PRODUCTION OF FILLING MATERIAL OF THE MOULD FOR MANUFACTURING OF METALLIC FOAMS WITH IRREGULAR INNER STRUCTURE

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https://doi.org/10.37904/metal.2022.4462

Abstract

The article presents the technology of manufacturing of precursors (special kind of filling mould material) for possibility to create a complex internal structure of the metallic foam casting. Due to the purpose for which the precursors are used, they must meet specific criteria. The material of the precursors must be sufficiently refractory to come into contact with the liquid metal, and the individual particles must also resist the movement of the melt within the mould. At the same time, however, in the context of this metal foam technology, it is essential that the precursors exhibit excellent collapsibility after casting - i.e. that they are easily removable from the resulting complex casting. Therefore, one of the conventionally used core mixtures appears to be the ideal material for the production of precursors. In this paper, the technology for the production of spherical precursors from a furan self-hardening mixture is described and verified. The motivation for the choice of material and all the sub-steps of the process - moulding into the core, tumbling, including the necessary accompanying tests of the mechanical properties of the core mixture being verified - are described.

Keywords: Casting, moulding mixture, metallic foam, porous metal, precursor

1. INTRODUCTION

The trend in the development of modern structural materials is to find a suitable combination of low specific weight and sufficient strength. These properties are achieved by several materials, including some foundry alloys. However, to achieve thin-walled components that also meet the low weight requirement, the limiting factor in the foundry industry is the use of existing technological processes. Another possible way to reduce the weight of manufactured components without negatively impacting their mechanical properties is to use metallic materials with artificially created pores in the structure - metallic foams [1].

Metallic foams are generally a very attractive material that offers a wide range of unique properties [1]. Among the most important ones we can include the ability to absorb impact energy (transport applications) [2,3], low density (lightweight structures) [4,5] and damping ability (acoustic barriers) [6]. The final material properties of the metallic foam are determined by the pores inside the foam. We can distinguish materials of different porosity [7], with regular or irregular arrangement of internal cavities [7,8], with closed or open interconnected pores [9]. Metallic foams are mainly used by combining their properties in so-called bifunctional or better still multifunctional applications [10] (see **Figure 1**).

The aim of the paper is to verify the possibility of producing this unique material by conventional foundry processes using moulding and core mixtures. The experiment of the paper aims to evaluate the possibility of using a furan no-bake mixture to produce so-called precursors (space holder material) for the production of metallic foams. The use of standard foundry technologies and materials [11] could contribute to the introduction of a more economically accessible process for the production of metallic foams.

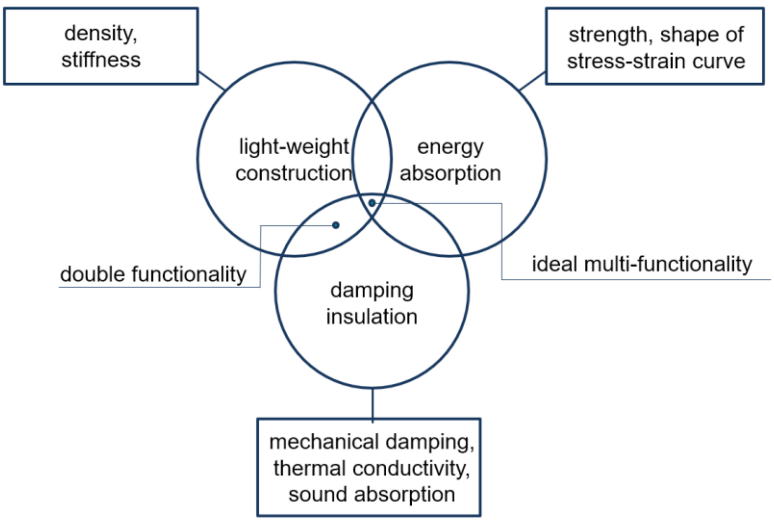

Figure 1 Bifunctional and multifunctional use of metallic foams [7]

2. METALLIC FOAMS PRODUCTION

Metallic foams can be prepared by various processes [12], but in most cases these involve complex operations and energy and economic costs, which significantly affect their price and thus the possibility of wider use.

According to the state, in which the metal is processed, the manufacturing processes can be divided into four groups. Metallic foams can be made from:

- liquid metal (eg. direct foaming with gas, blowing agents, powder compact melting, casting, spray forming) [13],
- powdered metal (eg. sintering of powders, fibres or hollow spheres, extrusion of polymer/metal mixtures, reaction sintering) [14,15],
- metal vapours (vapour deposition) [16],
- metal ions (electrochemical deposition) [1].

Current research in the development of metallic foam manufacturing processes is therefore generally focused on finding low-cost technologies for their production. One possible route is the introduction of conventional foundry processes into metallic foam production technology. Foundry technologies could offer an economical, time-saving and in many cases environmentally friendly option for the production of cast metal foams with a wide range of internal structure morphologies related to shape, size, regularity of distribution or degree of interconnection of internal pores. At present, some of the foundry methods for the production of metallic foams are already commercially used in the world. However, it is even more necessary to pay attention to these technologies and to continue to develop them - there are over 200 foundry plants in the Czech Republic, but none of them is engaged in the commercial production of metallic foams.

2.1. Infiltration of the molten metal into mould cavity filled with presursors

One process that fulfils the idea of low-cost production of metallic foams in terms of the materials used is the infiltration of liquid metal into a mould cavity filled with precursors. This technology is based on the use of conventional foundry processes, where the process of producing the casting is carried out in a completely standard way, with the only difference being that the mould cavity is filled with a special filler material (called precursors) before the metal is poured in. These particles touch each other and are removed from the finished casting after the metal has solidified. This creates a complex internal structure of cavities (pores) inside the casting. The principle of this technology is shown in the **Figure 2**.

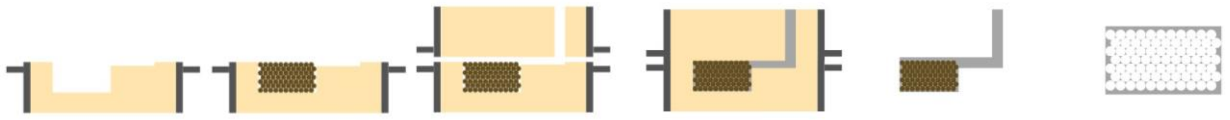

Figure 2 Principle of the technology of infiltration of the molten metal into mould cavity filled with presursors. From left: bottom half of the mould with cavity, cavity filled with precursors, mould folding, infiltration of liquid metal into the mould cavity, removal of the casting, casting of metallic foam after removal of the gating system and precursors

The shape and size of the precursors are key parameters in this technology as they directly influence the shape and size of the pores in the metal foam. The interconnectedness of the pores also plays an important role - the precursors can only be removed from the casting if they are all touching each other. If the precursors remain embedded in the metal metric, we would be talking about a different type of composite material, the so-called syntactic foam [17].

In previous experiments [18], several materials and processes for precursor production have been evaluated (see **Figure 3**). Based on the findings of these experiments, it was assessed that the focus should be on the production of precursors of the same shape from core mixtures showing great collapsibility after casting (furan no-bake).

Figure 3 Example of individual types of precursors, from left ceramic material based on $Al_2O_3{\cdot}SiO_2$, shards of cores (Croning technology), furan no-bake mixture [18]

3. PRECURSOR PRODUCTION - EXPERIMENT

The perfect shape of the precursor appears to be a sphere, but this shape is disadvantageous in terms of the contact of the individual precursors. The spheres touch each other only at a point, which may impair the removal of the precursors from the final castings. Therefore, the main objective of the experiment was to evaluate whether other precursor shapes could be produced.

The experiment evaluated the furan no-bake core mixture for the possibility of making precursors of different shapes. First, the composition of the core mixture was determined - see **Table 1**.

Table 1 Composition of furan no-bake core mixture

	Basic sand	**Binder**	**Catalyst**
	Foundry silica sand	Furan resin <75% FFA	Based on p-toluensulfonic acid
Name	BG 27 (Biala Góra)	Ecofur 2375	100T5D
Supplier	Sand Team	Mazzon	Hüttenes-Albertus
Dosage [wt. %]	100	1	45 (to the binder content)
Dosage [g]	5,000	50	22.5

The mixture of basic sand and activator was mixed on a laboratory paddle mixer for 1 minute for better homogenization. After this time, binder was added to the mixture and the mixtures were again mixed for 1 minute.

For the production of precursors, two special 100-cell (10 x 10) core boxes were designed and fabricated using 3D printing technology (see **Figures 4-6**).

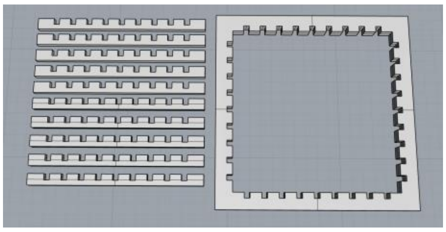

Figure 4 3D model of the unfolded core box

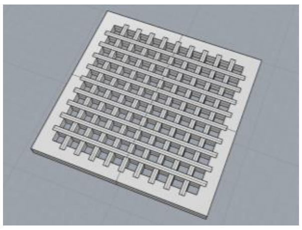

Figure 5 3D model of the folded core box

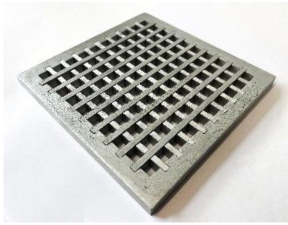

Figure 6 Core box ready for filling the core mixture

The workability time of the mixture was 5 min and was measured using a touch strength measuring instrument (DISA Georg Fischer +GF+).

The handling strength for disassembly of the cores was reached 2 h after mixing the mixture. Afterwards, the individual samples were left in laboratory conditions to so-called "cure and ventilate". This time was set, as the necessary time indicated by the manufacturer of the furan resin, at 24 h after mixing, when the mixture should reach a sufficient strength for use in casting.

The resulting precursors were therefore cubes with an edge length of 10 mm (see **Figure 7**). This was the starting material for further processing of the precursors. In order to find the optimum precursor shape, it was decided that all the precursors produced (1,200 pieces) would be divided into individual batches (100 pieces each). These batches were weighed and sequentially placed in a laboratory apparatus with a rotary sieve designed for determination of abrasion loss. One batch was left completely without abrasion in its original state in the shape of a 10 x 10 x 10 mm cube. Each batch of precursors was then rubbed in the device for a predefined period (20-140 s). The batch was then weighed again to determine the abrasion value.

Figure 7 Shape of precursors after removal from the core box

Due to the assumption of decreasing precursor size with increasing rubbing time, it was chosen to work with two sets of precursors (2x100 pcs) at times $\geq$ 80 s. The change in precursor shape was subsequently evaluated using a Keyence VHX 6000 digital microscope. **Table 2** defines the abrasion times for each set of precursors.

Table 2 Rubbing times for individual precursor sets

Nr. of batch	1	2	3	4	5	6	7	8	9	10	11	12
Rubbing time [s]	0	20	40	60	80	80	100	100	120	120	140	140

Figure 8 shows the percentage increase in abrasion of the precursors with increasing rubbing time. The graph shows how much material is removed from the precursors with increasing rubbing time. In the case of an abrasion time of 140 s, this is more than half the weight of the precursor.

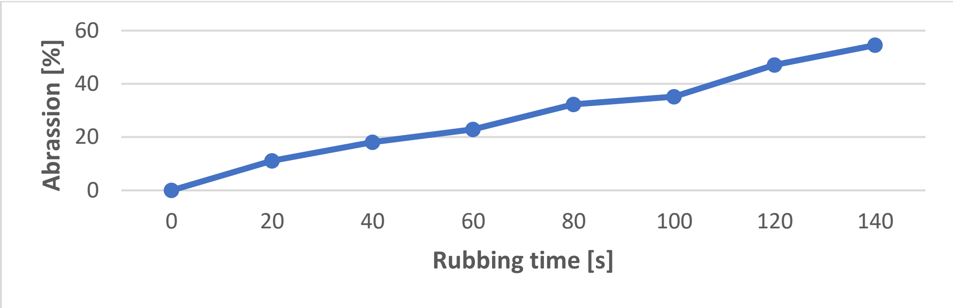

Figure 8 Increase in abrasion loss with increasing rubbing time

The shape of the precursor changed in parallel with increasing rubbing time. However, there was no loss of material in the entire volume at the same time, i.e. all surfaces were abraded, but only a gradual rounding of the edges and corners of the precursor and thus a gradual change from cubic to spherical shape. The gradual evolution of the shape change from the original cubic shape and the change in diagonal size can be seen in **Figure 9**.

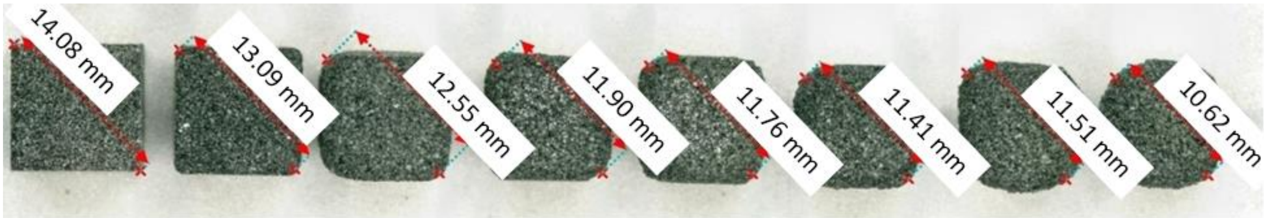

Figure 9 Change in precursor shape with increasing abrasion time - from left 0 s, 20 s, 40 s, 60 s, 80 s, 100 s, 120 s, 140 s

The difference between the original state and the state after abrasion of 140 s is seen in **Figure 10**. The figure shows that there is no significant change in the size of the precursor during rounding.

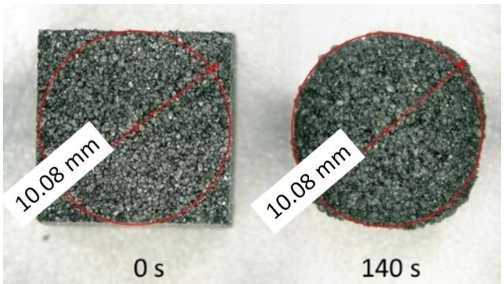

Figure 10 Shape of the precursors before and after maximum rubbing time

4. CONCLUSION

It was evaluated that the observed core mixture (furan no-bake) is suitable for the production of precursors. By designing and fabricating a simple core box, the precursor production procedure was verified and it was evaluated that different shapes of precursors can be achieved by their successive rubbing.

The precursors will be further validated in the metallic foam casting process and the ideal precursor shape will be evaluated. Once the ideal shape of the precursor is found, a core box with the desired shape can be designed.

Establishing a simple manufacturing process for precursors of the same size and shape will help to optimize the process of infiltration of liquid metal into the mold cavity filled with precursors. This will make the cast metallic foam material more accessible to both manufacturers and users.

ACKNOWLEDGEMENTS

This research was funded by the project No. CZ.02.1.01/0.0/0.0/17_049/0008399. The contribution was worked out with the support of the Technology Agency of the Czech Republic - TH02020668. Work was carried out in the support of project of "Student Grant Competition" number SP2022/15.

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