

Body Lightweight Design and Scalability with Structural Foam Solutions

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ABSTRACT

In this paper polymer structural foams are being investigated in body structure applications. There are two major polymer foam technologies for structural applications: the well-known epoxy based insert solutions and the PUR injection foams.

Here we focus only on the PUR injection foams and its structural applications. It will be shown where such structural foams can be applied in the body structure in order to enable lightweight design or to scale the structural performance. Reliable CAE methods for crash simulation as well as several body structure application examples will be presented and evaluated.

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INTRODUCTION

Weight reduction is one of the key enablers in vehicle design to reduce fuel consumption and CO₂-emission. The biggest weight reduction potential in a vehicle can potentially be found in the body structure. Therefore in all areas of vehicle research and development new materials and related manufacturing and joining technologies are under investigation.

On the other hand there is a trend in the automotive industry to build more and more derivatives on one common platform, including heavy battery electric and hybrid powertrain vehicles. This means, that the body structure must ensure attribute performance for the lightest, but also for the heaviest variant. It is obvious that there must be some kind of structural overdesign of the structure for the lightest derivative. In order to avoid overdesign, design solutions that enable structural scalability can be applied.

For both areas, lightweight design and structural scalability, the group of the porous materials show large potential.

In nature most of the materials, which can be observed, are porous materials. Wood, cork, sponges and bones are some examples. The development of such natural porous materials has many reasons. The main driver is the principle

of minimal use of material and weight in order to achieve a high stability of the final structure.

For vehicle applications polymer structural foams can be used in volume production. Two major polymer foam systems are in use for high volume vehicle production:

1. Insert solutions: plastic or metal carrier with heat-activated expandable structural adhesive (after expansion called "structural foam") on the outer side, applied in the body shop during body assembly. The adhesive expands in the EC paint oven and connects to the surrounding metal structure to build a local reinforcement.

2. PUR injection foam solutions: the PUR foam is being injected in the body structure after the paint shop and before wax application, expands, connects to the surrounding structure and hardens to build a local reinforcement.

In this report we focus only on the PUR injection foam solutions. The foam selected for all the investigations is structural foam of 380g/L density from the company DOW, called BETAFOAM™ (source: DOW: 89100-89124 technical data sheet, /1/). BETAFOAM™ 89100 and BETAFOAM™ 89124 are two components (see Fig. 1) used to make a high-density, all-water blown rigid polyurethane foam.

Foam is produced by the rapid mixing of both components under high shear conditions. The foam has



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adhesion to primed metal surfaces. Some typical mechanical properties of PUR injection foam in injected condition are shown in Fig. 2.

Composition	BETAFOAM® 89100	BETAFOAM® 89124
	MDI based Urethane Pre- polymer	Polyether/ Polyol Blend

Fig. 1. Composition of PUR injection foam /1/

Density	g / L	380
Young's Modulus	MPa	200
Compression Strength (at 20% compression)	MPa	7
Confined Compression Strength (at 20% compression)	MPa	12
Failure Strain in Tension	%	6

Fig. 2. Typical properties of PUR injection foam /1/

BETAFOAM™ 89100 and BETAFOAM™ 89124 can be pumped from bulk containers into heated meter mix and dispense equipment (see Fig. 3). The proper mix ratio is in turn dispensed manually or robotically through an impingement mix gun into the body structure and fills out the requested cavity. Local ventilation might be recommended while dispensing this system /1/.

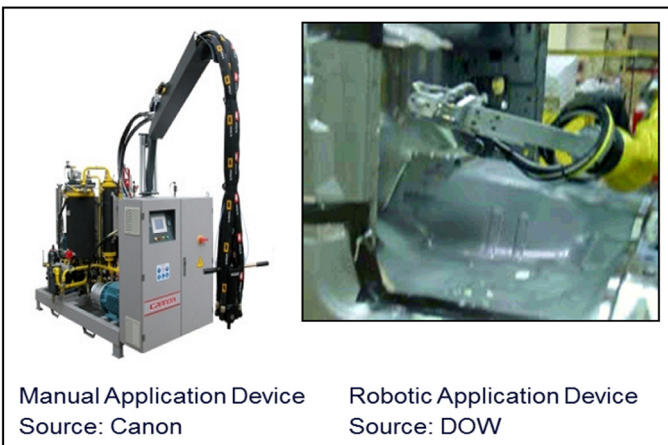


Fig. 3. Typical application devices

In this paper BETAFOAM™ 89100/89124 is used to locally increase the strength and section capacity of automotive body structures or to scale the performance or enable lightweight design solutions. In this case the foam enables down gauging of the surrounding metal structure. Some typical application areas within the body structure are highlighted in Fig. 4.

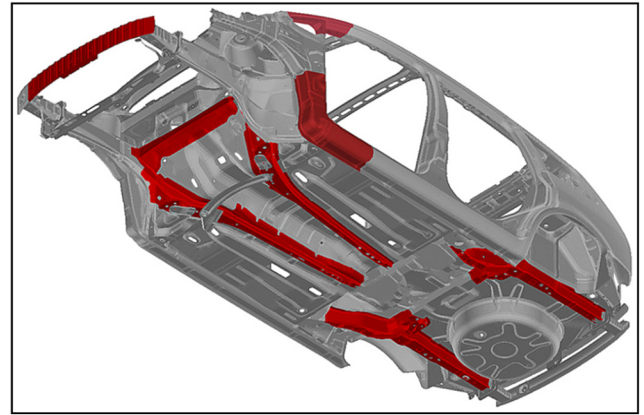


Fig. 4. Typical foam application areas in the body

BASIC INVESTIGATIONS ON PUR FOAM

Several material characterization tests have been performed with the target to understand the mechanical properties of PUR injection foams and to develop reliable CAE methods: static and dynamic compression tests on foam cubes, tensile tests on dog-bone specimens and confined compression tests on cylindrical samples (see Fig. 5).

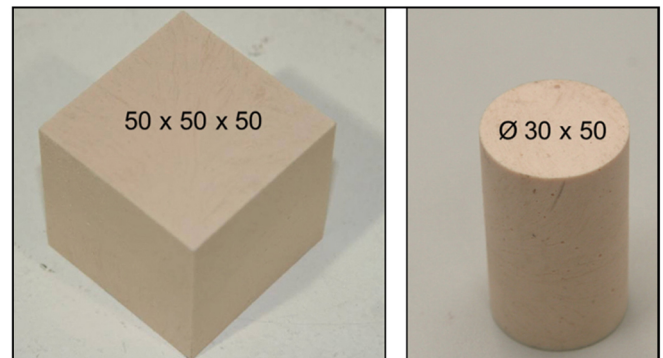


Fig. 5. Foam test samples (dimensions in mm)

In Fig. 6 the test setup for the compression tests and a tested sample are shown.

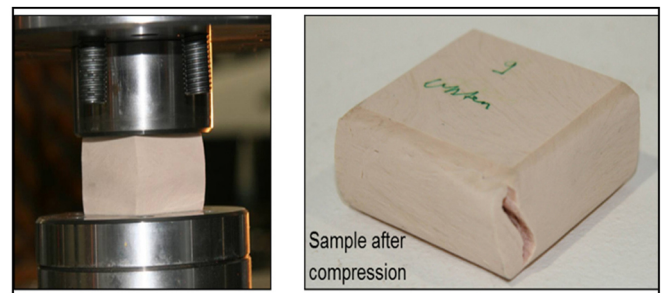


Fig. 6. Compression test set-up and tested sample

Additionally drop tower tests have been performed on foam cubes (Fig. 7.) in order to understand the high strain rate behavior which can occur under impact conditions. Compared to the quasi-static compression tests, the results of the dynamic tests show a higher initial resistance, but also a sudden failure. The failure is caused by sudden compression of the entrapped air, which builds up a high pressure in the closed cell foam.

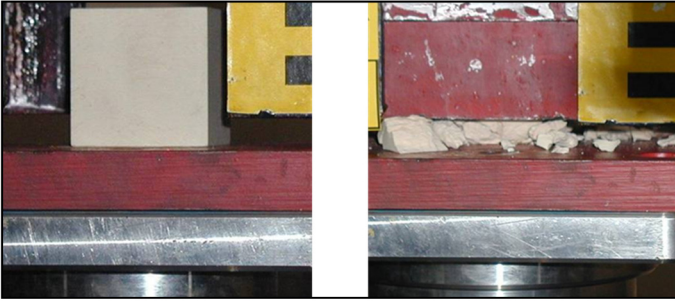


Fig. 7. Foam cube before and after impact test

CONFINED COMPRESSION TESTS

Confined compression tests on cylindrical samples have been done to simulate the behavior of structural foam under confined compression conditions in the body structure. Confined compression may exemplarily occur if the foam is sitting in a closed sheet metal section (all outer foam walls are directly in contact with the surrounding metal structure) and the structure is loaded e.g. during crush testing.

For the confined compression test, the cylindrical sample (Fig. 8) is located completely in a cylindrical hole and then axially compressed by a cylindrical punch.



Fig. 8. Test sample ($L=50\text{mm}$), before and after test

The stress-strain curve of the confined compression test is similar in shape with the free compression curve, but the plateau strength in confined compression is approximately 60% higher than in the free compression test. In Fig. 9 the normalized compression stress (normalized by the free compression stress) is shown. This effect caused by hydrostatic pressure will be taken into account for CAE investigations.

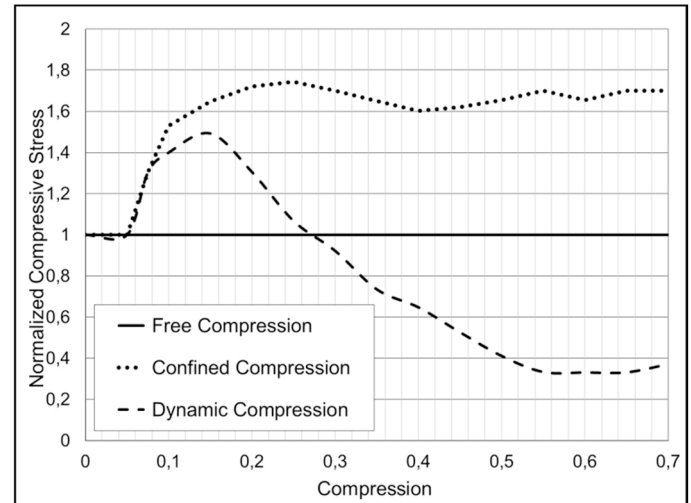


Fig. 9. Physical test results on PUR foam specimen

TENSILE TESTS

A new type of test specimen has been designed to perform pure tensile testing. The specimen geometry takes into account that a certain minimum amount of foam (some 500 ml) must be injected during a single injection shot. Therefore the developed cylindrical dog-bone like specimen has a relatively large size and volume (Fig. 10). Two samples are produced in a double attached tool in one injection shot.

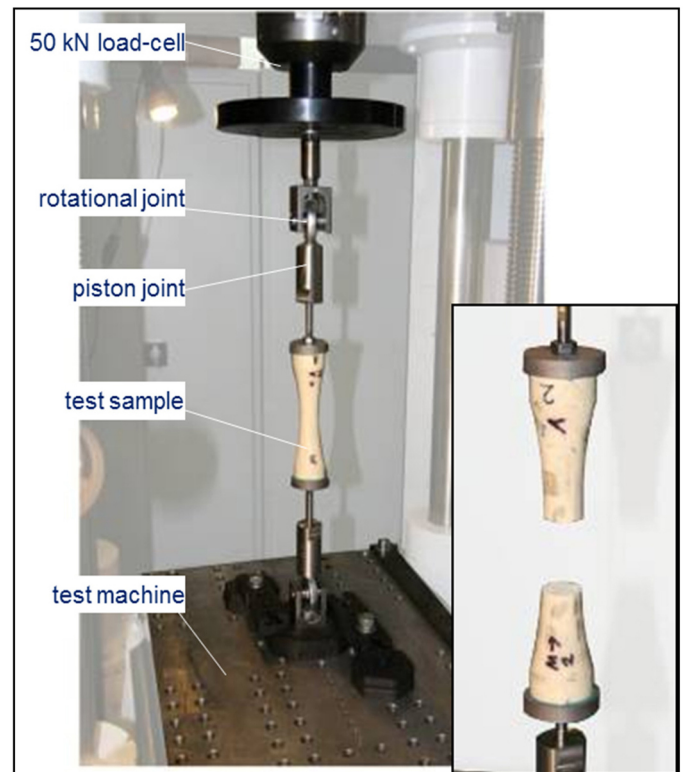


Fig. 10. Tensile sample (170mm length, 30mm dia.)