POLSKA AKADEMIA NAUK
Arch. Metall. Mater. **63** (2018), 4, 1847-1851

DOI: 10.24425/amm.2018.125114

I. KROUPOVÁ*[#], P. LICHÝ*, L. LIČEV**, J. HENDRYCH**, K. SOUČEK***

**EVALUATION OF PROPERTIES OF CAST METAL FOAMS WITH IRREGULAR INNER STRUCTURE**

Internal structure of metal foams is one of the most important factors that determine its mechanical properties. There exists a number of methods for studying the nature of the inner porous structure. Unfortunately most of these processes is destructive and therefore it is not possible to reuse the sample. From this point of view, as a suitable method seems to be the ability of using the so-called X-ray microtomography (also micro-CT). This is a non-destructive methodology used in a number of fields (industry, science, archaeology, medicine) for a description of the material distribution in the space (e.g. pores, fillers, defects, etc.). In principle, this technology works on different absorption of X-ray radiation by materials with changing proton number. The contribution was worked out in collaboration with experts from the Faculty of Electrical Engineering and Computer Science of the VŠB-Technical University of Ostrava and it is focused on the analysis of internal structure of the metal foam casting with irregular arrangement of internal pores by using micro-CT. The obtained data were evaluated in the commercial software VGStudio MAX 2.2 and in the FOTOM$^{NG}$ system. For the evaluation of these data a new specialized module was introduced in this system. Several methods of pre-processing the image was prepared for the measurement. This preliminary processing consists, for example, from a binary image thresholding for better diversity between the internal porosity and the material itself or functions for colour inversion.

*Keywords:* metal foams; irregular structure; precursor; porosity; micro-CT

## 1. Micro-CT

X-ray microtomography (also micro-CT) is a method that uses radiograms to create a section through a physical object without the necessity to destroy it.

Tomography is a very versatile testing and research method. It finds its application in industrial practice, when examining a wide variety of materials and products. This method is known to general public in particular through the use in health care, where it also plays a very important role. Here the radiograms are used for viewing the internal organs and tissues in 3D movies without the need for invasive surgery.

The micro-CT method is becoming more widespread in the industry while exploring the internal structure of the used materials and for visualization of internal structure of products. Earlier techniques often require the destruction of the test sample but this may be undesirable in some cases when locating and understanding problematic steps of production. Therefore the tomography is used in such cases when it is necessary to maintain the integrity of the tested sample. It must be added that the integrity of the sample can be kept in such cases only when the piece has such dimensions that allow its location and rotation within the space for samples in the given CT [1].

### 1.1. Evaluation of porous materials

X-ray tomography is a very effective tool for the characterization of porous materials. With its aid the information about the surface, distribution and the size of individual pores throughout the sample volume can be obtained [2]. With subsequent image analysis it is possible to determine the volume of open and closed pores, thus also the total porosity of the given sample [3]. This method can be used for checking the objects of any material, whether it is a polymer or metal. Micro-CT is commonly used for evaluating the internal structure of natural porous materials – bones, rocks, wood, etc. In addition to the natural porous materials there are also numerous artificially created materials with cell internal structure. These can also include metal foams. Porous metals and metal foams are materials that contain in their structure the pores that are intentionally created. Their specific internal structure gives them a very convenient combination of physical and mechanical properties, such as low specific weight and high rigidity together with high capability to absorb the impact energy. In the framework of the concept of "metal foam" we can talk about materials both with closed and interconnected internal cavities – pores – with different layout, shape and size [4-6].

* VŠB-TECHNICAL UNIVERSITY OF OSTRAVA, FACULTY OF MATERIALS SCIENCE AND TECHNOLOGY, DEPARTMENT OF METALLURGY AND FOUNDRY ENGINEERING, 17. LISTOPADU 15/2172, OSTRAVA-PORUBA, CZECH REPUBLIC
** VŠB-TECHNICAL UNIVERSITY OF OSTRAVA, FACULTY OF ELECTRICAL ENGINEERING AND COMPUTER SCIENCE, DEPARTMENT OF COMPUTER SCIENCE, 17. LISTOPADU 15/2172, OSTRAVA-PORUBA, CZECH REPUBLIC
*** INSTITUTE OF GEONICS OF THE CAS, STUDENTSKÁ 1768, 708 00, OSTRAVA-PORUBA, CZECH REPUBLIC
[#] Corresponding author: ivana.kroupova@vsb.cz

Thanks to these properties, metal foams can be used in a wide range of sectors of human activity from vehicle construction, thermal engineering to medicine. However, the application potential of these materials is limited by the economic demands of their production technologies. In most cases, these are costly methods based on complicated procedures and the use of non-standard and expensive input materials. For this reason, the application of casting processes for the production of this material is a suitable solution [7,8].

Mastering of inexpensive ways of manufacturing of metal foams without requiring equipment for production facilities with investment-intensive machines and equipment is a prerequisite for full utilization of the application potential of this material. In order to develop such a process of the production of metal foams, it is essential to obtain feedback about the final castings – e.g. with micro-CT method.

Evaluation of properties of metal foams by using the micro-CT can then be the basis for subsequent optimization of casting processes of their production (Fig. 1).

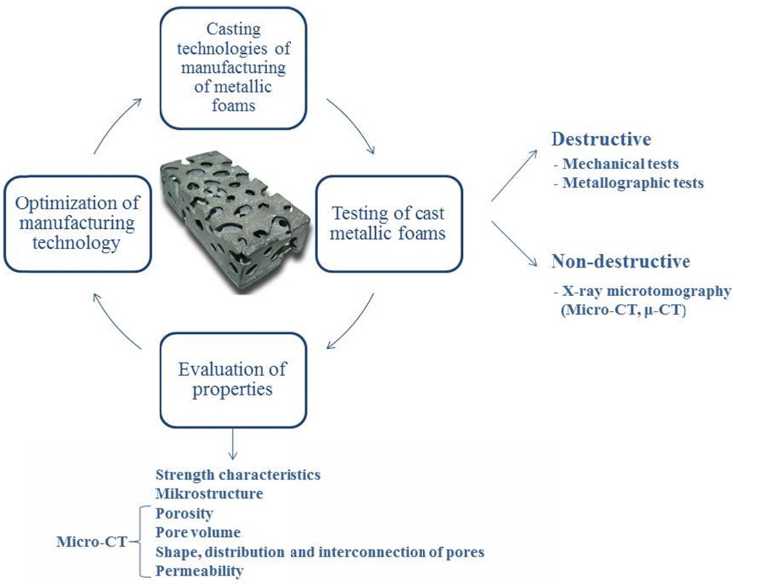



Fig. 1. Diagram of the optimization of casting processes of metal foams production in dependence on evaluation of properties of these castings

## 2. Experiment

For the purpose of the experiment a metal foam casting with irregular arrangement of internal cavities was made. This casting was subsequently evaluated by the micro-CT method.

### 2.1. Metal foam

There exists a number of methods of porous metal materials production. Some of the technologies are similar to processes for foaming of polymers and on the contrary the others are developed with regard to characteristic properties of metal materials such as their ability of sintering or the fact that they can be electrolytically applied [4].

Production processes can be divided into four main groups and namely according to a state in which the metal is processed – porous metal materials can be made from metal vapours, liquid metal, powdered metals or ionized metal. We are able to produce metal foams from non-ferrous alloys as well as iron alloys.

The metal foam sample studied in this contribution was made using the conventional foundry processes. In the case of foundry methods of the production of metal foams the castability of alloys is the most important technological property. In general, pure metals and alloys of eutectic composition have the highest values of castability [9]. The material of the examined casting is the alloy based on Al-Si (AlSi10MgMn). Under the term foundry methods we can imagine the production of metal foams by casting of liquid metal into a common foundry mould.

Irregular arrangement of internal pores can be achieved for example by using the semiproducts which fill the mould cavity. These semiproducts – precursors – of the given shape and size are located in the mould cavity and cast with liquid metal. Precursors must meet certain criteria. In particular, they must be made of a material that retains its shape when in contact with liquid metal (sufficient strength, low abrasion, heat resistance), and they must also have a good collapsibility after casting. A condition for a successful removal of all precursors after casting is their sufficient amount in the mould cavity – the granules can be removed only in a case when all of them are touching each other (the formation of interconnected pores). The principle of the mentioned technology is shown in figure 2.

Precursors for the purpose of the experiment were made from a core mixture (or from discordant dropped cores made by the C-method) [10]. The final form of the filler material was achieved by breaking the core into smaller lumpiness (10-30 mm) and then by grinding these particles (Fig. 3).

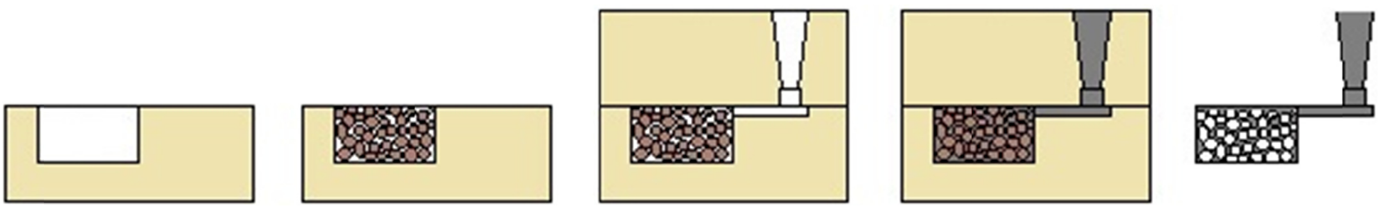


Fig. 2. The principle of the liquid metal infiltration into the mould cavity filled with precursors, from the left: the mould, the mould cavity filled with precursors, the assembled mould, metal casting into the mould cavity, a metal foam casting after removal of precursors

Fig. 3. Precursors – the Croning technology

### 2.2. The micro-CT analysis

The sample was measured with the aid of one pair of X-ray detectors. For the CT scanning a microfocus X-ray tube (XWT-240-X-Ray, WorX, Germany) working in a microfocus mode (the point size 4.0 μm) with a voltage of 80 kV, current 210 μA and 16.8 W output was used. A flat panel (XRD-1622-AP-14, Perkin Elmer, the USA) of dimensions 40 × 40 cm, pixel matrix of 2048 × 2048 and pixel spacing of 200 μm was used as a detector.

By adjusting the spacing to the distance of the detector focus field 1325 mm and the distance 125 mm from the object the projection magnification factor 10.6 was reached, which led to resolution of 18.87 μm per pixel in the projections and 18.67 μm per voxel during 3D reconstruction. Geometric parameters were chosen so as to achieve the best resolution with regard to the size of the sample and the detector area.

For the image correction in projection shots a standard correction of „the dark field“ and „the open beam“ together with „the beam hardening correction“ (BHC) was used. Data for the BHC were got for a set of aluminium filters of thickness of 0.2, 0.4, 0.6, 1.0, 2.0, 4.0, 6.0, 10.0, and 20.0 mm, the image correction for each filter was calculated from 100 shots, the acquisition time 999 ms. For the tomography the 800 projections were done, each of which was ascertained the average of two images taken with exposure time of 999 ms.

For the Micro-CT processed data a new module for the FOTOM$^{NG}$ system was introduced. This module consists of two parts. The first part is focused on the preliminary processing of the image, and the second part for measuring the samples.

Preliminary processing of the image has several steps as follows:

1. Cropping the objects – we are able to crop the sample with a circle (Fig. 4a).
2. Binary thresholding – The principle is based on the evaluation of the brightness of each pixel of the image. Then we have to choose the brightness value (threshold) for which it is true that all pixels with lower brightness than the threshold value belong to the pore of the background and the background of the image. Otherwise, pixels with brightness higher than the threshold value belong to the foreground (provided that the object of interest is brighter than the background) – the solid material of the metal foam sample (Fig. 4b).
3. Resolution between pores and the image background – in this phase the rear part is assigned to the grey colour, the pores to the black colours and the solid material to the white colour (Fig. 4c).
4. Colour inversion – This step is important especially for modeling the 3D voxel. It depends on whether we want the internal pores have been painted white or black colour (Fig. 4d).

The process of measuring the samples – the ratio R between the values of pixels and metric units need to be defined. This is done by setting the two control points and their actual distance in metric units. Now the pixels that represent the pores and solid material can be counted. Then using the ratio R the porosity area can be calculated from a single image or the set of the entire series of images. As the output from the measurements we can create a series of images for the 3D voxel model or a set of results [11].

Fig. 5 shows the studied metal foam casting with irregular distribution of inner cells (a) and its 3D model rendered using the micro-CT method (b).

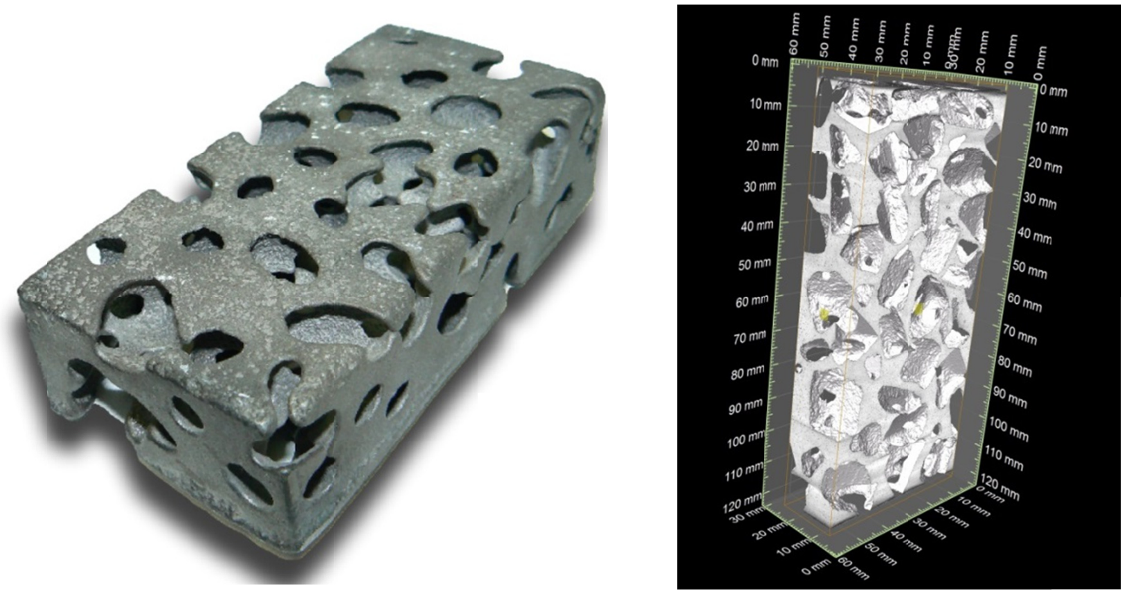
### 3. Results

For metal foam samples we are able with this technology to monitor and evaluate the size and distribution of individual intentionally created pores (so called effective porosity) – see figure 6. With these processes it is also possible to determine the ineffective porosity, i.e. that one which was formed in given the casting as a result of physical-chemical processes that occur within the given production technology. As the ineffective porosity of castings can be indicated e.g. the defects due to volume changes during casting crystallization and solidification (so called shrinkage) or gas defects (of metal, mould or core).

These results can help us in the next steps to optimize the process of production of cast metal foams. We will be able to precisely define the influence of using the core mixtures (large amount of precursors in the mould cavity) for example on the formation of gas defects in the casting.

a) b) c) d)

Fig. 4. From the left – (a) cropping the object, (b) binary thresholding of the image, (c) resolution of the samples and background, (d) colour inversion




a) b)

Fig. 5. (a) – a metal foam sample, (b) 3D model of the metal foam sample

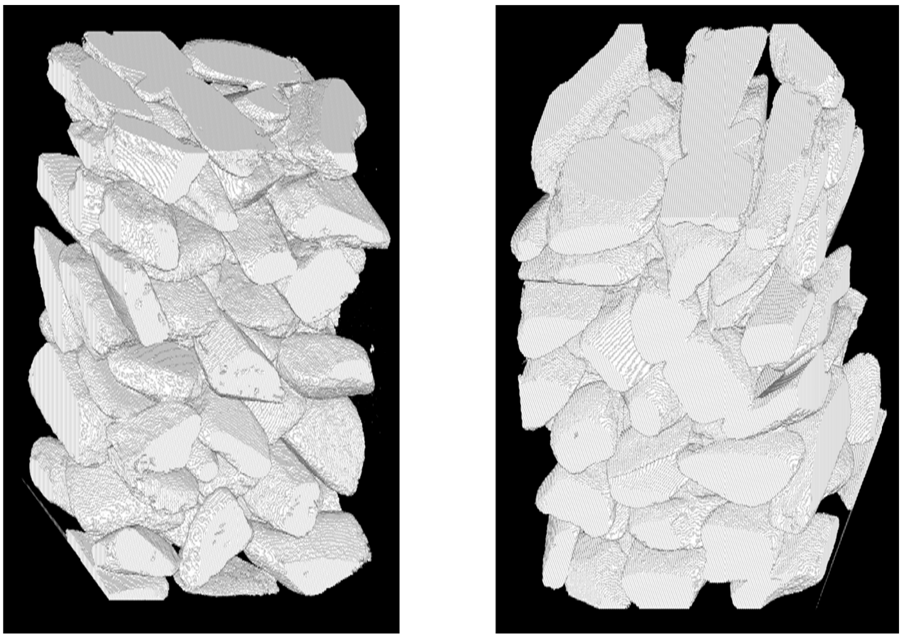


Fig. 6. Irregular distribution of the pore in the metal foam casting

Fig. 7 shows the porosity in individual sections of the metal foam sample with studied area of the casting section was 1.800 $mm^2$. The main advantage of the given technology is the ability to evaluate the material (casting) with quite non-destructive test and to get a comprehensive idea of the internal pore distribution – both intentionally and unintentionally created.

## 4. Conclusion

The use of the micro-CT method is very useful for the purposes of the description of internal structure. As any other method, this one has its own limitations too. Above all, it is necessary to compare the same part of the sample. Secondly, the accuracy of the results depends on the method of setting the pores boundaries (the binary thresholding, resolution of the sample and the background, colour inversion). Usually it is manually specified and therefore it depends on the personal experience of the operator. In this respect it is appropriate to undertake the analysis by the same person.

We would like to focus on next research regarding the influence of internal changes of structure on strength properties of metal foams.

So in the case of metal foam the presented method is suitable for examination of complex internal structure of castings. Thanks to this, it is able to evaluate not only the so-called effective

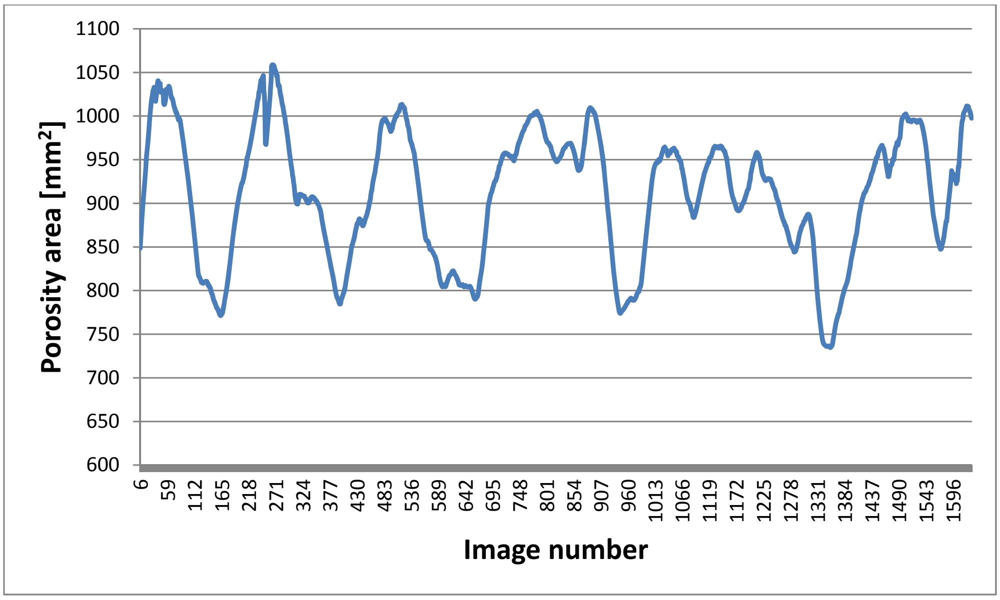



Fig. 7. Porosity of the metal foam sample in individual sections

porosity, i.e. the shape, size, layout, and the interconnectedness of the intentionally created pores, but even ineffective porosity which arises as a result of the production technology of cast metal foams (e.g. shrinkage).

**Acknowledgement**

The contribution was worked out with the support of the Technology Agency of the Czech Republic – TA02011333 and TH02020668, project of "Student Grant Competition" numbers SP2018/77 and SP2018/60 and the Grant Agency of the Czech Republic – GACR P103/15/06700S.

## REFERENCES

[1] R. Gajdošík, Charakterizace porézních materiálů pomocí RTG mikrotomografie. Zlín, 2014. Bakalářská práce. Univerzita Tomáše Bati ve Zlíně.
[2] W.K. Krajewski, J. Lelito, J.S. Suchy, P. Schumacher, Computed tomography – a new tool in structural examinations of castings, Archives of Metallurgy and Materials **54**, 2, 335-338 (2009).
[3] E. Maire, X-ray tomography applied to the characterization of cellular materials. Related finite element modeling problems, Composites Science and Technology **63**, 16, 2431-2443 (2003).
[4] J. Banhart, Manufacturing routes for metallic foams, Journal of Minerals, Metals and Materials **52**, 12, 22-27 (2000).
[5] I. Kroupová, V. Bednářová, T. Elbel, F. Radkovský, Proposal of method of removal of mould material from the fine structure of metallic foams used as filters, Archives of Metallurgy and Materials **59**, 2, 727-730 (2014).
[6] P. Lichý, T. Elbel, I. Kroupová, F. Radkovský, Preparation and evaluation of properties of cast metallic foams with regular inner structure, Archives of Metallurgy and Materials **42**, 3, 1643-1646 (2017).
[7] J. Banhart, Manufacture, characterisation and application of cellular metals and metal foams, Progress in Materials Science **46**, 6, 559-632 (2001).
[8] F. García-Moreno, Commercial Applications of Metal Foams: Their Properties and Production, Materials **85**, 9 (2016).
[9] J. Hampl, T. Elbel, T. Válek, Document Application of thermodynamic calculations in the research of cast irons structure, Metalurgija **54**, 2, 323-326 (2015).
[10] N. Špirutová, J. Beňo, V. Bednářová, Alternative utilization of core sand for green sand system, Materiali in tehnologije **47**, 5, 557-561 (2013).
[11] L. Ličev, Systém FOTOM$^{NG}$: architektura, funkce a použití. Praha: BEN – technická literatura, 2015.