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## PROPOSAL OF METHOD OF REMOVAL OF MOULD MATERIAL FROM THE FINE STRUCTURE OF METALLIC FOAMS USED AS FILTERS

### METODA USUWANIA MATERIAŁU FORMIERSKIEGO Z DELIKATNEJ STRUKTURY PIANY METALOWEJ STOSOWANEJ JAKO FILTR

Metallic foams are materials that are subject of an ongoing research with the broad applicability in many different areas (e.g. automotive industry, building industry, medicine, etc.). These metal materials contain in their structure artificially created pores. These pores give them specific properties, such as: large rigidity at low density, high thermal conductivity, capability to absorb energy, etc. Since the discovery of porous metallic materials numerous methods of production have been developed. The aim of the paper is to introduce effective casting methods of manufacturing of metallic foams, namely cast metal filters from the aluminum alloy. Research deals with investment casting with use of pattern made of polymeric foam, which is used for production of metallic foam with open pores. The main disadvantage of this procedure consists in removing the mould material without damaging the fine structure of the cast filter. Plaster is used as the mould material and the most important result of this paper is the presentation of the effective procedure of plaster removal from the porous structure of cast filters.

*Keywords:* metallic foam; aluminum foam; manufacturing of metal foam; cast metal filter

Piany metalowe są przedmiotem wielu badań gdyż znajdują szerokie zastosowanie w wielu dziedzinach np. produkcji samochodów, budownictwie czy w medycynie. W swojej strukturze zawierają sztucznie wytworzone pory, zapewniające uzyskanie specyficznych właściwości jak duża wytrzymałość, niewielka gęstość, wysokie przewodnictwo cieplne zdolność do absorpcji energii itp. Od czasu wynalezienia porowatych materiałów metalowych opracowano wiele metod ich wytwarzania. Celem opracowania jest wprowadzenie efektywnych metod odlewniczych produkcji pian metalowych, szczególnie ze stopów glinu. Studium zajmuje się precyzyjną metodą odlewania przy zastosowaniu modelu wykonanego z piany polimerowej stosowanej w produkcji piany z otwartymi porami. Główna niedogodność metody polega na trudności usuwania materiału formierskiego, bez naruszenia delikatnej struktury odlewane go filtra. Jako materiał formierski stosuje się gips i najważniejszym wynikiem pracy jest przedstawienie efektywnej procedury usuwania gipsu z porowatej struktury odlanego filtra.

### 1. Introduction

Cellular materials are widespread in everyday life and they are used for cushioning, insulating, damping, constructing, filtering purposes, as well as many other applications. Highly porous materials are known to have a high stiffness combined with a very low specific weight. Cellular materials are for this reason frequently used in nature as constructional materials (e.g. woods and bones). The fact, that even metals and metallic alloys can be produced as cellular solids or metal foams, is not as well known as the possibility to foam more traditional engineering materials, such as polymers, ceramics or glass. Metallic foams offer interesting perspectives due to the combination of their properties, which are related to the metallic character on the one hand, and to the porous structure on the other hand [1, 2, 3].

Since the discovery of porous metallic materials numerous methods of production have been developed. Some technologies are similar to those for polymer foaming, others were

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 [4].

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 [5, 6]:

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

Cellular metallic materials are finding an increasing range of applications. A decision, whether a suitable porous metal or metal foam can be found to solve a given problem, depends

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on many conditions, summarised here by the following keywords [7]:

- **morphology**: type of needed porosity (open versus closed), amount of needed porosity, size scale of desired porosity, total required internal surface area of cellular material;
- **metallurgy**: metal or alloy or required microstructural state;
- **processing**: possibilities for shaping the foam or cellular solid or for manufacturing composites between the foam and conventional sheets or profiles;
- **economics**: cost issues, suitability for large volume production.

The first point, in particular, is crucial for any evaluation of cellular metallic material applications. Many applications require that a medium, either liquid or gaseous, is 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 1). Normally, a difference is made, depending on the fact whether the application is “functional” or “structural”, the difference between these two notions is, however, rather gradual. The question, which metals or alloys are suitable for manufacture of the given type of cellular structure, is also important. Structural, load bearing parts have to be light because otherwise they would be made from conventional massive metals or alloys [7].

## 2. Casting methods of metal foam production

Investment casting with use of pattern made of polymer foam is used for production of metallic foam with open pores, which copies the shape of the polymer foam. A polyurethane foam cavity is first filled with sufficient refractory material, such as plaster (or a mixture of mullit, phenolic resins and calcium carbonate). The assembly is then heated to 700°C,

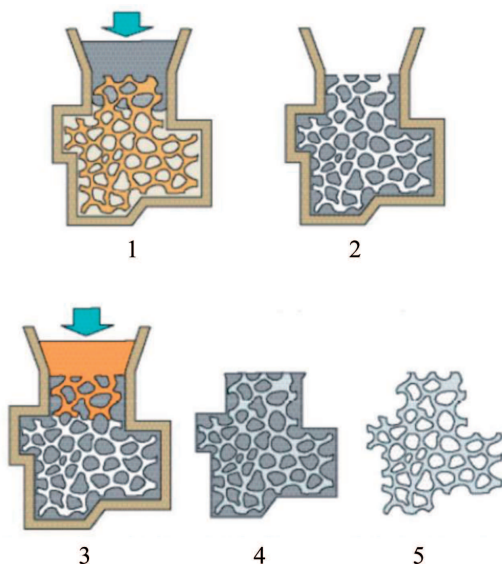


Fig. 1. 1 – polymer foam infiltrated with plaster, 2 – removed polymer, 3 – infiltrated with metal, 4 – metal foam in mould, 5 – removed mould, final metal foam. Source: [9]

to fire the plaster and remove the polyurethane foam. Molten metal (aluminum alloy) is then poured into the mould – again, combinations of vacuum and high pressure casting can be used to ensure full infiltration. The plaster is then dissolved, to give a net-shape metal foam with an identical structure to the original polymer foam [4, 8] (see Fig. 1-4).



Fig. 2. Polymer foam



Fig. 3. Plaster mould

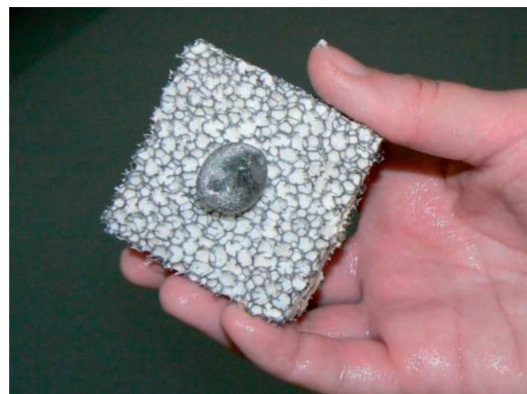


Fig. 4. Metal foam with remains of plaster mould

## 3. Cleaning of castings

Removal of the metallic filter from the plaster mould is followed by the next step – cleaning of filter by removing the plaster, which fills its pores.

Removal of mould material from the fine structure of material can be performed by the following procedures:

- mechanically (dissolution of plaster under flow of water),
- application of ultrasonic bath,
- dissolution of plaster in a 1M solution of nitric acid  $\text{HNO}_3$

#### 4. Cleaning of castings – evaluation

Dissolution of superfluous plaster in water (see Fig. 5) appeared to be an unsuitable method. The plaster forms a compound  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ , which is insoluble in water.

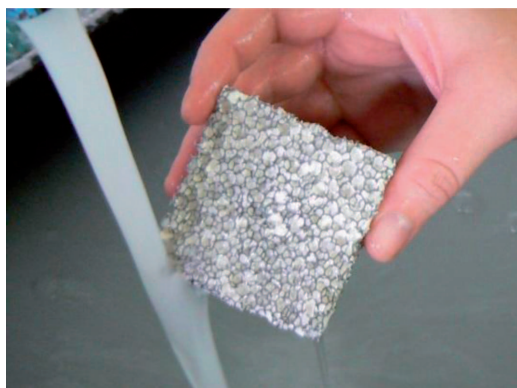


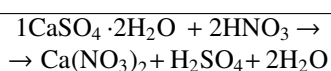
Fig. 5. Flushing of plaster in water

Use of ultrasonic bath for removal of plaster from metallic foam gave better results (see Fig. 6). This procedure is efficient, but it is rather time consuming (action of ultrasonic bath must last for 12 hours).



Fig. 6. Cleaning of metallic filters in ultrasonic bath

Another method consists in removal of plaster from the pores of metallic foam by its dissolution in 1M solution of nitric acid  $\text{HNO}_3$ . When the plaster is immersed into this solution a reaction starts, which transforms the insoluble compound  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$  into calcium nitrate  $\text{Ca}(\text{NO}_3)_2$ , which is soluble in water.



By weighing of several castings of metallic foams with the plaster in their pores and without it we determined the average amount of plaster, which had to be removed, and by subsequent calculations we defined the necessary quantity of nitric acid for dissolution of plaster in one sample.

More efficient alternative of this procedure consists in primary mechanical removal of part of plaster from the foam (e.g. by its flushing under a stream of water), thanks to which mass of plaster per one sample is reduced and therefore the calculated quantity of acid can be used for dissolution of plaster in two or even more samples. Another possibility consists in the use of stronger solution of the used acid, which would reduce the volume of solution necessary for the reaction.

It follows from the calculations given below that in total  $653 \text{ cm}^3$  of 1M  $\text{HNO}_3$  is needed for ensuring a complete running of reaction.

$$\begin{array}{l} \text{1) } 100\% \text{ HNO}_3: \\ 1\text{mol sádra} \dots\dots\dots 2\text{mol HNO}_3 \\ 172\text{g sádra} \dots\dots\dots 126\text{g HNO}_3 \\ 56\text{g sádra} \dots\dots\dots X \text{ g HNO}_3 \end{array}$$

$$X = \frac{126 \cdot 56}{172} = 41,02\text{g}$$

$$\begin{array}{l} \text{2) } 1\text{M HNO}_3: \\ v \text{ 1dm}^3 \dots\dots\dots 63\text{g HNO}_3 \\ \rho = 1,0312 \frac{\text{g}}{\text{cm}^3} \end{array}$$

$$m = \rho \cdot V = 1,0312 \cdot 1000 = 1031,2\text{g}$$

$$w = \frac{63}{1031,2} = 0,061 = 6,1\%$$

$$\begin{array}{l} \text{3) } 6\% \text{ HNO}_3: \\ 41,02\text{g HNO}_3 \dots\dots\dots 100\% \\ X \text{ g HNO}_3 \dots\dots\dots 6\% \end{array}$$

$$X = \frac{41,02 \cdot 100}{6,1} = 672,46\text{g} = 673\text{g}$$

$$V = \frac{m}{\rho} = \frac{673}{1,0312} = 652,8 = \boxed{653\text{cm}^3}$$

The procedure itself consists in dissolution of plaster in 1M solution of nitric acid  $\text{HNO}_3$  during 1 hour, followed by flushing and drying of the casting. Fig. 7 presents perfectly cleaned castings.



Fig. 7. Castings after removal of plaster in 1M solution of  $\text{HNO}_3$

## 5. Conclusions

Difficulties in the process of investment casting with use of pattern made of polymer foam include removal of the mould material without damaging the fine structure too much.

Several procedures for removal of mould material (plaster) from the fine structure of the filter were tested – dissolution of superfluous plaster in water, removal of plaster by application of an ultrasonic bath, and distribution of plaster in 1M solution of nitric acid.

The method of dissolution of plaster in nitric acid appeared to me the most efficient one. Application of this method is not accompanied by any deformations or damage to the brittle structure of the casting.

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