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Design of Proven Technology of Metal Foam and Porous Metal Casting Production

F. Radkovský *, V. Merta, T. Obzina
VSB - Technical University of Ostrava, Czech Republic
* Corresponding author. E-mail address: filip.radkovsky@vsb.cz

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Abstract

The article describes the design of a proven technology for the production of metal foam and porous metal by the foundry. Porous metal formed by infiltrating liquid metal into a mould cavity appears to be the fastest and most economical method. However, even here we cannot do without the right production parameters. Based on the research, the production process was optimised and subsequently a functional sample of metal foam with an irregular internal structure - a filter - was produced. The copper alloy filter was cast into a gypsum mould using an evaporable model.
Furthermore, a functional sample of porous metal with a regular internal structure was produced - a heat exchanger. The aluminium alloy heat exchanger was cast into a green sand mould using preforms. Also, a porous metal casting with a regular internal structure was formed for use as an element in deformation zones. This aluminium alloy casting was made by the Lost Foam method. The aim is therefore to ensure the production of healthy castings, which would find use in the field of filtration of liquid metal or flue gases, in vehicles in the field of shock energy absorption and also in energy as a heat exchanger.

Keywords: Casting, Porous metal, Metallic foam, Lost Foam, Heat exchanger

1. Introduction

Metal foams are materials in which pores are intentionally formed. In terms of macrostructure, these are cellular materials with a high porosity, which ranges from 40 to 97% by volume, depending on the production technology [1].

Aluminum foam and its alloys are the most widely used in industrial practice. Aluminum foam excels in its properties, which are: high rigidity at low density, excellent damping properties, the ability to absorb impact energy, recyclability, non-flammability, health safety and the ability to withstand aggressive environments. The fact that no toxic products (gases) are released from it at high temperatures allows it to be used even in areas where plastics in particular have been used so far.

The possibilities of their application depend on both the material and its morphology, which derives from the technology of its production. The parameters determining the properties of porous metals and metal foams are: porosity, shape, distribution, pore size and their orientation, degree of interconnection of individual pores [2].

Porous metals and metal foams in the field of structures have enormous application potential. Significant weight reduction while maintaining the required mechanical properties can be achieved, for example, by suitable surface reinforcement of porous metal components in places where the greatest tensile stress is expected [2].

In cars, safety is very important, which is related to deformation zones. These deformation zones must absorb energy during the impact, thus ensuring greater safety for the crew. The elements that are exposed to the greatest stress include fenders, side elements, door pillars, sills, or other elements that must absorb energy and can be filled with aluminum foam.

Porous materials, depending on the size, amount and degree of openness of the pores, excel in either low or high thermal conductivity. This is used, for example, in thermal insulators or non-flammable heat shields [3] or, conversely, in heat exchangers using metal foams made of aluminium alloys [4]. Liquid or gaseous media can also flow through the open pores of the material, which can accelerate cooling or heating. When connected correctly, it can therefore serve as a radiator or heater. Areas of application with individual examples are listed, see Table 1.

Table 1.
Areas of application of metal foams

Use in industry	Possible applications in the given industry
Automotive industry [5]	Filtration and separation of particles
Rail transport [6, 7]	Silencers
	Heat exchangers and refrigeration equipment
Mechanical engineering [8]	Catalyst supports
	Liquid flow regulators
Construction [9]	Acoustic elements
Energetics [10]	Electrochemical applications
	Water purifiers

Experimental objective

Porous metals represent a new type of material with low density, large specific surface area and new physical and mechanical properties. The aim of the project is the development of foundry technologies for the production of metal foam castings. The condition for the use of metal foams is to master the inexpensive methods of their production without additional demands on the retrofitting of foundry workplaces with any investment-intensive machines and equipment. Therefore, the purpose of the project is the development of foundry technologies based on gravity casting into sand or metal foundry moulds. With the development of foundry methods, the production portfolio of foundries will be expanded by new products with higher added value of the product.

2. Experiment

2.1. Metal sponge used for filtration

Based on laboratory and field tests within the solution of the project TACR TH02020668, a functional sample of a cast metal filter made of Al and Cu alloys was created using the technology of cast metallic sponge production by a two-stage investment casting process using an evaporative polyurethane pattern. The possibility of using cast metal filters with irregular internal structure, with open and fully interconnected pores, in foundry production as filters for filtration of liquid metal in foundry form was verified. There is variability in shape and dimensions of cast metal filter and also it can be manufactured with different porosity, resp. pore size which allows the production of filters with different filtration efficiencies for use in the production of a wide portfolio of different types of castings. It is used in the heating industry for the filtration of gases and liquids [11].

2.1.1 Manufacturing of copper alloy filter

Polyurethane (PUR) foam supplied by the Czech supplier Eurofoam TP s.r.o. based in Brno. This foam, with open pores, is sold under the number Bulpren S 32450. PUR foam was cut to dimensions 40x30x20 mm and was provided with an inlet, see Figures 1 and 2.

Fig. 1. Pattern preparation, Fig. 2: Pattern with inlet channel

A plaster mould was used for casting, where the cuvette has a diameter of 80 mm and a height of 80 mm. Insert the pattern prepared in this way in a cuvette into the Indu Mix vacuum mixer and cover with a lid. Mix gypsum and cast under reduced pressure.

Eurovest gypsum mixture from SRS-Ltd. was used for the production of the mould, which is an economical variant of the jewellery gypsum mixture. In order to achieve the greatest possible fluidity and thus the best ability of the mixture to fill the cavities of the pattern, the largest, recommended by the manufacturer, water dosage, i.e. 40%, was chosen.

The annealing cycle was selected according to a procedure directly designed by the manufacturer, which is shown in Figure 3.

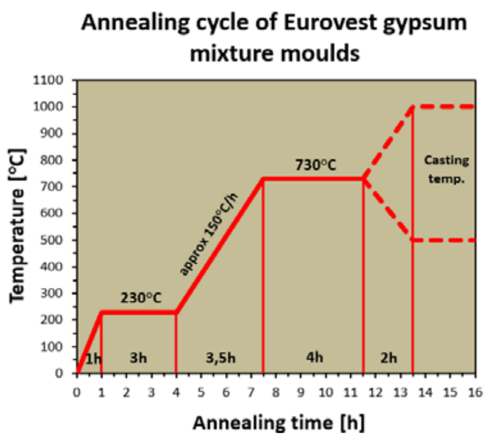

Fig. 3. Annealing cycle

2.1.2 Casting on a tilting vacuum furnace

First, the batch was prepared by cutting smaller bronze blocks weighing about 40 g from one large block.

Subsequently, the charge was placed in a crucible with a graphite liner. An annealed mould was placed in the working chamber of the Indutherm MC 15 induction device at the desired temperature. After closing the chamber, melting began, at a reduced pressure of 20 mbar.

First, the batch was heated sharply to 1200℃ at an inductor power of 80%. This was followed by staying at this temperature until the melting of the charge began. During melting, there was a sharp drop in temperature (950 - 1050℃), caused by the consumption of latent heat. Then the melt was slowly heated, at an inductor power of 20%, to the selected casting temperature of 950°C.

Once the casting solidified, the working chamber flipped back to its original position, equalizing the pressure. The chamber opened and the mould was removed. Based on previous research Department of Metallurgy and Foundry, the mould was quenched in a water bath, where the gypsum was broken and the casting was released (Figs. 4 and 5).

Fig. 4. Casting after gypsum mould breaking

Fig. 5. Cleaned casting

2.1.3 Benefits in industrial production and discussion

The introduction of the use of cast metal filters for the filtration of liquid metal in the foundry mould can be expected to reduce scrap in foundries and increase the quality of castings produced. At the same time, in non-ferrous metal foundries, when using metal filters based on the same element as the cast alloy, the costs associated with cleaning and refining the melt from disparate particles and harmful elements introduced into the melt during remelting of returnable materials with cast ceramic filters or metal filters on Fe base. According to the authors of the article [13], research into the production of metal foam filters has long been in the interest of many authors, however, with the use of commonly available materials and optimisation of production, production can still become more economical. To compare costs, as stated by the authors of the article [15], production from metal powders is several times more expensive.

2.2. Porous metal for use as a heat exchanger

Based on laboratory and field tests within the solution of the project TACR TH02020668, a functional sample of a heat exchanger made of aluminium alloys with a regular internal structure was prepared by gravity casting into a conventional foundry mould from a moulding mixture. This exchanger can be used for heating/cooling of flowing media - gases and liquids. Areas of application are in the heating industry, thermal engineering, heating/cooling of media - gases and liquids.

2.2.1 Manufacture of metal exchanger from aluminum alloy

Porous metals can be produced in various ways, but current methods of their production are economically demanding. In the energy sector, metal foams are used exclusively as heat exchangers. The heat exchanger, which includes metal foam, gains an increased contact area and thus ensures higher heat transfer efficiency. The permeability of the exchanger allows the use of foam with an open structure and higher porosity. The production of a heat exchanger as dealt with, for example: [10], a high final price of products can be derived due to the high costs of production technologies.

For this reason, it seems appropriate to address the possibilities of producing this material using foundry technologies, where the lowest costs are expected. In connection with the development of these technologies, a method of infiltrating liquid metal into the cavity of a mould filled with a preform was created, while the preform subsequently forms the porous structure of the final product. The size, shape and degree of openness of the pores then indicate the resulting properties of the material in the area of thermal conductivity. To increase the economy of production of heat exchanger castings, it is suitable to use the simulation program MAGMASOFT 5.4 - Autonomous Engineering. With a suitable program setting, correct entry of boundary conditions and determination of suitable goals, it is possible to predict the location of critical points in the casting, or correctly dimension the design of the inlet system, the size of which may be closely related to e.g. the use of liquid metal [16, 17].

Based on the analysis of the author’s heat exchanger [18] in the environment of the ANSYS CFX simulation program, the geometry with ball cores (preforms) appears to be effective for heat transfer. In Fig. 6 is shown the layout of the temperature field in the casting cavity. The first selected variant for real production thanks to the previous experiment was a geometry with 4 floors of preforms, where 2 floors are always continuous. The preform casting can be seen in Fig. 7.

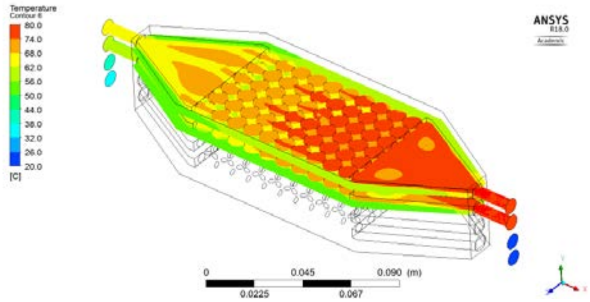

Fig. 6. Hot side of the heat exchanger [17]

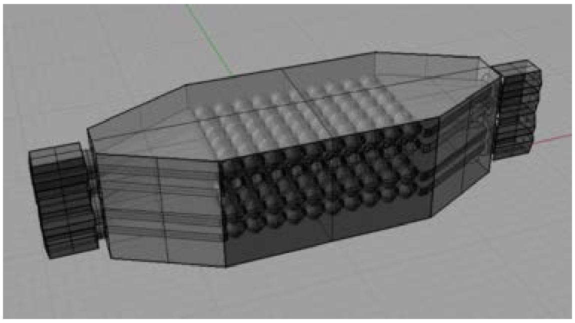

Fig. 7. Model of the casting with cores [16]

2.2.2 Mould making and casting

The preform was manufactured by the Foundry and Model Workshop Nove Ransko s. r. o. by shooting into the nucleus. The sand used in the core sand was Bukovno 27 and was shot on a Laempe core shooter. It was a sand with granulometry with a mean grain diameter d50 = 0.23 mm. The binder used was from ASK under the trade name Ecocure 16/26 with a dosage of 0.6%. Curing was performed again with a tertiary amine.

The wooden pattern with "marks" and elements of the gatting system was made of wood according to the exact dimensions of the resulting simulation from MAGMASOFT 5.4, see Fig. 8. Dimensions of the wooden pattern with core prints LxWxH 380x85x102 mm, runner: LxWxH 500x40x17 and 6 mm, sprue basin: LxWxH 50x50x30 mm, pouring cup: diameter 40 and 30 mm and height 170 mm and sprue: diameter 80 and 95 height 65 mm. Then the production of the foundry mould could start. The foundry mould in this case consists of three parts. The upper and lower part of the mould is made by hand ramming from green sand and the middle narrow part is made from a moulding sand with the trade name Bentomix Oil. In Fig. 9 is a photograph taken during the mould making process. The aluminum alloy charge was melted on an electric resistance furnace. The casting temperature was 755 °C. Fig. 10 shows the casting after knocking out of the mould and the preforms and the cut-off gating system have also been removed. After final finishing and non-destructive inspection of internal quality, it is possible to continue working with the casting of porous metal.

Fig. 8. Wooden pattern of casting and gating system

Fig. 9. Mould with inserted preforms

Fig. 10. Detail of the resulting heat exchanger casting

2.2.3 Benefit in industrial production and discussion

Due to the increase in the thermal conductivity of metal exchangers, it is possible to assume an increase in the production volume, a decrease in the size of the exchangers while maintaining the same efficiency (increase in the inner surface). As this is a common foundry technology used to produce porous metals, a reduction in the cost of manufacturing heat exchangers can be expected. Considering that the authors either deal with mechanical/chemical/thermal properties and neglect the economic side of production [18], they use the expensive conventional method of manufacturing an exchanger with an irregular internal structure [19], [20] the producing the exchanger by simple casting technique is the cheapest. For a predefined regular internal structure, we can predict thermal and mechanical properties.

2.3 Porous metal for use as structural

Based on laboratory and field tests within the solution of the project TACR TH02020668, the process of production of metal foams using the technology of a one-stage precision casting process using a one-time evaporable model made of polystyrene was verified. The resulting cast metal foam with a regular structure then meets the generally stated unique properties of metallic porous materials, i.e. low specific gravity, high stiffness and strength, the ability to absorb deformation energy and at the same time very good acoustic and insulating properties. As part of the project solution, the technology of production of these materials from alloys based on Al, Cu and Fe was verified. Areas of application are found in the automotive and aerospace industries, shipping and rail transport, construction and engineering.

2.3.1 Production of porous metal grids from aluminum alloy

When calculating the possibility of using precision casting technology with the possibility of an evaporable model for the production of porous metals with a regular internal structure. This method is commonly used today and is known under the trade name Lost Foam. In practice, they are used for the production of complex castings. This procedure has now been shown to prove very well in the production of porous metals - the way in which a casting with a very complex and regular internal structure without the use of cores is produced.

The pattern model was made of expanded polystyrene (EPS) and consisted of two types of grids, with vertical and horizontal ribs. In total, the pattern consisted of eight glued grids. When assembling it, the vertical grids alternated with the horizontal ones. The individual grids were cut from a larger semi-finished product supplied by the same company H - TIPOL Halasta, spol. s r. o. The individual layers were assembled into a whole using double-sided adhesive tape. The size of one layer was chosen 110x110x6 mm. When using 8 floors, the total final size of the pattern was 110x110x48 mm. In Fig. 11 is an example of a bonded porous pattern.

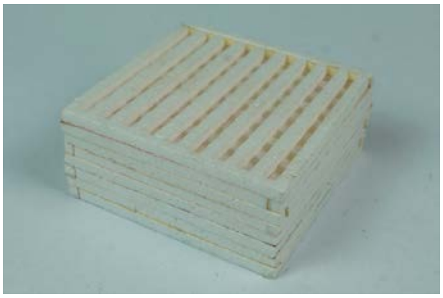

Fig. 11. Glued pattern of porous metal from EPS

The calculation of the gating system, which is given below, is important for the correct dimensioning of the entire casting process. In order to ensure fast filling, the inlet system was designed as an overpressure. The gating system was then designed as slightly oversized in order to achieve higher rigidity of the resulting glued pattern [21]. Ratio of individual elements of the inlet system: gate area 1: area of the distribution runner 1.1: area of the sprue pole 1.2. For the surface treatment, the protective alcohol coating Foundrylac ZBM / 365 was used again in only one layer, which was allowed to air dry for 24 hours, the method of application - dipping and necessary repairs were performed with a brush.

2.3.2 Mould making and casting

The binder-free moulding compound (dry sand) with a composition of 100% Quartz sand GL 21 (d50 = 0.20-0.24) was chosen as the mould material. A metal flask measuring 340x230x160 mm was used for moulding. The pattern was covered with dry sand and compacted by vibration. The melting of the aluminium alloy AlSi10 (CSN 42 4331) took place in an electric resistance furnace LAC 80/13 and the casting temperature in the experiments was in the range of about 760 °C. In order to increase the casting height, a funnel was therefore used, which is connected to the inlet pole and lies on the surface of the finished mould. The resulting casting was subjected to pressure tests. Compression took place up to the maximum, which is important for accurate recalculation of the performed deformation work.

Fig. 12. Cleaned casting, material AlSi10MgMn CSN 424331, top view [22]

Fig. 13. Cleaned casting, material AlSi10MgMn CSN 424331, bottom view [22]

2.3.3 Benefit in industrial production and discussion

When introducing a proven technology for the production of cast metal parts with a porous structure, we can predict an increase in production volume, as it is a unique material with high utility properties. Because for the production of cast metal foams with a regular structure, standard methods for the production of castings are used. It can be assumed that the cost of manufacturing these cast parts will not increase.

3. Conclusions

3.1 Possibilities of application of cast metal filters

Thanks to the technology of production of cast metal sponges using a two-stage investment casting process using an evaporative polyurethane pattern, it is possible to produce cast metal filters from various alloys. Due to the variability of properties, these filters can be used in many industrial filtration equipment designed for the filtration of gases and liquids, where it is possible to use these cast metal filters to increase the efficiency of the filter unit and also increase the life of the filter itself. One of the special applications is the use of these cast metal filters within the foundry industry for the filtration of liquid metal directly in the gating system inside the mould. The use of a filter in the inlet system increases the internal quality of the casting and reduces the occurrence of foundry defects and thus reduces scrap. The advantage of using cast metal filters is the possibility of using a filter made of an alloy of the same base metal as the material for the production of the casting. This eliminates the above-mentioned difficulties in reusing returnable material and remelting scrap with filters made of disparate materials (metallic and non-metallic).

3.2 Possibilities of application of the resulting heat exchanger castings

Thanks to the technology of infiltration of molten metal into the mould cavity, we can create a cast metal foam with a regular arrangement of inner cells. One possible application of castings with such a complicated internal cavity is a heat exchanger. For the purpose of verifying the efficiency, variants were simulated to simulate the flow of liquid medium through the metal foam. The computational analysis showed that the heat exchanger designed in this way could find its application in engineering practice. It achieves better results than a conventional tube heat exchanger, which is found, for example, in water heating boilers. Its thermal efficiency is higher and even the pressure losses correspond, as the results of the heat exchanger have shown [23]. Due to its construction and robustness, such a heat exchanger could also be used in nuclear energy. The advantages can be considered its modularity or usability as a deformation safety element and heat exchanger in synergy for heavy traffic.

3.3 Possibilities of application of the resulting grid castings

Thanks to the technology using a disposable evaporable model made of EPS, it is possible to produce cast porous metal with a regular cellular structure. Such a material could then be used in applications where the emphasis is on the material exhibiting the same properties throughout its volume. This cannot be achieved, for example, with today's commercially produced porous metals and metal foams with an irregular distribution of internal cavities.

These castings could therefore also be considered for application in the field of transport - i.e. use in deformation zones of vehicles.

Another possible area of application of these castings could be, for example, the area of development of lightweight structures.

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