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An Alternative Process for the Production of Oriented Fibre Reinforced Syntactic Metal Foams

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Abstract

Metal foams are cellular materials with outstanding specific mechanical properties, such as high specific energy absorption capacity, owing to its cellular structure. Metal foams are cellular materials with good specific mechanical properties, such as high specific energy absorption, owing to the metal matrix. The aim of this study is to simplify the reinforcement of syntactic metal foams with directional fibres. In previous studies, the fibres were positioned using an external orientation frame. To avoid this, reinforcing material layers in a prefabricated mesh form were placed in the crucible, which is thus perpendicular to the direction of the casting. The fabrication resulted in syntactic metal foam samples reinforced with fibres oriented along two axes.

Keywords: *metal foam, syntactic foam, fibre reinforcement.*

1. Introduction

Nowadays, there is an increasing demand for materials with low density and high strength. Conventional materials such as metals and ce-ramics cannot always meet these increasingly strict requirements.

The problem can be approached from two different directions: either the density of high-strength materials must be reduced, or the strength of low-density materials must be increased. This can be achieved by using composites, which combine high-strength and low-density materials in such a way that they com-pensate for each other's shortcomings in meeting the requirements while exploiting their advantages.

1.1. Composites

Composites are combination of materials which differ in composition or form on a macro scale. The constituents may retain their identities in the composite. Normally, the constituents can be physically identified, and there is an interface between them [1]. These components are the high-strength reinforcing material, which can absorb the load, and the matrix material which holds the reinforcing material units together, transmitting the load to them and protecting them from environmental influences.

The bond between the two main constituent parts is of great importance, the strength of the bond that is formed influences the behavior of the composite. A transition layer may be formed, but in many cases the effect is not beneficial for the application [2–4].

In aluminium matrix composites, the effect of different reinforcing materials is investigated, these reinforcing materials can be in the form of grains, fibres, fibre bundles or quilts [5–7]. In the case of fibre reinforcement, it can be short staple fibres, which, due to its random arrangement, has similar effect in all directions as the grains. Or it can be directional fibre reinforcement [8, 9], in this case, the reinforcing material only acts in the direction of the fibre axis, but the reinforcing effect is greater.

1.2. Metal foams

Metal foams are cellular materials with a metallic matrix in which a cellular internal structure is developed to reduce mass [10]. On the basis of the internal porous structure, they can be classified into open-cell foams, in which the internal cells are permeable [11], and closed-cell foams, in which the individual cells are separated by a solid cell wall [12]. A subgroup of closed-cell foams are syntactic foams, in which the porous structure is formed by the introduction of a filler into the solid matrix [13]. Syntactic foams are considered as composite materials. Owing to their low density, they have brain specific mechanical properties, but they cannot withstand tensile stresses due to their cellular structure.

1.3. Goal of this study

In previous research [14, 15] the possibility of using oriented fibre reinforcement was investigated. In these studies, the reinforcing fibres were placed parallel to the casting direction to increase the tensile strength. However, a complex manufacturing process was required to produce this structure. The goal of this study is to simplify the manufacturing process.

2. Materials

Al99.5 aluminum was used as matrix material due to its low density and high ductility. The exact composition of the alloy was measured with a WAS PMI-MASTER SORT optical spectrometer (Worldwide Analytical Systems AG, Uedem, Germany), the composition is presented in Table 1.

Table 1. *Chemical composition of the Al99.5 matrix*

Elements	Weight %
Al	99,5
Si	0,0293
Fe	0,335
Cu	<0,0050
Mn	<0,0050
Mg	<0,0010
Zn	0,0100
Cr	<0,0050
Ni	0,0108
Ti	<0,0010
Sn	0,0367

The filler material used was expanded glass beads in the size range of Ø2.87±0.50mm, purchased from Stikloporas (Stikloporas UAB, Druskinikai, Lithuania). The reinforcement material used was stainless steel mesh 1.4307 (X2CrNi18-9) with Ø0.64±0.02 mm fibre diameter, purchased from Jurotissu Kft. (Jurotissu Kft., Budapest, Hungary). The reinforcement and the filler is shown on Fig. 1.

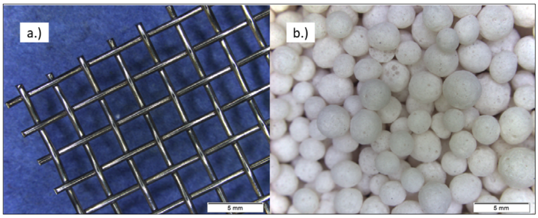

Fig. 1. *a) Reinforcing mesh and b.) filler*

3. Simplified manufacturing process

The filler and reinforcement were layered in a 60×60×380 mm S235JR steel crucible with a wall thickness of 2 mm. The distance of the mesh pieces used as reinforcing material from each other along the axis of the casting direction was measured on the basis of the filler volume: the theoretical volume of the 10 mm high filler layer was 31.36 ml. This was rounded to 31 ml during construction and measured with a measuring cylinder. After this volume of filler was added, manual vibration was applied to ensure that the surface was perpendicular to the axis of the casting. This was repeated seven times, and then 95 ml (30 mm layer) of filler was placed over the final layer of mesh to create reference samples. The layering steps are shown in Fig. 2.

The prepared charge was also sealed from above with 1.4307 steel mesh to prevent displacement of the filler particles during infiltration. The crucible was heated to 550°C in a Prothermo Hoffmann B-70 box furnace (Prothermo Hoffmann Kft., Kecskemét, Hungary) and held for 1.5 hours. The matrix was heated to 750 °C in an Inductor IF-15 induction melting furnace (Inductor Kft., Diósd, Hungary). The melt temperature was measured with a Maxthermo MD-3003 K thermometer (MAXIMUM ELECTRONIC CO., LTD., Taipei Hsien). The molten matrix was poured into the crucible,

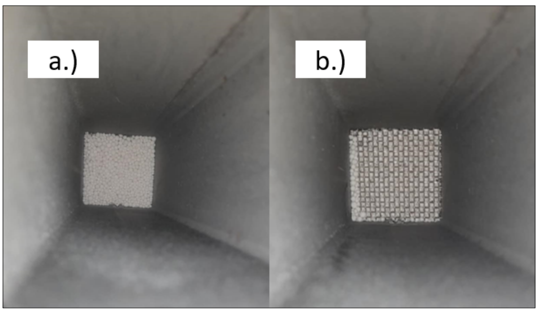

Fig. 2. *Placement of a.) filler and b.) reinforcement in the crucible.*

and infiltration was performed using 400 kPa (4 bar) argon gas pressure. The crucible was allowed to cool to room temperature in the open air.

Samples were taken from the block, some of which were ground and polished with a diamond suspension of 1 μm grain size for microscopic examination.

4. Results

Density was determined from geometric dimensions and mass. The value was 1.63±0.06 g/cm^3 for the reinforced specimens and 1.26±0.01 g/cm^3 for the reference specimens without reinforcing fibres. The use of reinforcing fibres increased the density by 23%.

The structure of the sample is shown on **Fig. 3**. The spacing of the reinforcing mesh layers placed was determined by stereomicroscopy between the fibres closest to each other along the axis of the casting, as shown in **Fig. 4**. The average distance between the fibres is 9.55±0.55 mm. This deviation from the intended distance of 10 mm is due to rounding, inaccuracies in the measurement of the filler volume, and better compaction due to the larger surface area of the crucible.

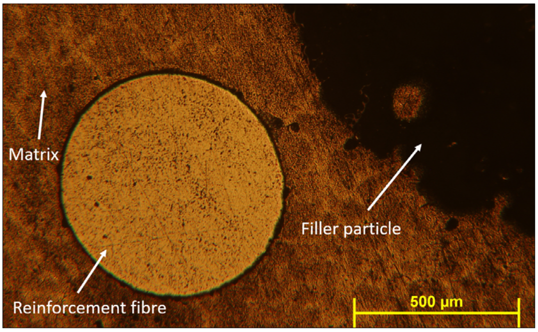

Fig. 3. *Metal microscopy image of the structure of mesh reinforced syntactic metal foam.*

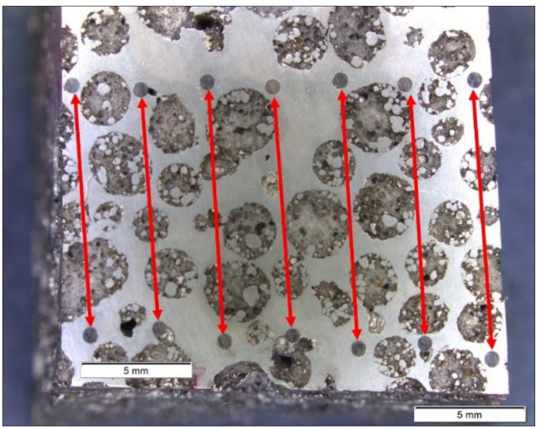

Fig. 4. *Illustration of the distance between reinforcement layers in the cross section.*

5. Conclusions

The following conclusions were drawn from the study:

- Low pressure infiltration (400 kPa) is a suitable process for the production of syntactic metal foams with oriented fibre reinforcement;
- The process used significantly simplifies the manufacturing process compared to methods used in previous research;
- the structure obtained is worthy of further testing, in particular to study the tensile and compressive properties;
- the use of the prefabricated mesh as reinforcing material deserves further testing for larger pieces with fiber orientation parallel to the casting direction to study tensile and bending properties.

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