MANUFACTURING TECHNOLOGIES OF CAST METALLIC FOAMS WITH IRREGULAR INNER CELL STRUCTURE

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Abstract

Since the discovery of porous metallic materials numerous methods of production have been developed. Porous metallic materials can be made from liquid metal, from powdered metal, metal vapours, or from metal ions. The aim of the paper is to introduce casting methods of manufacturing of metallic foams with irregular cell structure. Metallic foams are materials with the broad applicability in many different areas (e.g. automotive industry, building industry, medicine, etc.). These metallic materials have specific properties, such as large rigidity at low density, high thermal conductivity, capability to absorb energy, etc.

Keywords: Casting, metallic foam, irregular cell structure, investment casting, precursor

1. INTRODUCTION

Metallic foams are materials, the research of which is still ongoing, with the broad applicability in many different areas (e.g. automotive industry, building industry, medicine, etc.). These materials offer interesting perspectives due to the combination of properties (**Figure 1**). The use of the foam material is optimal in such cases when at least two or more its merits are used at the same time [1].

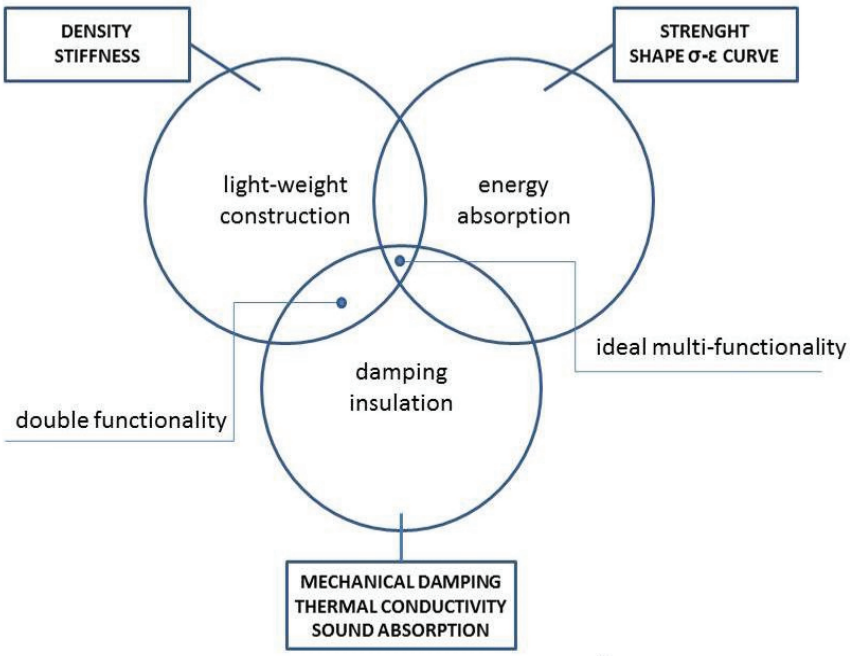

Figure 1 The combination of properties of metallic foams

One of the major advantages that these materials can offer is a weight reduction with minimal impact on its mechanical properties. This is achieved by artificial created pores. Size, shape, distribution and the degree of interconnection of the pores influence the resulting properties of the metallic foam. Porous metals may be made from a wide variety of alloys, e.g. alloys of Al, Cu, Mg, Zn, Pb [2].

Despite the high potential still we find only sporadic application of this material. This fact is mainly due to its method of preparation, which in most cases is very complicated and requires special equipment and technologies.

At VSB - Technical University of Ostrava (Department of Metallurgy and Foundry Engineering) the research dealing with optimization of manufacture of this unique material by a foundry way is currently underway. Within the production of metallic foams with irregular arrangement of inner cells were verified by a investment casting process using a evaporable model and the infiltration of the molten metal into the mould cavity filled with precursors.

Casting technologies of metallic foam production referred to in this paper are based on the use of existing materials and process procedures, which are commonly used in foundries. Precise definition and subsequent implementation of these manufacturing technologies could enable further expansion of these materials and using their full application potential.

2. PROPERTIES AND UTILIZATION OF METALLIC FOAMS

The most important parameters for these porous materials are the porosity, pore diameter, their size, distribution, shape, orientation, the degree of interconnection of the pores. Further on the characteristics of the base material - the alloy, or the density of the created material [3].

Porosity may achieve 30 % to 93 % depending on the method of production and material used. By changing the process parameters it is possible to obtain porous structure with various sizes and shapes of pores and with different types of arrangement (regular or stochastic) [4].

Size, shape, distribution and the degree of interconnection of the pores influence the resulting properties of the metal foam. These parameters affect in particular the thermal conductivity of the material, its ability to dampen vibrations or to absorb energy [5].

Many applications require that a medium, either liquid or gaseous, be able to pass through the cellular material. There may be a need for various degrees of ‘‘openness’’, ranging from ‘‘very open’’ for high rate fluid flow to ‘‘completely closed’’ for load-bearing structural applications, and appropriate materials satisfying these conditions have to be found (see **Figure 2**). [1].

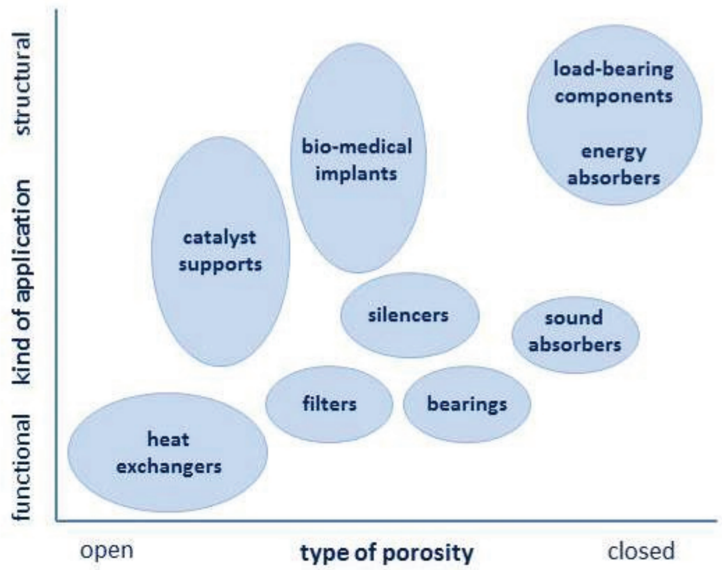

Figure 2 Applications of cellular metals grouped according to the degree of ‘‘openness’’ needed and whether the application is more functional or structural [1]

3. MANUFACTURING TECHNOLOGIES OF METALLIC FOAM PRODUCTION

There are numerous methods of production of porous metallic materials. Some technologies are similar to those for polymer foaming, others are developed with regard to the characteristic properties of metallic materials, such as their ability to sintering or the fact that they can be deposited electrolytically [1, 2].

According to the state, in which the metal is processed, the manufacturing processes can be divided into four groups. Porous metallic materials can be made from [1]:

- **liquid metal** (eg. direct foaming with gas, blowing agents, powder compact melting, casting, spray forming)
- **powdered metal** (eg. sintering of powders, fibres or hollow spheres, extrusion of polymer/metal mixtures, reaction sintering)
- **metal vapours** (vapour deposition)
- **metal ions** (electrochemical deposition)

This paper is primarily aimed at casting technologies of metallic foam production (the production from a liquid phase). Under the term casting technologies we can imagine manufacturing metallic foams by casting molten metal into a conventional foundry mould.

4. CASTING TECHNOLOGIES OF METALLIC FOAM PRODUCTION - EXPERIMENTAL

Within the production of cast metallic foams with irregular arrangement of inner cells were verified by a investment casting process using a evaporable model and the infiltration of the molten metal into the mould cavity filled with precursors.

a) Investment casting - use of evaporable pattern

The most common foundry method of manufacture the metallic foams with open pores is a method with the use of a disposable evaporable polymeric pattern - polymeric foams (most commonly polyurethane foam - PU foams).

The principle (**Figure 3**) consists in casting the polymeric foam with the refractory material, followed by drying and annealing of the mould when the foam pattern is evaporated. Molten metal is then poured in the resulting cavity. After removing the heat-resistant material the cast metal foam with open pores is obtained which is an exact copy of the foam pattern

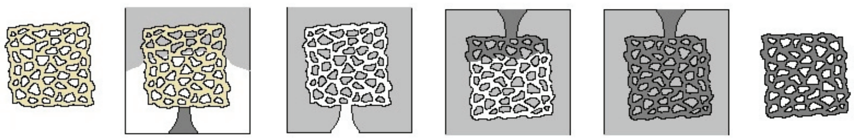

Figure 3 Principle of investment casting with use of pattern made of polymer foam: from left - polymer foam, polymer foam infiltrated with plaster, removed polymer, infiltrated with metal, metal foam in mould, removed mould, final metal foam

One of the key steps in this production process is the choice and processing of a material suitable for manufacture of a mould - plaster in this case. The material for the mould manufacture in particular must have sufficient heat resistance, the mixture must have good fluidity to be able to fill all the small pores of the PU foam.

As the heat-resistant material for the manufacture of moulds the plaster Satin Cast 20 of the firm Kerr Lab is chosen that is designed for making the castings from precious metals. This special plaster is a fine one and it can faithfully copy the surface of a complex pattern. After casting the plaster has an excellent collapsibility.

Making of a mould then consists in casting the pattern with the plaster and at the same time the plaster must fill all the pattern cavities. The pattern is stuck on an accessory silicone hat that serves for creating the gate. A metal cover (cuvette) is put on the hat and the plaster is cast into the system prepared in such a way. The made up moulds are left for two hours on the air and then they are dried at temperature 40 °C for 2 h.

After drying of moulds a next step follows - their annealing. During annealing the free water and the chemically bound water are removed and the PU foam is evaporated

For casting of various alloys (Cu alloys, Al alloys) it is necessary to define different annealing cycles. For casting the Cu alloys with higher melting temperature (higher casting temperature) it is necessary to anneal the plaster moulds to higher temperatures - to eliminate the thermal shock during casting, and to increase the melt fluidity into the complex mould cavity. Annealing cycles can be seen in **Table 1**.

Table 1 Annealing cycles of plaster moulds

annealing cycle	temperature, increase, soak at temperature	temperature, increase, soak at temperature	temperature, increase, soak at temperature
1	120 °C, 8 °C/min; 8 h	320 °C, 10 °C/min; 8 h	800 °C, 20 °C/min; 10 h
2	120 °C, 8 °C/min; 8 h	550 °C, 10 °C/min; 8 h	1100 °C, 20 °C/min; 10 h
3	120 °C, 8 °C/min; 8 h	550 °C, 10 °C/min; 8 h	1000 °C, 20 °C/min; 10 h

The most commonly used is the annealing cycle No 1 which is suitable for the subsequent casting of Al alloys (low melting temperature or low casting temperature).

But for casting of Cu and Fe alloys it is necessary to increase the annealing temperature, i.e. to heat the moulds to higher temperatures. Therefore the annealing cycle No 2 was recommended. This annealing cycle proved to be unsuitable - the moulds annealed to such high temperatures show impaired collapsibility after metal casting.

A plaster sample has been subjected to differential thermal analysis (DTA - **Figure 4**) in which it was found that at temperatures of 1100 °C the $CaSO_4$ is disintegrated to CaO and SO_3 (degradation of the mould).

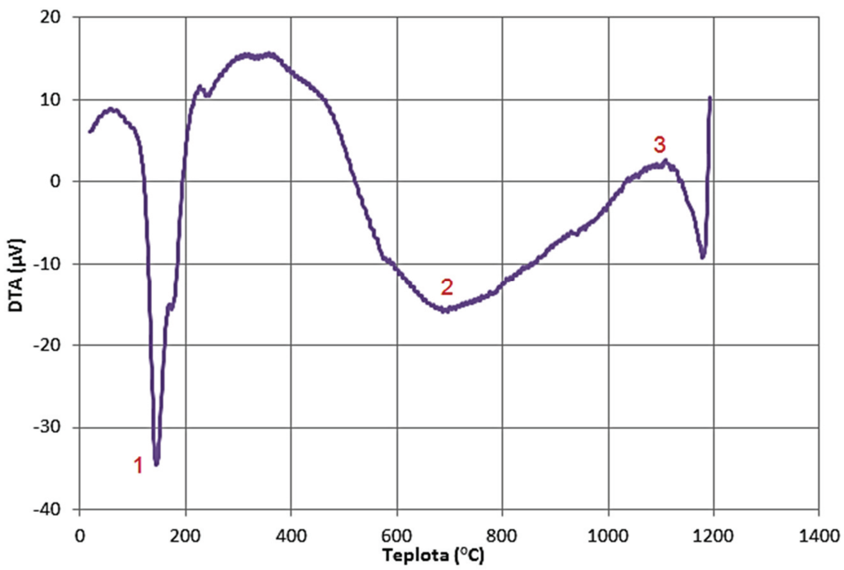

Figure 4 DTA of the Satin Cast plaster - 1 the loss of free bound water, 2 the loss of chemically bound water, 3 the disintegration of $CaSO_4$

After the differential thermal analysis (DTA) three significant changes can be observed on the resulting curve. The first range (150 °C) represents the loss of free bound water, then the second represents the loss of chemically bound water (700 °C). The third area (1100 °C) shows the disintegration of $CaSO_4$ to CaO and SO_3 due to high temperatures. This process is irreversible and the moulds annealed in such a way are unusable due to the loss of good collapsibility after casting. If the annealing temperature is reduced to the max. 1000 °C the $CaSO_4$ doesn't disintegrate and the plaster (plaster mould respectively) maintains its optimum properties.

After the evaluation of the plaster DTA the annealing cycle No 3 was designed. The moulds annealed in such a way have good collapsibility after casting but for casting the Cu and Fe alloys the mould temperature is too low. When casting these alloys the metal misruns into the mould cavity due to high temperature jump. On the contrary for casting the Al alloys the mould prepared in such a way is "overheated".

This procedure for manufacturing of metallic foams with irregular inner cell structure is time consuming and requires a perfect mastery of all steps of the production process - choice of pattern, mould material optimally set the annealing cycle of moulds, removing moulding material from complicated cavities of resulting casting. For these reasons another technology of manufacturing of cast metallic foams with stochastic arrangement of inner cells using precursors have been proposed.

b) Infiltration of molten metal into mould filled with precursors

Irregular arrangement of inner pores can be achieved also by using „particles" - precursors, which fill the mould cavity. These precursors which have given shape and size are placed in the mould cavity and the molten metal is poured over them. Precursors must meet certain criteria. Particularly, they must be made of material, which preserves its shape at impact of the molten metal (sufficient strength, low abrasion, refractoriness) and they must allow also good disintegration after casting. Principle of the method is shown in **Figure 5**.

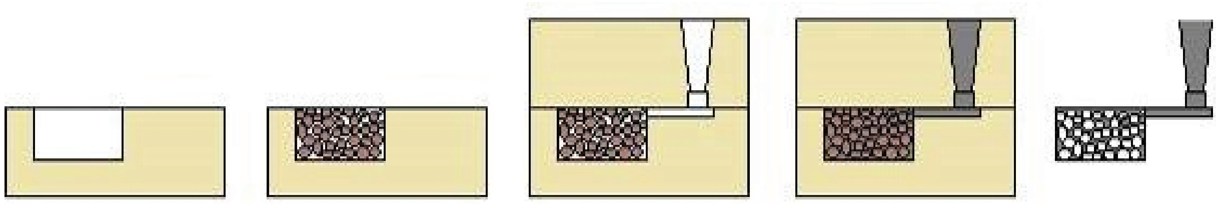

Figure 5 Principle of infiltration of molten metal into mould filled with precursors, from left: mould, mould cavity filled with precursors, composite foundry mould, pouring molten metal into mould cavity, cast metallic foam after removing precursors

In the experiment we made castings with irregular cell structure with use of precursors based on conventional moulding mixtures (organic types). There were two types of precursors:

Precursors - Croning process

Core particles were manufactured from moulding mixture (respectively from reject cores made by Croning process). Final globular shape of core precursors was achieved by splitting in to small pieces (10 - 30 mm) and followed by tumbling. A mould cavity was filled with these precursors. Mould was made from commonly used green sand (i.e. bentonite bonded moulding mixture). The disadvantage of these precursors is their irregular shape (**Figure 6**), which is determined by uneven tumbling of the cullet due to nonuniform hardening of the default core mixture. Therefore, new technology of precursors manufacturing has been proposed - use of moulding mixture bonded by furan resin. This way of manufacturing of precursors should ensure the achievement of the same size, shape and the resulting characteristics of precursors.

Precursors - Furan moulding mixture

To create these precursors were used as core box plastic grille. By using this core box cubes of a side of 25 mm were created. These cubes were followed by tumbling. The proposed technology ensures the production of precursors of the same size, shape and properties (**Figure 7**).

Figure 6 Precursors - Croning process

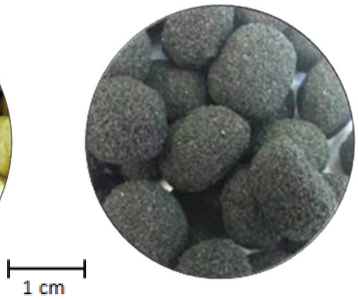

Figure 7 Precursors - furan moulding mixture

5. CONCLUSION

Metal foams are progressive materials with continuously expanding use. Mastering of production of metallic foams with defined structure and properties using gravity casting into sand or metallic foundry moulds will contribute to an expansion of the assortment produced in foundries by completely new type of material, which has unique service properties thanks to its structure, and which fulfils the current demanding ecological requirements. Manufacture of foams with the aid of gravity casting in conventional foundry moulds is a cost advantage process which can be industrially used in foundries without high investment demands.

The principle of the above-mentioned technology is the infiltration of liquid metal into the foundry mould cavity. These technologies enable the production of shaped castings - metallic foams with irregular cell structure. In the production of precursors can moreover be assumed using of the material, which would be in other cases waste - reject cores or excess moulding mixture.

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