOL™ PHENOLIC FOAM: A ROBUST SOLUTION FOR NUCLEAR-GRADE SHOCK ABSORBERS

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ABSTRACT

In design of type B package for transporting nuclear materials, wood is traditionally used as shock absorbing material in impact limiters. From a mechanical point of view, this material is very efficient along its main axis and reasonably efficient in the transverse plane. Its most obvious drawback is its sensitivity to fire. This last point has been under sustained scrutiny recently [1,2,3].

Substituting phenolic foams to wood is a way to address this problem. Phenolic foams have proved their outstanding mechanical and fireproof abilities in mining application and can be used for shock absorbers of type B transportation packages. FENOSOL™ belongs to this class of foams and has been used for that purpose and integrated to designs like the TNF-XI developed jointly by COGEMA logistics and NFI or the R83 developed by ROBATEL Industries to transport used LEU fuel from the High Flux Reactor in Petten and HOR in Delft to the intermediate storage facility HABOG at COVRA, Nieuwdorp, as well as waste from the Mo-99 production from its facilities in Petten and thus to replace in 2019 the CASTOR® MTR-2 cask currently in use.

ROBATEL Industries has been leading an extensive chemical and mechanical characterization program to increase the predictability of casks and equipment designs based on that material. An accelerated aging program has also been initiated to predict the behaviour of this foam after years of use in type B casks. FENOSOL™ foam properties appear to be insensitive to most environmental parameters. The R79 cask illustrates how these data can be used within dynamic FEA simulations to design a Type B cask.

1. INTRODUCTION

Shock absorbers are a classical safety feature of products in the nuclear industry. They provide robust protection against mechanical damage of sensitive equipment. They are usually made of a shock absorbing material wrapped in a stainless-steel casing. Depending on the application, shock absorbers usually fall into one of the following categories:

1. Axial shock absorber for static applications
2. Multiaxial shock absorber for mobile loads

Shock absorber of the first category can use materials with optimal properties in a given orientation while in the second case, good isotropic properties are required. While a variety of devices and materials can be used for light loads, the choices are significantly narrowed for high kinetic energy impacts as higher plateau levels and efficiency are required. Foams, wood, and honeycomb-shaped materials have this property, with very anisotropic properties for the last two cases. Safety regulations also add stringent requirements concerning fire characteristics of these materials [1], further reducing the range of possible materials available to the cask designer: Type B casks that are typically used for spent fuel transportation are required to sustain a 9m free drop followed by a 30mn engulfing fire at 800°C.

The aim of a shock absorber is to reduce the damage on a piece of equipment during an accident by dissipating a maximum amount of energy during its compression while keeping the acceleration below a desired threshold. As a consequence, the perfect shock absorber materials display a flat stress for any compressive strain between 0% and 100% (cf. Fig. 1). Certainly, a real shock absorber material cannot be compressed up to 100%; the real shock absorbing material has a stress-strain relationship that displays a fairly different profile, with an initial linear increase of the stress in the elastic regime, a long plateau at the required stress level with a little slope, and finally a stiff increase in the densification regime, as shown in Figure 1. The efficiency of such a material, the energy absorbed below a stress threshold per unit volume, is then the area below the curve up to the stress threshold. A consequence is that there is an upper limit of energy that can be absorbed by a given volume of shock absorber, even in the perfect case. Moreover, the actual efficiency of a shock absorber material is usually half to one fourth of the efficiency of the perfect shock absorbing material for a given stress threshold. Increasing the shock absorber volume is then necessary to increase the energy absorbed. As a result, the shock absorber is one of the main features of a Type B transportation cask, representing up to 20% of the total mass and 30% of the total volume of the cask.

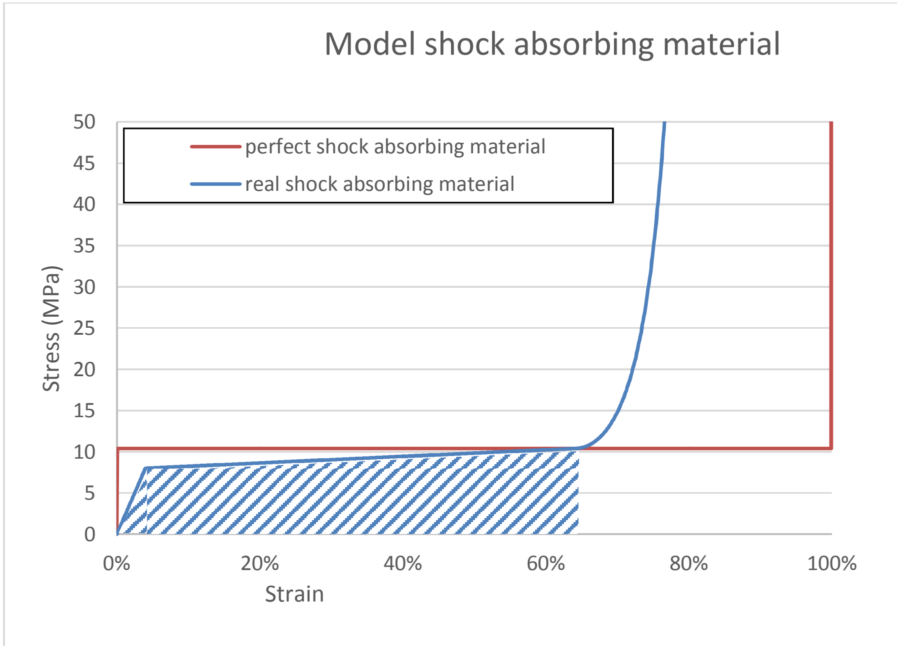

Figure 1. Stress as a function of the compressive strain of a typical shock absorbing material. The dashed area represents the energy absorbed below a 10MPa threshold

THE SEARCH FOR THE PERFECT SHOCK ABSORBER

The perfect shock absorber material must fulfil a number of mechanical and chemical properties, while staying perfectly reliable for the longest time at a minimum cost. An illustration describing some of these properties is shown in Figure 2. Many of the features are a trade-off; any given shock absorbing material will excel in some areas and lack in others.

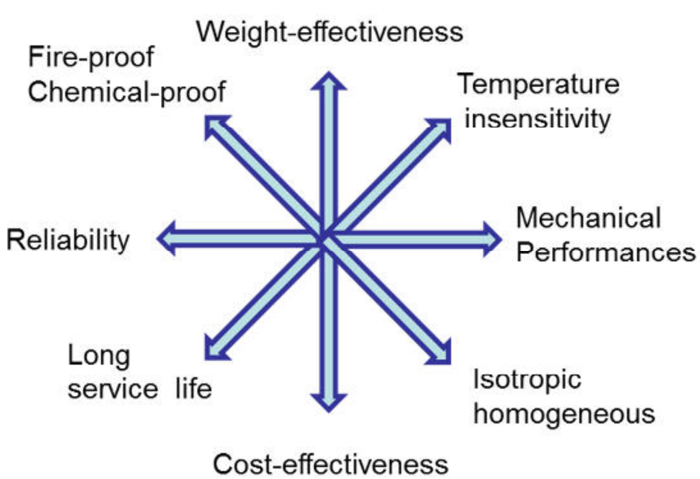

Figure 2. The properties of the perfect shock absorber material

In the case of multiaxial shock absorbers for mobile load, wood is the traditional choice. Very efficient along the main axis and reasonably efficient in the transverse plane, it can be used for protecting transportation casks from drops at various angles. However, its obvious drawback is its sensitivity to fire. This last point has been under sustained scrutiny recently [2][3], with chimney effects leading to complete post-combustion of wood based shock absorbers.

The use of wood induces other hardships; if its mechanical properties are excellent, they are highly sensitive to humidity, temperature, and may vary from one source to another. In comparison, synthetic shock absorbing materials have lesser mechanical properties, but they are less sensitive to environmental parameters, and are reliably consistent from batch to batch. As a consequence, shock absorbers based on these materials do not need to be oversized in the design phase to compensate for this variability.

Honeycomb materials have good overall properties along their main axis but have negligible energy absorption capacity in the normal plane. As a consequence, their efficiency is extremely sensitive to their orientation during impact. Moreover, while they may be insensitive to fire, their geometry provides them with no fire retardation capacity along their main axis, and the aluminium honeycomb is even an excellent thermal conductor. A qualitative diagram describing some of the material trade-offs is shown in Figure 3.

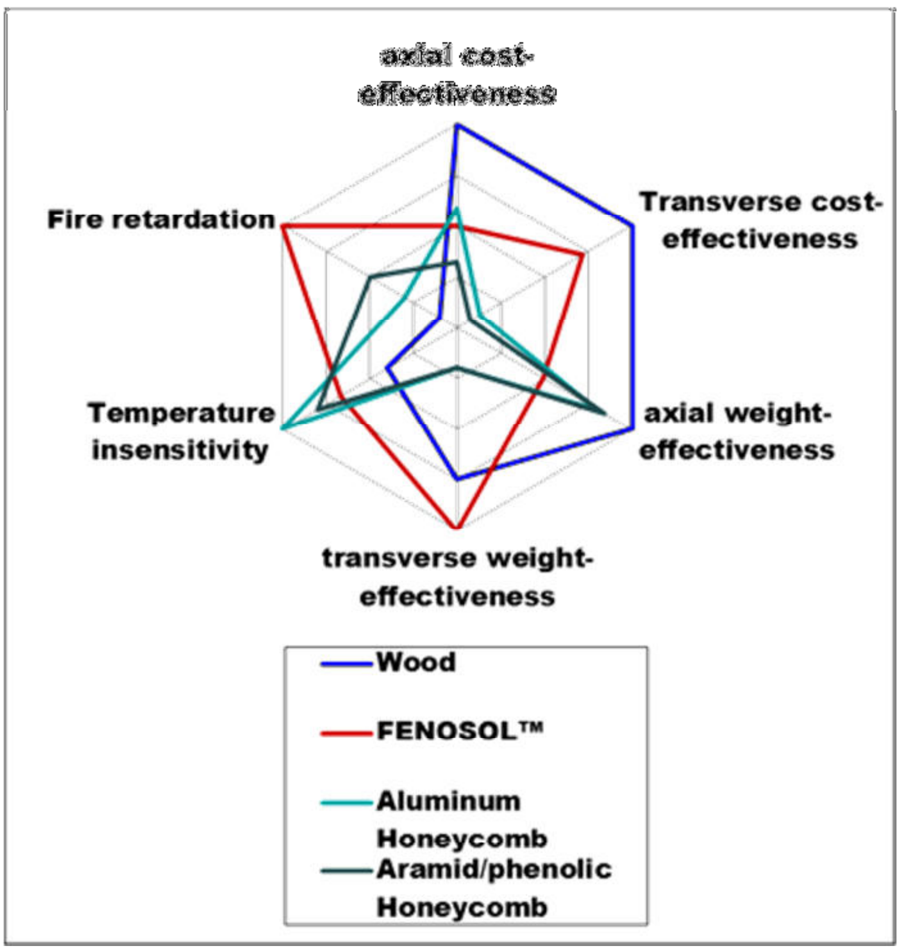

Figure 3. Respective advantages of the different classes of shock absorbing materials

FENOSOL™ FOAM PERFORMANCE

Synthetic foams like FENOSOL™ have isotropic mechanical properties that are only slightly less than the axial mechanical properties of the honeycombed structures along their main axis, but without any angle dependency. The main remaining trade-off is then between the stress threshold that has to be minimized and the energy absorbed to maximize.

The single-formulation, single-process of FENOSOL™ can be adapted to produce foams with an adjustable plateau stress level as shown in Figure 4. The plateau stress can be adjusted through the foam density. This advantage simplifies the design of shock absorbers and improves our knowledge of this material as it allows us to experiment with various densities.

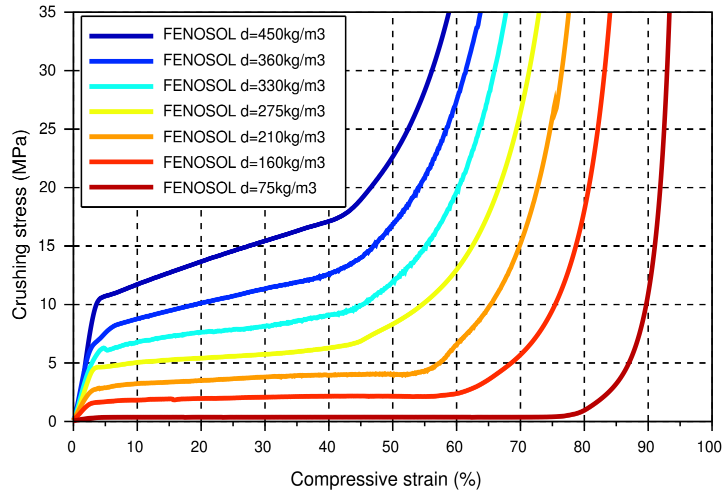

Figure 4. Stress as a function of strain of FENOSOL™ foam for various foam densities at T=20°C.

Knowledge is the key to understanding and thus to safety, and FENOSOL™ foam properties can be used to feed numerical simulations of dynamic impacts, as shown in Figure 5. These simulations are a key component of the safety analyses for type B transportation casks and static shock absorbers; they allow simulation of drop cases without the need to perform expensive systematic real-scale drop tests. These simulations are only validated with actual drop tests in the most penalizing cases to ensure safety. Building a reliable model for the shock absorber requires using a well-known material with a complete mechanical characterization [4]. Based on the experience of more than 10 cask designs over the last 10 years and extensive in-laboratory characterization, a multi-variable model is available for FENOSOL™ which takes into account density, temperature, aging, and impact speed. The FENOSOL™ foam numerical model allows for accurate simulations of drops in excellent agreement with real-scale drop tests.

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