METALLURGY FOR EVALUATION OF METALLIC FOAMS

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Abstract

Porous metallic materials have generally an extensive potential for various applications. It is therefore necessary to know the basic properties of these unconventional materials. The objective of this paper is development and optimisation of metallurgy for evaluation of selected mechanical properties of metallic foams manufactured by foundry methods on hydraulic equipment, as well as definition of exact conditions for testing. Attention is paid also to the method and verification of related calculations of consumed power (deformation work).

Keywords: Metallic foam; evaluation; mechanical properties; strength; deformation work

1. INTRODUCTION

The concept of metallic foam is known already for more than 70 years. During this time this special material appeared in many forms and shapes and numerous methods for its manufacture were developed. It also still finds new uses in various industries and in design. This material offers first of all the possibility of reducing the weight of the product with the least possible impact on its strength. The weight reduction is achieved by deliberate creation of pores, bubbles, voids or holes in the material. These cavities may have different distribution - regular or irregular. They may have a structure with open pores (that are mutually interconnected) or with closed pores (separated from each other). It is possible to create just porous metal or metallic foam with a solid surface crust. Metallic foams can be made from many alloys, such as alloys of Al, Cu, Mg, Zn, Pb, Ti, Cu, Fe, Ni [1, 2, 3].

2. METHODS FOR MANUFACTURE OF CELLULAR METALS

Since the discovery of porous metallic materials numerous methods for their production were developed. Some technologies are similar to those used for the manufacture of polymeric foams, and others are developed with respect to the characteristic properties of metallic materials. According to the state, in which the metal is processed, it is possible to divide the manufacturing processes into four groups. The porous metallic materials may be made from [1, 4]:

- **Molten metal** (e.g. direct foaming of molten metal, foaming agents, casting, etc.)
- **Powder metal** (e.g. sintering of powders, fibres or hollow balls, reactive sintering)
- **Metallic vapours** (vapour deposition)
- **Metallic ions** (electrochemical deposition)

Porosity can reach 30 % up to 93 %, depending on the manufacturing method and the material used. By changing the parameters of the manufacturing process it is possible to obtain a porous structure with different pore sizes and shapes and with different types of arrangements (regular or stochastic) [5].

3. PROPERTIES AND APPLICATIONS

This material offers the particularly the following most important properties:

- **Reduction of mass**: porous metals are very light and it is possible to achieve very high strength by application of ribbing.

- **Absorption (damping) of energy**: it uses ability of this type of material to get deformed under pressure and absorb in comparatively small volume big amounts of energy. This property can be used in transport industry for deformation zones of vehicles.
- **Absorption (damping) of sound and vibrations**: replacement of organic foam material in environment with extreme thermal and mechanical loads.
- **Thermal insulation**: metallic porous materials preserve high mechanical properties even at high-temperatures.
- **Exchange of heat or electricity**: metallic porous materials with open structure have large specific surface, which gives them better abilities of heat exchange [5, 6].

4. EXPERIMENTAL

High demand for use of this material in many industries is related to many advantageous properties of metallic foams. For this reason it is necessary to know the basic properties of these materials. The experiment was therefore focused on optimisation of mechanical properties of metallic foams produced by casting technology. The porous material has the ability to absorb impact energy, it is thus important to monitor the compressive strength and the subsequent total consumed energy (deformation work), which is needed for compression of the material. The castings were made from three different alloys - Silumin AlSi10, tin bronze CuSn10, cast iron with lamellar graphite LLG. Example of casting is shown in **Fig. 1**.

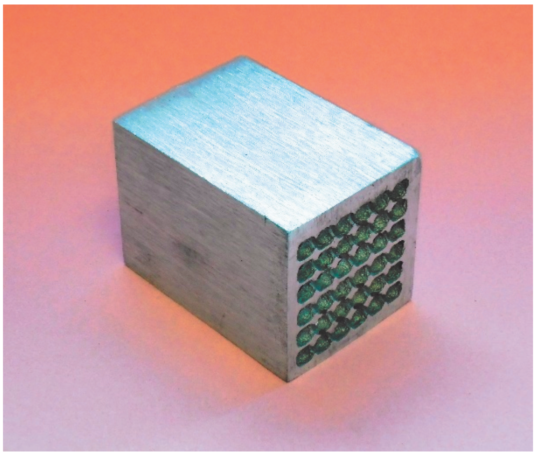

Fig. 1 Casting of metallic foam made of the alloy AlSi10 after machining

4.1 Procedure of experiment

Produced castings and metallic foams were machined and cut to the samples of different sizes. Size and shape of the samples was chosen in respect to the construction of the sample in such a way, that full surface was at compression test in horizontal position. Prepared samples were tested by compression and servo-hydraulic testing equipment LFV 100kN made by the company walter+bai ag (Switzerland), allowing the maximal compression force of 100 kN, in the laboratory of the VSB - Technical University of Ostrava. The feed rate of the crossbeam of this machine was 4 mm per minute. Larger samples were then tested by compression on the hydraulic testing machine Zwick Z600 with the maximum compressive force of 600 kN and the feed rate of the crossbeam of 10 mm per minute. This equipment is located in the testing centre of the company Vitkovice Steel. A total of 9 samples were tested. The samples 1-5 were tested on the equipment LFT 100 kN and the samples 6-9 on the equipment Zwick Z600 with preliminary load of 100 N. The samples 1 and 2 were cut to the size of 30x28x46 mm (see **Fig. 2**). The samples 3-8 were cut to the same size of 63x48x89 mm (see **Fig**

3). The last casting marked as the sample No. 9 was not cut to the smaller size, but it was only machined to the size of 63x65x90mm (see **Fig. 1**). A detailed description of all the tested samples is presented in **Table 1**.

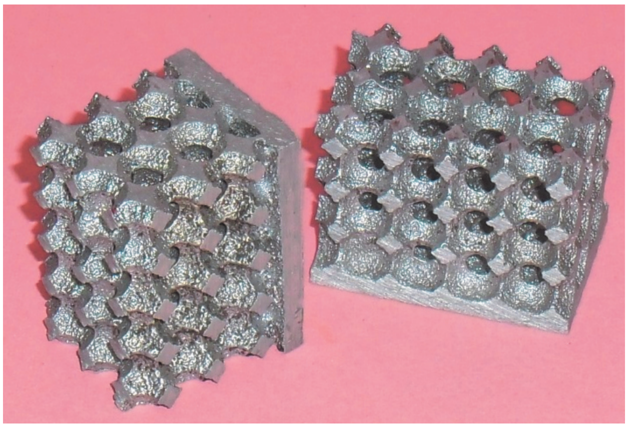

Fig. 2 Samples 1 and 2, alloy AlSi10

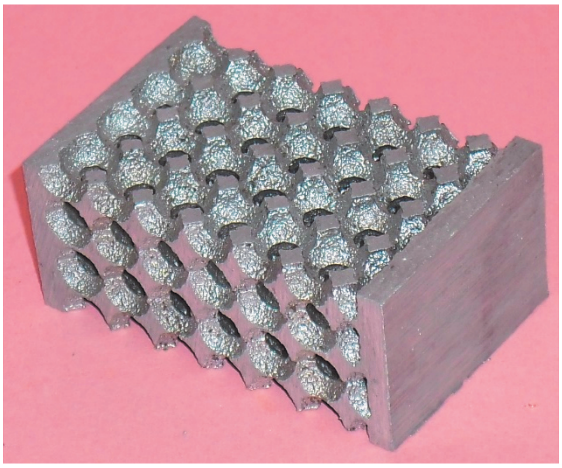

Fig. 3 Size of the samples 3 - 8, alloy AlSi10

Table1 Detailed description of individual samples and values measured at compression test

Sample No.	Alloy	Size [mm] (*h* x *w* x *l*)	Type of instrument	Feed rate [mm/min]	Max. compression force F_{max} [kN]	Max. deformation [mm]	Strain energy forces *W* [J]
1	AlSi 10	30x28x46	LFV 100kN	4	70.73	7.23	374
2	AlSi10	30x28x47	LFV 100kN	4	63.62	5.91	270
3	AlSi 10	63x48x89	LFV 100kN	4	32.99	4.56	124
4	LLG	63x48x89	LFV 100kN	4	82.69	2.03	117
5	CuSnIO	63x43x89	LFV 100kN	4	96.53	10.91	780
6	AlSi 10	63x48x89	Zwick Z600	10	276.18	36.13	5580
7	CuSnIO	63x48x90	Zwick Z600	10	598.09	29.54	10200
8	LLG	63x43x89	Zwick Z600	10	271.25	44.52	3500
9	AlSi 10	63x65x90	Zwick Z600	10	322.68	39.31	

4.2 Compression test and calculation of strain energy

Test of stress deformation was performed in order to verify the ability of mesh material to absorb energy by deformation.

Material's ability to absorb energy can be determined by evaluating the stress-strain curve. Such a curve is shown in **Fig. 4** on the left. Three areas can be distinguished on the curve: the first area corresponds to the linear elastic deformation of the sample, a peak may occur at the end of this area. The second area shows the deformation at constant stress and in the third area a sharp increase of stress takes place due to strengthening of the material by deformation. The following requirements are imposed to the materials designed to absorb the impact energy: the first peak on the diagram should be as small as possible and the second should be long and preferably without fluctuations. The energy absorbed by a unit volume of material corresponds to the area below the curve of the stress-strain and is indicated in **Fig. 4** on the right. [7]

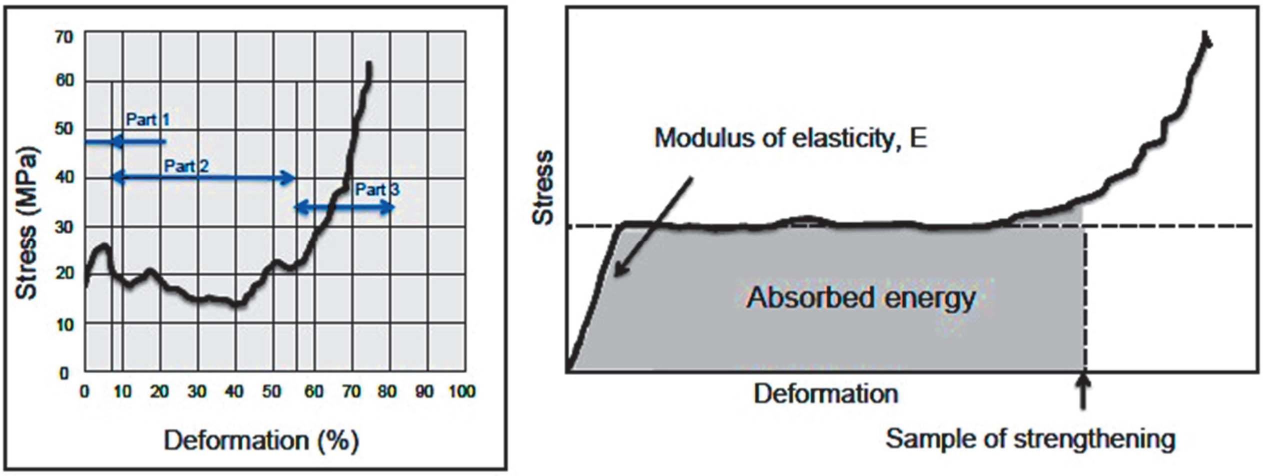

Fig. 4 Evolution of the stress-strain curves at compression test [7]

Calculation of the strain forces is made from the total area under the stress-strain curve. The data for the determination are obtained from the measuring instrument for compression testing. The procedure is as follows: the content of the area below the stress curve S can be divided into individual sections - triangles S1 and blocks S2. From those data we can calculate the total area S using the formula (1). **Fig. 5** shows a diagram illustrating possibilities of calculation of work of strain energy forces.

$$S = S1 + S2 \tag{1}$$

S1 is given by the product of the difference 2 of the consecutive power values in [N] and of the difference between two consecutive values of compression in [m] in absolute value. S2 is given by the product of the precedent value of force in [N] and of the difference between two consecutive values of compression (deformation) in [m]. Total area below the curve represents the work of strain forces in [J].

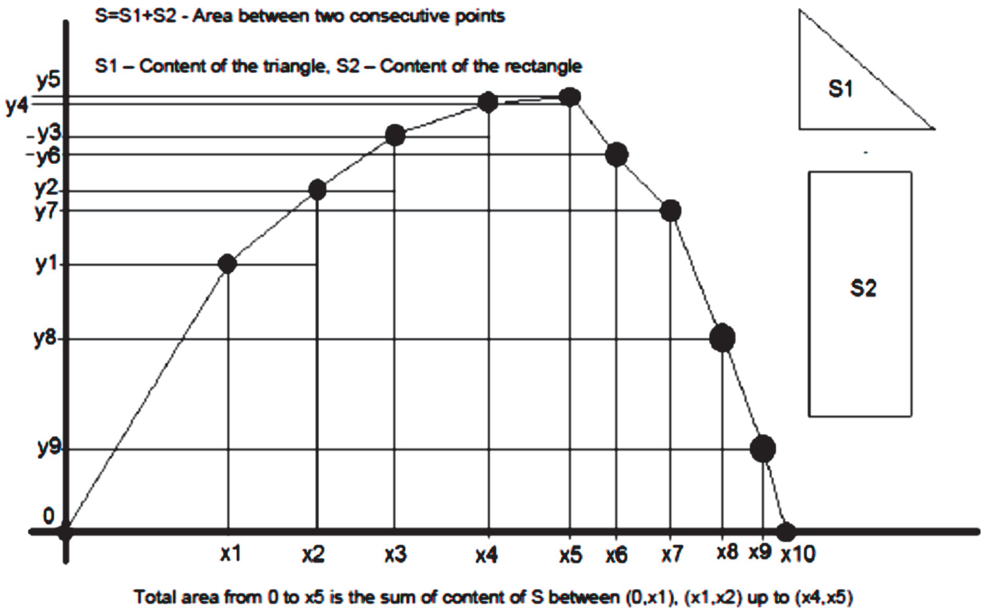

Fig. 5 Calculation of the work of strain forces from the stress-strain curve

5. RESULTS AND THEIR DISCUSSION

Testing on the universal testing machine LFV 100 kN of the company walter+bai ag:

The highest compressive forces and strain was achieved in the sample No. 5 (CuSn10), from which follows also the highest value of the work of strain forces, which has the value of 780 J. The samples 3 (AlSi10) and 4 (LLG) showed in principle an identical work of strain forces, namely 124 J and 117 J. The course of their stress-strain curves was, however, different. In the case of silumin approximately half of the maximum compressive strength was achieved than in the case of cast iron, but on the other hand approx. double maximum strain. In the variant of the samples with the size of 30x28x46 mm the obtained values of the work of strain forces were 374 J and 270 J.

Testing on the hydraulic testing equipment Zwick Z600:

The highest value of work of strain forces was measured in the sample No. 7 (CuSn10), namely 10200 J. In the samples No. 6 (AlSi10) and 8 (LLG) a similar compressive force was achieved, the strain was higher in the sample No. 8 (LLG). Work of strain forces was, however, lower in sample No. 8 (LLG), namely 3500 J against 5580 J achieved in AlSi10. It happened again due to the difference evolution of the stress-strain curves. In the case of silumin we can observe a gradual increase in the first area of the diagram and slow descent in the second area. In the case of LLG we see an immediate steep increase in the first area of the diagram, while in the second area we see an uneven descent and rise of the curve at low values of compressive force. Although in the case of the sample No. 9 (AlSi10) with the size of 63x65x90 mm we achieved the maximum value of compressive force and strain from the diagram, but we did not obtain from the measuring device accurate data for calculation of the work of deformation forces. The sample made of CuSn10 and LLG of this size was not tested due to insufficient compressive force of the equipment Zwick Z600.

CONCLUSIONS

The samples of metallic foam were subjected to a compression test on two hydraulic devices in order to determine their mechanical properties of energy absorption. The test samples were prepared in three sizes. The smallest sample size did not work, the obtained values were low and it was not possible to achieve a full evidence of material properties. The original, i.e. the largest size of the sample size was also not suitable, because provided devices had low compressive force for full compression of the sample. The medium size of the sample, i.e. 63x43x89 mm was the best for comparison of the overall results, but it was necessary to perform the compression test on the more powerful equipment with a load of 600 kN. Out of the three tested materials, the best absorption of energy was achieved by the sample made of the alloy CuSn10, in which the work of strain forces exceeded 10000 J. Considerable disadvantage of this material is, however, its high specific density. The alloy AlSi10 also gave interesting results, where the work of strain forces exceeded 5500 J, while specific density of this alloy achieves almost one-third of that of the alloy CuSn10.

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