Hybridfoams - a new approach for special applications

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1 Introduction

Hybrid foams are a new advanced type of cellular materials and defined as combination of two mono-material foams of different material classes (polymer, metal and ceramic) which are connected on a macroscopic level. Such hybrid foams can be classified in two different types depending on the structure: at first the interpenetrating hybrid foams where the foamed materials are in a co-continuous state and secondly particulate hybrid foams where one foamed particulate material is embedded in a foamed matrix [1].

Due to their high volume fraction of voids and the resulting high compressibility foams are advantageous materials for impact absorbing or protection systems as well as lightweight core material in sandwiches. Apart from there high specific mechanical values, the absolute values of strength and stiffness just as the deformation behavior has to be adapted with respect to the applications. Furthermore, the integration of additional non-mechanical functions will get more importance. For that purpose, thermal and acoustic insulation or vibration damping might be realized by the use of cellular materials. Each mono-material foam exhibits specific properties (Fig.1) [2]. With the approach of hybrid-foam synergetic effects are expected: higher values of relevant properties, some additional properties and new property combinations may be realised for enhanced multi-functionality of the material and the final product.

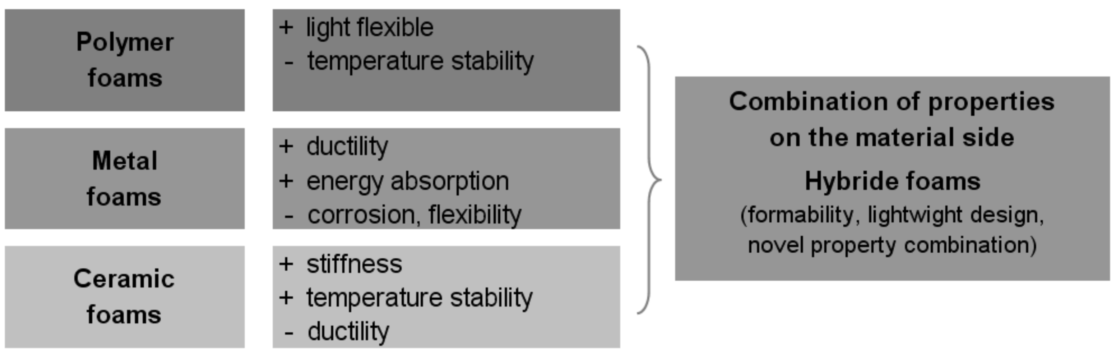

Figure 1. specific properties of the mono material foams

In the following, one approach to generate interpenetrating hybrid foams is introduced. As host foam open cell steel foam is used and all cells of its open cellular structure are interpenetrated either by polymer foam or by new direct ceramic foam [3]. The cell size of the polymer and ceramic foam had to be much smaller than of the steel host foam.

2 Experimental

2.1 Metal host-foam

As mentioned above, open cell steel foam was used as host for polymer or ceramic foam. The manufacturing of the open-cell steel foam was realized by the replica technique, developed at Fraunhofer Institutes Ceramic Technologies and Systems and Institute for Manufacturing Technology and Advanced Materials Dresden as describes by Adler et al. [4]. For the following experiments metal powder from alloyed steel 1.4016 was used with a particle size of d_{90} < 10 µm. After the manufacturing of the green structures, a thermal debindering was followed and structures were sintered in hydrogen atmosphere at 1280°C for 1 hour. Figure 2 shows typical micrograph of the cell-struts with microporosity lower than 2% (Fig. 2) and ferritic microstructure due to the cooling in the furnace (Fig. 2b).

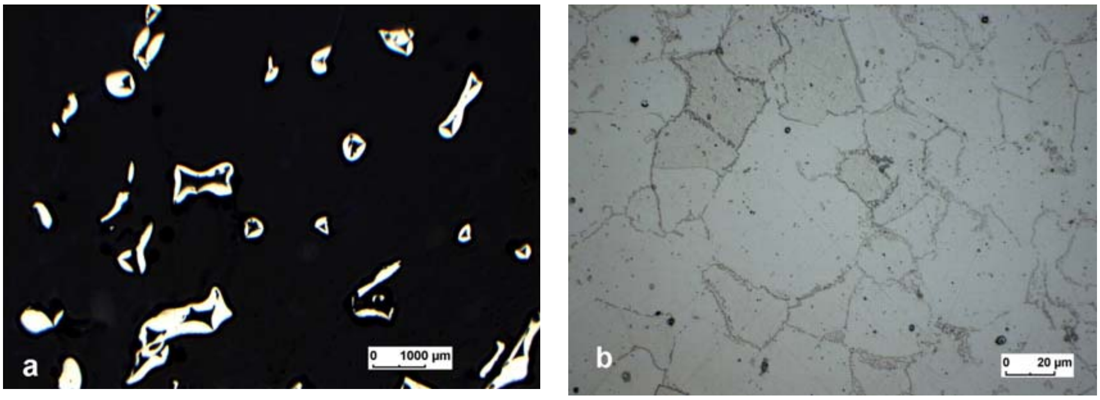

Figure 2. micrographs of sintered (1280°C, H_2, 1h) open cell 1.4016 steel foam, a) cell struts with typical porosity less then 2%, b) typical microstructure, etched V2A-Beize

2.2 Metal-ceramic hybrid foams

For the manufacturing of metal-ceramic hybrid foam samples the direct foamed SiC (DSiC) [3] was incorporate into the open cell steel foam. The process for preparation of DSiC starts with a slurry preparation. The stabilized slurry consists of the ceramic material, water, binder and additives. As ceramic raw material SiC (F360 and NF 2/025, from ESK-SIC GmbH) and a milled borosilicate glass binder (Schott AG) were used. The slurry was dispersed, homogenized and pumped into a foaming device to mixe slurry and gas to the wet foam. The properties of the wet foam allowes penetrating all cells of the sintered steel host foam sample. After drying the wet foam, a sintering process was followed. To avoid the melting of the metal foam while sintering the DSiC, a low sintering temerature of 900°C is realized by the glass binder. As shown in figure 3a, the sintered DSiC forms the interpenetrating foam phase in the metal host foam.

2.3 Metal-polymere hybrid foams

Expandable polystyrene (EPS) is a well known particulate polymer foam and it is used for various applications with different requirements: e.g. as plats isolating the facade of a house, as packing for many consumer product or as crash absorbing materials in sport helmets. The EPS-product receives its final shape in the shape moulding machine. The process consists of the following steps: the pre-expanded and intermediately stored material is transported into the mould, hot steam plastifies the beads and causes them to expand, the individual beads contact each other directly and fuse to form the moulding part.

If open cell steel foam was applied to the mould the polymer beads penetrate into the open cells in the mold filling step. During the shape moulding process, the beads expand and fuse together inside the cells and among each other (Fig 3b). Two different types of EPS were used: EPS 475U (Suncolor® micro, Sunpor Kunststoff GesmbH) and EPS Cup (INEOS NOVA International SA) for the hybrids.

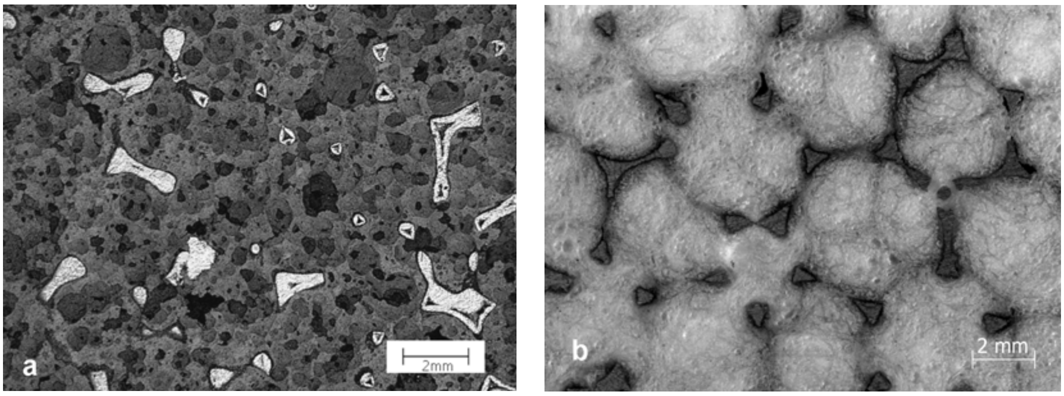

Figure 3. hybrid foams with steel host foam, a) interpenetrating DSiC foam (grey, steel: white) b) interpenetration expandable polystyrene foam (white, steel: dark grey)

2.4 Compression testing

Compression tests were carried out at Fraunhofer Institute for Mechanics of Materials (Halle) on an electromechanic Zwick testing machine. A constant crosshead speed of 0.5 mm/min under standard climate (23°C / 50 % r.h.) was used and the resulting compressive stress vs. strain curves were analysed (Fig. 4, Tab. 1) according to the DIN 50134. Five (EPS three) samples of each material were tested.

2.5 Non-destructive testing by resonace-frequence-damping-analysis

For characterization the damping and Young´s modulus of metal-ceramic hybrid foams the resonace-frequence-damping-analysis (RFDA) was used. At first open cell foam samples (steel alloy 1.4404 and 1.4767) with geometry of approximately 21 x 2 x 5 cm³ were measured, secondly infiltrated with the DSiC and sintered as described above. This steel-DSiC hybrid foam samples were measured as well (Fig. 5).

3 Results and discussion

Figure 4 shows one representing compression stress vs. strain curve of each foam sample: mono material foams (polymer, ceramic, metal) and the hybrids: metal-polymer (MP1, MP2), metal-ceramic (MC1, MC2). Table 1 contains characteristic average stress values: parameter R_{eH} is defined as the stress value of the first local maximum in the compressive stress-strain curve (if exists). The plateau-stress R_{plt} was averaged in the range of 0.1 to 0.2 of strain. The parameter *m* is the slope of quasi-elastic line at first sample loading (in that case not from a hysteresis loop).

The curves of EPS-samples and the curve of metal foam showing typical ductile deformation behaviour in contrast to the DSiC-foam where a brittle deformation after a first maximum in stress was observed.

For the metal-polymer hybrid, a negligible increase in density compared to the metal foam was measured. The results of compression test indicate a slight increase in R_{plt} because of the low supporting effect of EPS for the metal foam. A stiffening effect by the EPS is not provable. The lower values of *m* of hybrid foam samples maybe caused by the different surfaces of samples in the sample to loading plate contact. In compression tests of metal-polymer hybrid samples it was observed, that deformation behaviour was more homogeneous up to strain of 0.4 compared to that of metal foam.

The metal-ceramic hybrids showing a first, less distinct, stress peak. The plateau stress R_{plt} was much higher then that of each mono foam material as well as the density with a value of 1.40 g/cm³. Independent from that, the deformation behaviour is controlled by the metal foam but in terms of strength supported by the ceramic foam.

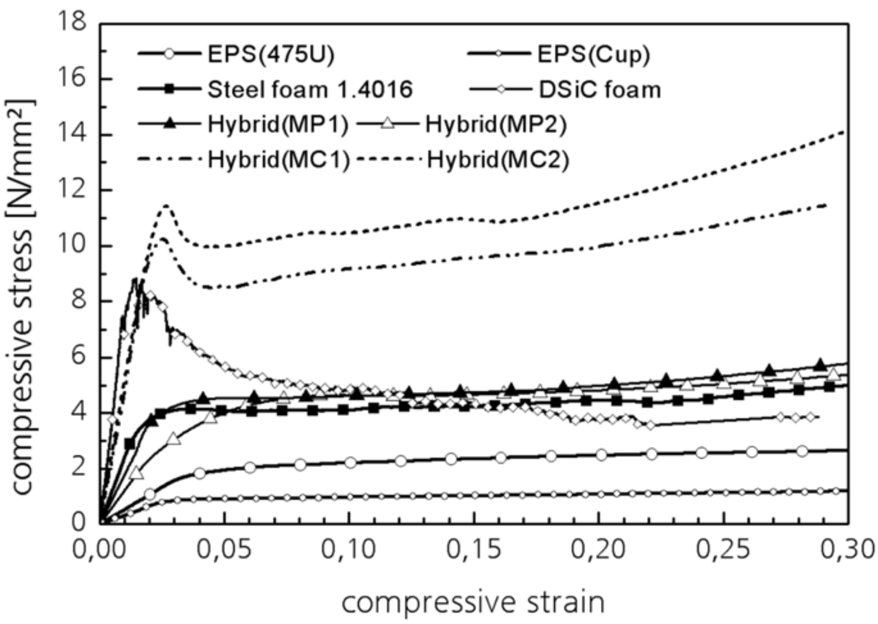

Figure 4. typical compressive stress vs. strain curves of the mono material foams and the hybrid foams (Tab. 1); samples: mono-polymer foams: EPS 475U and EPS Cup; mono-ceramic foam; DSiC foam; mono-metal foam: open cell steel foam 1.4016; hybrid foams: metal-polymer: MP1/MP2; metal-ceramic: MC1/MC2

Table 1. results of the compression test of the mono material foams and the hybrid foams

	m [N/mm²]	R_{Plt} 0.1<e<0.2 [N/mm²]	R_{eH} [N/mm²]	Density av [g/cm³]
EPS 475U	52	2.3	-	0.18
EPS Cup	38	1.1	-	0.10
DSiC (mono)	721	3.7 brittle	8.6	0.90
Steel foam 1.4016	218	4.2	3.9	0.74
Hybrid (MP1) 1.4016 /EPS 475U	139	4.6	-	0.82
Hybrid (MP2) 1.4016 /EPS Cup	175	4.6	-	0.76
Hybrid (MC1) 1.4016 /DSiC (ppi 8)	444	11.0	10.9	1.45
Hybrid (MC2) 1.4016 /DSiC (ppi 20)	440	9.4	9.6	1.40

The results of RFDA are presented in figure 5. It can be shown that beside the density increase, Young´s modulus and damping are enhanced by the hybrid approach. The values for Young´s modulus are in the region of polymers (EP, PMMA, PVC) and wooden materials like MDF (medium density fibreboard). Obviously, there is a reinforcing effect in metal-ceramic hybrid foams caused by the high stiffness of the ceramic component. Additionally, the metal-ceramic hybrid foam shows improved damping compared to the metal foams, but values are lower than of organic materials in the diagram. The reason for the improvement of damping is not obvious, but it is assumed that if the metal struts of the open cell network carry the oscillation energy, it can be dissipated to thermal energy through internal friction in the metal-ceramic interface and inside ceramic foam.

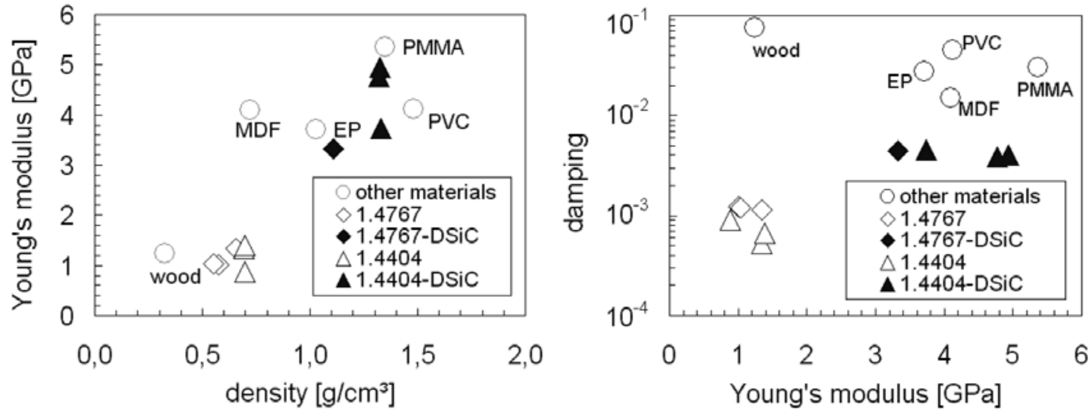

Figure 5. results for Young´s modulus and damping measured by resonace-frequence-damping-analysis of selected polymers and wooden materials (MDF), open cell steel foam (1.4404 and 1.4767) and same steel foam samples with interpenetrating DSiC

4 Conclusion

Two examples for interpenetration hybrid foams were presented, both based on open cell steel foam as host material which was interpenetrated either with polystyrene foam or with a direct foamed SiC-ceramic. The results of compression tests and non-destructive RFDA show promising material properties. For the metal-polymer hybrid, an improvement of deformation behavior with a negligible increase in density could be observed.

Trough the combination of metal and ceramic foam the density nearly doubles compared to each mono material foam. The strength increases clearly and deformation behavior changes from brittle to ductile. The RFDA shows that Young´s modulus of hybrid foam is improved and values are similar to polymer and wooden materials (e.g. EP, PMMA, PVC, MDF) but compared to these organic materials the temperature resistance is higher. Even if mono steel foam with same density reaches comparable values of strength and stiffness, the reinforcement by DSiC is an easy and cheap alternative. And in addition, an improved thermal insulation is to be expected. Furthermore, the RFDA shows an enhanced damping for the metal-ceramic hybrid foams. Consequently it might by a promising material for sandwich cores because it sustains higher shearing loads with additional thermal insulation and good mechanical damping.

Actual research work of metal-ceramic/polymer hybrid foams is focused to the improvement of compressive strength and specific energy absorption particularly for crash relevant deformation rates. The metal-ceramic will be evaluated for applications as stiffening elements in machine tools and robotized automation. Furthermore, high speed compression tests for both metal-ceramic and metal-polymer hybrids are planned with respect to pedestrian crash protection. The development of hybrid foams is accompanied by the development of a numerical simulation tool, which allows prognosticating mechanical, thermal and acoustic properties of many foam combinations [5].

5 Acknowledgement

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