Proceedings of the 17th International Symposium on the Packaging and Transportation of Radioactive Materials
PATRAM 2013
August 18-23, 2013, San Francisco, CA, USA

Qualification Test Program of Polyisocyanurate Rigid Foam for the Use in Type B(U)F Packages

Thomas Breuer
Nuclear Cargo + Service GmbH (DAHER-NCS)

Stefano Ricchetti
DUNA-Corradini

Stefan Offermanns
Materials Testing Institute
University of Stuttgart (MPA)

ABSTRACT

It is a common practice to use polyurethane foam in packages for radioactive material due to its good mechanical properties acting as shock absorber combined with a good thermal protection. The company DUNA-Corradini, developed a polyisocyanurate rigid foam, which is a further development of polyurethane foam providing superior mechanical rigidity, temperature resistance and fire reaction. The intention of DUNA-Corradini and DAHER-NCS is to qualify these foams for nuclear packages, especially for the DN 30 designed by DAHER-NCS as a protective structural package for 30B cylinders.

Most of the qualification tests were performed at MPA Stuttgart (Germany) using a guided drop rack. Influence of temperature in a range from -40° to +80° C, humidity, cumulative loads and foam cells orientation were taken into consideration. Another major issue of this qualification program was to investigate the differences between static and dynamic conditions.

For the dynamic drop tests, in order to achieve the best comparable results to the drop test conditions defined by IAEA, a drop height of nine meters was chosen. The weight of the drop mass was adjusted to the foam properties to achieve an impact energy comparable to the characteristics in the package.

In these drop tests, force and acceleration are measured, as well as deformations detected by optical measurement methods with a sampling rate of 100 kHz over the whole impact. From this curve other quantities, such as energy absorption and compression strength of the foam can be determined.

The results of this qualification tests show a very high reproducibility with tight tolerances and little variation of the measured values. This, along with the availability of several densities of the foam (resulting in a well controllable and adaptable compression strength), allows accurate prediction in FE simulations of the overpack behavior and a high standard in quality control of its serial production.

INTRODUCTION

The DN 30 is a protective structural packaging (PSP) designed by DAHER-NCS which is currently in the licensing process. A 30B cylinder is protected by this PSP during its transport. The package consists of a top half and bottom half, both built of an inner and outer shell made of stainless steel, see Figure 1 and Figure 2. As core material CORAFOAM polyisocyanurate (PIR) foam is assembled between these two shells for two main reasons: to act as shock absorber in case of drops and as thermal insulator to reduce the heat exchange between the 30B cylinder and the environment.

A test program was developed to determine the mechanical behavior of PIR foam in dynamic and static conditions, tested on special foam samples and validated by calculations and drop tests of the whole package.

This new concept should bring the innovation to have a package equipped with a core material which ensures appropriate mechanical and thermal insulating properties and ensure reproducibility of the material characteristics since every batch is strictly controlled by the manufacturer.

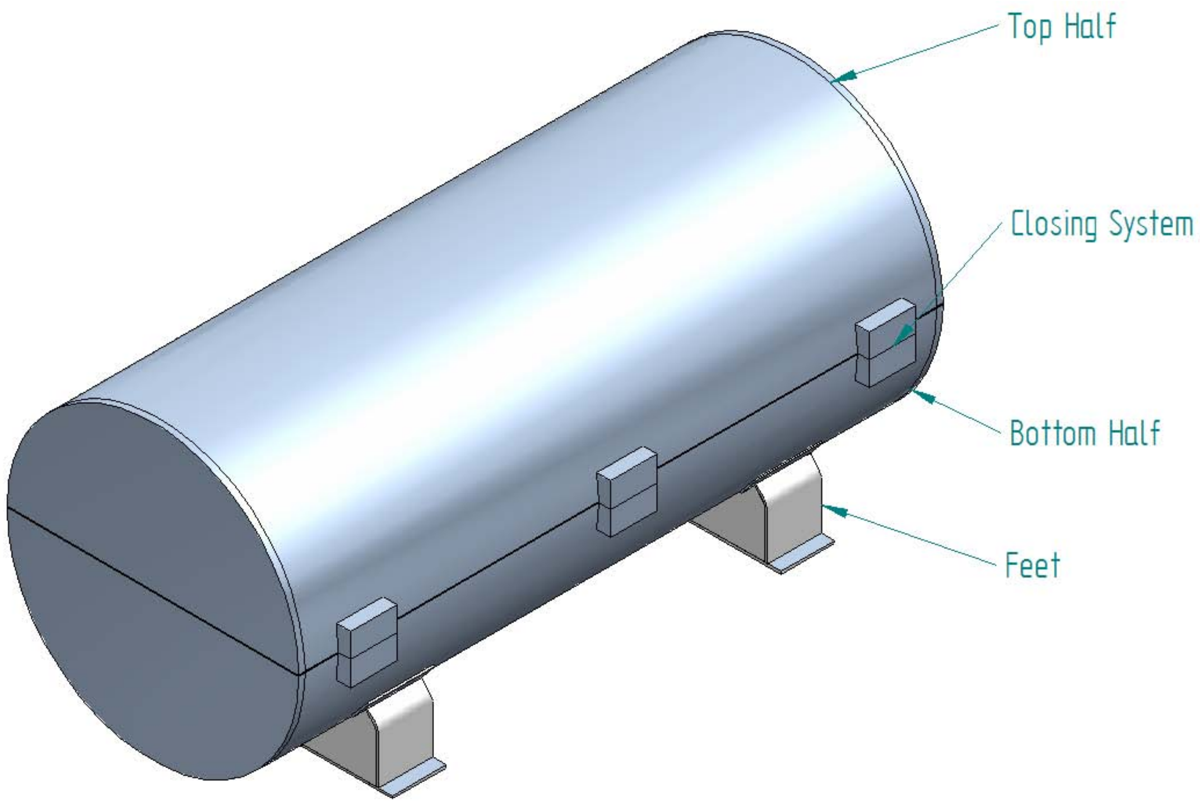

Figure 1: DN 30 with its main components

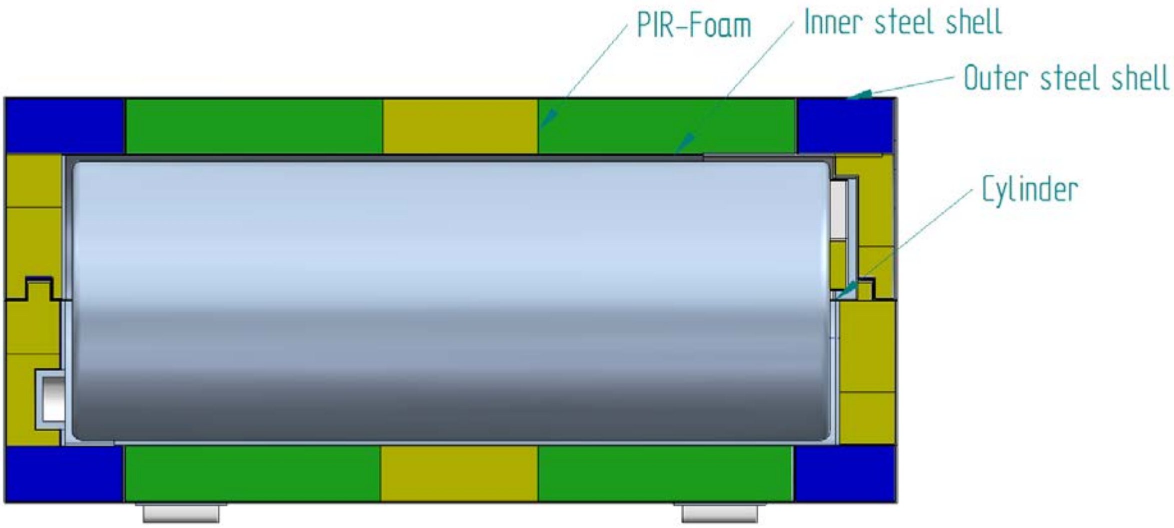

Figure 2: Assembly of DN 30, Cut-Drawing (green: softest foam; yellow: middle hard foam; blue: hardest foam)

PROPERTIES OF PIR

Polyisocyanurate foams (PIR) are a special kind of polyurethane foams (PU) with good resistance to the temperature and fire performance, thanks to the high-crosslinking degree and to the trymer rings chain that provides also higher stiffness and rigidity compared to PU foam.

CORAFOAM RTS is the name of polyisocyanurate foams family (PIR), based on MDI (methane-diphenyl-di-isocyanate) produced by DUNA-Corradini continuous foaming process. Corafoam RTS foams are 100% CO_2-blown, granting a full compliance with Montreal Protocol and any other regulation regarding environmental protection.

CORAFOAM RTS foams can be considered almost isotropic materials, showing practically the same mechanical properties along all directions (see Figure 3). This is a typical compressive stress graph where it is shown that the parallel to cells growth and perpendicular one behavior are almost completely overlapped.

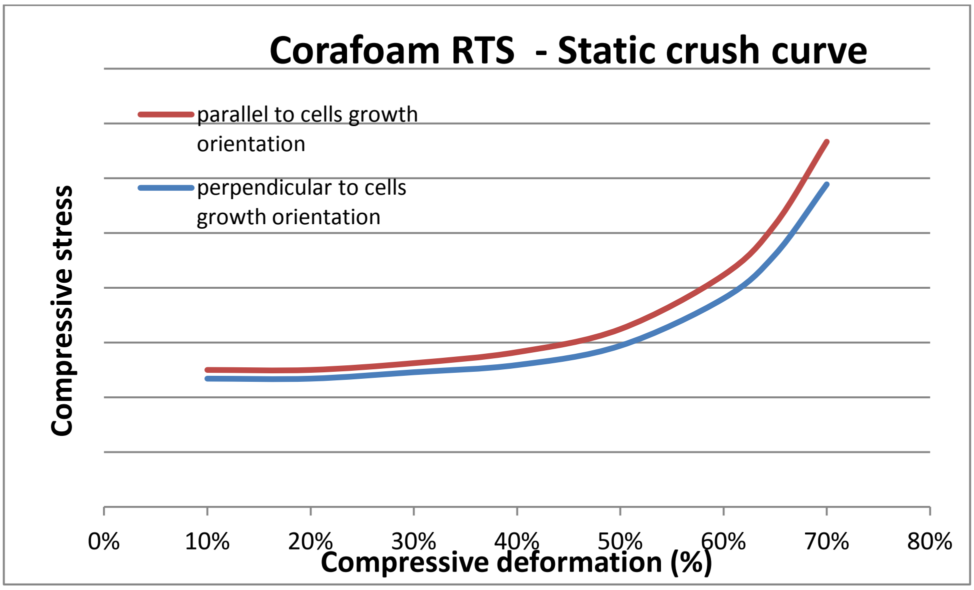

Figure 3 Static compression strength; Comparison load parallel / perpendicular to cell growth orientation

TEST PROGRAM

To investigate the properties of PIR foam in dynamic conditions comparable to these conditions, which will occur during the drop tests of the DN 30, an extensive test program was carried out. The following tests are part of this program:

- **Dynamic drop tests on unframed samples**
  These tests were carried out to get a first idea of the mechanical behaviour of PIR foam in dynamic conditions. These tests were used for the design of the DN 30 to choose the type of foam and adjust the assembly.
- **Dynamic drop tests on framed samples**
  Samples which were put in a tube made of stainless steel were used to carry out this test series. A frame was used to avoid the lateral expansion of the foam during drop tests. This situation correspondences with the setting in the DN 30, because also here the foam is surrounded by steel which means the expansion perpendicular to the drop direction is restrained. These tests were carried out with all kinds of foam used in the DN 30 in dependence of the foam orientation (perpendicular and parallel to its production way) and in a temperature range from – 40°C to + 80°C. The drop height was 9 m for all drops in accordance with the 9 m drop of the PSP. The drop weight was adjusted to the expected compression strength of the samples. The height of the samples was chosen equal to the thickness of the foam layer in the DN 30 with 160 mm.
- **Quasi-static compression tests on framed samples**
  As a comparison to the dynamic tests, these tests were carried out. So the influence of the dynamics was investigated. These tests were also performed with samples in both directions (perpendicular and parallel to its orientation) in the same range of temperature.
- **Influence of humidity**
  To evaluate the influence of humidity, compression tests with dry samples and samples which were stored in an atmosphere with 100% humidity for a long time were carried out.
- **Influence of cumulative loads**
  The influence of cumulative load was investigated by a drop tests with a height from 1.2 m followed by a drop test from a height of 9.0 m on the same sample. These results were compared to a single drop from 10.2 m height.

MEASUREMENT OF EXPERIMENTAL DATA

Dynamic drop tests

Specimens where conditioned for at least 12 hours in a cascade refrigerator in case of -40° C and -20° C and in a convection oven in case of +50° C and +80° C, respectively. The specimens for +20° C were conditioned in a climate chamber at +20° C and 60 % relative humidity for at least 72 hours. The specimens were removed directly prior the tests. The cumulative load tests were performed under ambient temperature.

In order to obtain the load a special load-cell based on strain gauges was used. Displacement was measured with an electro-optical (Zimmer) extensometer which measures the displacement of a black and white target using the image converter method. Additionally a redundant displacement-measurement was done by using a laser distance sensor based on the triangulation-method. The impact velocity was captured by radar.

Acceleration was measured with a piezoelectric accelerometer which has a range of ±5000 g and a natural frequency of 20 kHz. The used charge amplifier had a lower cutoff frequency of 16 Hz. The acceleration signal was used to validate the force-measurement by multiplying the signal by the mass of the drop-weight. Furthermore the double integrated acceleration-time curve gives a further check of the displacement.

The data were recorded by using a data acquisition system, type ESAM Traveler CF with a sampling rate of 100 kHz. The test setup is shown in Figure 4.

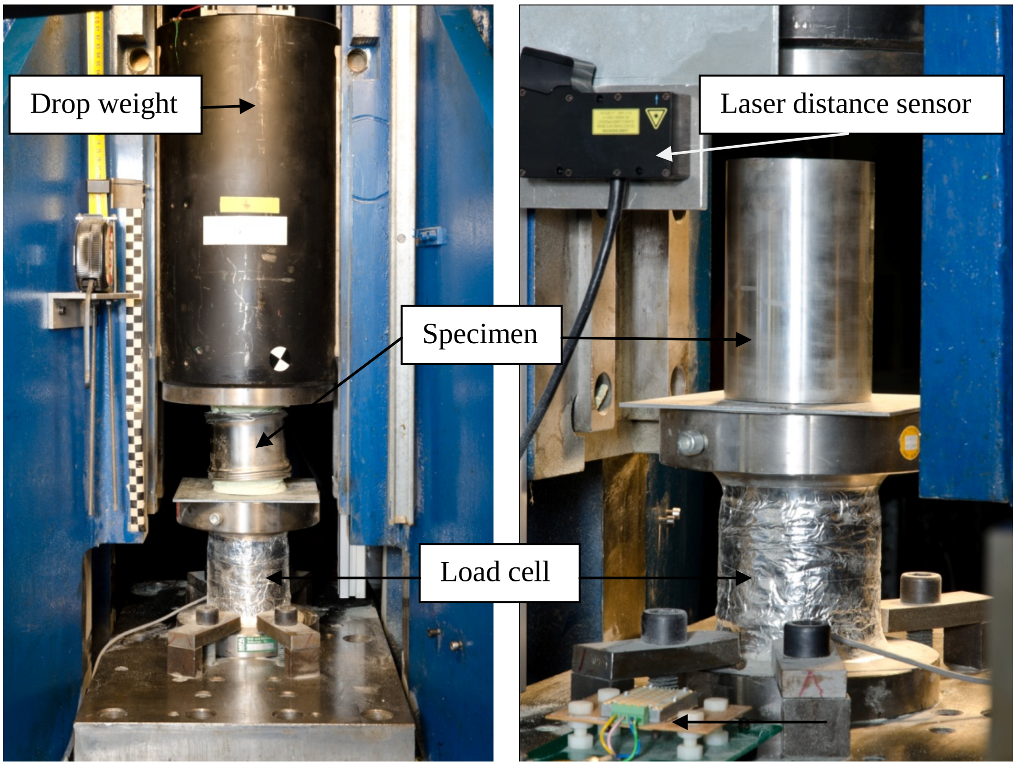

Figure 4 Test setup for the dynamic drop test – left: front-side – right: back-side

Quasi-static compression tests

Test with compression load were performed at a servo-hydraulic testing machine of the type MTS 2250 kN with 2.2 MN load capacity and integrated load cell. The machine was driven displacement-controlled with a constant displacement rate of 1.0 mm/s. The specimens were fixed between two plane steel plates. The maximum displacement was chosen in that way, that the strong increase of force at the end of the force-displacement-curve is captured. Displacement is measured by a cable position transducer.

For each test temperature the specimens were conditioned in a climate chamber for at least 12 hours and removed from the climate chamber directly prior to the test.

RESULTS

Humidity

Tests carried out on foam samples in 100% humidity conditions showed that the moisture does not influence the PIRs compression strength. As shown in the table below, the differences between the values are not relevant in statistical terms.

Direction of load	**Standard conditions; 296 K, 50% humidity**	**100% humidity for 10 days at room temperature**
Parallel	1	0.976
Perpendicular 1	1	0.982
Perpendicular 2	1	0.972

Table 1 Experimental results of static compression strength, influece of humidity, nominized average values

Comparison of framed and unframed samples

Figure 5 shows dynamic drop tests on samples with a frame and samples without a frame. The samples were cylindrical ones with a height of 160 mm (equal to foam thickness in DN 30). Figure 6 shows the configuration for the framed samples.

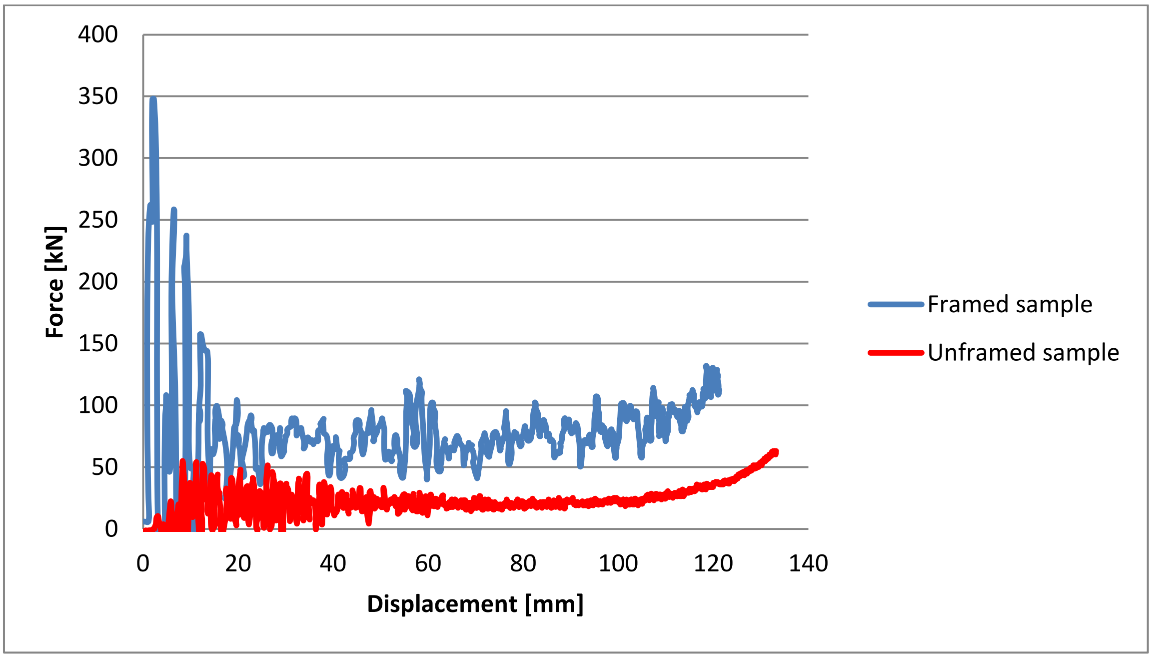

Figure 5 Compression test on framed and unframed sample

The frame influences the results of the drop tests in two ways: On the one hand the samples become stiffer due to the additional steel (for this kind of foam approximately factor 3), on the other hand the curves show more peaks in contrast to the smooth trend of the unframed samples. This effect does not only appear because of some high frequently forces but mainly because of the folding effects in the frame. Furthermore the zone of increasing forces after the constant compression force is reached earlier because the expansion perpendicular to the drop direction is restrained.

Figure 6 Framed sample, used for compression tests

Comparison static and dynamic compression strength

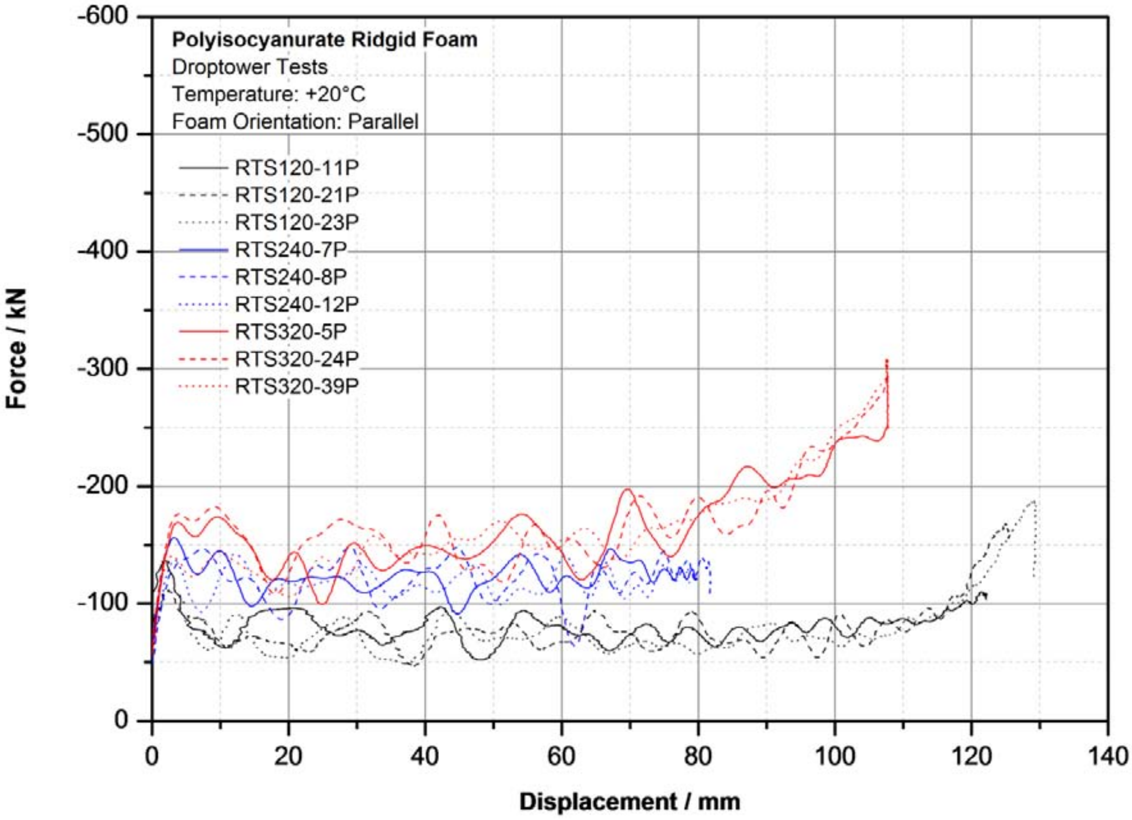

Figure 7 Force – Displacement curves for three kinds of foam, dynamic drop tests

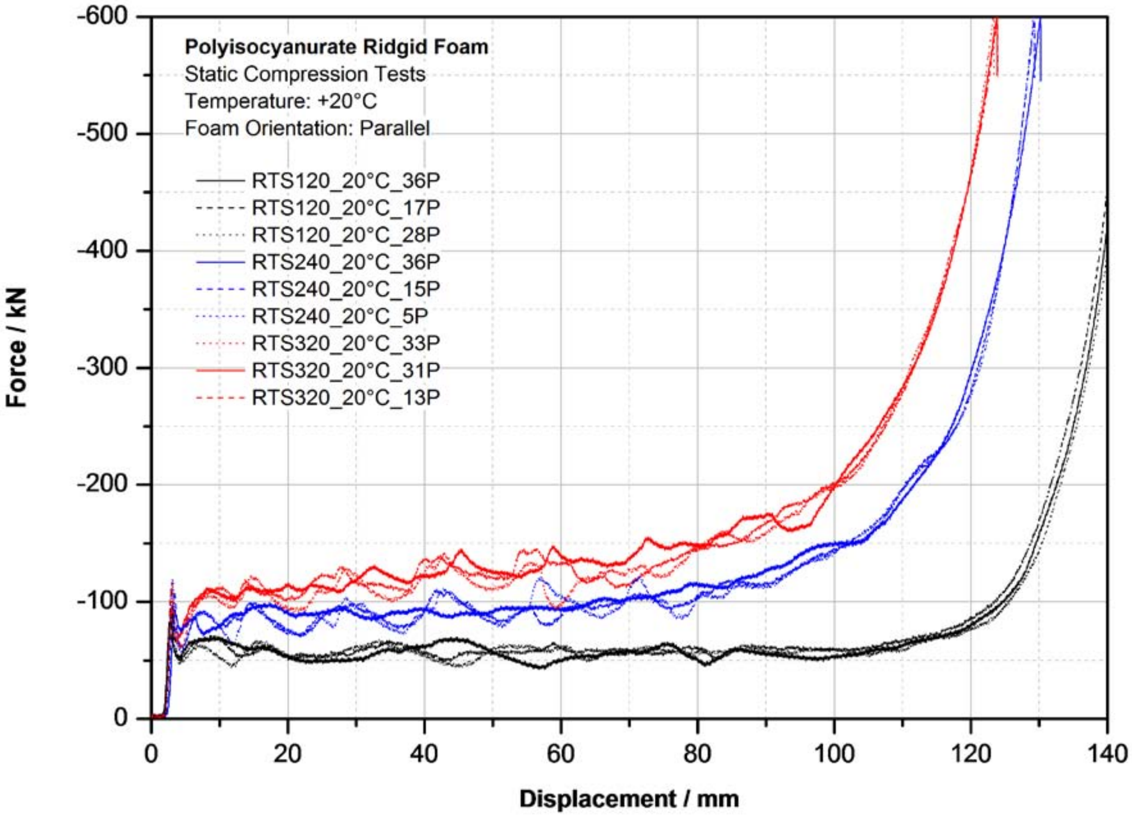

Figure 8 Force – Displacement curves for three kinds of foam, static compression tests

A comparison of the compression force is given in Figure 7 and Figure 8 for all kinds of foam used in the DN 30 PSP. The dynamic data result from a 9 m drop on the samples, the force signal was smoothed with a low-pass FFT-filter of 2500 Hz. The dimensions of the samples were equal.

The curves for static and dynamic compression are quite similar. After a zone of linear increasing forces (to approximately 3 mm) the force stays constant for a huge way of deformation until the force increases quickly again beginning from approximately 100 mm. The total height of these samples was 160 mm.

Because of the dynamic effects, the samples react stiffer in these conditions. The stiffening factor between static and dynamic conditions is around 1.5 for all kinds of foam tested in this way.

Influence of temperature

CORAFOAM RTS foams, due to their chemical structure and to the high crosslinking degree, present a very good thermal resistance: the graph below shows figures as function of temperature, where even in critical conditions these PIR family preserves more than 60% of the compressive strength value at standard conditions.

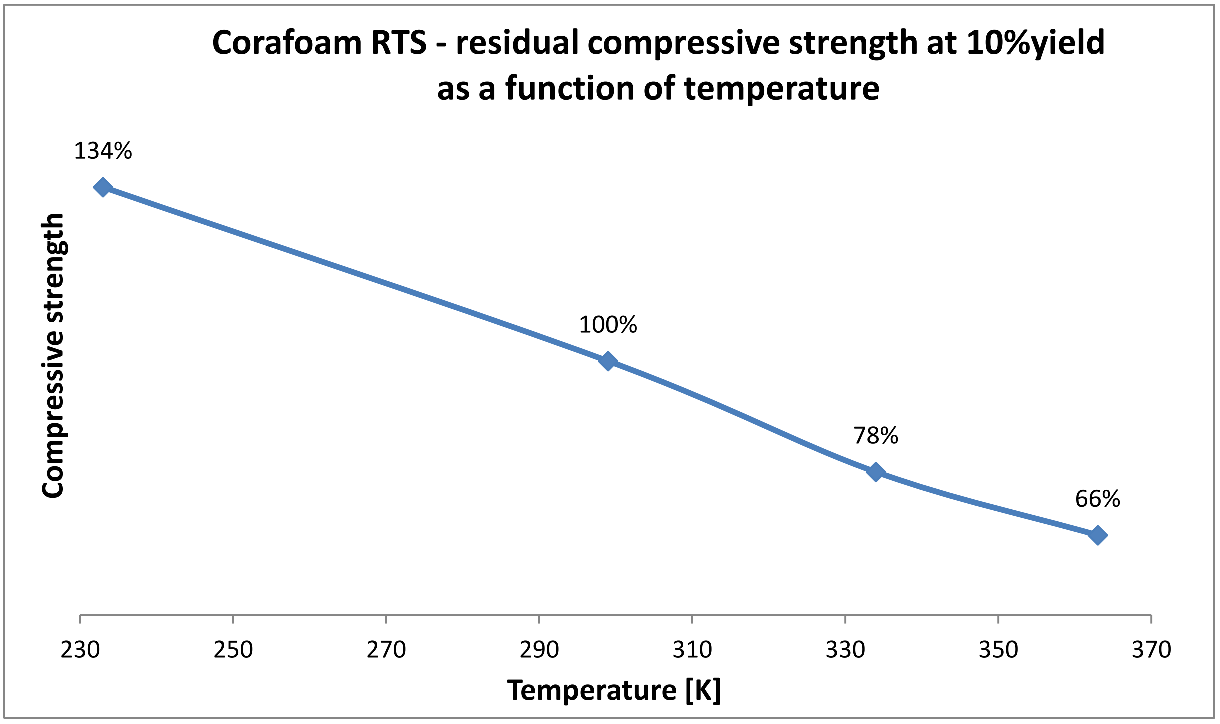

Figure 9 Temperature dependence of compressive strength in static conditions

The influence of temperature is given in Figure 9 and Figure 10 for static and dynamic conditions for -40°C to +80°C. The temperature dependence is linear in both conditions, for lower temperatures as well as for higher temperatures. The increase or decrease in the compression strength is moderate for both conditions with approximately 1/3 of the compression stress for ± 60°C.

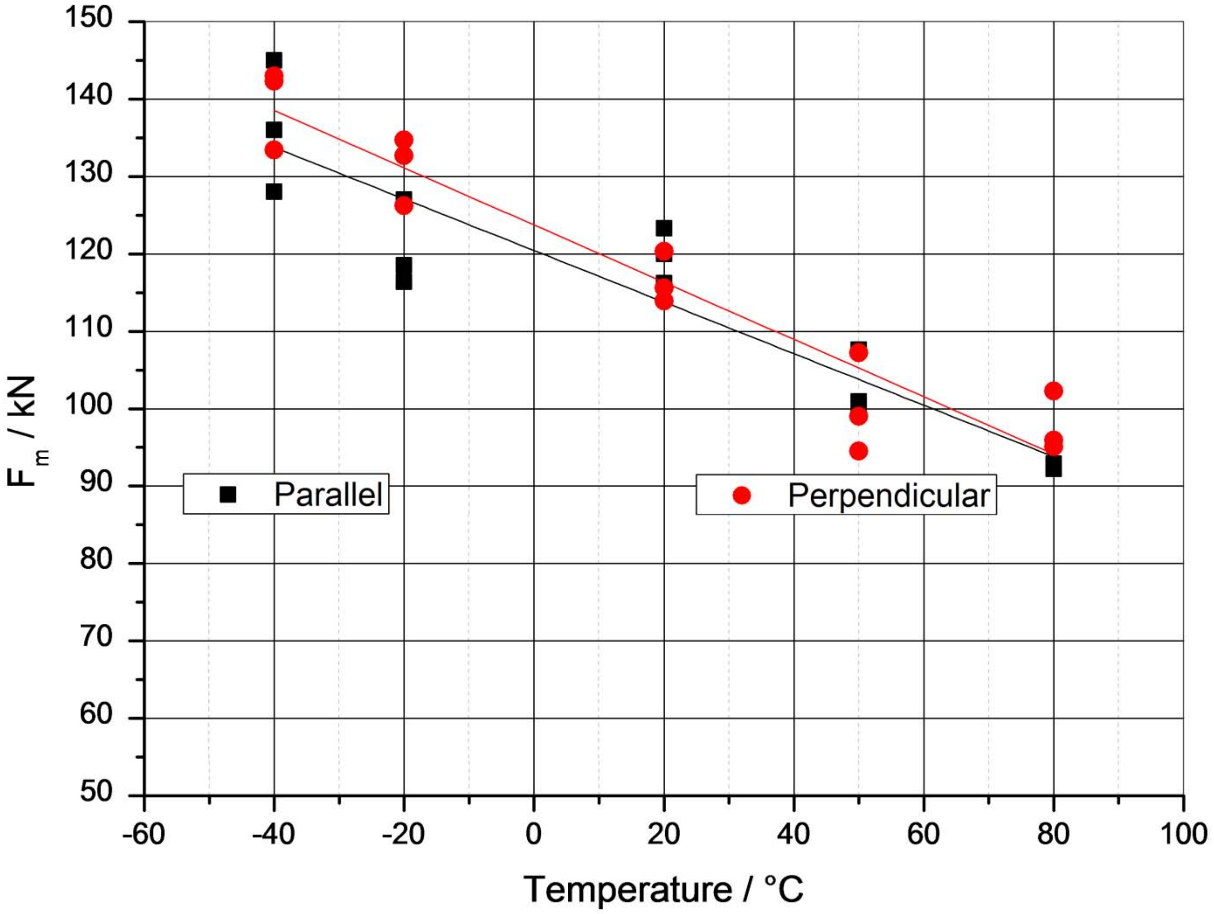

Figure 10 Temperature dependence of compressive strength in dynamic conditions

SUMMARY

An extensive test series was developed and carried out by DAHER-NCS, DUNA-Corradini and MPA to investigate the mechanical behavior (compression strength) of PIR foam in static and dynamic conditions. In these tests the influences of temperature, foam cell orientation, humidity, cumulative loads and a frame around the foam were taken into account. The tests showed a great reproducibility and only a small dependence of the parameters humidity and temperature. Because of this, the foam has excellent properties for its use in the DN 30 PSP, where it acts as shock absorber and thermal insulation.