Cost-Efficient Metal-Ceramic Composites - Novel Foam-Preforms, Casting Processes and Characterisation

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Summary

Because of their dissatisfactory cost-performance ratio metal matrix composites (MMC's) are still not established in industry, although they show improved properties compared to pure metals in some application fields. The present paper describes the development of enhanced MMC's based on silicon carbide (SiC) foams made by the Schwartzwalder process. Therefore, foams with cell sizes of 30, 45 and 60 ppi based on pressure less sintered SiC (SSiC) were developed. They were coated with layers of coarse SiC particles, which form a rough strut surface. The ceramic content of the foams could be increased to values of 20-30 mass%. Additionally, foam preforms based on clay-bonded SiC (as they are known from molten metal infiltration) were tested.

The preforms were infiltrated with aluminium alloys AlSi9Cu3 and AlSi7Mg0.6 and cast iron EN-GJSA-XNiCr35-5-2 and EN-GJL-250. For aluminium alloys high pressure die casting (HPC) as well as gravity casting was applied, whereas iron was only infiltrated by gravity casting.

For high pressure die casting an excellent interlocking of metal and preform was observed because of the microporosity of the rough surface of the SSiC foam struts. By the use of gravity casting preform cells up to 45 ppi could be well infiltrated. Microporosity in the ceramic coating and the typical hollow struts of the foams did not show metal infiltration.

Even by use of moderate ceramic volume fractions pressure-infiltrated aluminium matrix composites showed a high specific stiffness of up to $E/\rho = 42$ GPa*cm³/g compared to conventional Al or Mg alloys ($E/\rho = 25\text{-}27$ GPa*cm³/g). Ceramic foam based MMC's produced by pressure less casting showed no advantages in mechanical properties compared to pure metals. Nevertheless it can be expected that they can provide improved wear resistance and lower thermal expansion coefficients.

Keywords: metal matrix composites, interpenetrating composites, silicon carbide foams, roughness, lightweight metal, cast iron, high pressure infiltration, pressure less infiltration, specific stiffness, wear resistance, thermal expansion

1. Introduction

Technological progress in sectors like transportation, machine construction and aerospace industry often requires materials which can combine low weight with high specific stiffness, strength and wear resistance even at elevated temperatures. This has spurred extensive research for composite materials based on light metals and ceramics (an overview can be found in [1]). Starting in the 1980s, ceramic fibres and particles, casting and infiltration technologies for the production of metal matrix composites (MMC) were developed and optimized and characterisation techniques for materials with highly heterogeneous structures and anisotropic properties were adapted. Nevertheless, MMCs has not achieved the high market dissemination which was predicted thirty years ago. A survey of Fraunhofer in 2000/01 showed that the most important reasons for this are an unsatisfactory cost-performance ratio and limitations of the reliability and of the knowledge of the material behaviour.[2]

Particle reinforced aluminium matrix composites are often produced by mixing the reinforcement phase into melts or powders followed by shaping steps (e.g. casting, extrusion). A homogeneous distribution of the reinforcement phase can be reached but the processes are expensive and complex. Difficulties commonly encountered with components produced homogeneously from MMC are the very high tool wear and low productivity during subsequent machining of the components. Furthermore, the content of the reinforcement phase is limited and the processes can lead to the formation of unwanted phases in the material. An alternative technology for the production of MMC is based on porous ceramic preforms which are infiltrated with molten metal. One major cost factor of the infiltration technique is the expense for the preforms which are often based on ceramic fibres. For this reason, the investigations presented in the following concentrated on low cost open-cell ceramic foams as preforms.

Foams were originally developed as filters for molten metal filtration and were thus mainly optimized for maximum thermo-shock resistance during their scheduled short operation life. They are currently produced in large numbers at moderate cost and can be generated with a wide range of geometry, porosity and composition. Contrary to fibre or particle-preform-composites, which were comprehensively analysed in the past, foam-based MMCs have not been in the focus of research. Known examples of research activities or industrial applications like ICE brake disks and mining equipment [3, 4] are based on the good wear resistance of foam based MMCs. Unfortunately, stiffness, toughness and creep resistance could not reach the high values of fibre based composites. The reasons are mainly the low ceramic volume content of the foam preforms [5] and bonding problems arising at the metal-ceramic interface due to the large thermal expansion mismatch between the metal and ceramic.

Generating ceramic foam based interpenetrating MMCs combining improved stiffness and strength with low production costs was thus the aim of a cooperation of three Fraunhofer institutes and the ACTech GmbH. For this purpose, open cell ceramic foam structures with a higher ceramic volume fraction than published before were developed by the Fraunhofer Institute for Ceramic Technologies and Systems. Beyond that foams with a special surface morphology were produced in order to achieve good mechanical interlocking of the metal and ceramic phase of the composites. Well-established and cost-efficient processes such as high pressure die casting for aluminium alloys and sand casting for cast iron were used to infiltrate the ceramic foams with metal melts at the Fraunhofer Institute for Manufacturing Technology and Applied Materials Research and at ACTech GmbH, respectively. To qualify these processes for the production of high-quality MMCs the handling, preheating, positioning and microstructure of the preforms had to be matched with suitable casting parameters. The results presented here are based on experiments with about 100 preforms for each casting method. Characterisation of the composite properties was carried out at the Fraunhofer Institute for Mechanics of Materials. Details of the manufacturing process for these composites and the resulting properties will be described in the present article.

2. Preform manufacturing

Schwartzwalder and Somers first described a manufacturing process for cellular ceramic foams in 1961.[6] In this technology a polymer sponge with a netlike structure is impregnated with ceramic slurry, squeezed out by roller machines and dried. During the subsequent thermal treatment the polymer sponge is burned out and the ceramic is sintered at temperatures above 1000 °C. Typical industrial filter foams showing total open porosities between 90-95% are produced by means of this process using glass-bonded silicon carbide, alumina or zirconia ceramics. The cell size of the foams is normally measured in pores per inch (ppi), and foams with 10-30 ppi are commonly used for molten metal filtration. Such foams are not ideally suited as preforms for MMCs because of their relatively poor mechanical properties, high amount of external phases and their low ceramic volume fraction. Compared to such foams, new foam materials made of pure sintered silicon carbide (SSiC) promise better infiltration properties because of their high thermal shock resistance and particular pore structure. In conventional cellular ceramic foams the porosity consists of large cells and hollow struts. The novel foams based on SSiC show 10-30 vol-% additional microporosity within the ceramic struts with micropore sizes of less than 20 µm.[7] The typical trimodal pore structure of the novel SSiC-foams is represented in Figure 1.

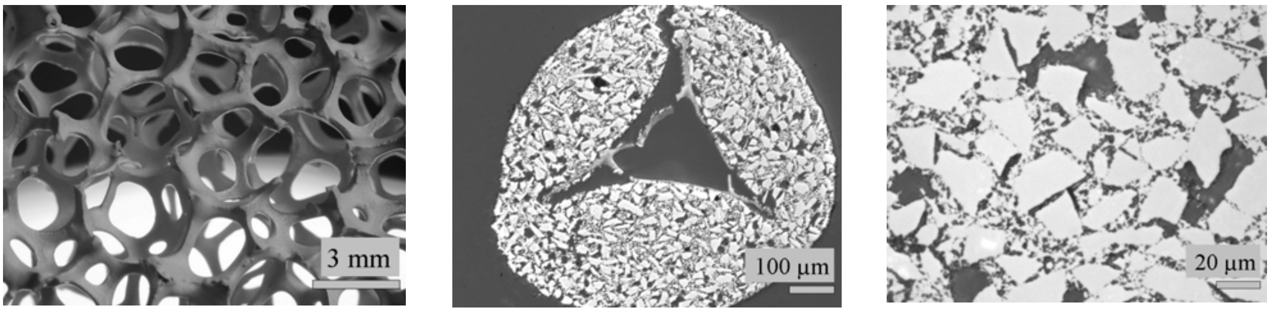


Figure 1: left: image of foam structure with cells; middle: micrograph of hollow foam strut (bright areas: ceramic, dark: embedding material); right: enlargement of the strut material showing microporosity (dark)

To evaluate infiltration behaviour of these new foam preforms made of SSiC, they were compared to preforms based on common clay bonded SiC (CB-SiC) in a first series of casting tests. The investigations were carried out with cell sizes of 30-60 ppi. After first casting experiments micrographs of the MMCs showed partial delamination between ceramic and metal independent of the material. A typical trend was recognized; convex areas of the foam struts joined the metal, but concave strut sections showed delamination and no bonding between the materials. This effect can be explained by the thermal mismatch of the foam and the metal matrix. SiC has a thermal coefficient of $4*10^{-6}$ K^{-1}, which is three times lower than that of cast iron and six times lower than that of aluminium alloys. This can lead to stresses and to the observed delamination at the metal-ceramic interface during the cooling phase.

Common ceramic foams are usually characterised by relatively smooth strut surfaces which provide only little mechanical interlocking of ceramic and metal in the composite structure. Furthermore, the interfacial energy of the metal-ceramic interface is low. As a result, neither strong chemical nor strong mechanical bonding at the metal-ceramic interface can be assured. To overcome these problems at least partly, ceramic foams used as preforms should have struts with rough surfaces for interlocking of the ceramic preform with the metal matrix. Additionally, they should have higher ceramic volume fractions exceeding 25 vol% in order to yield composites with high stiffness and high wear resistance.

In order to reach these goals additional steps were included into the manufacturing process. The new process chain for the rough strut surface preforms is presented in Figure 2. Usually, the thermal treatment of the foam ceramic is a one-step process including pyrolysis and sintering. In the modified process the thermal treatment is interrupted after the pyrolysis step. Then, a second coating step is performed with a suspension made from coarse particles with an average size of 20-50 µm. For this purpose, the pyrolysed and presintered foams were immersed in the particle suspension, homogenised by centrifugation, dried again and sintered finally. Depending on cell size, centrifugation parameters and ceramic particle size employed, the ceramic volume fraction of the foams was increased drastically by this process from 10 vol % to 30 vol.%. [8]

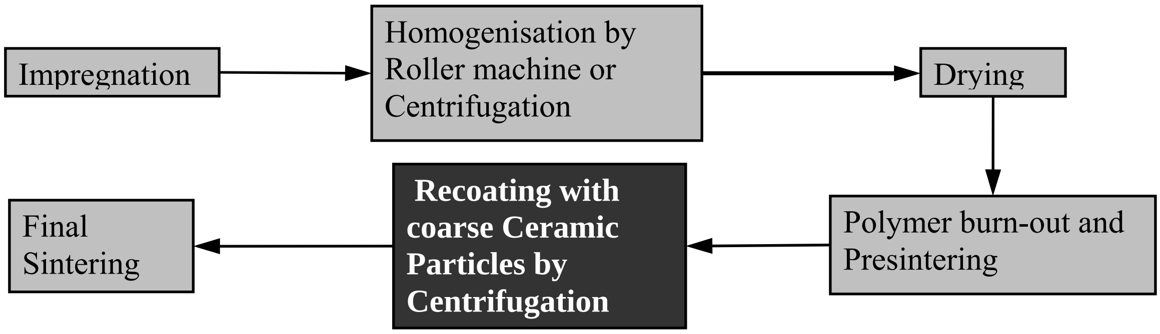


Figure 2: Manufacturing process of the novel foam preforms

Figure 3 shows the surface structure and the section of the novel ceramic foam with a rough strut surface and enhanced ceramic content. The original round struts produced in the first coating procedure and the porous coating of the second step can still be distinguished in the cross section photograph (Fig.3 right). Surface roughness and microporosity measurements were used for quantitative characterisation of the struts. Surface measurements were performed with a Hommel Tester T8000 using DIN 4768 and BET with a micromeritics ASAP 2010 using DIN ISO 9277.

Table 1 shows that the surface roughness correlates with the average size of the ceramic particles used for coating. In the first coating step powders with a bimodal particle size distribution of coarse (23 µm) and fine (2 µm) grains were used. This resulted in a relatively smooth surface with a roughness of 10 µm. After recoating the roughness of the struts increased approximately to the values of the average sizes of the used particles. Thus, by using e.g. a F360 SiC powder with an average grain size of 23 µm a surface roughness of 19 µm was achieved. One would expect an increase in surface area if the surface roughness increases. BET measurement of the uncoated and coated foams showed, however, almost the same values of specific surface area for all foams (Table 1). Obviously the surface is dominated by the microporosity which all foams possess.

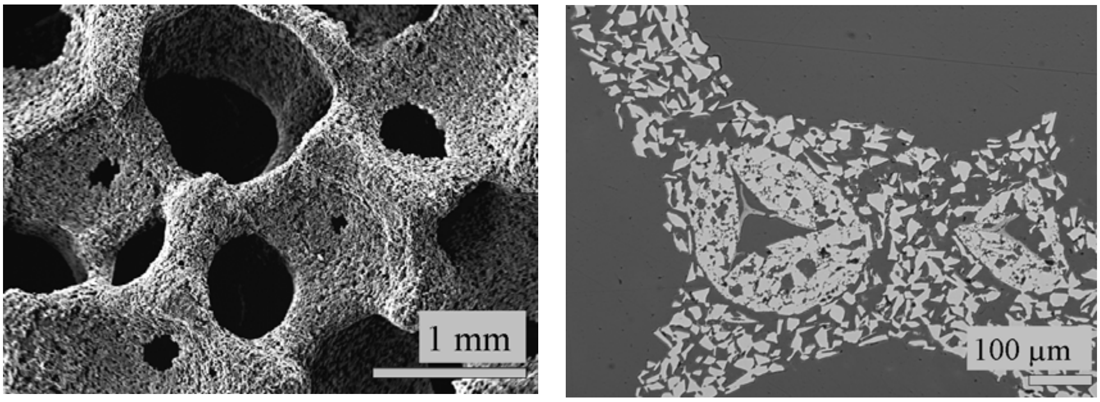


Figure 3: left: SEM image of a coated preform with a rough surface, right: micrograph of a coated preform (light: ceramic, dark: embedding material).

Table 1: Roughness and specific surface of SSiC foams recoated with different particle sizes in comparison to a typical SSiC foam surface; cell size ppi 20

Material variation	**Surface Roughness Rz [µm]**	**Specific Surface BET cm²/cm³**
original SSiC foam(bimodal particles: 40% 2 µm, 60% 23 µm)	10.1 +/- 2.0 µm	8330
recoating with 23 µm particles	19.2 +/- 1.7 µm	8560
recoating with 44 µm particles	42.9 +/- 4.3 µm	7350

3. Metal infiltration

3.1 High pressure die casting (HPC)

High-pressure die casting is characterised by a high level of automation and short casting cycle times. Solidification times are also very short so that melt filling velocity and design of melt flow (Figure 4, right) are fundamental parameters of process control for preform infiltration. If the melt velocity is too high, air will be entrapped leading to gas porosity in the casting, if it is too low, melt will solidify too fast for complete preform infiltration. Another aspect to be considered is the pressure of the melt exerted upon the preform structure. A certain pressure is needed for infiltration to overcome capillary forces caused by the non-wetting behaviour of the melt but it must not exceed the structural strength of the preform. Furthermore, the Darcy-Forchheimer-Law predicts that the mechanical impact on the foam by the melt flow through the porous structure increases non-linearly with melt flow velocity. For the infiltration experiments a high-pressure die casting machine (Bühler SC N/66) and a mould with a plate cavity (plate dimensions 120mm x 80mm x 12mm, casting weight 1,6kg, Figure 4) were used for the castings which allowed easy production of preforms and machining of specimens for subsequent characterisation experiments. The casting machine used was of real-shot controlled type, the plunger velocity was controlled in the first phase and pressure controlled in the second phase of the filling process. More than 100 specimens were produced with variation of the process and material parameters.

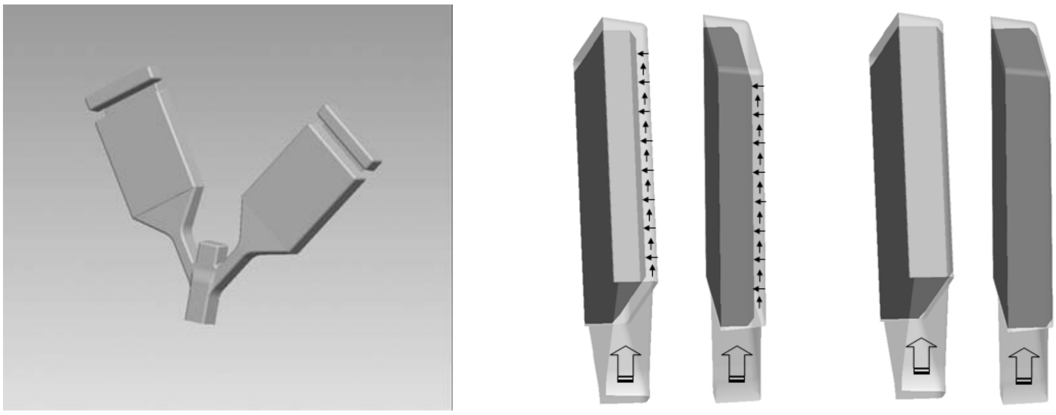


Figure 4 left: Geometry of test casting, right: different designs of melt flow for infiltration of preform

Prior to the infiltration the mould (300 °C), sleeve (300 °C) and preforms (700-850 °C) were preheated. The temperature of the aluminium melt (AlSi9Cu3) was varied between 700 °C and 800 °C. The casting holding pressure was 80 MPa, the melt velocities lay between 0.6 m/s and 2.5 m/s which is typical rather for squeeze casting processes. The preforms were fixed into the mould using spring-like steel sheets. After infiltration the castings were controlled using a radioscopy unit YXLON MU2000 with a 160 kV tube.

The casting experiments showed that different foam preforms (CB-SiC, SSiC, 45 ppi, porosity 76-84 %) could be infiltrated successfully. Melt velocity had to be kept below 0.7 m/s in order to prevent damage of the ceramic foam structure and evidently heat loss during transfer from the furnace to the sleeve had to be controlled carefully to reduce premature solidification and viscosity increase of the melt. The experiments revealed that the most critical process aspects were the de-aeration of the mould and the limitation of heat losses during melt transfer from the furnace to the mould system.

In order to increase ceramic content of the composite further experiments were carried out in which the preform foams were infiltrated with particle containing aluminium melts. For this the SiC containing Al alloy Duralcan F3D.20S was mixed with AlSi9Cu3 to adjust a particle content of 10 vol %. Infiltration parameters were not changed.

3.2 Gravity casting

Commonly, MMCs are manufactured applying pressure-assisted casting methods to overcome capillary forces, differences in the thermal expansion coefficients and to reach high composite densities. However, free flow of metal melts through ceramic foams with pore sizes of 10-30 ppi is known from filter applications. In order to investigate whether this phenomenon can be used for production of MMCs, gravity sand casting experiments were also carried out varying the metal matrix alloy and the ceramic foams. Two lightweight Al alloys (AlSi9Cu3 and AlSi7Mg0.6), two cast iron alloys (EN-GJL-250, lamellar, perlitic and N-GJSA-XNiSiCr35-5-2, austenitic) and SSiC and CBSiC ceramic foams with single coating and a cell size of 30, 45 and 60 ppi were used in sand casting infiltration studies.

For the preparation of the casting moulds and Croning® sand cores (similar to regular shell sand) were used. The moulds were generated by laser sintering according to CAD data generated before. Advantages of this technique are, its versatility combined with close tolerances and its feasibility for mass production. The moulds for the material screening experiments contained cavities (see Fig.5) for cylindrical foam-preforms with a diameter of 25 mm and a length of 80 mm. About 80 moulds were infiltrated with aluminium alloys and cast iron. After this preliminary survey, the most promising material combinations were cast with a rectangular geometry of a 150 x 100 x 8 mm³ preform dimension for property measurements.

Just like for the HPC casting experiments the preforms were preheated to 700 °C to reduce thermo-shock of the ceramic. However, measurements showed that the handling time needed for mould insertion leads to a cooling of the preforms to 300 °C, which is especially critical for iron casting with melt temperatures of more than 1380 °C.

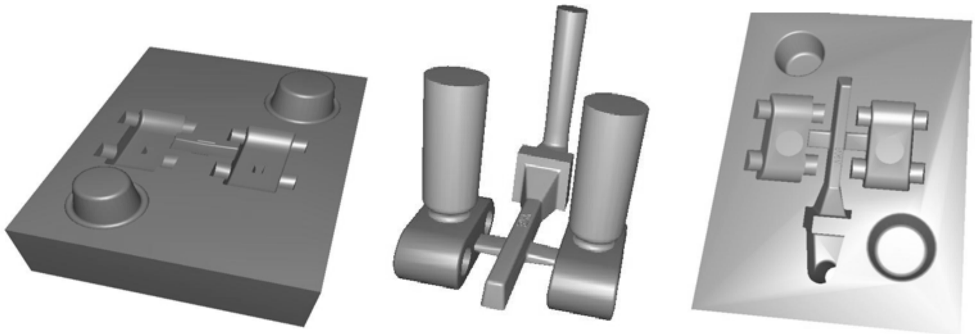


Figure 5: left/right: upper and lower mould; middle: sample with gating system and feeder

Results of infiltration experiments by sand casting are shown in Table 2. In order to evaluate infiltration behaviour samples were cut and optically examined after cooling (Fig.6). For further validation cross sections of successfully infiltrated MMCs were prepared and polished for materialographic interface analysis. Due to different wetting angles and thermal expansion coefficients of metals and ceramics cast iron results in better foam infiltration than Al alloys for all cell sizes and foam materials. Surprisingly, coarse ppi 30-preforms could be well infiltrated with AlSi7Mg0.6. Only slight debonding (D) between preform and metal was observed (Fig. 7 left). Small reaction zones (RZ) were observed in the iron composites which were particularly pronounced for SSiC-based MMCs. The generation of RZ can be accelerated by the high casting temperatures of over 1300 °C (Fig.7 right). They consist of SiFeO compounds.

Table 2: Matrix of variation and evaluation of sand cast MMC, + for complete infiltration, - for non-infiltration, RZ for reaction zone at the surface, D for delamination

	CB-SiC			SSiC		
Cell-size	ppi 30	ppi45	ppi60	ppi30	ppi45	ppi60
AlSi9Cu3	+, D	-	-	+, D	-	
AlSi7Mg0,6	+, small D	-				
EN-GJL-250		+			+, RZ	
N GJSA-XNISICR35-5-2	+	+	+	+, RZ	+RZ	+, RZ

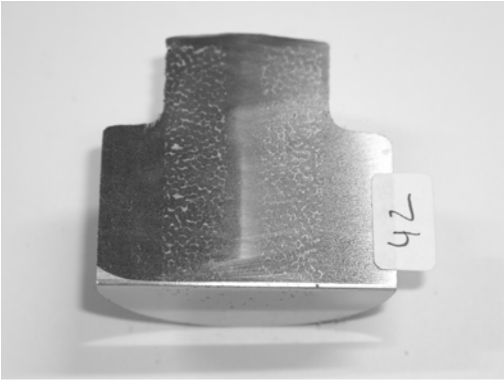
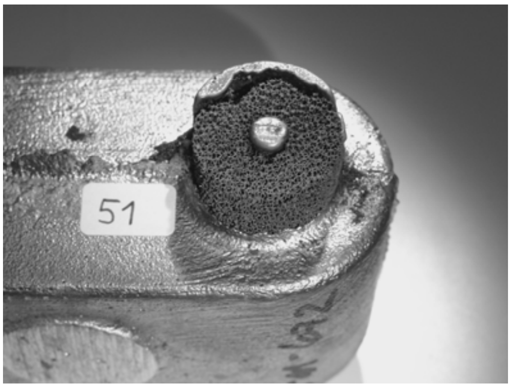
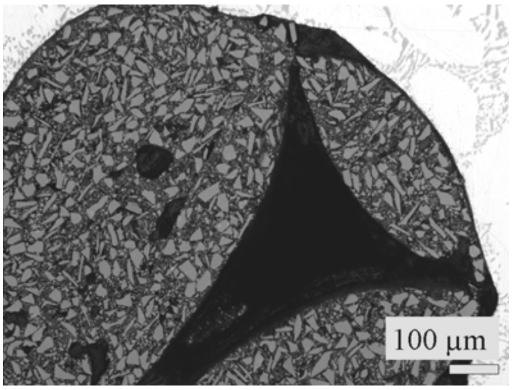
 

Figure 6: left: N GJSA-XNISICR35-5-2 + CB-SiC successful infiltration , right AlSi9Cu3 + SSiC ppi 45 no wetting

By comparing both casting processes the penetration efficiency is lower for sand casting than for pressure casting as was to be expected. Using pressing during casting all porosity in the foam including cells, hollow struts and microporosity, is filled, whereas for sandcasting only the cells are infiltrated.



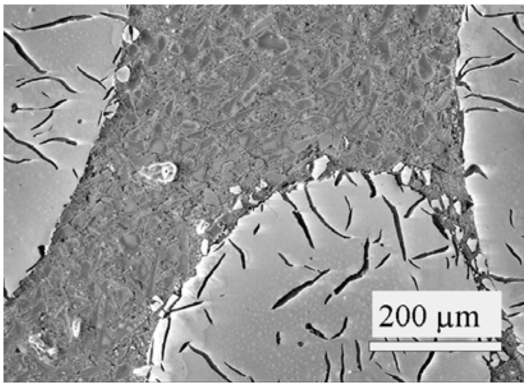


Figure 7: Materialographic section of composites, left: AlSi7Mg0,6 and CB-SiC-foam right: EN-GJL-250 and CB-SiC foam

4. Properties

4.1 High pressure die casting (HPC)

In general, the HPC AlSi9Cu3/SSiC composites were completely infiltrated and showed densities close to the theoretical density (see Table 3). The low porosity and interpenetrating network microstructure of the composites should lead to high bulk and shear moduli according to existing material models.[9, 10] For AlSi9Cu3 reinforced with 20 % SSiC foam Young's moduli exceeding 100 GPa are expected.[9] In order to validate these predictions, the Young's modulus was experimentally determined from the frequency of the first bending resonance of rectangular bars. Indeed, preform based composites containing 24 vol. % SiC showed a Young's modulus of 118 GPa – an increase of about 60 % compared to the unreinforced AlSi9Cu3 alloy. Generally, a good agreement of the experimental data with the lower bound of the Tuchinskii model [9] was found for the MMC based on the coated foams. Composites derived from uncoated foams had lower Young's moduli which were typically not higher than those of the AlSi9Cu3 matrix alloy (Fig. 8). The main reason for the different stiffness of composites made from coated and uncoated foams is obvious from Fig. 9. The composite made from uncoated SSiC foam shows debonding of the metal-ceramic interface in some places whereas the coated foams have a sound interface. The debonding is most likely caused by thermal misfit stresses and crack formation occurring during cooling of the composites after the infiltration process. This assumption is substantiated by a cracking noise which was produced by the composites after they were removed from the casting die.

Table 3: Properties of metal-infiltrated SSiC foams (45 ppi)

	Ceramic content [vol. %]	Density [g/cm³]	Theoretical density [g/cm³]	Young's Modulus [GPa]	Bending strength [MPa]
AlSi9Cu3	0		2.77	71 [12]	216* [12]
AlSi9Cu3/ SSiC	23	2.75	2.84	70±10	52 ± 18
AlSi9Cu3/ SSiC 23 µm coated	24	2.82	2.84	118±4	173 ± 20
Duralcan F3D.10S/ SSiC 23 µm coated	31	2.85	2.87	121±4	173 ± 22

* tensile strength

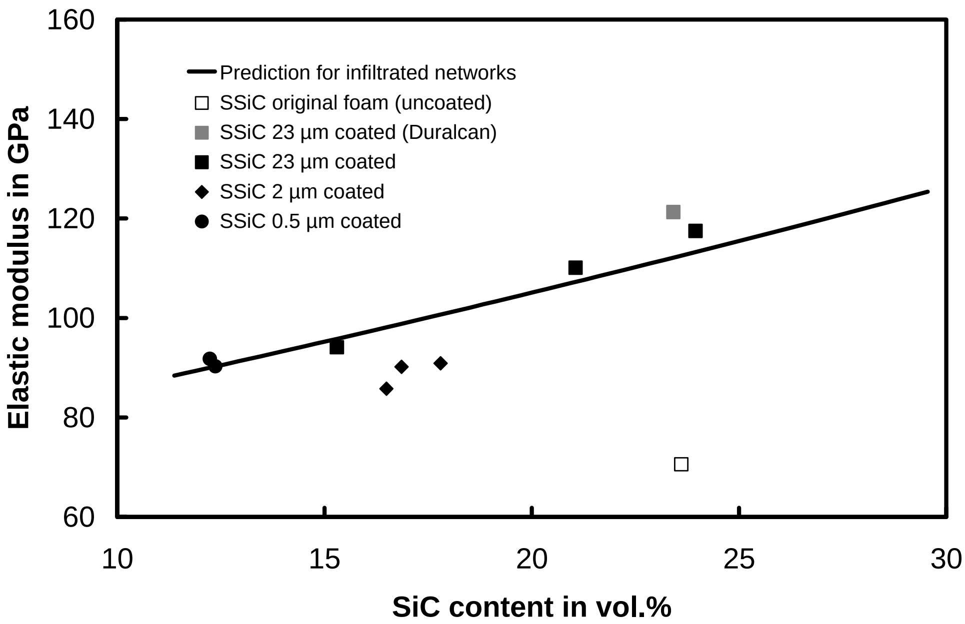


Figure 8: Young's modulus of different Al-infiltrated SiC foams as a function of the ceramic volume fraction. All foams had a cell size of 45 ppi, for the recoated foams the size of the particles used (between 0.5 µm and 23 µm) is indicated. Data points are experimental values, the solid line is the prediction of a micromechanical model for interpenetrating composites.[9]

The average bending strength of such uncoated AlSi9Cu3/SSiC composites is only 52 MPa with a relatively large standard deviation of 18 MPa (see Table 3). As can be seen from the fracture surface (Fig. 10), the weak metal-ceramic interface in the uncoated foam composites forms a preferred path for crack propagation. In combination with the pre-existing cracks before loading (as visible in Fig 9) this leads to poor structural properties of the uncoated foam composites. Fracture surfaces of composites produced from coated foams showed much better interlocking of metal and ceramic phases (Fig. 10, right) and plastic deformation could be observed on the microscopic scale. Although these composites were still brittle, they had a much higher bending strength of 173 MPa with a moderate scatter of 20 MPa, i.e. they are almost as strong as the die cast alloy AlSi9Cu3. As mentioned before, due to the relatively large cell size of the ceramic foams it was possible to infiltrate these with an aluminium alloy containing 10 vol. % dispersed SiC particles of 10-20 µm size (Duralcan F3D). The Duralcan based composites showed a slightly higher Young's modulus of 121 GPa compared to the composite AlSi9Cu3/SSiC 23 µm coated, but no increase in ultimate strength.

The fatigue behaviour of the composites was tested using hourglass shaped cylindrical specimens of 20 mm gauge length and a gauge diameter of 4 mm. The fatigue limit of the AlSi9Cu3/SSiC 23 µm coated composite in tensile tests with stress ratio R=0.1 was about 50 MPa (maximum stress). For this stress ratio, pure AlSi9Cu3 die cast under optimum conditions can reach a fatigue limit of 115 MPa maximum stress.[11] The fatigue limit of the Duralcan F3D.10S/SSiC composites was considerably higher (90 MPa maximum stress), but still less than that of the Duralcan alloy without foam reinforcement (140 MPa maximum stress).[12]

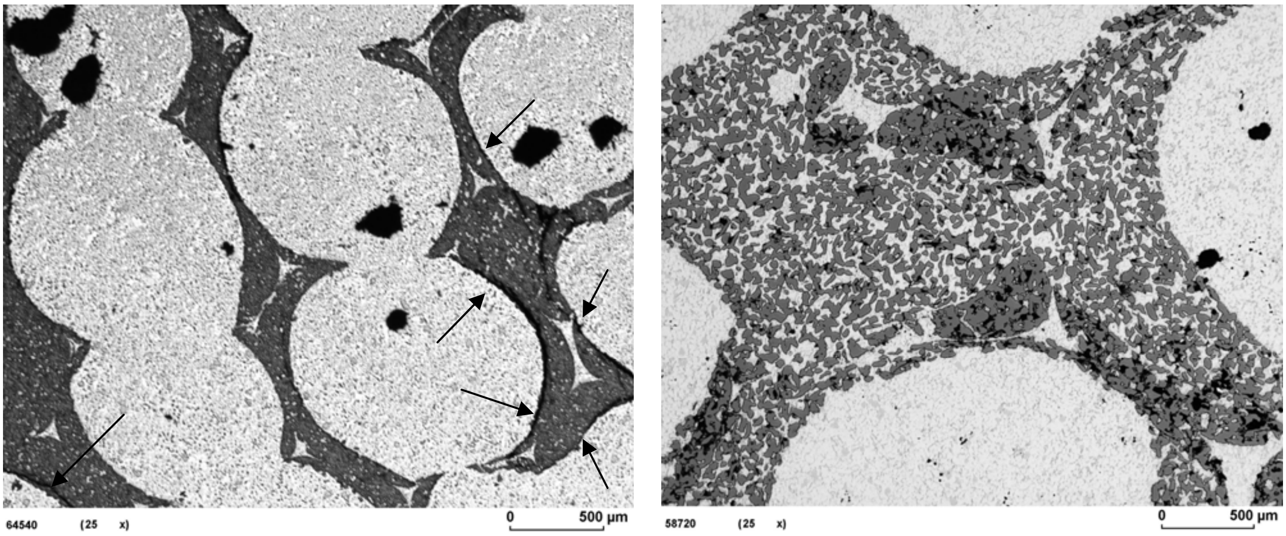


Figure 9: Micrographs of metal infiltrated SSiC foams; bright: AlSi9Cu3, dark: SSiC. left: uncoated SSiC foam showing decohesion at the metal-ceramic interface (arrows), right: SSiC foam coated with coarse particles prior to infiltration. No delamination is visible here, but some dense strut areas are not completely infiltrated.

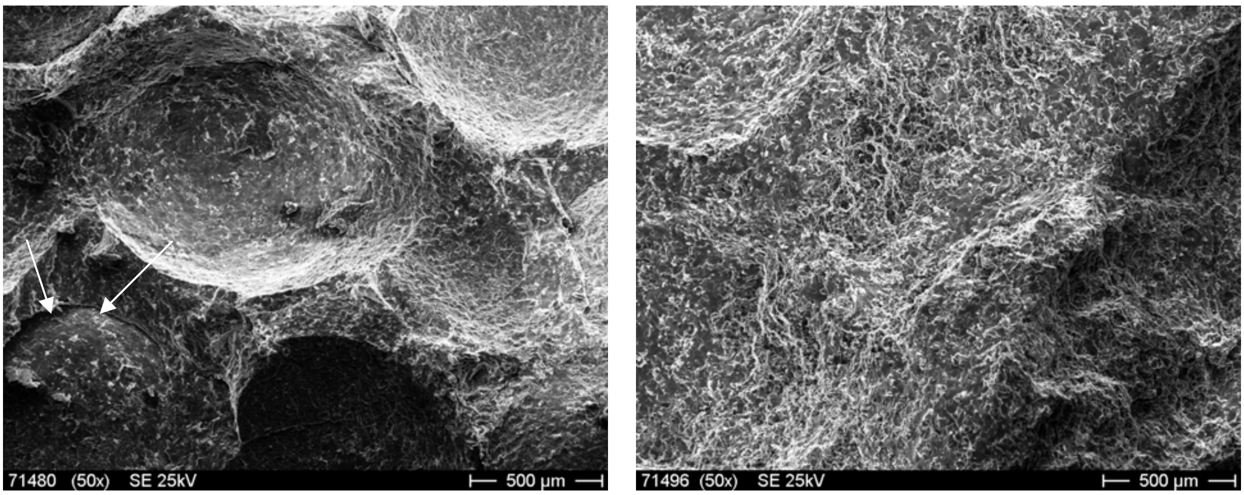


Figure 10: Fracture surfaces of aluminium infiltrated SSiC foams. Left: composite from uncoated foam. Fracture preferentially along smooth metal-ceramic-interfaces, decohesion visible (arrows). Right: SSiC foam coated with coarse particles. No macroscopic decohesion at metal-ceramic interfaces.

4.2 Gravity Casting

Table 4 shows the mechanical properties of different SiC foams infiltrated by pressureless casting. Both, infiltrated SSiC and CB-SiC foams showed a density about 5-7 % lower than theoretical indicating significant porosity. This is in accordance with the materialographic sections of these materials which show that the hollow struts of the foams are not filled during pressureless casting (compare Fig 7 left).

In combination with the lower ceramic content of these presureless cast composites (between 8.5 and 11.7%) this porosity leads to Young's moduli lower than those of the bulk alloys without foam reinforcement (Table 4). The bending strength of the composites made by presureless casting is also significantly reduced compared to the bulk alloys.

Table 4: Properties of CB-SiC and SSiC foams (45 ppi) infiltrated with EN-GJL-250

	Ceramic content [vol. %]	Cell Size [ppi]	Density [g/cm³]	Theoretical density [g/cm³]	Young's Modulus [GPa]	Bending strength [MPa]
EN-GJL-250	0		7,1		103	250*
EN-GJL-250/SSiC	11.7	45	6,33 ± 0.05	6,64	89 ± 11	140 ± 18
EN-GJL-250/CB-SiC	8.5	45	6,42 ±0,05	6,77	95 ± 2	174 ± 17
AlSi7Mg0.6	0		2,66		72	320*
AlSi7Mg0.6/CB-SiC	10,6	30	2,49 ± 0.01	2,71	49 ± 2	171 ±19

5. Discussion of results and conclusions

Novel ceramic foam preforms with recoated struts show improved properties for use in the production of metal matrix composites compared to state-of-the-art ceramic foams. While maintaining the typical foam production process the ceramic content could be increased to values of 20-30% adding only one coating step. The rough strut surface of these foams makes them particularly suitable for the production of metal matrix composites as it impedes debonding at the metal-ceramic interface.

SiC foams made of pressureless sintered (SSiC) and clay bonded SiC (CB-SiC) with high thermal conductivity and strength were infiltrated by means of two casting methods with aluminium alloys AlSi9Cu3 and AlSi7Mg0.6 and cast iron EN-GJSA-XNiCr35-5-2 and EN-GJL-250. Good macroscopical infiltration of preforms could be observed both for high pressure die casting as for sand casting with aluminium alloys. However, the composite quality is determined by infiltration of the hollow struts and microporosity, which was only observed for the pressure cast MMCs. Aluminium infiltration of preforms with pore sizes down to 60 ppi was possible using pressure casting. With sand casting best results were achieved for cast iron and clay bonded silicon carbide foams with middle cell sizes of 45 ppi.

Even with the moderate ceramic volume fractions used, the pressure-infiltrated aluminium matrix composites show a high specific stiffness of up to $E/\rho = 42$ GPa*cm³/g when compared to conventional Al or Mg alloys ($E/\rho = 25\text{-}27$ GPa*cm³/g). This makes them attractive for applications in mechanical engineering where low inertia and high stiffness is

* Tensile strength

required. However, static and cyclic strengths of the composites are reduced in comparison to the unreinforced matrix alloys. Variants with additional particle reinforcements (Duralcan-alloy) showed advantages in cyclic tests in comparison to MMCs with conventional aluminium matrix alloy. Ceramic foam based MMC produced by presureless casting showed no advantages in mechanical properties, but it can be expected that they can provide improved wear resistance and lower thermal expansion coefficients compared to the unreinforced alloys.

The main advantage of the MMC variants presented here is their relatively low-cost manufacturing process compared to fiber based composites. All used processes, foam manufacturing as well as casting, are well suited for mass production. While the iron-based composites are interesting for components with high wear resistance, the aluminium based pressure-casted MMCs are expected to be useful for thermally stressed lightweight parts with high stiffness or creep requirements.

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