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INVESTIGATION OF BIMODAL ALUMINIUM MATRIX SYNTACTIC FOAMS FILLED WITH CERAMIC HOLLOW SPHERES

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Abstract

In this study bimodal A413 matrix syntactic foams filled with ceramic hollow spheres (CHSs) were produced and examined by computer tomography (CT) and quasi-static mechanical testing to determine the mixing properties of the hollow spheres and the strength of the metal foam. Two hollow spheres of different nominal diameters (d_1 = 2.4 mm and d_2 = 7.0 mm) were used in equal volume ratio. The produced metal foams have a density of 1.61±0.03 g/cm^3, with smaller inclusions and some defective hollow spheres in the structure. The foams have an average compressive strength of 120 MPa and a specific mechanical energy absorbing capacity of 43.5 J/cm^3. As a result of the upsetting tests, the matrix material is separated from the CHSs, breaking the connection between them.

Keywords: *bimodal metal foams, mechanical testing, ceramic hollow spheres.*

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1. Introduction

Cellular materials have high specific strength and energy absorptive properties due to their particular structure associated with their low density. Therefore, nowadays, researchers are trying to artificially create such materials in various load-bearing and impact absorbing elements. With the production of metal foams, this goal is achievable [1].

Metal foams are typically made from a light metal base material. Of these, Al and Mg matrix materials are widespread, but Fe, Zn and other metals can also be used [2–5]. The cells are filled with gas to reduce the density, and the metal foams formed as a result of their structure can be grouped as open or closed-cell foams. To improve strength and designability, so-called metal matrix syntactic foams (MMSFs) are often produced, which are characterized by the fact that the cells are formed by hollow spheres or foamed second phase of uniform distribution and size. The most common filler materials are ceramic hollow spheres (CHSs), besides which iron hollow spheres and low-cost foamed materials are also used to make metal foams [6–9].

The filling ratio of the spherical second phase of the MMSFs in the case of random close packing (RCP) is ~ 64 %. Increasing this factor further reduces the density of the structure. This increment can be accomplished by the random arrangement of spheres of different diameters. If two types of filler have the same property in all but one dimension, it is called bimodal. The bimodality of MMSFs is defined by the difference in the diameters of the filler material [10].

Tao et al. investigated Al6082 matrix syntactic foams filled with bimodal ceramic microspheres (75-125 µm and 250-500 µm). The total porosity of the bimodal metal foams they produced was 10 % higher than the porosity of metal matrix syntactic foams, and their initial deformation was 8 % higher [11].

Orbulov and his research team investigated the compressive properties of AlSi12 matrix foams filled with bimodal (150 μm and 1425 μm) Globocer CHSs. It has been shown that the compressive strength of bimodal metal foams can be reliably estimated from the properties of metal matrix foams containing only smaller or only larger hollow spheres using the mixture rule **[12]**.

2. Materials and methods

In this research, A413 casting aluminium alloy was used as matrix material, which contains: 11.0-13.0 % Si; max. 1.3 % Fe; 1.0 % Cu; max. 0.5 % by weight Ni; 0.35 % w/w Mn; max. 0.15 % Sn; 0.1 % Mg and the balance Al.

The filler used was high purity Al_2O_3 hollow spheres with nominal diameters of $d_1 = 2.4$ mm and $d_2 = 7.0$ mm. The properties of the CHSs were detailed in a previous study by our research team **[13]**.

Bimodal metal foams were made by low-pressure infiltration. The technological parameters are listed in **Table 1.** These parameters are the preheating temperature (T_{pre}) and time (t_{pre}) of the hollow spheres, the infiltration pressure (p_{inf}) and time (t_{inf}), and the temperature of the molten matrix (T_{matrix}). The aluminium was heated in an IND IF-10 induction furnace. For introducing the infiltration, argon gas was used, which was passed through an insulated pipette to the melt.

Table1. *Infiltration parameters.*

T_{pre} (°C)	t_{pre} (min)	p_{inf} (kPa)	t_{inf} (s)	T_{matrix} (°C)
500	45	300	5	650

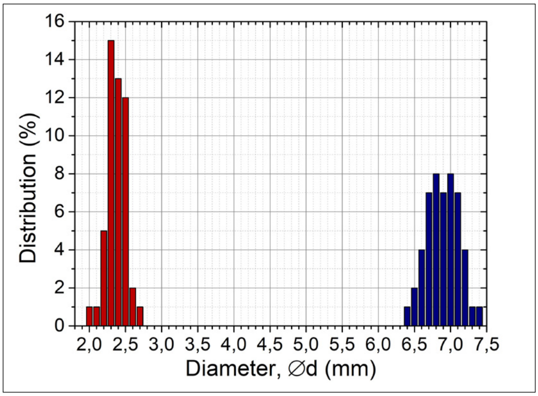

Figure 1. *Diameter distribution of the hollow spheres used in the same volume ratio.*

In the present study, bimodal metal foams were made with equal volume of small and large hollow spheres. Theoretical filling ratio in the space based on the mathematical model is 72.8 % **[10]**. This applies to two discrete diameter values and perfectly spherical elements, so the calculated value is error-prone. The size distribution of the filler is shown in **Figure 1.** at the same volume ratio of the two hollow spheres (1:1).

During the measurements, the densities of the created specimens were determined, and CT scans were performed on a YXLON Y.CT Modular instrument. To determine the mechanical properties of the MMSFs, upsetting tests were performed at a crosshead speed of 5 mm/min on an Instron 5989 electromechanical universal material tester with a 600 kN load cell. The results were then evaluated according to ISO 13314:2011 **[14]**.

3. Results

The measured density of the manufactured bimodal metal foams was 1.61±0.03 g/cm^3 based on weight and geometric measurements. Compared to the density of the A413 matrix material (2.66 g/cm^3) this is a significant decrease, but it is important to note that the theoretical bulk density gives a value of 1.4 g/cm^3, which is notably different from the actual measured value. The reason for this is easy to see since even the diameters of the hollow spheres do not take two discrete values, and their circularity are subjected to deviations, has 6-8 % error on average **[13]**.

Computed tomography (CT) images provide insight into the interior of the material and provide visual feedback of errors and deficiencies in the material (**Figure 2.**).

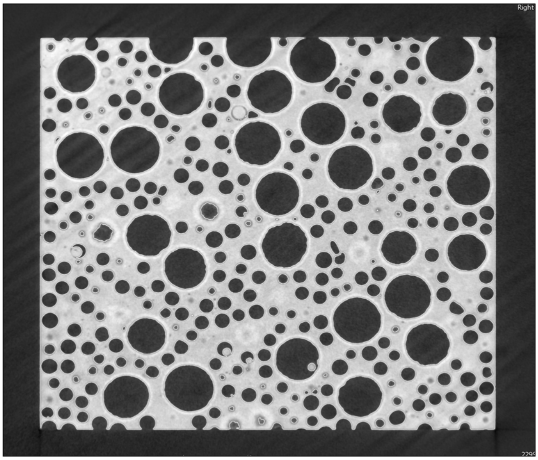

Figure 2. *A 2D slice of CT scan.*

Some hollow spheres have leaked aluminium, which increases the overall density of the structure. Furthermore, it is observed that due to the shrinkage of the melt, some inclusions appear within the matrix material, this is called undesired porosity. Further measurements are needed to quantify the distribution.

Figure 3. shows the pressure curves from the data recorded during the compression tests. The zone of the measurement results and the arithmetic mean of the measurement results are dotted. The plateau characteristic of the measured composites is significantly different from the characteristic curve obtained with the Al1050 matrix material, because it is not monotonic[7].

The metrics evaluated by the standard are listed in **Table 2.** The maximum stress (compressive strength) and its deformation, as well as the work, are denoted by the index "c". The other values indicated are in standard designations [14]. During the upsetting tests, the bimodal metal foams disintegrated, the matrix material and CHSs became unaffected during the failure. This phenomenon is illustrated in **Figure 4.**

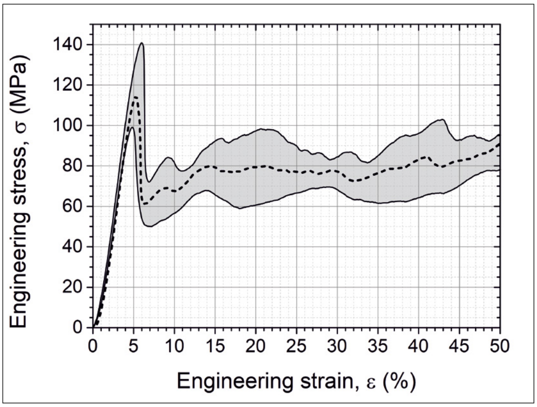

Figure 3. *The standard deviation of the measurement results, with the arithmetic mean.*

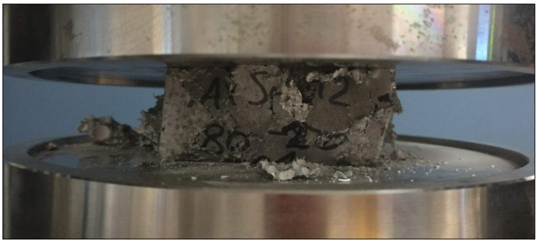

Figure 4. *Damage of the investigated metal foams during upsetting tests.*

Table 2. *Results of upsetting test.*

Indicator	Value	Standard deviation
σ_c (MPa)	120	29
ε_c (%)	5.39	0.80
W_c (J/cm^3)	3.23	1.33
σ_{pl} (MPa)	77	18
ε_{ple} (%)	54.31	0.86
W (J/cm^3)	43.50	16.82
W_e (%)	64.22	0.96

4. Conclusions

In conclusion, the properties of the studied bimodal metal foams provide important information for the scientific field of metal foams. During this research, the following observations were made:

- theoretical modelling of the space-filling is erroneous due to imperfections of the real material;
- the manufactured bimodal metal foams have an average density of 1.62 g/cm^3;
- the test samples had an average compressive strength of 120 MPa and plateau stress of 77 MPa;
- absorbed specific mechanical energy was 43.50 J/cm^3;
- the results of compression tests show significant variance. The reason for this is the uniqueness of the metal foams and the randomness of the CHS packing. More measurements are needed for more accurate results;
- the metal foams disintegrate during bulking with these particular materials, and the matrix material is no longer in contact with the CHSs.

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