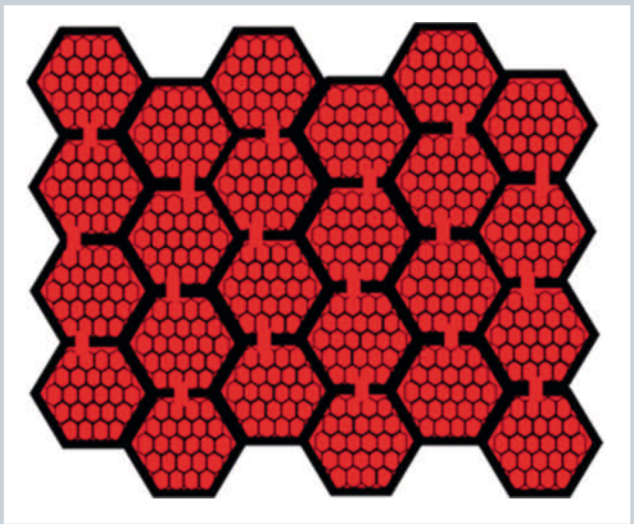
Multifunctional Hybrid Foams



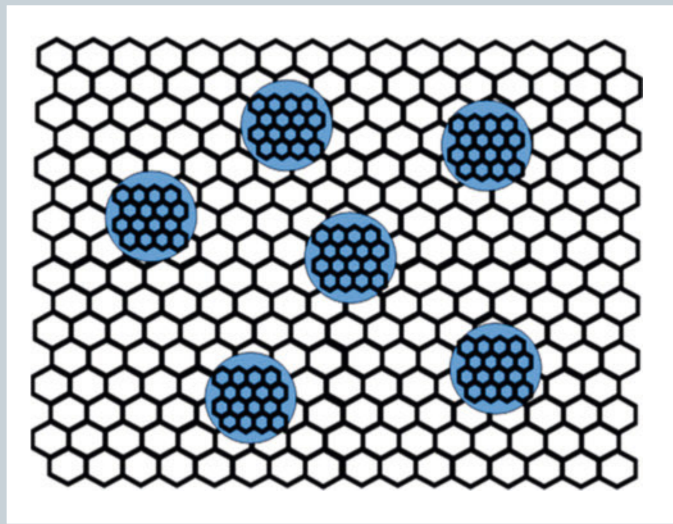


Fig. 1. The researchers developed new technologies for interpenetrating (left) and particulate hybrid foams (right) (figures except Fig. 2: Fraunhofer ICT)

New Applications. Today, foamed materials are crucial to many everyday products. Innovative hybrid foam solutions open up possibilities for significantly increasing the applications scope of this class of materials.

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Foamed materials are not only lightweight; they also often have many technically interesting properties, such as a high specific stiffness and good energy absorption capacity. Steadily growing technical and legal requirements mean that foamed monomaterials, for example when used as crash elements in cars, are reaching their limits. As part of a research project, the Fraunhofer Institute for Chemical Technology (ICT), over many years of working together with four partner institutes (**Table 1**), developed hybrid foams that significantly extend the application limits of foams. The successful material combination in each case is not only implemented at part level, but already at the material level.

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For this purpose, the researchers developed new technologies for interpenetrating and particulate hybrid foams (**Fig. 1**). Besides metal/ceramic hybrid foams, polymer-based hybrid foams are also gaining in potential when it is necessary to satisfy requirements that are already fairly contradictory – for example the combination of plastic and elastic deformability at very different energy levels. The particulate hybrid foams that are described here permit this functional integration with hardly any constraints on the geometrical formability.

Fig. 2. The foamed aluminum particles (APM) are encapsulated with polymer foam (photo: Fraunhofer IFAM)

Combinations of Metal, Ceramic and Polymer Foams

The basis of the particulate hybrid foams is the particle foam technology that is currently familiar primarily from processing expanded polystyrene (EPS) and expanded polypropylene (EPP). Products made from these monomaterial foams are predominantly used in thermal insulation (e.g. building insulation and insulated packaging) and in mechanical shock absorption (e.g. motorbike crash helmets, bumpers, packaging technology). Such applications exploit the special advantages of these materials, such as

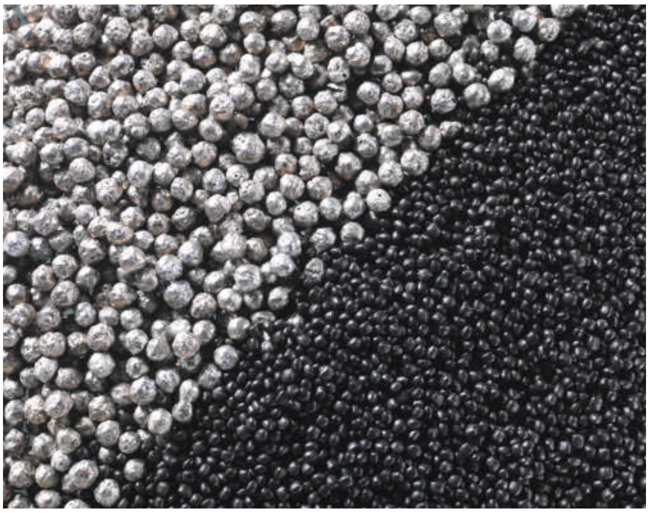

Fig. 3. The hybrid foam materials APM and EPP are stored separately in silos and only mixed together during the feeding process

Institute	Project contribution
Fraunhofer Institute for Chemical Technology (ICT), Pfinztal, Germany	Polymer foams and project coordination
Fraunhofer Institute for Manufacturing Technology and Advanced Materials (IFAM), Bremen, Germany	Metal foams and material simulation
Fraunhofer Institute for Mechanics of Materials (IWM), Freiburg, Germany	Testing and simulation
Fraunhofer Institute for Silicate Research (ISC), Würzburg, Germany	Interface modification
Fraunhofer Institute for Ceramic Technologies and Systems (IKTS), Dresden, Germany	Ceramic foam

Table 1. Five Fraunhofer Institutes are working hand-in-hand on this project

- low weight,
- good 3-D formability,
- high specific mechanical properties,
- good thermal insulation, and
- good mechanical damping capability.

As a result of the joint research project, technologies are available for combining the aforementioned advantages of the polymer foams at material level with the properties of foams from other material classes in a multicomponent material. Thus, with a highly developed processing technology, polymer foams can be supplemented with very varied properties, such as the greater strength and energy absorption of metals or the high thermal resistance and stiffness of ceramics by combining EPS or EPP with ceramic and metal particle foam structures.

The combination of metal and polymer foam particles described in greater detail below is most impressive for its properties. The two together, because of their material-specific stiffnesses, combine a very different energy absorption capacity at two different force levels in one component. Besides traditional foamed PP particles (EPP), the material combination is also based on metal particle foams, including advanced pore morphology (APM) **(Fig. 2)**.

Metering and Feed Equipment for Particulate Hybrid Foams

To combine the two materials together, the project partners have refined a molding process that is currently used for the industrial production of EPP/EPS parts. The specific challenges in combining metal and polymer foam particles are primarily the result of

- their widely differing densities and the resulting sedimentation phenomena during mold filling,
- their different flow and filling behaviors,
- the stiffness of the metal particles (problems of bridging),
- wear of the filling equipment, and
- surface adhesion of the material classes to one another (plastic/metal).

	EPP	APM 7
Manufacturer [-]	–	Fraunhofer IFAM
Material [-]	PP	AlSi7
Diameter [mm]	~ 3	~ 7
Bulk density [kg/m³]	65–75	350–370

Table 2. These two materials were processed into a polymer/metal hybrid foam using a modified automatic molding machine

The key points of the development work were the analysis and optimization of the filling behavior and the process control during part manufacture on an automatic molding machine used for the studies (manufacturer: Erlenbach GmbH, Lautert, Germany). The foams used for manufacturing particulate foams (EPP and APM, **Table 2, Fig. 3**) are stored separately in silos on the modified line and only mixed together during the feed process. The aim of the development was to optimize the mix and filling processes in order to reproducibly manufacture particulate hybrid foams.

As a central element, novel metering equipment was developed for generating homogeneous mixtures with a precisely preset ratio between the polymer and metal particles. Additionally, the filling injector of the pneumatic feed system was adapted to permit a stable process, even with large (up to 10 mm diameter), non-elastic aluminum foam particles.

As a result, the enhanced hybrid foam process was suitable for achieving a particular morphology and defined mechanical and physical properties. The potential of the process can be illustrated using crash parts made of particulate hybrid foams bonded by injection-molded semi-encapsulation **(Fig. 4)**.

Optimized Particle Adhesion

The adhesion between polymer and metal foam particles requires particular attention. Besides the integration of the metal particles by encapsulation with

Fig. 4. The crash demonstrator consists of particulate EPP-APM hybrid foam bonded with an injection-molded semi-encapsulation

polymer foam (interlocking adhesion), the interfacial adhesion between the two materials in the project was optimized and thereby the fixing of the metal particles in the formed part was increased, which leads to improved part integrity, particularly under strong part deformation.

Consequently, a new process technology for applying polymer adhesion coatings to the aluminum particles was developed. The adhesion promoters that were applied permit significantly easier processing and, most of all, better integration of the functional metal particles.

Simulation of Hybrid Foams

In many end applications, particularly automotive engineering, predictability of the part properties by structural simulation is an important prerequisite for the industrial introduction of new materials. The project participants took account of this by extending the existing tools for predicting the "effective" macroscopic properties of foams with a prediction model for simulating hybrid foams. Based on a homogenized structure of the monomaterials involved, numerical determination of the macroscopic mechanical and physical properties is possible over a wide mixing range of the material components involved.

The quality of the simulation was demonstrated by comparing the simulation results with the part properties actually obtained. The tools that were developed are of course also suitable for predicting the properties of monomaterial foams.

Applications in Multifunctional Crash Elements

Using the new processing technique described above, the foam core of a crash element could be produced with a largely homogeneous mixture of metal and polymer foam particles (**Fig. 4**). This technology demonstrator provides an excellent example of the advantages of particulate hybrid foams. It combines elastically flexible deformability at a material level and plastic energy absorption at high forces (**Fig. 5**). The elastic deformation of the EPP particles elastically and reversibly absorbs, e.g., the forces of a light impact during parking a car. The deformation only takes place in the polymer foam component.

In the case of a higher-energy crash (**Fig. 5**, lower two loading cases), the metal particles come into contact as a result of the more severe deformation. Due to the supporting function of the surrounding injection molded shell, the significantly stiffer metal particles can no longer slide over one another under this strain, and absorb a large proportion of the crash energy through their deformation. The resulting shape change is plastic and therefore irreversible. In this high-energy crash case, the polymer foam only performs a shape-giving role and prevents the crash element from falling apart after the external load is removed (central crashed element in **Fig. 4**).

The deformation behavior of the particulate metal/polymer hybrid foam in this low-compression area is similar to that of a pure polymer foam (**Fig. 6**), is this case made of expanded polypropylene (EPP). Only when the deformation displacement that is available in the EPP volume component has been largely used up does the force level increase significantly. In cases with a 50:50 mixture with metal particle foam (APM), this transition takes place at about 40 % total deformation, since the polymer foam component is already approximately 80 % compressed here – the deformation at which a further compression of the pure polymer component already presupposes high forces and, primarily, the metal particles begin to come into contact with one another, and thereby the second phase of the metal particle deformation begins.

If such a hybrid foam continues to compress, the force level increases strongly. A large degree of energy is absorbed by the initial plastic deformation of the metal particles. For example, the force level at →

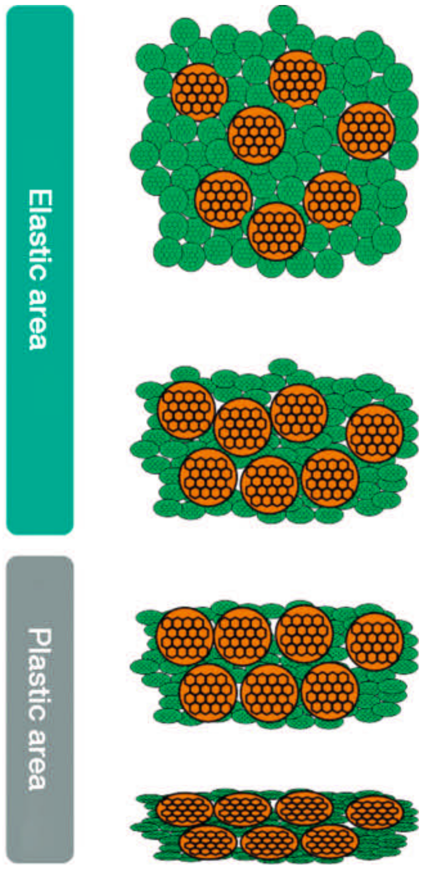

Fig. 5. Schematic two-stage deformation behavior of particulate hybrid foams. Elastically flexible deformability at a material level is combined with plastic energy absorption at a high force level

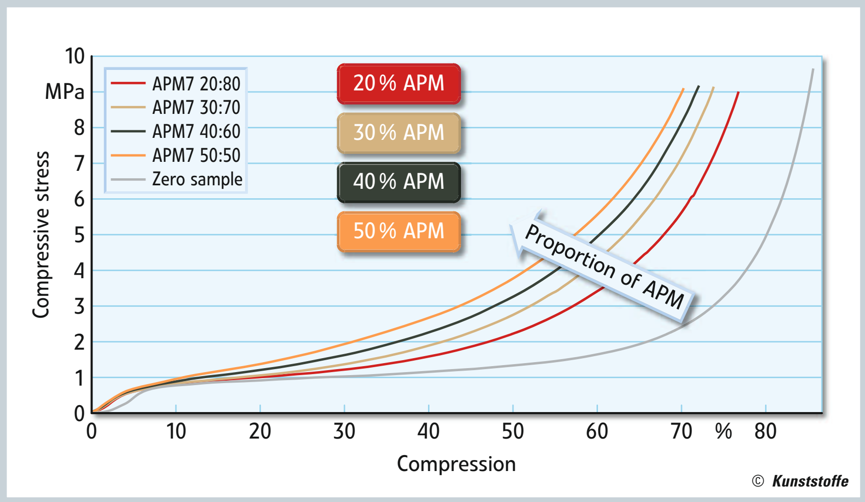

Fig. 6. Stress-compression diagram of the hybrid foams of different APM contents in the compression test. Only when the deformation displacement that is available in the EPP volume component has been largely used up does the force level increase

60 % total deformation lies at approximately six times the level of pure EPP foam. At 20 % deformation, the force level is only at 1.4 times that level, which particularly illustrates the multistage energy absorption of the hybrid foams.

Summary

The hybrid foam variants presented here open up completely new application areas. Varying the material composition allows the deformation behavior to be adjusted within a wide range. The particulate polymer/metal hybrid foams that have been developed thus offer large potential for smart, multi-stage energy absorption in crash applications. ■

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