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Acta Materialia Transylvanica 5/1. (2022) 18–22.
DOI: Hungarian: https://doi.org/10.33923/amt-2022-01-05
English: https://doi.org/10.33924/amt-2022-01-05

ACTA MATERIALIA TRANSYLVANICA

Reinforced Matrix Syntactic Foams Filled with Ceramic Hollow Spheres

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Abstract

Metal matrix syntactic foams are cellular materials in which the matrix is metal and within that matrix are non-metallic cells formed by filler material. These materials have low density, and besides that, they have high compressive strength and energy absorption. The main goal was to improve these properties by reinforcing the matrix with ceramic grains. During the experiment, molten A356 aluminium (7Si-0,3Mg) was infiltrated between the mixture of the filler and the reinforcement material. The specimens were produced with low-pressure infiltration. Different reinforcement materials were used: aluminium-oxide with three different grain sizes and colour designations and one type of silicon carbide. After heat-treatment, standardised compression tests were executed on the specimens. The results were compared to the results of the non-reinforced samples.

Keywords*: syntactic metal foam, reinforcement in matrix material, compression test.*

1. Introduction

Nowadays, porous, cellular materials are becoming more and more common in engineering applications, one of which is the subject of our research is metal foams. Their success is due to their low density, high specific energy absorption capacity, and strength.

Metal foams can be divided into two groups based on their structure, open and closed cell materials. The difference between the two groups, as their name suggests, is how separated the cells in the material are. In the case of closed-cell foams (**Figure 1**) the individual cavities are entirely separated from each other. In contrast, in the case of open-cell foams (**Figure 2**) there is no material boundary between the adjacent cells, the material-deficient areas meet.

As mentioned, metal foams have good specific mechanical properties in addition to their low

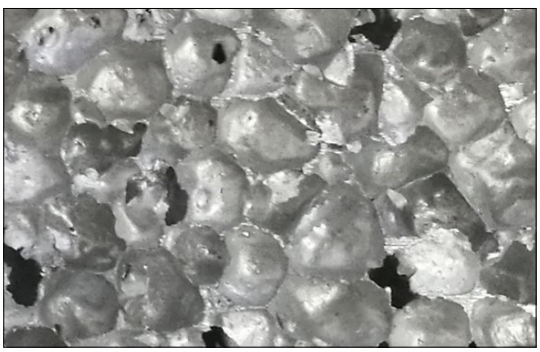

Figure 1. *Image of closed-cell metal foam.*

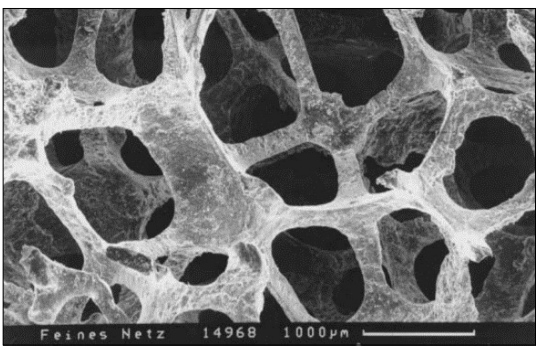

Figure 2. *Image of open-cell metal foam.* **[1]**

density. Several methods have been developed to improve these properties further and manipulate them for their intended application. These foams are referred to in the literature as functional metal foams, where the aim is to provide structural advantages in addition to the properties mentioned. Examples of these are the production of tubes filled with syntactic foam, which can withstand specifically bending stress [2], and varying the distribution and amount of filler in different parts of the foam according to function [3–5].

Furthermore, the size of the filler also has a significant effect on the mechanical properties. The strength properties can be variable by using different size fillers in the same material or mixing different filler materials [6–8]. In the case of non-reinforcing foams, this can be achieved by changing the manufacturing parameters [9].

The main goal of our research is the production and development of syntactic metal foams reinforced in their matrix material, and the investigating of their mechanical properties by quasi-static compaction testing.

Ceramic nano- and micro-particles have been successfully used in solid composites [10–12]. There is a chance that it is not possible to use a nano- or micro-sized reinforcement because the melt would press it to the bottom of the sample during infiltration. Nevertheless, based on the properties of the ceramic particles, we set up a hypothesis that a reinforcing material with a particle size in the 0.1-1 mm size range will also improve the tested mechanical properties.

2. Materials and methods

2.1. Materials

In our research, our matrix material was A356 aluminium alloy (7Si-0.3Mg). The filler material was a Glober® ceramic spherical shell sold by Hollomet GmbH. The ceramic spherical shells were aluminum-oxide marked with a typical diameter of 2.29 ± 0.16 mm [13, 14]. The hollow interior of the spherical shell will give the porosity of the metal foam. The reinforcing material was Al_2O_3 and SiC grains purchased from Granit Csiszolószerszámgyártó Kft. Stereomicroscopic images of the filler and reinforcing materials are shown in Figure 3. The nominal size of the reinforcing materials is known from the series of sieve sizes, which gives us an interval to determine the exact size of the reinforcing materials; it was measured on the microscopic images. The results are shown in Table 1.

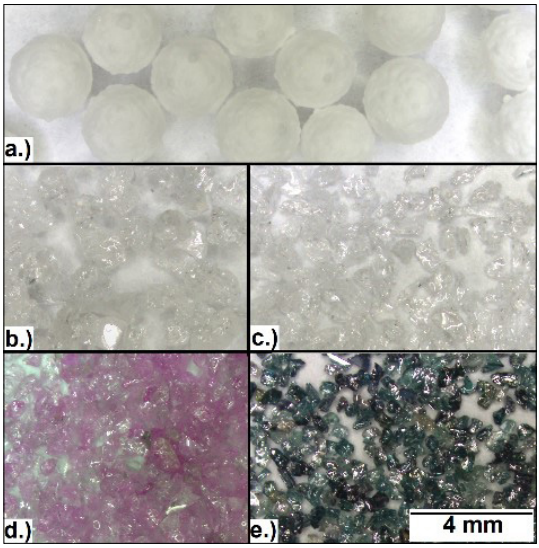

Figure 3. *Images of filler material (a), FS 18 Al_2O_3 (b), FS 40 Al_2O_3 (c), FS 46 Al_2O_3 (d), and FS 46 SiC (e) captured with stereomicroscope.*

Table 1. *Average particle size of reinforcing materials*

Reinforcing material	Nominal diameter (mm)	Measured diameter (mm)
FS 18 Al_2O_3	FS 18 (1 mm – 1.4 mm)	1.20±0.21
FS 40 Al_2O_3	FS 40 (0.4 mm – 0.7 mm)	0.63±0.09
FS 46 Al_2O_3	FS 46 (0.35 mm - 0.6 mm)	0.51±0.08
FS 46 SiC	FS 46 (0.35 mm - 0.6 mm)	0.45±0.09

2.2. Production of specimens

We used 20 wt% of the reinforcement for each case. The reinforcing material and the filler were mixed manually until it was visually determined that the reinforcing material was sufficiently distributed among the filler.

The inner surface of the used 40×50×240 mm enclosing molds was treated with graphite to facilitate casting removal using graphite spray. The degassing bore of the sample was sealed with aluminium-oxide paper, which allows air trapped during the casting to escape but prevents the melt from escaping.

After filling the mixture into the mold, a stainless-steel mesh was inserted atop the mixture. This was necessary because the density of the filler was lower than the melt, so it would float to the top and cause inhomogeneity problems. The molds were preheated for 1 hour at 600 °C in.

The A356 (7Si-0.3Mg) matrix material was melted in an induction furnace and heated to a low viscosity melt. After the furnace was turned off, the melt temperature was measured with a digital thermometer. After the temperature reached 840 °C, the melt was poured onto the top of the mixture. The gas inlet pipe was then placed on it, fixed in the gripping frame, and the argon gas was finally released at a pressure of 500 kPa. This squeezed the melt through our mixture.

The samples were air-cooled, and four specimens with an enclosure size of 30×30×40 mm and four specimens with 10 mm side length were processed from each block for quasi-static compression testing and microstructural examination.

Each sample was heat treated to increase strength. First, it was heated at 300 °C/h rate to 535 °C, held for 4 hours, then quenched in water. The second step involved heating at 200 °C/h rate to 150 °C, holding for 15 hours, then quenching in water [15].

2.3. Measurement methods

Samples for microstructural examination were grinded (with P60 - P4000 grind paper) and polished (by diamond suspension with a particle size of 3 µm and 1 µm) and then examined under optical microscopes.

The manufactured specimens' mechanical properties were investigated with a compression test based on ISO 13314: 2011 [16]. The quasi-static compaction test was performed on an MTS 810 universal electromechanical material testing machine. The device was equipped with a 250 kN load cell. Each specimen was compressed with a 4 mm/min cross-head speed to at least 50 % engineering strain value for comparability. To reduce friction, a 0.3 mm thick Kolofol Teflon foil was placed between the contact surfaces of the cross-head and the specimen.

Using the stress-strain data pairs, engineering stress-engineering strain curves were constructed in which the compressive strength (σ_c) was the first local maximum after elastic deformation, the plateau stress ($\sigma_{plateau}$) being the average stress in the range of 10 % to 40 % deformation, and the energy absorbed up to 50 % deformation (W_{50}), which is the area under the curve up to 50 % strain were examined (Figure 4).

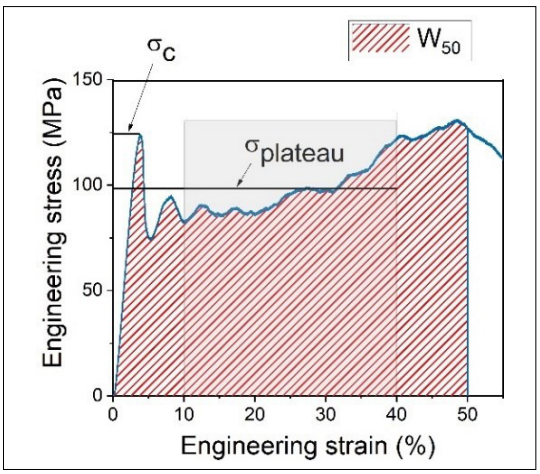

Figure 4. *Interpretation of tested mechanical properties.*

3. Results

The microstructural analysis indicated that the matrix developed a good connection with both the filler and the reinforcement material during infiltration, there was no considerable porosity or segregation on the boundaries of the filler or the reinforcement material. (Figure 5).

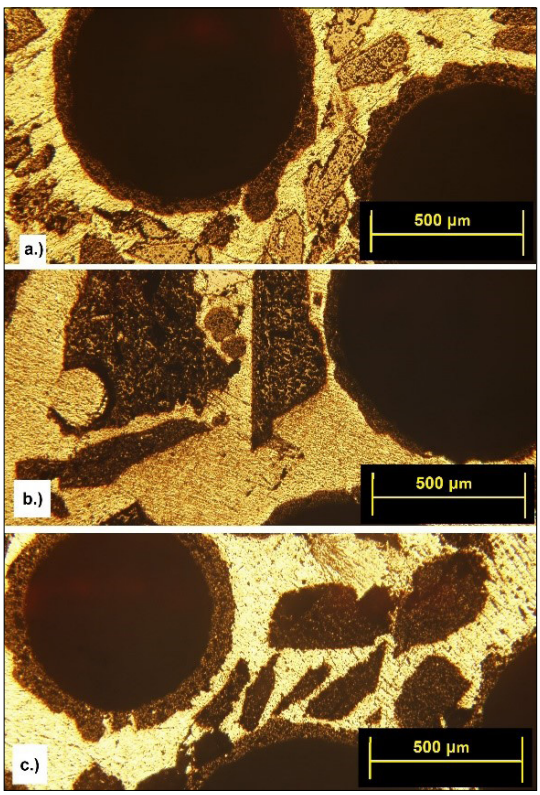

Figure 5. *Microstructure in the case of application of the FS 46 SiC (a), FS 18 Al_2O_3 (b) and FS 40 Al_2O_3 (c) reinforcement material (captured with an optical microscope).*

During the preparation of the specimens for microstructural analysis, we encountered the problem that due to the hardness of the filler- and the reinforcement material, the grains of the sanding paper were torn out, and scratched the already polished parts.

During the comperade of the results of the reinforced samples and the non-reinforced, it was shown that the reinforcement material always raised the compressive strength, but in the plateau region, the non-reinforced sample shows a monotone growing character, while some parts of the curve of the reinforced samples are monotone decreasing (**Figure 6**).

The results of the experiments are summarized in **Table 2.**

Table 2. *The examined mechanical properties*

Reinforcing material	Density (g/cm^3)	σ_c (MPa)	W_{50} (J/cm^3)
Non-reinforced	1.65±0.02	108.24±6.49	44.50±2.49
FS 46 SiC	1.78±0.06	124.94±4.61	39.50±4.65
FS 40 Al_2O_3	1.85±0.08	133.11±2.67	41.23±2.13
FS 46 Al_2O_3	1.79±0.08	116.42±9.83	36.42±4.20
FS 18 Al_2O_3	1.88±0.07	133.76±7.79	43.90±3.21

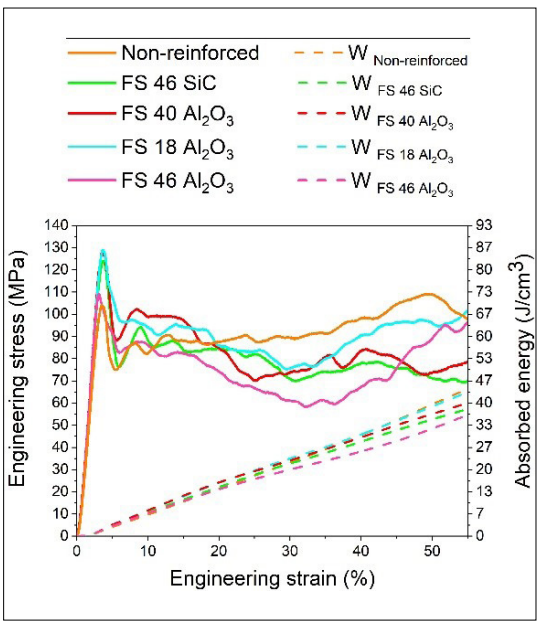

Figure 6. *The engineering stress-engineering strain curves and absorbed energy-strain curves of the different samples.*

4. Conclusions

From the results obtained during the research, we reached the following conclusions:

- Low pressure infiltration is an applicable method to produce syntactic metal foams reinforced in the matrix material, the reinforcement material is distributed to an appropriate extent evenly.
- There was an appropriate connection between the matrix and the filler and the matrix and the reinforcement material without porosity or segregations on grain boundaries.
- The usage of ceramic reinforcement is not always well-founded:
  - The ceramic filler material provides good mechanical properties.
  - The main benefit of reinforcement is the growth of compressive strength, it increases the compression strength by more than 17 % on average
  - From the reinforcement materials we used during the experiments the FS 18 Al_2O_3 was the best for application.

Acknowledgments

The research reported in this paper is part of project no. BME-NVA-02, implemented with the support provided by the Ministry of Innovation and Technology of Hungary from the National Research, Development and Innovation Fund, financed under the TKP2021 funding scheme, and the NRDI Fund (TKP2020 NC, Grant No. BME-NCS) based on the charter of bolster issued by the NRDI Office under the auspices of the Ministry for Innovation and Technology. This work was supported in part by the Hungarian Scientific Research Fund under Grant agreement OTKA FK_21 138505.

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