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

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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 (TiH_2) which begins to decompose when heated above around 465°C into Ti and gaseous H_2. 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 TiH_2 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 As soon as these are dispersed in the melt, the stirring system is withdrawn, and a foam is allowed to form above the melt.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

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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.

Figure 1. The F3S.20S composite.

Figure 2. The foaming agent.

For the experiments we used a Goldbrunn 3000 furnance (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 borone nitride suspension to be easier removable.

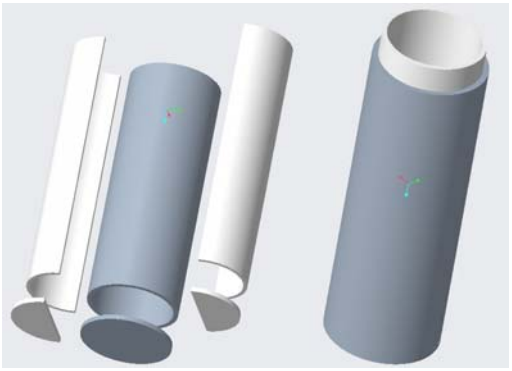

Figure 3. The design of new crucible.

Figure 4. Experiment devices.

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 TiH_2 is added was 750°C, while the percentage of the TiH_2 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 mm^3 cubes. All

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 8.7mm/min.

Figure 5. After cooling process.

Figure 6. Metal foam samples.

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.

Table 1. Geometrical and structural parameters of the specimen.

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.

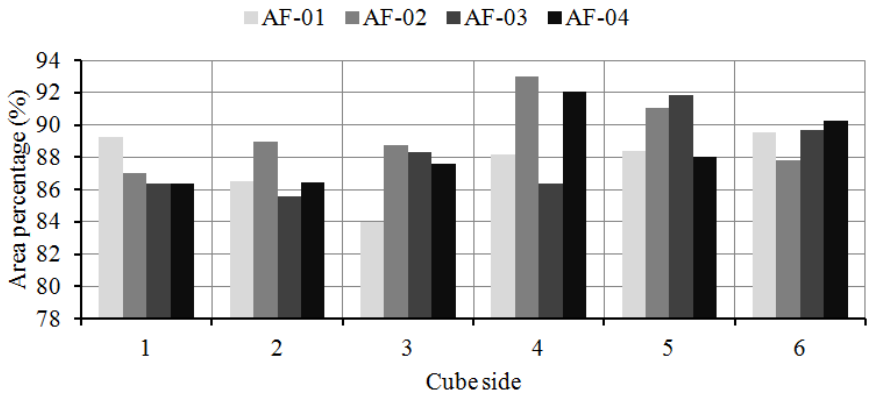

Figure 7. Results of the area percentage determination.

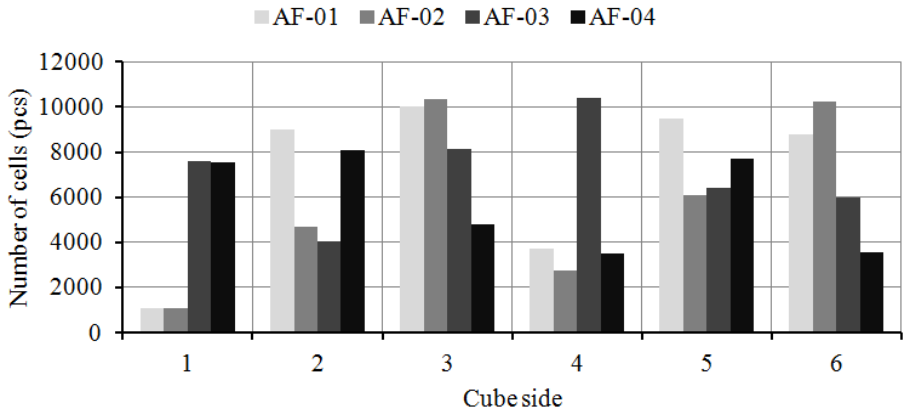

Figure 8. Results of the cell number calculation.

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 9. Compression test.

During the tests, the force-displacement curve (Figure10.) were registered and processed according to the ruling standard for the compression test for porous and cellular materials.

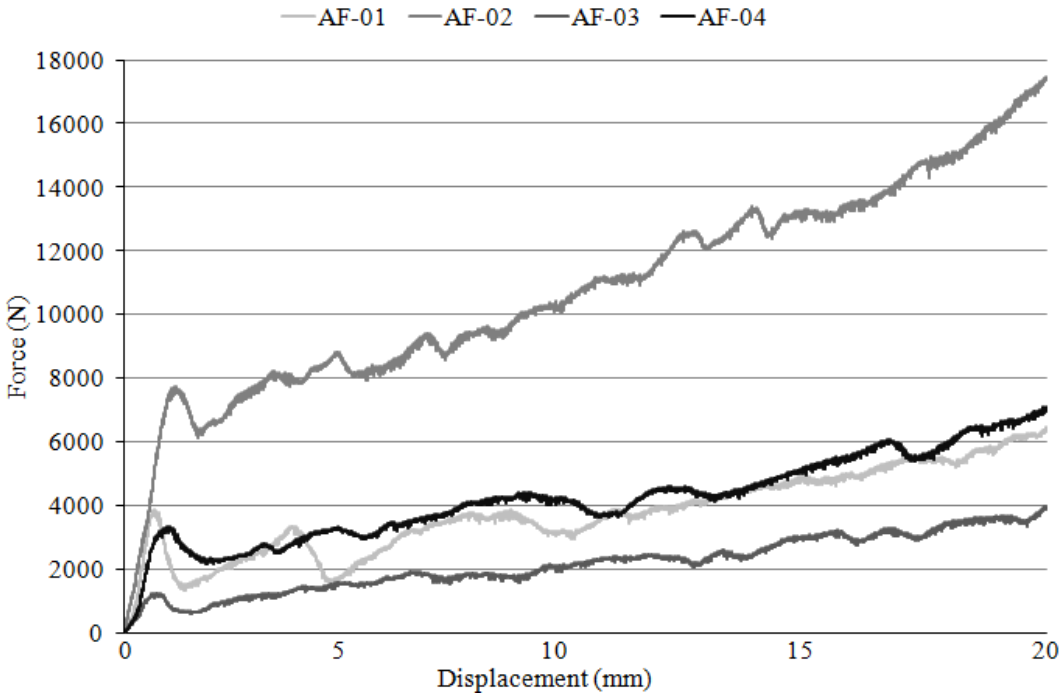

Figure 10. Force-displacement curves of the specimens

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 TiH_2 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.

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