

USE OF FENOSOL™ FOAM IN THE DESIGN OF NEW TRANSPORTATION PACKAGES

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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. Its thermal insulation is evaluated, and particularly its post combustion behaviour after fire test has to be evaluated. This item has been treated by the article “Consequences of the wood post Combustion should be evaluated considering each package shock absorber design” Paper #456, presented at PATRAM 2013.

In order to address this in our safety analysis and to keep a competitive and innovative edge, Robatel Industries, co-owner with the CEA (Commissariat à l’Energie Atomique et aux Energies Alternatives) of the FENOSOL™ foam, launched extensive research and development effort to fully characterize and improve the FENOSOL™ foam, as a replacement material for wood in impact limiters.

This foam is phenolic based, well known as an excellent fire shield (M1 classified), it neither propagates flames, nor produces toxic fumes (F1 classified), and it has already been accepted by the French nuclear safety authority (ASN) as a shock absorbing material in cask designs. Along with thermal properties, mechanical properties are tested at Robatel Industries, in its dedicated laboratory, on several foam densities, different temperatures, in static and dynamic. HAC Crash tests (9m drops) were successfully performed on an actual ROBATEL cask design 1/3 scale model. In collaboration with a French university, the chemical evolutions and microstructure are being studied.

Results show that Fenosol™ is an advantageous alternative to wood in shock absorbing applications. Robatel Industries has already designed its two next type B casks impact limiters using Fenosol™. This material is now entering its industrial phase, and in addition to use in impact limiters, it will also be proposed in other fields of our industry.

1. Introduction – Overview of the industrial context

The FENOSOL™ foam had been used for over 10 years in over 10 cask designs and in the fabrication of over 1000 packages. Looking for a continuation of the supply of FENOSOL™ foam, the CEA set up a partnership with ROBATEL Industries to take over the fabrication and supply of this material.

With its long nuclear history of more than 60 years and its strong experience and involvement in the design of radioactive material transportation packages (with about 80 approved type B cask designs over the 30 past years, and over 1000 manufactured), ROBATEL Industries has already developed proprietary formulations compounds and concretes for thermal and neutron shielding (PNT7™ and compound9™, 10, 21 and 22), which are still under a continuous improvement plan. These were, and are still, implemented in transportation and/or storage casks, shield walls, hotcells, NPPs around the world.

Since the acquisition of the FENOSOL™ phenolic foam formulation and fabrication processes, ROBATEL Industries has launched a new Research and Development program to characterize this foam in its finest details, in order to provide more information to our clients, extend the range of applications and improve its properties.

2. Description of FENOSOL™ foam

FENOSOL® is a rigid phenolic foam, it can be poured in a wide range of densities, from 30kg/m³ up to 700 kg/m³. It can be either casted directly into a metallic envelope to fully fill the voids, or molded into standard shape blocks and machined at will.

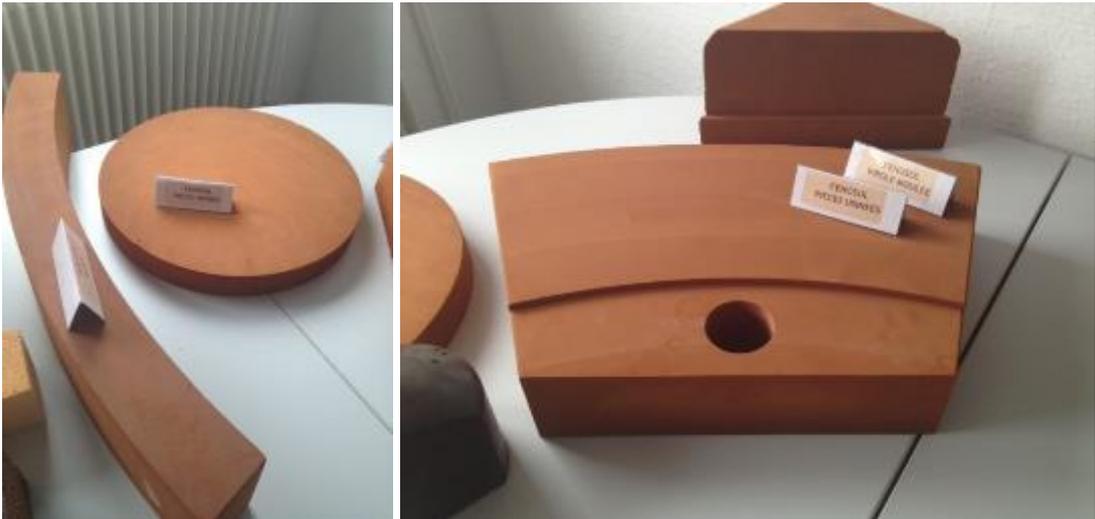


Figure 1 – Machined blocks of Fenosol™ Phenolic foam.

Mechanical properties:

The characteristics and applications of the foam adapt to technical scope of work, the lowest density (30kg/m³) provides very high thermal insulation properties and a light weight, where heavier densities provide one of the most efficient isotropic shock absorbing material.

Its Stress-strain curve shows, after an initial elastic behavior, a plateau going beyond 65% of volumetric crush, making it ideal for installation in impact limiters for transportation casks, and for installation around hot cells as thermal shield and shock absorber, saving weight and space.

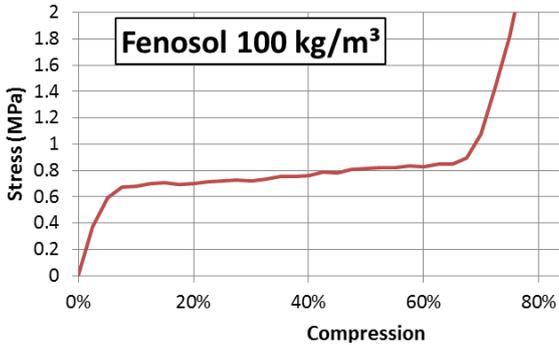


Figure 2 – Stress-strain curve of Fenosol™ foam (100 kg/m³ at 20°C)

Thermal and fire resistant properties:

The temperature range of use as shock absorbing material is wide going from -180°C up to +120°C, without significant change in structural and thermal properties. In addition, the material in a thermoset foam and therefore, it doesn't melt when exposed to fire.

FENOSOL® is classified M1 and F1 according to French standard which means it neither propagates heat nor flames, and it hardly emits black and toxic smoke. No post combustion was observed.

This foam is a very good firewall material and a thickness of 3cm is sufficient to resist to a flame for above 30 minutes. Figure 3 below shows that in case of thermal degradation FENOSOL® retains its structure and geometry, and remains in position on the support.



Figure 3 – Fire test comparison between Fenosol™ phenolic foam and fireproof Polyurethane, polyurethane and polystyrene foams.

FENOSOL® foam thermal conductivity reaches very low values for the low densities. A very high rate of closed cells enable to optimize thermal insulation properties.

On the other side, Experiments have shown that the foam is very low permeability to water vapor. Therefore, FENOSOL® is moisture resistant and will not deteriorate with prolonged exposure in a humid environment.

Environment and safety considerations:

FENOSOL® contains no CFCs or HCFCs, and is fiber-free and odorless.

In case of fire, very low smoke emerged, and they are not harmful to either humans or the environment. FENOSOL® contributes to respect for the environment by bringing reliability and safety.



Figure 4 – Fire Test comparison between phenolic and polyurethane foam

Summary of benefits

Properties	Units	FENOSOL Standard	Values Mini - Maxi	Methods
Density	kg/ m ³	200	30 – 700	ISO 845
Compressive stress at 10% deformation	MPa	> 2	0,1 – 15	ISO 604
Compressive stress at 50% deformation	MPa	> 3	0,1 - 50	ISO 604
Thermal conductivity	W.m ⁻¹ .K ⁻¹	0,05	0,02 - 0,08	ISO 8990
Specific heat	J.g ⁻¹ .K ⁻¹	2,7 à 20°C	-	-
Fire Rating	-	M1	M1	NF P 92-501
Smoke ranking	-	F1	F1	NFX 10-702
Dimensional stability	%	0,1	-	ISO 2796
Temperature of use	°C	-180 à +120	-	-
Closed cell	%	55	30 - 95	ISO 4590
Amount of Carbon	%	> 65	-	-
Amount of Hydrogen	%	> 7,2	-	-
Amount of chlorine	ppm	< 20	-	-

Table 1 - Summary Table of FENOSOL® properties

- Molded or casted: production of parts with complex shapes and filling large volumes and small gaps.
- A wide range of densities.
- Rigid and lightweight material.
- Very good mechanical properties.
- Good insulation properties.
- Very good fire behavior: do not spread flames (M1 classification).
- Negligible emissions of black and toxic smoke (F1 classification).
- Very low permeability to water vapor: moisture resistant.
- Contains no CFCs or HCFCs: respect for the environment.

3. Research and development program

In 2014, ROBATEL Industries have launched a research and development program to update and revalidate all the characteristics of the original Fenosol™ foam using the latest standards, and to propose new versions of this product.

To start, ROBATEL Industries focused on researching and implementing the Fenosol™ foam in its Type B transportation casks impact limiters. The critical mechanical property of FENOSOL™ is its crush strength. It can be measured on a confined sample using a universal mechanical tester. The crush stress as a function of the compressive strain is obtained by measuring the force at a constant quasi-static compression speed. For a shock absorber material, the stress required to crush the sample follow a three-part behaviour: after an initial elastic behaviour, a plateau appears that dissipates the shock energy, which finishes by a steep ascend of the stress due to the densification process. The longer the plateau, the more efficient the material is as a shock absorber. (See Figure 2).

These crush strength results are used to build multivariable models of the foam behaviour accounting for the effects of temperature or densities. These models are powerful tools to identify the most adapted variant of FENOSOL™ to a given situation. For example, it has been used to demonstrate that as a phenolic foam, Fenosol™ crush strength is only moderately affected by temperature increase.

Dynamic effects are also evaluated by comparing static crush tests with drop test experiments performed at our facilities. Using a non-linear transient dynamic finite element analysis software, LS-Dyna, simulations of crush tests and drop test experiments are performed to benchmark our analytical models. One case is illustrated in Figure 5 , where the behaviour of a FENOSOL™ shock absorber under a rigid load is studied. This approach allows generalising the experimental results and developing specific shock absorber geometries optimised for a given situation.

Whipping - T=40deg - Drop n 3 - Angle 10
Time = 29.999

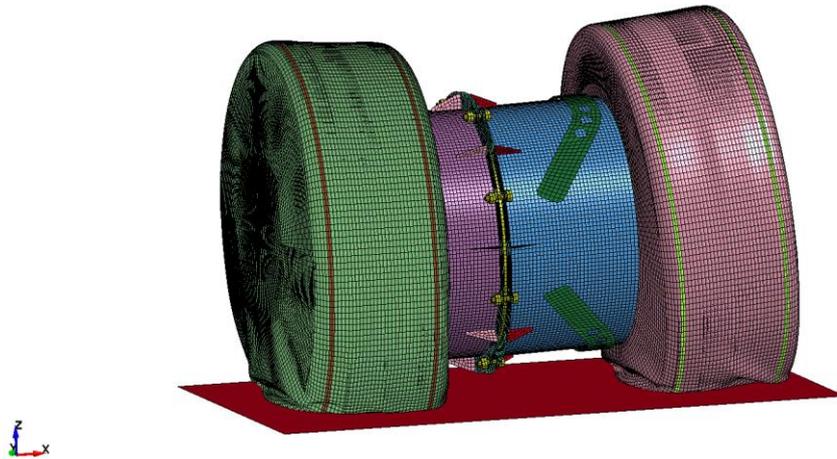


Figure 5 – Drop test simulation of a ROBATEL Industries R79 cask scale model with a Fenosol™ foam impact limiter using LS-DYNA.

By fully characterising this foam, path for future improvement can be identified. Thus, the macroscopic properties obtained through crushing experiments or dynamic simulations are confronted to the chemical composition and microstructure to better understand the key factors and derive improved FENOSOL™ foam variants for upcoming applications. Through a collaboration with the Polymer Materials Engineering Laboratory of a French University, advanced characterization technics like swiping electronic microscope (SEM) imaging, rheological experiments or nuclear magnetic resonance (NMR) spectroscopy are used to better understand the origin of these key properties.

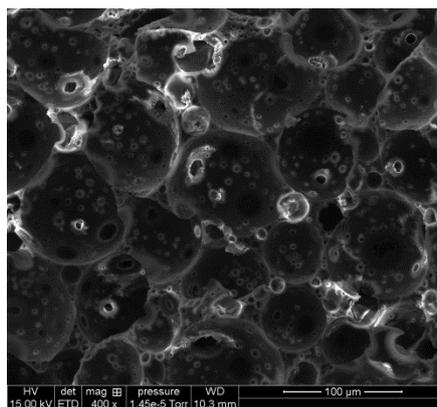


Figure 6 - SEM picture of FENOSOL™ foam of 375kg/m³ showing the cell structure.

The thorough characterisation program that has been set will allow ROBATEL Industries to provide any specific information that would be needed by our customers for the original Fenosol™ foam, but we will also be able to offer enhanced versions with new improved formulations to satisfy even more demanding and dedicated applications.

4. Conclusion

Fenosol™ is currently used in the design of impact limiters, insulation and fire protection of high security cask, for the transport of sensitive materials for nuclear and military applications. ROBATEL Industries have successfully implemented Fenosol™ in the two latest type B cask designs, with a drop test campaign performed on a scale model in July 2015 including nine meter End, Side and Corner drops at critical temperatures, and pin puncture tests.

This versatile Fenosol™ foam proposes a real advantageous alternative to wood in shock absorber designs for casks, static shock absorbers used in nuclear plants. Its thermal and fireproof properties make it a strong contender for fire shield doors, replacement of aerated concrete thermal shields, and other custom insulation and fire shield applications.