Using FENOSOL™ Phenolic Foam as a Shock Absorber for Type B Packaging – 17256

Jared Bower
Robatel Technologies, Roanoke, Virginia, USA, Engineering Manager

Thomas Garnier
Robatel Industries, Genas, France, R&D Engineer

Alain Joudon
CEA/DEN/DSN/STMR, Cadarache, France, Deputy Head of the Department of Transportation of Radioactive Materials

ABSTRACT

Type B and fissile material transportation packages are designed to withstand deformation from dynamic forces experienced during impacts in hypothetical accident conditions. A critical aspect is to ensure the containment system is not breached. The package design normally includes impact limiters made up of a shell filled with energy-absorbing material. Various types of materials are used as energy absorbers, including wood, foam, and honeycomb structures.

Synthetic foam is an ideal material for impact limiters; it has isotropic material properties, it acts as a heat insulator during fire conditions, and it maintains structural integrity at high temperatures. In addition, the density of the foam may be controlled during the manufacturing process, allowing the cask designer flexibility to select the right density for each application. The foam properties can be used as inputs for numerical simulations of dynamic impacts. These simulations are a key component of the safety analysis report for Type B transportation casks.

Robatel has recently invested in equipment to produce FENOSOL™ phenolic foam in our factory for use in our cask designs. This acquisition was made jointly between Robatel and the CEA, with Robatel ensuring the industrialization of the product. In the past decade, this foam was successfully integrated into more than 10 European cask designs, and there has been extensive in-laboratory characterization of its properties. FENOSOL™ has already been accepted by the French Nuclear Safety Authority (ASN) as a shock absorbing material for use in cask designs.

Since the acquisition of the phenolic foam production process by Robatel, a new research and development program has been launched to provide more accurate information to our clients, extend the range of application of this foam, and to improve its properties. Robatel has built an extensive database of material characteristics through the use of a universal mechanical tester, a scanning electron

microscope, and a nuclear magnetic resonance spectrometer. In addition, Robatel has successfully implemented FENOSOL™ in two recent cask designs. This included scale model drop testing of a 9 meter drop in three orientations, and a pin puncture drop test.

Robatel is in the process of producing FENOSOL™ samples for testing according to ASTM standards. Various densities will be included in the study. The testing will include durometer hardness, specific heat, thermal conductivity, compressive strength and modulus, and tensile strength. Once the testing is complete, Robatel will compile the data in the form of product specification sheets for each density. These information sheets and test reports will be used to validate FENOSOL™ for use in future impact limiters for the North American Type B cask market.

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.

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%. 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. The maximum absorbed energy can only be increased by increasing the shock absorber volume. Certainly, a shock absorber material cannot be compressed up to 100%; the typical shock absorbing material has a stress-strain relationship that displays a long plateau at the required stress level followed by a stiff increase in the densification regime, as shown in Figure 1. Thus, the actual efficiency of a shock absorber material is usually half to one fourth of the efficiency of the perfect shock absorbing material in terms of energy absorbed below a stress threshold. 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.

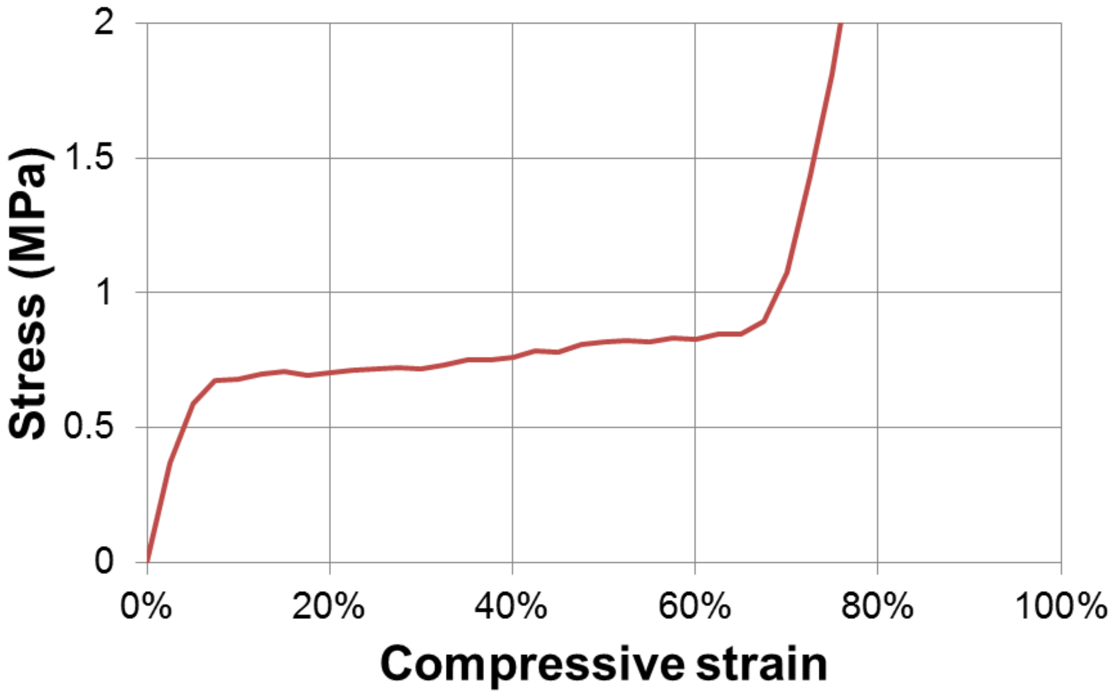

Figure 1. Stress as a function of the compressive strain of a typical shock absorbing material

THE SEARCH FOR THE PERFECT SHOCK ABSORBER

The perfect shock absorber material must fulfill 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.

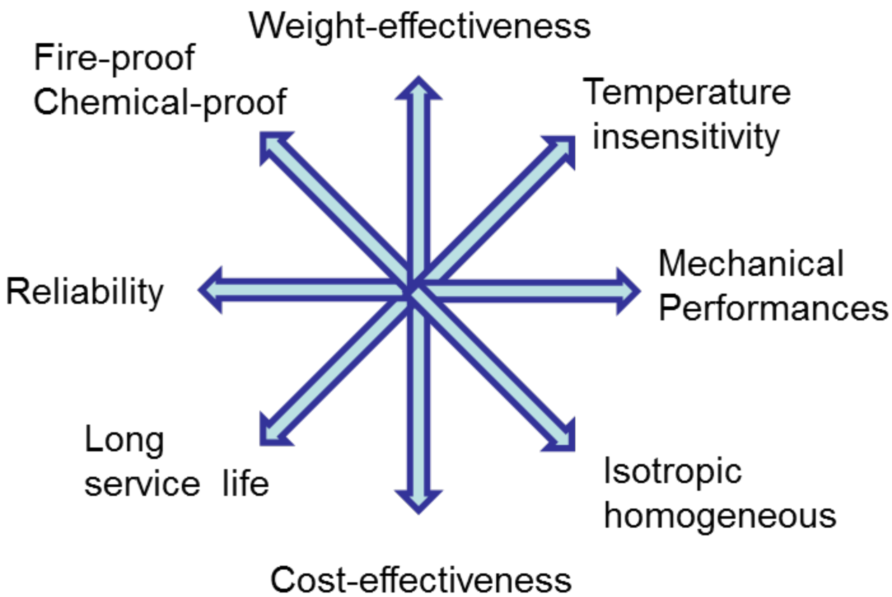

Figure 2. The properties of the perfect shock absorber material

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 aluminum honeycomb is even an excellent thermal conductor. A qualitative diagram describing some of the material trade-offs is shown in Figure 3.

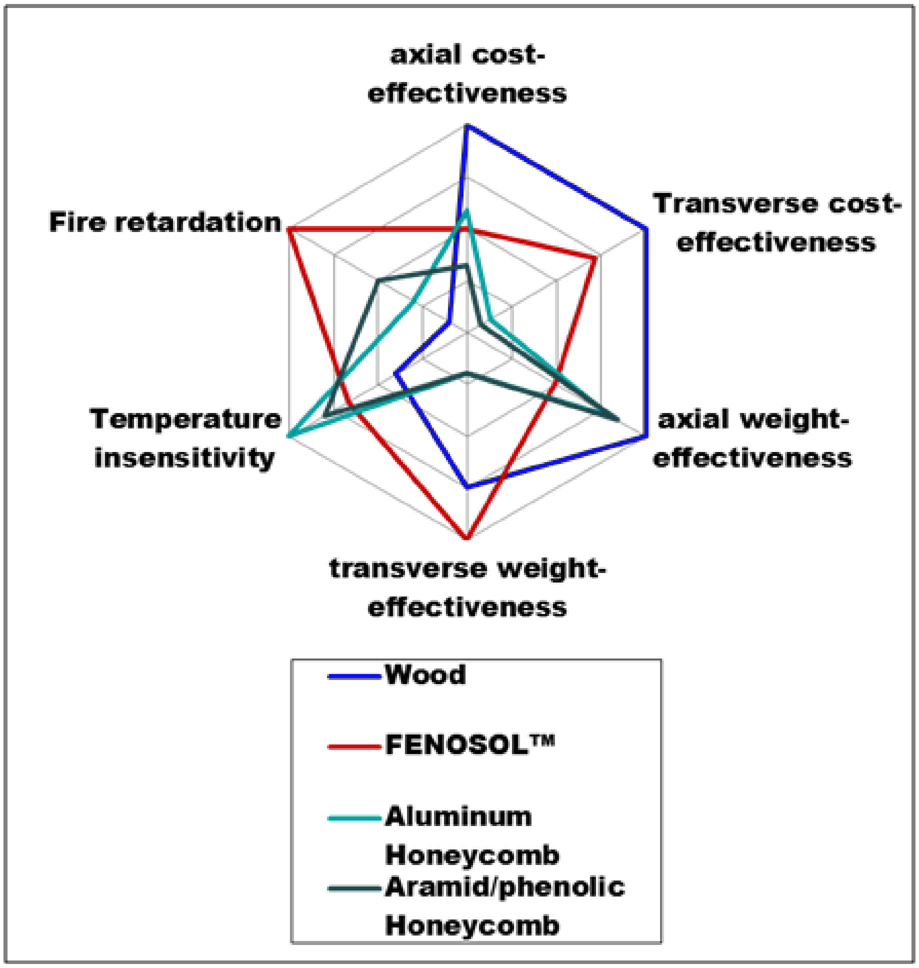

Figure 3. Respective advantages of the different shock absorbing materials

FENOSOL™ FOAM FIRE 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. Along with its good mechanical properties, FENOSOL™ adds excellent fire retardation properties. Figure 4 shows the results of thermal gravimetric analysis (TGA) of the FENOSOL™ foam. Below 200°C, no solid state parts of the foam are affected, as only free water and phenol are removed, preserving the mechanical structure and properties. The phenolic carbon structure ensures its integrity even at high temperatures: at a 600°C exposure, 45% of the structure is left, maintaining the cellular structure and the thermal insulation properties: the micrometer-sized cell structure of FENOSOL™ shown in Figure 5 provides it with excellent heat insulation properties and a conductivity of $0.037 Wm^{-1}k^{-1}$ to $0.15\ Wm^{-1}k^{-1}$ depending on the chosen density. It can withstand direct exposure to a 600°C flame and self-extinguish.

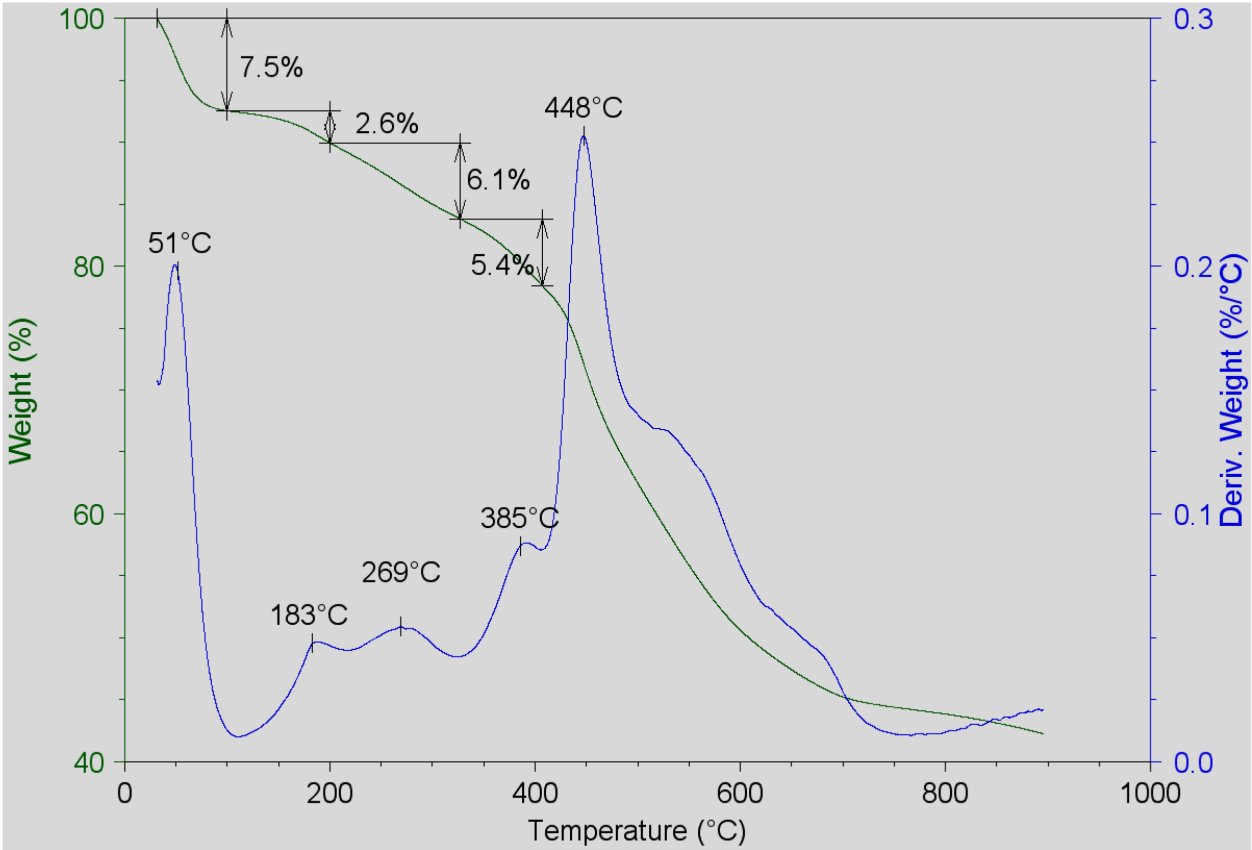

Figure 4: TGA of Fenosol™ foam at10°C.min^{-1} in helium

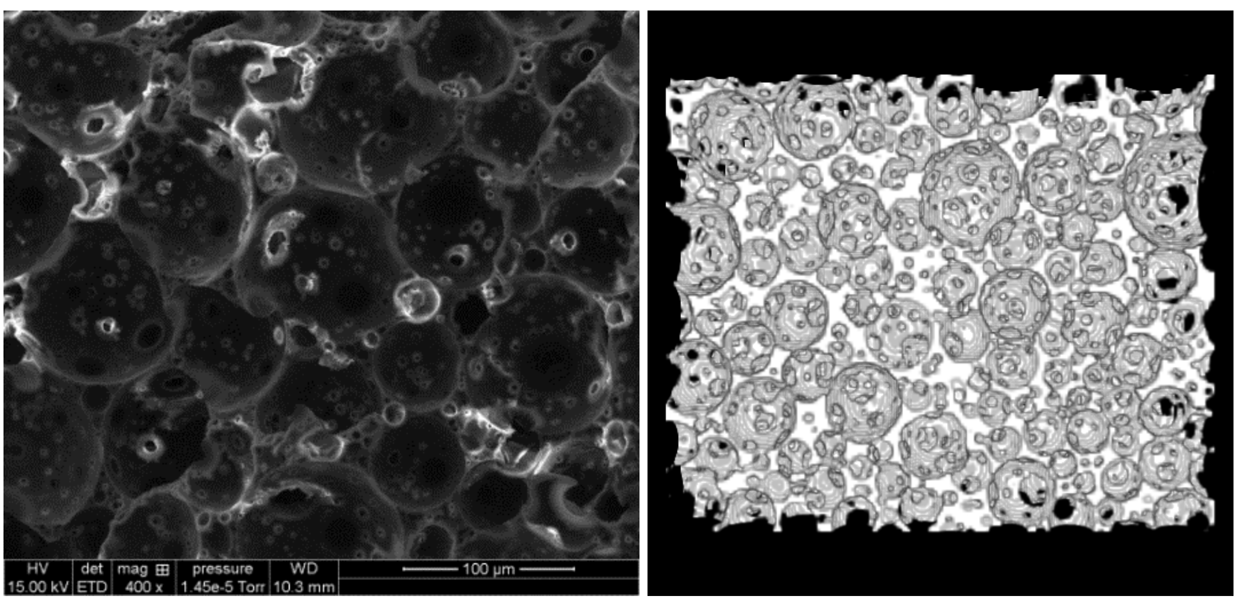

Figure 5. LEFT: SEM picture of FENOSOL™ foam, density = 375kg/m³, Right: reconstruction of the 3D structure using X-ray tomography.

FENOSOL™ FOAM MECHANICAL PERFORMANCE

The single-formulation, single-process of FENOSOL™ can be adapted to produce foams with an adjustable plateau stress level as shown in Figure 6. 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.

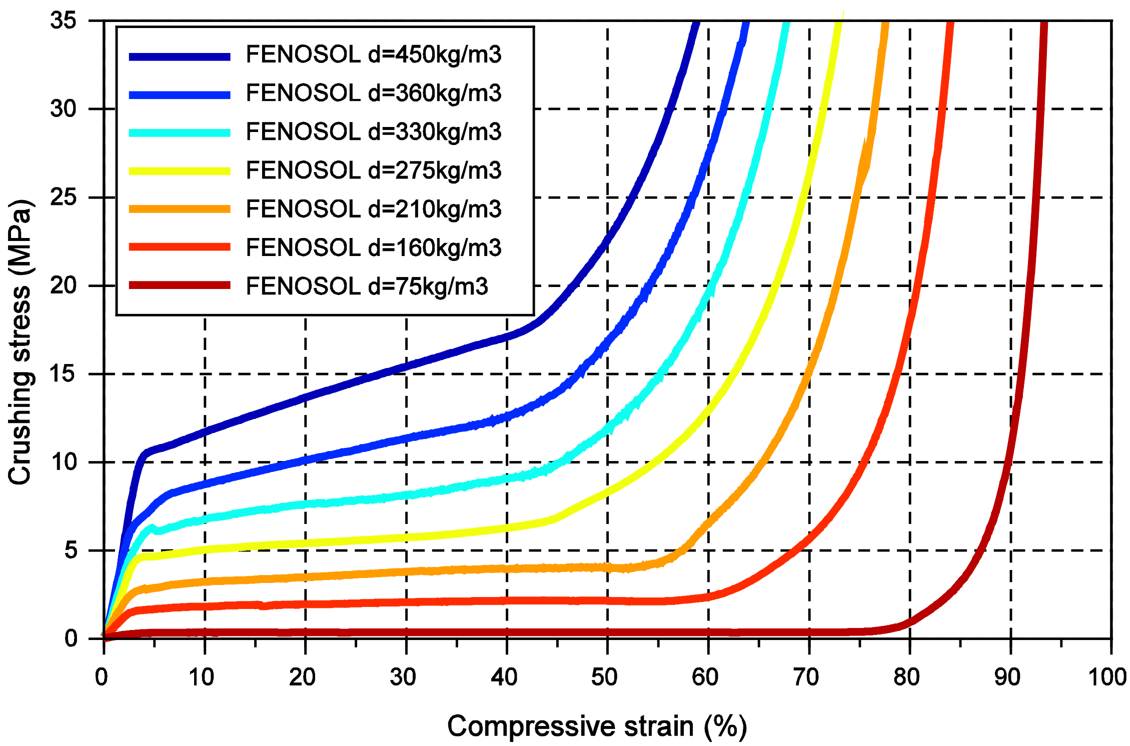

Figure 6. Stress as a function of strain of FENOSOL™ foam for various foam densities at T=20°C.

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 7. 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.

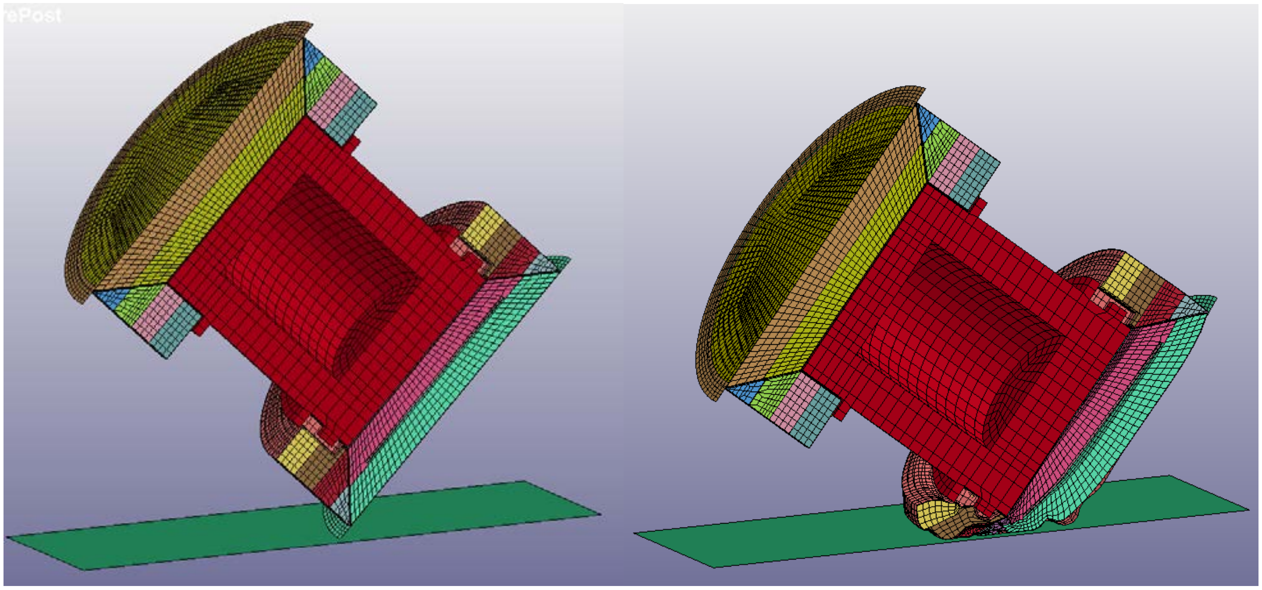

Figure 7: LS-dyna FEM crash simulation of type B cask and deformation of shock absorbers

FENOSOL™ QUALIFICATION IN THE USA

Although the properties of FENOSOL™ foam are well understood based on past performance and laboratory testing in Europe, Robatel recognizes the importance of having qualified test results according to ASTM standards for use in the USA. We are currently performing testing according to ASTM standards in order to characterize the mechanical properties and fire behavior.

CONCLUSION

FENOSOL™ foam combines isotropic mechanical properties, fire-retardant properties and extensive knowledge of these properties based on laboratory tests and industrial feedback. Thus, the use of such a foam enhances safety-by-design for shock absorbers while remaining cost effective in most situations.

REFERENCES

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