CHARACTERISATION OF CELLULAR METALLIC MATERIALS MANUFACTURED BY CASTING METHODS

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Abstract
Porous metals and metallic foams are metallic materials containing pores in their structure that are intentionally created. Their specific structure then gives them a very advantageous combination of physical and mechanical properties, such as low density and high rigidity along with high capability of absorption of impact energy. The research work carried out at the Department of Foundry Engineering of the VSB – Technical University aims to study a technique of producing porous metals by simple and cost effective methods for achieving porous structures using conventional principles of gravity casting in sand moulds. Given the specific character of the cast product, the production process, while derived from conventional founding presupposed mastery of certain specific conditions to guarantee reproducible results. We mention in particular: the precursor composition, temperature of the alloy, thermal properties of the mould, thermal properties of the precursors, filling mode, simulation of filling and solidification of cellular part. First results summarizes casting technology verification and mechanical properties obtained. 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 ecological requirements.

Key words:
Porous metals, cellular metals, metal foams, manufacture, casting methods

1. INTRODUCTION
The appropriate way to reduce the weight of manufactured parts without adversely affecting their strength is the use of porous metallic materials with different internal arrangement of intentionally created cavities. Inspiration could be natural materials that are already well proven for thousands of years - organic porous building materials (wood, bone, coral, etc.) capable of transmitting high mechanical stresses at a low weight.

The term cellular metal is a general term describing a material in which any kind of gaseous voids are dispersed, in the porous metal pores are usually round, while the terms of foam metal or metal foam are used for porous metal produced by foaming of the melt, in which the pores are not interconnected ("structure with closed pores"). In addition, we have the term metal sponge, which is used for highly porous materials, in which pores are connected in a complicated manner and the structure can not be divided into individual cavities ("structure with open pores") [1]. The term metallic foam is, however, very often used as a general designation of porous material even in professional literature.

2. MANUFACTURING METHODS OF CELLULAR METALS
Since the discovery of porous metallic materials numerous methods of production have been developed. 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.
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 [2]:

- **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)

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).

### 2.1 Properties and applications of cellular metals

Specific structure of the cellular metals gives them a very advantageous combination of physical and mechanical properties, and possibilities of application:

- **reduction of weight**: porous metals themselves are lightweight and when connected with thin ribs, they can achieve the same values of mechanical strength as it is required for conventional heavy structures
- **absorption of energy**, the most promising feature: it uses the ability of this type of material to deform under a constant and relatively low stress, and thus to absorb in the relatively small volume large amounts of energy. This property can be used in transport, especially in personal vehicles for protection of the interior in the case of car crash [3]).
- **absorption of sound and vibrations**: substitute of organic foam materials in an environment with extreme thermal and mechanical stress;
- **thermal insulation**: metallic porous materials retain high mechanical properties even at high temperatures and even when exposed to flames they do not release any organic vapours;
- **protection against explosions and impacts**: both for non-military and military purposes:
- **exchange of heat or electricity**: metallic porous materials with open structure have very large specific surface area, which gives them better exchange capabilities.
- **medicine**, which uses porous metals for bone and dental implants - (titanium metallic foams), the structure of which is closer to the structure of human bone, and titanium is well tolerated by the organism.

Despite the uniqueness of properties and wide range of possibilities of use, the examples of practical permanent applications are not large. Nickel foam materials are serially manufactured and used as electrodes in rechargeable batteries for portable devices (mobile phones, laptops), titanium foams are used as implants. At present, the most explored porous metal materials are aluminum foams, which can be documented by the development of prototypes as well as practical applications (small series for AUDI, LAMBORGHINI crash zones). The reasons of a still limited use of cellular metals are primarily economic. That's why the current interest (as reflected by a growing number of new published studies and possibilities of industrial applications [4,5,6,7]) is focused mainly on the development of technologies enabling production of foam materials at the costs, which would allow their widespread use.
3. EXPERIMENTAL APPROACH

The research work carried out at the Department of Foundry Engineering of the VSB –Technical University aims to study a technique of porous metals manufacturing by simple and cost effective methods for achieving porous metallic structures using conventional principles of gravity casting in sand moulds. Production of metallic foams using conventional gravity casting into foundry moulds presupposes cost-efficient process than other still known technologies such as powder metallurgy, metal evaporation and ionization. In the Czech Republic cast metallic foams are not yet produced.

The subject of the performed research was testing infiltration techniques to manufacture metal foams with different cellular structure. Infiltration techniques are based on infiltration of liquid metal between various filler materials (called preform or precursor) placed in the mold. The preform must satisfy a certain number of criteria. In particular it must not contain disconnected island of material so that could be completely eliminated from solidified metal. It must be made of a material that retains its shape during liquid metal infiltration (sufficient strength, low abrasion) and could be destroyed after casting to leave the porosities.

Preform/core manufacturing

Regular cellular structure can be achieved using different types of preforms which fill the mold cavity. Using preform like a core not filling the whole mould cavity can enable to manufacture a casting with solid surface layer and internal porous structure.

Core box manufacturing

For the manufacturing of sand preform/core it was necessary to prepare a core box. Due to the complex lattice shape of the core, a sectional core box was designed consisting of five-part, which allowed an easy removal of the core.

The core box (Fig.1) was designed with use of the program ProEngineer. Fused Deposition Modelling technology, (which is one of technologies of Rapid Prototyping and 3D printing, enabling very rapid manufacture of physical model or of final product on the basis of computer data) was used for core box manufacturing. The model is constructed by adding layer after layer of thermoplastic acrylonitrile-butadiene-styrene (ABS). This material - thanks to its properties makes possible to use the models as functional prototypes, mould making patterns and direct production (the so-called Direct Digital Manufacturing).

![Fig. 1 3-D model of the core box designed with use of the program ProEngineer [8]](image1)

![Fig. 2 Core box made of ABS [8]](image2)

The core box prepared in this manner (Fig. 2) can be used for manufacturing of preforms/cores from appropriately selected sand mixtures.

Material used for preform/core manufacturing was CO_{2} hardened alkaline phenolic process. The resin is an alkaline phenolic one, containing a linking substance stabilised at a high pH, approximately 14. Curing
occurs by gassing with carbon dioxide, which dissolves in the water solvent of the resin, so lowering its pH and activating the linking substance.

**Moulding mixture composition**

100 w.p. silica sand GRUDZEN LAS 22

2-3% alkaline phenolic resin Novanol 145 (ASHLAND SÜDCHEMIE-CZ)

Curing time 60,90s

Sand testing included: shear strength [MPa], friability [%] – measured immediately after carbon dioxide curing and then in the time interval 120 hours for the storage ability assessments. Determining of shear strength values after heating in the temperature interval 300-600°C express the collapsibility of the given moulding mixture. Tests were carried out to assess its optimal composition. The data collected for each test are based on an average of three samples.

4. **RESULTS AND THEIR DISCUSSION**

Primary shear strength of the moulding mixture containing 2% of resin Novanol 145, was overmuch low to enabling essential handling operation, that is why subsequent tests were interrupted and measurements were carried out only on the mixture containing 3% of Novanol resin and different curing time (Tab.1).

<table>
<thead>
<tr>
<th>hour</th>
<th>mixture 1 - 60s</th>
<th>mixture 2 - 90s</th>
</tr>
</thead>
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<tr>
<td></td>
<td>shear strength [MPa]</td>
<td>friability [%]</td>
</tr>
<tr>
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<td>0,48</td>
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</tr>
<tr>
<td>120</td>
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<td>20,86</td>
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As it shown on the Fig.3 and Fig.4 below mixture carbon dioxide cured for 90s has better strength properties and lower tendency to erosion expressed by friability. Preform can be stored for 5 days without deterioration in quality. The collapsibility of both mixtures is comparable.

Preform/core was then manufactured from assessed moulding mixture (3% Novanol resin, curing time 90s) using conventional core making techniques (ie. molding mixture compaction in the prepared core box and CO₂ curing). The special attachment to the supply of CO₂ (made by using the Fused Deposition Modelling technology) allowed the more uniform curing of the whole preform/core volume and thus also better mechanical properties of the preform/core. The preform so produced was completed and placed in a mould cavity. Mold was made from commonly used green sand (ie. bentonite bonded moulding mixture).
Materials used for casting was AlSi10MgMn alloy (pouring temperature 710°C) and cast iron with lamellar graphite according to EN GJL-200 (pouring temperature 1320°C).

After casting the heat from the metal gradually destroys the resin of the sand, making destruction of the preform easy in case of cast iron. Al alloys with a lower pouring temperature require once a short annealing for easier elimination of preform from porosities.

5. CONCLUSION

Performed experiments have demonstrated the possibility of manufacturing casting with both regular cellular structure and solid skin in a single casting operation using infiltraton technique. The optimal composition of the sand mixture for preform/core manufacturing was determined on the basis of attempted tests. The selected mixture has a sufficient strength and abrasion resistance enabling handling operation. Relatively good collapsibility allow to destroy it after casting (or additional annealing).

Mastering of production of metallic foams with defined structure and properties using gravity casting into sand 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. Metal foams are progressive materials with continuously expanding use. In the Czech Republic cast metallic foams are not yet produced.

**Fig. 5** Casting with regular cellular structure and solid casting skin  
**Fig. 6** Cut casting prepared to pressure tests

ACKNOWLEDGEMENTS

*This work was elaborated within the frame of the research project TA02011333 (Technology Agency of the CR)*

REFERENCES


