

TENSILE PROPERTIES OF AN INFILTRATED INTERPENETRATING POROUS SiC MMC

Matthias Merzkirch¹, Bastian Kraft and Kay André Weidenmann²

¹Institute for Applied Materials IAM–WK, Karlsruhe Institute of Technology,
Kaiserstr. 12, 76128 Karlsruhe (Germany)

Email: Matthias.Merzkirch@kit.edu, web page: <https://www.iam.kit.edu/wk/>

² Institute for Applied Materials IAM–WK, Karlsruhe Institute of Technology,
Kaiserstr. 12, 76128 Karlsruhe (Germany)

Email: Kay.Weidenmann@kit.edu, web page: <https://www.iam.kit.edu/wk/>

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ABSTRACT

A simple route for manufacturing porous silicon carbide preforms with the help of polymer waxes for tailorable pore structure is used in order to produce preforms different pore architecture. The main aim is to achieve an interpenetrating composite material with low residual porosity and a higher ductility in comparison to silicon carbide bulk material. The quality of the manufactured composite is analyzed by means of metallography which attests a very good infiltration of the composite. Residual porosity can mainly be lead back to the closed porosity of the SiC preforms due to the manufacturing route chosen. The current work focuses on the determination of the mechanical properties under tensile loading of silicon carbide - AlSi12 infiltrated composite samples. The aim is to determine the deformation and damage behaviour of this novel material. For this purpose miniature tensile samples have been manufactured as there is only a small volume of the manufactured semi-finished preforms available. The aim of the work is to deduce relationships between the process parameters (wax ratio, initial porosity resp.) microstructure (pore morphology and infiltration quality, residual porosity resp.) and mechanical properties (strength).

1 INTRODUCTION

Metallic based composites with an interpenetrating phase architecture offer several outstanding properties like high stiffness and strength at room and elevated temperatures at relatively low densities. Due to their relatively high thermal conductivity and low CTE aluminum alloy matrix composites with silicon carbide reinforcement are potential materials for thermal management applications under weight critical conditions.

In a previous work [1] a simple route for manufacturing porous silicon carbide preforms with the help of polymer waxes for tailorable pore structure is presented. It deals with the variation of SiC-to-wax ratio in order to produce preforms with varying porosity and different pore architecture. Detailed investigations on the elastic properties of the silicon carbide preforms have been described in [2].

The manufacturing route and characterization of the mechanical properties under compressive loading of gas pressure - with a eutectic aluminum alloy AlSi12 – infiltrated SiC samples with selected porosities have been shown in [3]. The main aim is to achieve an interpenetrating composite material with low residual porosity and a high strength.

2 MATERIALS AND EXPERIMENTAL

2.1 Materials

The fabrication includes the mixture of silicon carbide powder (AMPERPRESS Alpha-Silicon Carbide Grade UF-15) with a particle size of < 38 µm (35 %), > 150 µm (3 %) with two polymer waxes - Viscowax (VW with a particle size of 250 - 630 µm) and Ceridust wax (CD with a particle size of 7.5 - 9.5 µm) - to customise the structure of the preform. Within this work only wax powder

mixtures of volume fraction of 50:50 (SiC:wax mixture) have been compounded. The wax ratio has been varied between VW:CD = 1:2 and 2:1. The second step includes the filling of a bottom die and the pressing of the samples with a uniaxial pressure of 40 MPa. Vacuum packaging was done to prevent contamination of the sample with oil during cold isostatic pressing in order to gain a relatively cylindrical pore structure. Pyrolysis (in Argon atmosphere) leads to melting and extraction of the wax from the manufactured preforms in order to receive a porous structure. Afterwards the preforms with a porous architecture were sintered in argon atmosphere at a maximum temperature of 2050 °C. Further details about the preform manufacturing procedure can be found in [1,2].

2.2 Gas Pressure Infiltration

The preforms have been placed, together with ingots of a eutectic aluminum alloy AlSi12, into an alumina crucible, see Fig. 1. The crucible was placed into the infiltration chamber which was sealed. The test started by evacuating the chamber up to a vacuum pressure of about 0.05 mbar. Afterwards heating (0.1 K/s) was started using an induction coil (and a mid-frequency generator) and a graphite susceptor for efficient coupling. After holding the aimed temperature of 720 °C for 2 h, Argon gas was then applied to pressurize (30 bar) the infiltration chamber. Afterwards pressure was kept constant during cooling the chamber by water circulation [3].

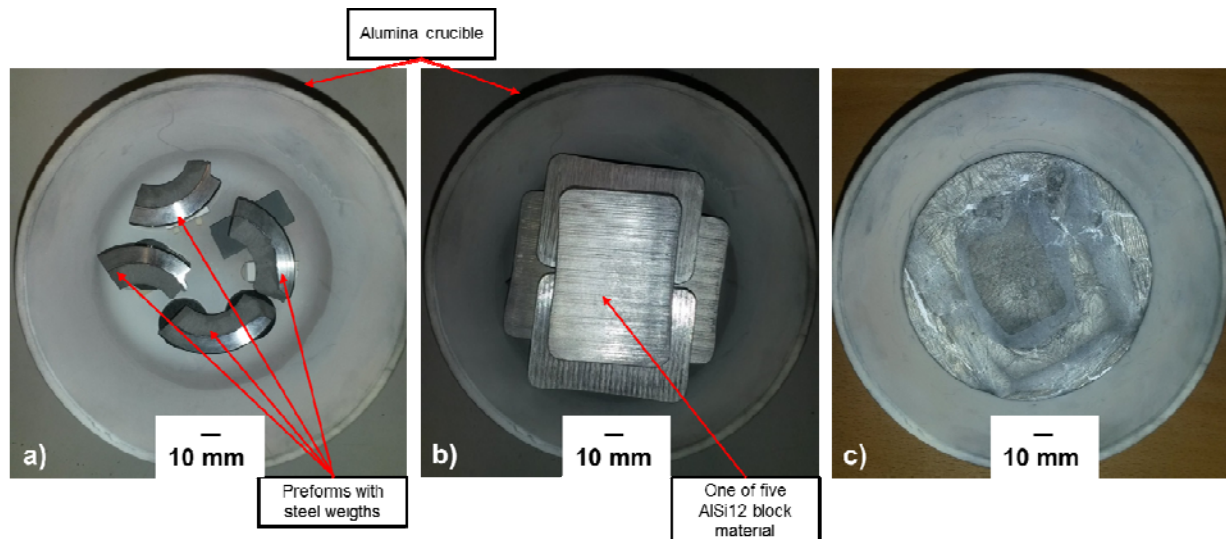


Figure 1: Crucible with preforms and weights (a) and AlSi12 ingots (b): a) and b) before infiltration, c) after infiltration.

After infiltration, cutting has been done in several steps starting with cutting the aluminum block for production of cuboid samples. Afterwards the radii for the measuring gauge have been ground. Fig. 2 a) shows a representative miniature tensile sample (according to [4,5]) in comparison to a 2 Euro cent coin.

Since this method is not standardized, every sample has been geometrically measured since both length and thickness of the sample may vary. The average dimensions ($l \times w \times t$) of the samples were approximately $20 \times 5 \times 2(-3) \text{ mm}^3$ with an average length within the measuring gauge of about 2-2.5 mm.

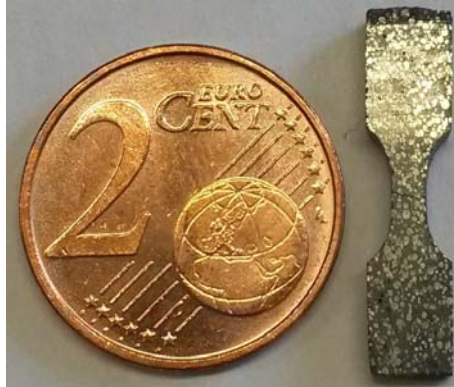


Figure 2: Representative miniature tensile sample (right) in comparison to the size of a 2 Euro cent coin.

Tensile Tests

Tensile tests have been carried out on a Zwick testing machine with a maximum load of 2.5 kN. The crosshead velocity was set to 0.2 mm/min and the preload was chosen to be 10 N. Fig. 3 depicts the experimental setup for the tensile tests including a camera for damage capturing. The aim was to determine strain with optical methods by utilizing the pattern of the MMC. Since the pattern is too coarse and the contrast too low this did not lead to any satisfying results. Therefore strain has been determined out of the corrected - with respect to the compliance of the testing machine - traverse path.

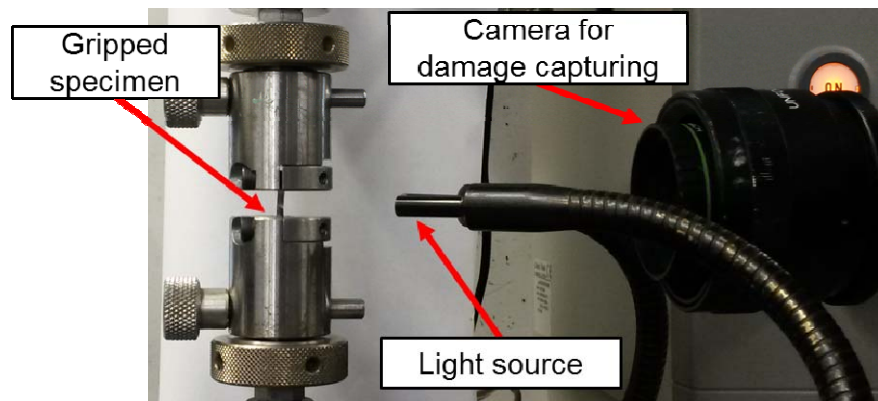


Figure 3: Experimental setup for the tensile tests with equipment for optical damage capturing.

3 RESULTS AND DISCUSSION

3.1 Materialographic analysis

As it can be seen from Fig. 4, the gas pressure infiltration process lead to a successful infiltration of the SiC preform. For both samples the large infiltrated pores can be seen which is observable by the bright aluminum alloy. Darker (black) areas suggest that these are not well infiltrated showing residual porosity. Sample with a high content of CD show a good infiltration of the small porous areas which resemble to canals. In contrast, sample with a high content of VW show a good infiltration of the large pores and a higher amount of residual porosity of about 7-9 % [3].

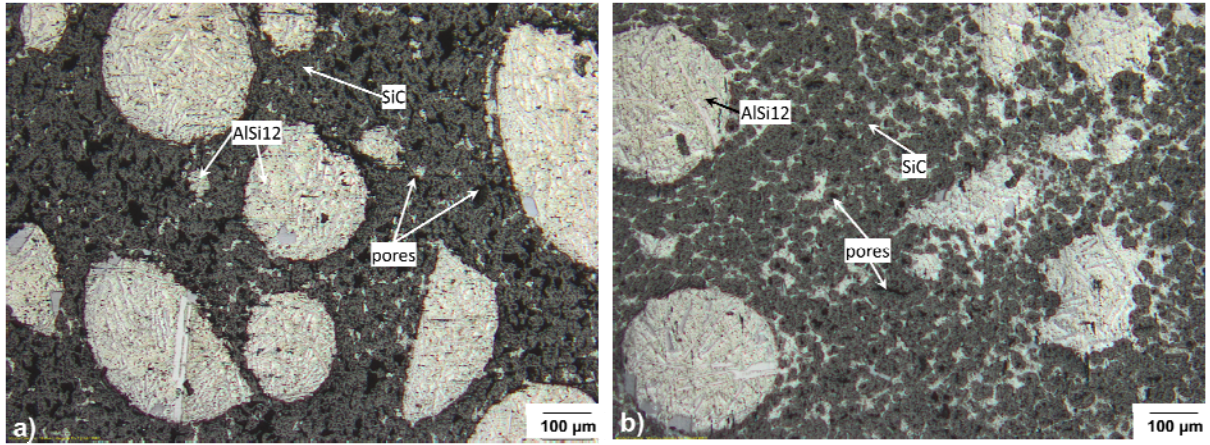


Figure 4: Sections of infiltrated SiC preforms VW:CD = 2:1 (a) and 1:2 (b).

3.4 Tensile Test

Fig. 5 depicts representative engineering stress-strain curves for both samples where a relatively small strength can be attested. Maximum strength could be reached for specimen VW:CD = 1:2, which is only about 31 MPa.

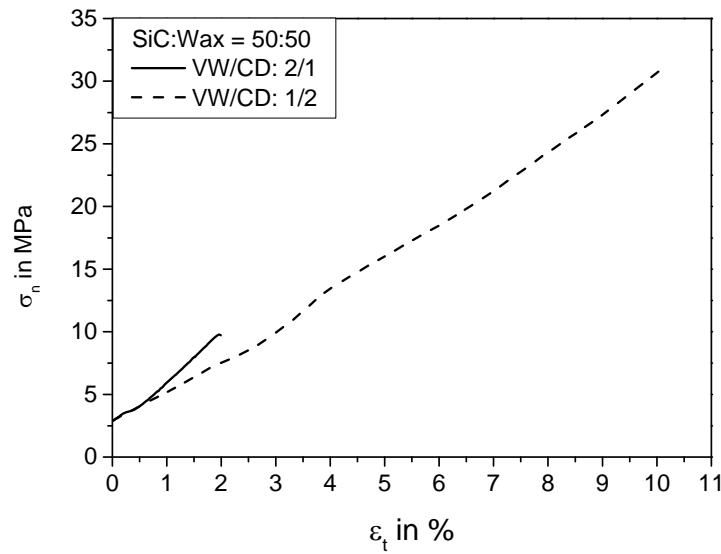


Figure 5: Nominal stress- total engineering strain plot of SiC/AlSi12 samples.

Due to the high fragility of the porous MMC, some of the samples already broke during gripping, before starting the tensile test.

3.5 Qualitative fractographic investigations

Fig. 7 depicts the damage evolution of a representative sample. In comparison to Fig. 7 a), Fig. 7 b) illustrates the crack growth within the ceramic constituent. In addition, Fig. 7 c) clarifies that crack growth occurs along the interface between the matrix material and the ceramic structure which can probably lead back to low interfacial strength.

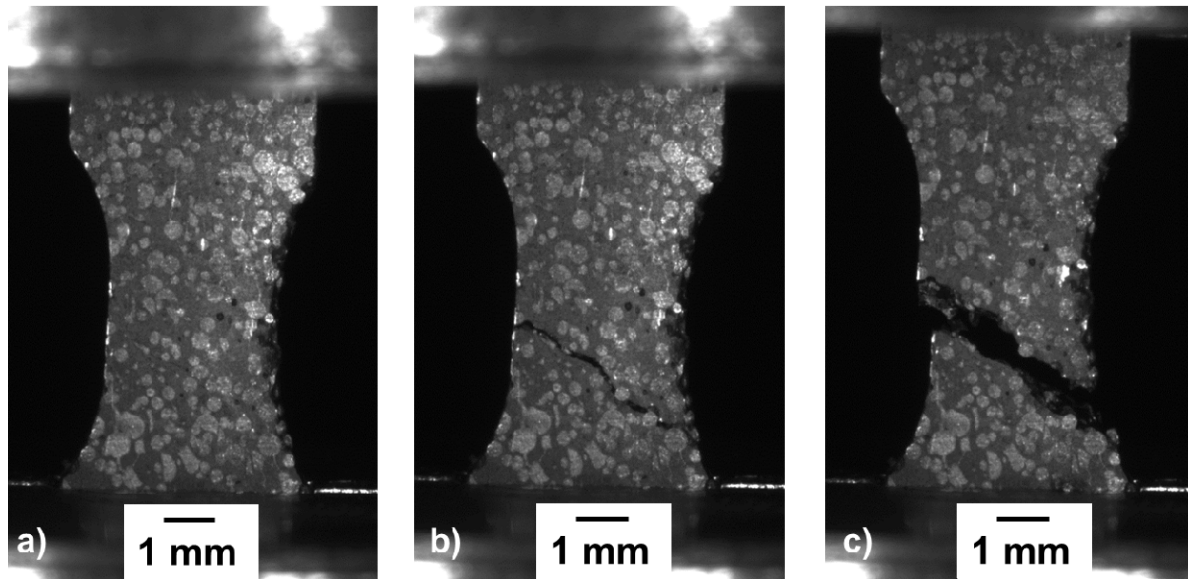


Figure 6: Representative damage capturing of infiltrated samples: a) during loading, b) before fracture, c) after fracture (size: 3.3 x 2.3 x 2 mm³).

4 CONCLUSIONS AND OUTLOOK

Since the current investigations only showed low strengths of the SiC-MMC, which can be lead back to the coarse geometry of the pores, improvement could be found by using MMC with an interpenetrating porous structure with finer pore geometry. As an example Fig. 8 depicts an Al₂O₃/AlSi12-MMC with much finer porous structure, (in comparison to Fig. 4).

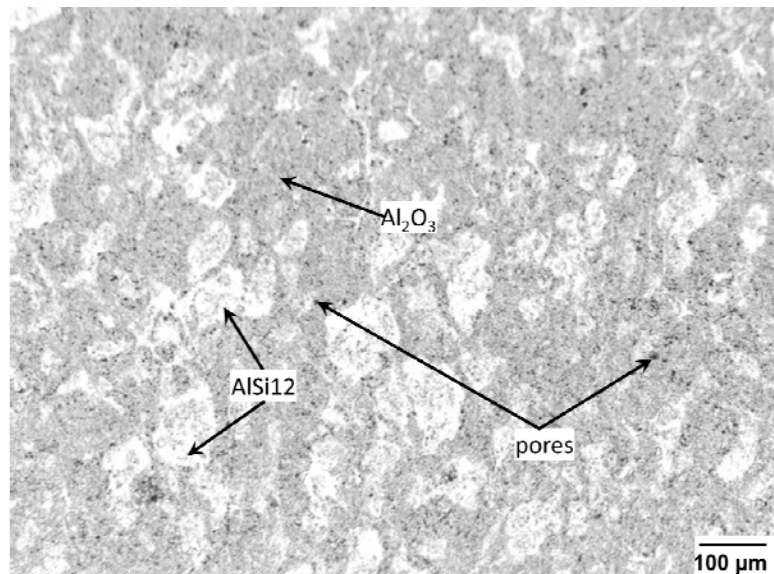


Figure 8: Section of an infiltrated Al₂O₃ preform.

The graph in Fig. 9 shows the representative engineering stress-strain curve of 2 exemplary tensile samples. It can be concluded that these samples show much higher strengths – in comparison to the SiC/MMC -, up to 111 MPa.

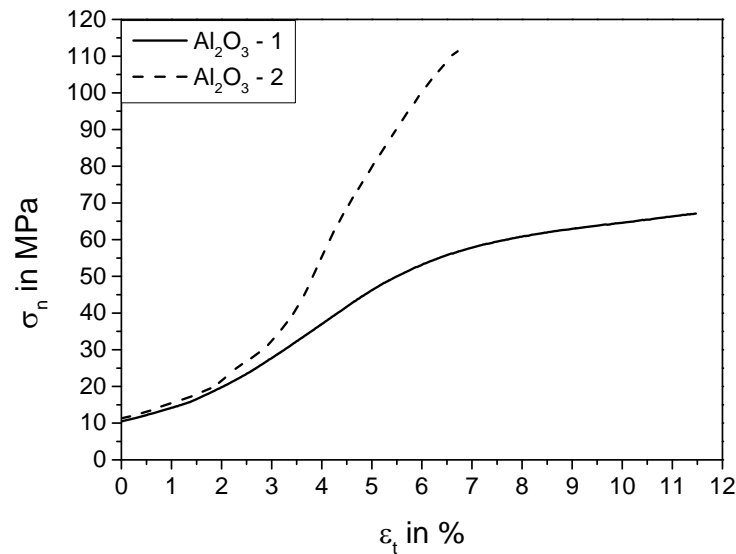


Figure 9: Nominal stress- total strain plot of Al₂O₃/AlSi12 samples.

Further investigation will focus on the tensile properties of SiC preforms consisting of a much finer porous structure (produced via a different manufacturing route) in order to obtain higher strength due to a finer network configuration. Additionally, optical strain measurement should be used in order to determine the elastic properties of these MMCs.

9 SUMMARY

The current paper deals with the producibility of SiC preforms and their infiltration. In addition it could be shown that tensile sample can be manufactured in miniature dimensions. Due to the relative coarse porous structure to the preform the infiltrated MMC showed a high fragility and a low strength. Remedy can be found by using a much finer geometry of the pores which was successfully shown on basis of porous alumina preforms infiltrated with AlSi12. SiC preforms with a comparable pore architecture are already focus of the current investigations.

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