Quality control of closed-cell metal foam produced by direct foaming

A Gáborá and T Mankovits

1University of Debrecen, Faculty of Engineering, Department of Mechanical Engineering, Ötemető Street 2-4, 4028 Debrecen, Hungary

E-mail: andrasgabora@eng.unideb.hu

Abstract. Metal foams have a lightweight cellular structure with excellent mechanical and physical properties. Although metal foams are popular, they are still not sufficiently characterized thanks to their extremely complex structure which is highly stochastic in nature. In this paper the influence of the technological parameters on the structure is analyzed. In laboratorial circumstances the production of closed cell aluminum foams depends on several factor. The purpose of the paper is to analyze the human factor on the quality of the metal foam specimens.

1. Introduction
Metal foams are relatively new and advanced materials with high stiffness to weight ratio, good thermal conductivity, good acoustic insulation and excellent energy absorption capability which make them ideal materials for a variety of applications [1–3]. Therefore, they have increasingly been employed for a wide range of applications, such as structural elements, automotive parts, sound and vibration absorbers or even biomedical implants [4–8]. There are different types of metal foam structures; open and closed metal foams [9-10], metal matrix syntactic foams [11-13] from different raw materials. Closed cell metal foams are produced by various methods, but the key step of their manufacture is the inclusion of air in the metal structure. The fact that gas pockets are present in their structure provides an obvious weight advantage and other favourable physical, mechanical, thermal, electrical and acoustic properties.

2. Materials and methods
Different metal alloys are foamed by mixing into them a so called foaming agent that releases gas when heated. The most common foaming agent is titanium hydride (TiH₂) which begins to decompose when heated above around 465°C into Ti and gaseous H₂. By adding titanium hydride to an aluminum melt hydrogen gas are rapidly produced. It creates bubbles that can lead to a closed cell foam. The process begins by melting aluminum and stabilizing the melt temperature between 670 and 690°C. The melt is then aggressively stirred and 1–2% of TiH₂ is added in the form of 5–20 µm diameter particles. As soon as these are dispersed in the melt, the stirring system is withdrawn, and a foam is allowed to form above the melt. When foaming is complete the melt is cooled to solidify the foam before the hydrogen escapes and the bubbles collapse.

In our experiments, for the raw material the F3S.20S (AA 359/SiC/20p) aluminum-based metal matrix composite with up to 20% silicon carbide (SiC) particles (Figure 1.) were used. The most
useful features of Duralcan® composites are their high strength, stiffness, wear resistance, thermal conductivity, their improved elevated temperature tensile and fatigue strengths and their low density and coefficient of thermal expansion. The silicon carbide particles are sufficient for viscosity modification. The foaming agent was the titanium hydride (Figure 2.). It is commercially available as a stable grey/black powder, which is used as an additive in the production of sintering powdered metals, production of metal foam, and in pyrotechnics.

For the experiments we used a Goldbrunn 3000 furnace (Maximum temperature: 1100 °C, Mass: 3 kg, Volume: 294 cm³, Power: 1900 Watt, 230V / 50Hz, Accuracy: ±0.5% temperature, Dimensions: 335 x 280 x 360 mm). The original graphite crucible is not applicable so we design and produce a new dismountable crucible. We used CAD systems to design the components and illustrate an assembly of them (Figure 3.). This crucible has two main parts: an outside closed form and an inner part which consist of two symmetric half parts.

Further used devices (Figure 4.): Kern EW400 Precision Scale (Range: Max=600g, Min=0.5g, Accuracy: 0.01 g), Struers Labotom-3 cutting machine, Metkom Forcipol 2V polishing machine, Metabo SBE 750 (0-3000 rpm) and Makita DDF458Z (0-2000 rpm) drilling machines, Turning machine, and for foaming process a mixing head. The used crucible was coated with a boron nitride suspension to be easier removable.

The experiments took place at the Department of Mechanical Engineering, University of Debrecen (Figure 5. and Figure 6.). For the quality of the metal foam specimen (e.g. structure, specimen size, compressive properties) the human factor has great effect. At all experiment the temperature when the TiH₂ is added was 750°C, while the percentage of the TiH₂ to the raw material was 1.5%. The mixing was made manually and human precision was also a factor in the adjustment of cutting cube specimens. After the foaming and cooling processes the samples were cut in 30x30x30 mm³ cubes.
the investigations were done according to the ISO 13314. To provide information from the cell
distribution digital quantitative image analyses were performed using macroscopic records from the
specimen’s surfaces. The compression tests were performed on an INSTRON 8874 type universal
testing machine at room temperature. The compression tests were carried out with the application of
lubricant. The deformation rate was maintained in quasi-static condition at 8.7 mm/min.

![Figure 5. After cooling process.](image1)

![Figure 6. Metal foam samples.](image2)

### 3. Result and discussion

For the investigation 4 experiment was analyzed and evaluated. Table 1 shows the result of the
specimen cut using universal cutting machine Struers Labotom-3. The porosity of each specimen was
also calculated. The porosity evaluation was based on weight and volume measurements.

| Properties      | AF-01 | AF-02 | AF-03 | AF-04 |
|-----------------|-------|-------|-------|-------|
| Edge length a1 (mm) | 30.25 | 30.75 | 30.2  | 29.45 |
| Edge length a2 (mm) | 30.18 | 30.98 | 29.74 | 30.09 |
| Edge length a3 (mm) | 29.97 | 30.55 | 29.16 | 29.67 |
| Porosity (%)     | 90.7  | 81    | 92.7  | 88.3  |

From Table 1 it can be seen that the edge length are not exactly the same and the porosity shows
great difference. Dimensional inaccuracy affects subsequent investigations (e.g. compressive test)
while the cube is not regular. The porosity difference is because of the mixing process which is
difficult to control if it is done manually.

Applying surface analysis from macroscopic images and the ImageJ software the area percentage
of the cells (Figure 7.) and the number of the cells (Figure 8.) for all faces of the specimen can be
calculated and determined. The process of the surface analysis is detailed in [14]. From the figures it
can be stated that the above geometrical properties highly depend on the mixing and from where the
specimens are cut from the produced sample. All of those have effect on the compressive properties of
the aluminum foams.
The compression tests were performed on an INSTRON 8874 type universal testing machine at room temperature (Figure 9.). The compression tests were carried out with the application of lubricant. The deformation rate was maintained in quasi-static condition at 8.7mm/min.

Figure 7. Results of the area percentage determination.

Figure 8. Results of the cell number calculation.

Figure 9. Compression test.
During the tests, the force-displacement curve (Figure 10.) were registered and processed according to the ruling standard for the compression test for porous and cellular materials.

The force-displacement curves show great deviation thanks to the different geometrical and structural properties of the specimens. The deviation can be observed even in the elastic region of the force-displacement curve which is an essential part for application purposes.

4. Conclusions
In our experiments Duralcan F3S.20S aluminum based metal matrix composite as a raw material was used with direct foaming in the melt by titanium hydride addition. Applying same temperature and TiH₂ concentrate the effect of the human factor for the quality of the produced aluminum foam specimens were analyzed. As a result great deviation on physical and geometrical properties can be observed between certain specimens which can be explained with the several manual manufacturing steps. The cellular structure of our specimens is not enough homogeneous, so for the future we are planning to change the technological process to more automated, using machines, particularly for the mixing process.

References
[1] Ashby M F, Evan A G, Fleck N A, Gibson L J, Hutchinson J W and Wadley H N G 2000 Metal Foams: A Design Guide, Butterworth-Heinemann
[2] Czekanski A, Attia M S, Meguid S A and Elbestawi M A 2005 On the use of a new cell to model geometric asymmetry of metallic foams, Finite Elements in Analysis and Design 41(13) 1327–1340
[3] Banhart J 2001 Manufacture, characterization and application of cellular metals and metal foams, Progress in Materials Science 46(6) 559–632
[4] Vendra L J and Rabiei A 2007 Evaluation of modulus of elasticity of composite metal foams by experimental and numerical techniques, Materials Science and Engineering: A 527(7–8) 1784–1790
[5] Tuncer N and Arslan G 2009 Designing compressive properties of titanium foams, *Journal of Materials Science* **44**(6) 1477–1484

[6] Kádár Cs, Chmelík F, Rajkovits Zs and Lendvai J 2004 Acoustic emission measurements on metal foams, *Journal of Alloys and Compounds* **378**(1–2) 145–150

[7] Djebbar N, Serier B, Bouiadjra B B, Benbarek S and Drai A 2010 Analysis of the effect of load direction on the stress distribution in dental implant, *Materials & Design* **31**(4) 2097–2101

[8] Kashef S, Asgari A, Hilditch T B, Yan W, Goel V K and Hodgson P D 2010 Fracture toughness of titanium foams for medical applications, *Materials Science and Engineering: A* **527**(29–30) 7689–7693

[9] Devivier C, Tagliaferri V, Trovalusci F and Ucciardello N 2015 Mechanical characterization of open cell aluminium foams reinforced by nickel electro-deposition, *Materials and Design* **86** 272-278

[10] Xiao L, Song W, Tang H, Zhu Z, Wang J and Wang H 2015 High temperature compression properties of open-cell Ni–20Cr foams produced by impregnation, *Materials and Design* **85** 47-53

[11] Orbulov I N and Májlinger K 2013 Description of the compressive response of metal matrix syntactic foams, *Materials and Design* **49** 1-9

[12] Orbulov I N 2012 Compressive properties of aluminium matrix syntactic foams, *Materials Science and Engineering: A* **555** 52-56

[13] Szlancsik A, Katona B, Bobor K, Májlinger K and Orbulov I N 2015 Compressive behaviour of aluminium matrix syntactic foams reinforced by iron hollow spheres, *Materials and Design* **83** 230-237

[14] Mankovits T, Budai I, Balogh G, Gábor A, Kozma I, Varga T A, Manó S and Kocsis I 2014 Structural analysis and its statistical evaluation of a closed-cell metal foam, *International Review of Applied Sciences and Engineering* **5**(2) 135-143