ON THE SCATTER OF EXPERIMENTS DONE WITH OPEN-CELL METAL FOAM IN OPEN LITERATURE

De Schampheleire S.*, De Jaeger P., De Kerpel K., Ameel B., Huisseune H., Bagci O., and De Paepe M.
*Author for correspondence
Department of Flow, Heat and Combustion Mechanics,
Ghent University,
9000 Ghent,
Belgium,
E-mail: Sven.DeSchampheleire@ugent.be

ABSTRACT

This paper reviews the available methods to study thermal applications with open-cell metal foam. For experimental research, the focus is on the repeatability of the experiments. Especially for open-cell metal foam, this is a major concern. Most published studies only report porosity and the number of pores per linear inch (PPI-value). In this work several points are raised why these values are not enough to characterize a three dimensional foam structure.

A different approach, which is studied in this paper, is to characterize the foam using µCT scans with small voxel sizes. The results of these scans are compared with frequently used correlations from open literature to calculate parameters like surface-to-volume ratio. Large differences with the correlations are observed. It is therefore recommended that any kind of experimental work using open-cell metal foam reports a proper geometrical characterization in order that one can repeat the experiments.

INTRODUCTION

Thermal applications

Heat exchangers are essential components in a wide range of thermal management applications, e.g., in the transport, domestic and industrial sectors. These devices are crucial because they have an influence on safety, environmental quality and energy use. In such devices, air is often used as a working fluid, due to its omnipresence. The low thermal conductivity results in an air-side thermal resistance, which can be more than 80\% of the total thermal resistance in heat exchangers working with air. Consequently, reducing this air-side thermal resistance can result in substantial performance augmentation, leading to cost, space, material and energy savings. Prior research has led to considerable improvements by investigating the influence of fluid characteristics, flow arrangements, material selection and extending the heat transfer surface area (through fins) [1]

In forced convection, these heat transfer enhancement techniques aim to maximize the product of the heat transfer coefficient and the heat transfer surface area per unit volume, whilst minimizing the air-side pressure drop. This results in all kinds of fin designs, most of the time heavily dependent on the application. The current state of the art fin type, for a non-corrosive environment, is the interrupted fin design, like the louvered fin or slit fins.

In natural convection, a similar optimization approach is used. In this case, the problem is even more complex, as the flow resistance will affect local temperatures and heat transfer coefficients. Pin fins and all kinds of different forms of plain fins (especially the inverted trapezoidal fin) can induce more air flow over the heat sink in comparison to a plain rectangular fin [2]. Further possible improvements can be achieved by the orientation of the fins themselves. For example, a flared pin design can improve the heat transfer performance significantly, as proposed by CoolInnovations. Another optimization is making the fins themselves more porous by perforating them [3].

A development that fits within this optimization process of `conventional' fins is the use of porous media. One example of a porous medium that can be used as a heat exchanger is a packed bed of spheres, which has a porosity of around 60%. Another porous material that has already drawn a lot of attention is open-cell metal foam. In Figure 1, the nomenclature of open-cell foam is shown. The struts of the foam are interconnected in the nodes forming both cells and pores.

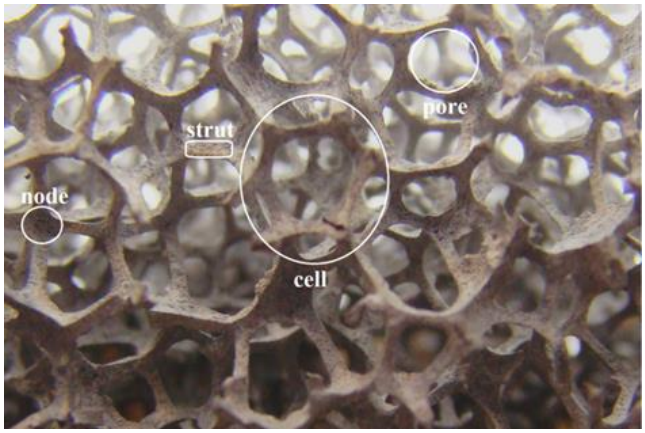

Figure 1 Nomenclature of open-cell metal foam

NOMENCLATURE

A_0	[m²]	interfacial strut area (middle of the strut)
d_1	[m]	smallest cell diameter
d_2	[m]	largest cell diameter
d_f	[m]	fiber diameter
d_p	[m]	pore diameter

Special Characters

ρ	[kg/m³]	density
σ_0	[m²/m³]	surface to volume ratio
ϕ	[-]	porosity
χ	[-]	tortuosity
Δ	[-]	difference

Subscripts

solid	solid
tot	total

Abbreviations

ERG	Energy Research and Generation
PPI	Pores Per linear Inch
SEM	Scanning electron microscope
μCT	Micro-tomography

Open-cell aluminium foam

There are different types of open-cell metal foam; this paper will focus on the foam type that performs best in thermal applications: cast open-cell metal foam, which has solid struts. Conversely, open-cell foam made through an electrophoretic deposition process has hollow struts. This significantly lowers its effective thermal conductivity.

Cast foam originates from the late 1960s and was invented by the 'Materials and Aerospace' division of Energy Research and Generation (ERG). This invention has led to the patent of Walz in 1976, which describes the manufacturing process of cast open-cell metal foam based on an organic preform. Most of the time, this preform consists of polyurethane. The metal foam by ERG Materials and Aerospace was intended for military and aerospace applications. Only since the mid 1990s, the technology became generally available for non-classified military and industrial applications. It is from that time that the annual publication rate on the topic has increased steadily. From 2000 on, the publication rate keeps increasing. In 2000, the German company M-Pore GmbH, in Dresden started making cast metal foam. Alveotec in France and Constellium in the Netherlands followed a few years later. Most of these companies are still closely related to the research industry.

Open-cell cast metal foam manufactured by either ERG Materials and Aerospace or M-Pore is made with an investment casting process based on a polyurethane preform. As the fabrication process of the organic preform is influenced by gravity, the resulting cells are oval shaped (see Figure 2(a)). A deterministic approach to obtain a model of such an organic preform is based on minimizing the total film energy of the surface between the solid and fluid phase.

On the other hand, the metal foam by Alveotec and Constellium is made by casting metal over a stacked bed of soluble spheres. These spheres can be either salt spheres or sand with a polymer bonding agent. After solidification of the metal, the spheres are then simply washed away with water. This process is known as leachable bed casting. The metal foam that is created with this manufacturing process has a more uniform and spherical cell shape (see Figure2(b)).

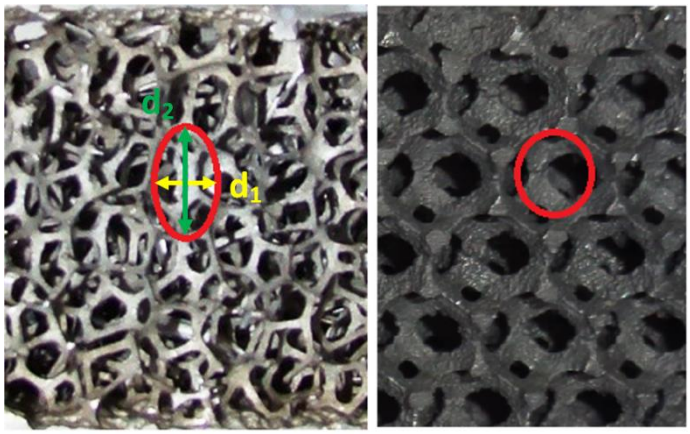

Figure 2 Two types of casted open-cell aluminium foams. (a) produced from a polyurethane perform made by ERG and (b) from a leachable bed casting made by Alveotec (painted black to increase emissivity).

Cast open-cell foam is known to have many interesting structural and functional properties:

- High porosity (higher than 80%). Typically, the porosity can go up to 95%. High porosity results in a low weight application.
- High interstitial surface area per unit volume.
- Good impact energy absorption.
- Excellent fluid mixing due to tortuous flow paths [4]
- Hybrid manufacturability: different foam materials (e.g., Al, Cu) can be sandwiched into one foam panel.
- Shapeable in three dimensions (obtainable via casting and/or co-casting techniques).
- Visually appealing.

Cooling applications with open-cell foam?

The two effective ways to study thermal applications with open-cell metal foam are through experiments and/or with computational fluid dynamics (CFD). Of course, both tools have their upsides and downsides. Experiments have the advantage that, if they are performed correctly, they are reliable and can serve as proof to the industrial clients or as a reference for further academic research. In this work there will be focused on experimental work only. However, generally for thermal foam applications a large number of parameters are involved to characterize the thermal performance completely:

- Type of open-cell metal foam: this includes the material and manufacturing technique, on the one hand, and the thickness of the foam, on the other hand. Both of these parameters will affect the effective solid conductivity and heat transferring surface area

- Geometrical characterization, as discussed later in this work.
- Orientation under which the metal foam sample is placed: metal foam is generally not isotropic, depending on the manufacturing technique. [5]
- Bonding methods [6]: commonly, this is achieved with a high conductive epoxy or by brazing/soldering. Although epoxy contact is the easiest to establish, it results in an inferior thermal contact resistance, which is especially problematic for forced convective applications.
- Cutting method [7]: machining can result in plastic deformation of struts at the foam edges, creating a local porosity variation. This deformation will also influence the amount of struts that are available for contact with a substrate when bonded together.
- Specific construction of the test rig.
- Effect of radiation [5]: determination of radiative properties is of great importance in buoyancy-driven convection and high temperature applications.
- Effect of fouling.

In this work, the influence of the characterization method on open-cell metal foam is discussed. Most of these parameters have been studied in the research group of the authors.

EXPERIMENTAL METAL FOAM STUDIES

Usability of Experiments

The understanding, prediction and/or optimization of the thermal-hydraulic performance of thermal applications relies on solving physical models on an appropriate geometrical scale. Thermal applications for open-cell metal foam can be found in a large variety of systems and under significantly different flow alignments. It seems that for these applications, the existing research mainly consists of experimental work. In the previous section, many parameters to be studied for applications with open-cell foam are discussed. Due to this, experiments are time consuming. Furthermore, the results of the existing experimental work show quite a large scatter [8]. This can be largely attributed to the characterization of open-cell metal foam in the open literature, as will be explained and illustrated later on. Moreover, in many cases, not all parameters mentioned in Section 'Cooling applications with open-cell foam?' are discussed in a research paper, like the employed contact or cutting technique. For example, Chumpio and Hooman [9] mention that thermal glue was used as a contact technology. However, the authors did not specify the type of glue. In Sertkaya et al. [10], the contact technology was not reported. Also the cutting technology will influence how many struts that can become in contact with the substrate/tube of the heat exchanger [7].

An essential part of a good research paper is that its results are repeatable. In this way, other authors are able to compare their results with work from the open literature. In this respect, there is much work to be done in the field of open-cell metal foam, since the authors frequently do not report a full characterization of the used foam samples, but instead only report bulk properties. Furthermore, most of the time these bulk properties were delivered by manufacturers of foam, like ERG. As will be discussed in the next paragraph, this leads to significant scatter on the results for the performance of the metal foam.

Working with bulk properties

Most manufacturers characterize their metal foam products by reporting both the numbers of pores per linear inch (PPI) and the volumetric porosity $\left(1-\frac{\frac{m_{solid}}{\rho_{solid}}}{V_{tot}}\right)$. The volumetric porosity is quite easy to measure with a relatively low uncertainty of 2%-3% [1]. In theory, the number of PPI should be quite easy to measure, as well. However, as the foam structure is inherently three-dimensional, the PPI value heavily depends on the direction in which the PPI is measured. This is also evident in Figure 1 and 2. At least three different PPI values should be reported for each foam sample, one in every dimension. Furthermore, the reported PPI values in the open literature are mostly multiples of five (5, 10, 15...), which is certainly not representative of the complex and three-dimensional structure of (cast) open-cell metal foam. However, the integration of the PPI value has led to a large commercial value. For actual foam samples, these PPI values are far from a multiple of five, as can be seen in Billiet et al. [5].

The review paper by Mahjoob and Vafai [11] shows that generally, only three parameters are used in correlations for the surface-to-volume ratio σ_0 and tortuosity χ: the volumetric porosity, PPI and an 'average fiber diameter' (d_f). The latter is also called the strut diameter and is measured with a microscope. However, there is no general consensus on how and where to measure d_f, as this fiber diameter varies over the strut length, as shown in Figure 3 for a foam made by ERG Materials and Aerospace. A detailed study of this axial variation was carried out by Jang et al. [12]. One way of dealing with this issue could be to report the location where the fiber diameter is measured (for example at $\frac{x}{l}=0$ in Figure 3).

Furthermore, depending on the Heywood factor also the shapes of the struts differs. In the range of porosities studied in this work however, the shape is more or less triangular.

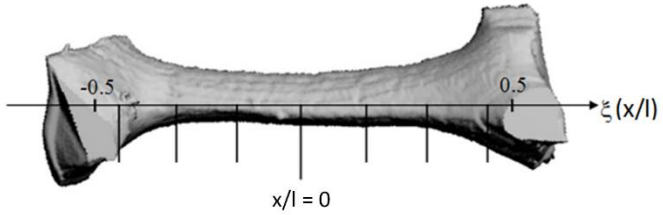

Figure 3 An illustration of the axial thickness variation along the strut length for a foam made by Energy Research and Generation (ERG)

In some correlations, as mentioned in the review paper by Mahjoob and Vafai [11], the average pore diameter (d_p) is used. This value is calculated either based on the PPI value provided by the manufacturer ($0.0254/PPI$) or through a correlation based on the average diameter. The correlation by Du Plessis et

al. [13, 14] for d_p is a frequently-used example of such a correlation (Eq. (1)). In Eq. (1), d_p is a function of both the tortuosity and the equivalent diameter of a cubic unit cell volume d. This equivalent diameter is a function of both fiber and pore diameter ($d = d_f + d_p$). Another frequently-used correlation for d_p is made by Calmidi [15] and depends on the fiber diameter d_f and the porosity ϕ (Eq. (2)).

$$d = d_p.\frac{2}{3-\chi} \tag{1}$$

$$\frac{d_f}{d_p} = 1.18\sqrt{\frac{1-\phi}{3\pi}}.1/(1-e^{-(1-\phi)/0.04}) \tag{2}$$

Furthermore, the authors often determine the surface-to-volume ratio in experimental studies to allow for a physical interpretation of the results and/or to compare the foam sample to other fin materials, like, e.g., louvered fins. In the open literature, this surface-to-volume ratio is frequently calculated through a correlation like the one by Calmidi and Mahajan [16] (requiring the fiber diameter d_f, the pore diameter d_p and the porosity ϕ) or the one by Fourie and Du Plessis [14] (depending on the tortuosity χ of the foam sample and the equivalent diameter d); see Eq. (3) and Eq. (4), respectively. In case of the correlation by Fourie and Du Plessis [14] is used, the tortuosity χ is also required and again calculated through a correlation (see Eq. (5)) [13].

Both correlations are frequently used in the open literature. The paper from Calmidi and Mahajan is cited over 500 times and is still in use, as can be seen from these recent citations: [17-18]. The work from Fourie and Du Plessis [14] is cited over 150 times and is generally less used recently in the open literature.

$$\sigma_0 = \frac{3\pi d_f}{(0.59d_p)^2\left[1-e^{-\left(\frac{1-\phi}{0.04}\right)}\right]} \tag{3}$$

$$\sigma_0 = \frac{3}{d}(3-\chi)(\chi-1) \tag{4}$$

$$\frac{1}{\chi} = \frac{3}{4\phi} + \frac{\sqrt{9-8\phi}}{2\phi}.\cos\left[\frac{4\pi}{3} + 1/3\cos^{-1}\left[\frac{8\phi^2-36\phi+27}{(9-8\phi)^{\frac{3}{2}}}\right]\right] \tag{5}$$

Other methods to characterize geometry

Other methods exist to (more effectively) determine the properties of foam samples. For example, the surface-to-volume ratio σ_0 can be determined indirectly via the Brunauer, Emmett and Teller (BET) method. This is a technique based on the gas adsorption/desorption at the interfacial surface area. With this method, the entire surface area down to the nanometer scale is measured. This means that the BET method can be used for analyses at the nanometer scale only. However, thermal analysis is performed on a continuum scale. It is important to note that the continuum assumption is only valid when the Knudsen number is smaller than 0.01. Consequently, for the continuum hypothesis to hold, the smallest characteristic dimension that can be considered is around 5 μm. Hence, the BET method will result in too large surface areas for the intended analysis [19], as nanometer scale variations do not influence the continuum scale behavior.

The BET method is also used by ERG Materials and Aerospace for calculating their surface-to-volume ratio σ_0 as reported on their website. In turn, this σ_0 value from ERG Materials and Aerospace is often cited by authors, disregarding the fact that this is a strong overestimation of the actual value relevant for thermal applications.

Another very powerful method to characterize the foam is by using micro tomography (μCT) scanning. This method has recently gained some interest, as many papers dealing with this topic are emerging [20, 21]. However, it is still not common practice to use it. The following paragraph will show why neither correlations nor the BET method can be used to characterize bulk properties for the foam. The accuracy of the correlations (although not mentioned) is far less than that from a μCT scan.

MICRO-CT SCAN: RESULTS AND DISCUSSION

µCT scan

A μCT scan virtually divides the solid structure in slices with equal thickness. Each slice is divided into a number of three-dimensional pixels, which are known as voxels. Each voxel is appointed a grey value, which depends on the interaction of X-rays with the material in that voxel. After stacking the digital slices in a full three-dimensional model, the foam's structure can be determined.

Once a virtual structure is available, structural characteristics can be obtained in a systematic way through image processing techniques and dedicated algorithms.

The X-rays used in the scanning equipment interact significantly different with a solid than with a fluid (or vacuum), allowing for a clear distinction between both phases. However, voxels at the solid-fluid interface contain both phases. Therefore, their grey values can span a large range. For further image processing, they need to be binarized, i.e., allocated to either the solid (one) or fluid (zero) phase. This operation is called grey scale segmentation or thresholding. In this work, the algorithm is based on a so-called dual threshold, which defines a threshold interval, combined with a labeling operation [22]. This means that neighboring voxels with grey values within the threshold interval are treated as a subset and are all assigned to a phase. The phase assignment is done by comparing grey values with the averaged threshold level of the interval. Grey values smaller than this averaged value are assigned to the fluid phase, while voxels with larger values are considered as solid material. This algorithm is also used in this work. For a more detailed description of the use of this technique to obtain, e.g., surface-to-volume ratios, the reader is referred to the work of De Jaeger et al. [7].

A drawback of these a μCT scans is that they are quite expensive and not straightforward to use in comparison with a microscope or the naked eye. The main difficulty lies in the choice of the averaged threshold level to allocate the voxels to either the solid (one) or fluid (zero) phase. A different threshold can yield significantly different allocations of fluid volumes [23] and, thus, a significantly different foam model. Furthermore, the voxel size itself can also significantly influence the results (as

shown in Figure 4). Figure 4(a) is constructed with a voxel size of 37.5 m, while Figure 4(b), which clearly shows more detail, is made through a scan with a voxel size of 8.5 μm. The surface-to-volume ratio of both reconstructions in Fig. 4 is respectively 720 and 860 m^{-1}: a relative difference of 19%. The scan here is done on at least 16 foam cells. The reported values are average ones. This shows that the voxel size, next to thresholding, is an important parameter [7]. The heat transfer performance of a fixed volume of metal foam is determined by the product of the heat transfer coefficient and the surface-to-volume ratio. The heat transfer coefficient is determined based on the measured performance and the determined surface-to-volume ratio. As long as the thermal performance is reconstructed using the same surface-to-volume ratio that was used to determine the heat transfer coefficient, the correct thermal performance will be obtained.

However, it is clear that the geometry obtained with a 37.5 μm voxel size and a 8.5 μm voxel size is fundamentally different on the continuum scale. This leads to the question whether this continuum scale roughness has a significant impact on the pressure drop and heat transfer behavior. Generally, this is not the case, as long as the flow is laminar or the roughness peaks are smaller than the thickness of the viscous sublayer in turbulent flow. For numerical simulations, the relevant surface-to-volume ratio is the one obtained on a scale that does not resolve the roughness effects that do not influence the flow.

Schmierer and Razani [24] scanned metal foam samples with four different voxel sizes, ranging from 115 down to 58 µm. They found an asymptotically converging surface-to-volume ratio. Another restriction on the voxel size is imposed by the continuum assumption with no-slip boundary conditions, upon which thermal and hydraulic analysis are commonly based (as is the case for this work). Due to the continuum hypothesis to hold and with air as a working fluid, it is not necessary to have a finer spatial discretization than voxel sizes in the order of 5 μm. As a result, the high resolution scan with a voxel size of 8.5 μm of Fig. 4(b) can be considered highly accurate [7].

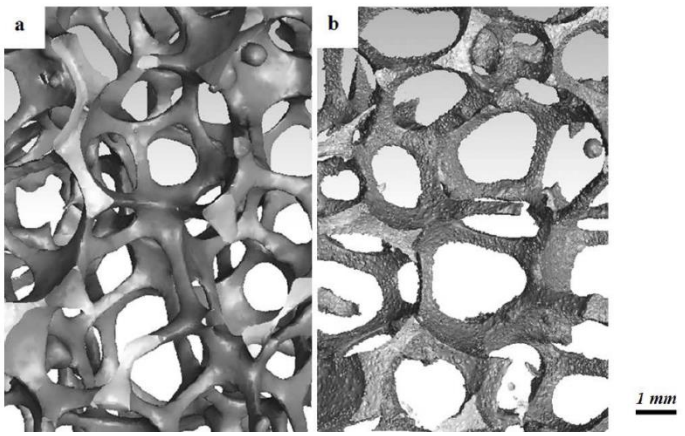

Figure 4. An illustration of the effect of voxel size for a μCT scan reconstruction with resp. (a) 37.5µm and (b) 8.5µm voxel size. Foam samples are made in-house.

Numerical models based on µCT

μCT scans can be used for a full characterization of the foam sample. However, some authors, like De Jaeger et al. [27], use a hybrid model. For this model, both cell diameters (d_1 and d_2, as indicated in Figure 1a) and the interfacial strut area (A_0) are measured with a μCT scan. This interfacial strut area is the average cross-sectional area in the center of the strut ($\frac{x}{l} = 0$ in Figure 3). The interfacial strut area shows a difference of merely 4% as the voxel size is reduced from 37.5 μm to 8.5 μm and is therefore not strongly influenced by the roughness. An extensive explanation on how this interfacial strut area can be calculated from μCT data can be found in [23]. With these three parameters, the authors were able to make a model of the complete foam structure. Based on that structure, the porosity and the surface-to-volume ratio can be calculated numerically. This allows the continuum scale roughness, which is resolved by the fine μCT scan to be neglected, for it does not contribute to the heat transfer performance. This is a hybrid model that calculates the porosity and surface-to-volume ratio based on d_1, d_2 and A_0, instead of using a correlation to obtain the surface-to-volume ratio σ_0 or performing a full characterization of the foam sample through a μCT scan. The surface-to-volume ratio with this hybrid model for the foam studied in Figure 4 is $859m^{-1}$. This is very close to the value obtained by μCT with a voxel size of 8.5 µm ($860m^{-1}$). This once again indicated the necessity of using small voxel sizes.

It is worthwhile to mention that cell diameter analysis for example can also be done via scanning electron microscope (SEM), as applied by Zhou et al. [25]. In this method, foam samples are prepared by filling them with a resin, i.e., cold mounting, and are then polished. The polished side is viewed under a microscope, allowing one to perform image analysis. This method is two-dimensional in nature, making it more prone to measurement errors. However, when done with care, it allows obtaining results that are in excellent agreement with μCT scans [25].

Foam	PPI	ϕ -	d_1 (mm)	d_2 (mm)	A_0 ($\times 10^{-1} mm^2$)	σ_0 (mm^{-1})	d_p (mm)
1	10	0.932±0.02	4.22±0.18	6.23±0.18	0.998±0.08	462±35	2.56±0.13
2	10	0.951±0.02	4.28±0.13	6.42±0.13	0.615±0.13	380±30	2.61±0.11
3	20	0.913±0.02	2.52±0.06	3.78±0.06	0.463±0.04	860±69	1.53±0.05
4	20	0.937±0.02	2.77±0.05	4.15±0.05	0.377±0.05	720±58	1.69±0.05
5	20	0.967±0.02	2.6±0.05	3.67±0.05	0.126±0.02	580±46	1.55±0.05

Table 1. Properties of studied foam samples, determined through a µCT scan with a voxel size of 8.5 µm. All reported foam samples were made in-house.

Foam	σ_0 (μCT) (m^{-1})	Calmidi and Mahajan [16] (m^{-1})	Fourie and Du Plessis [14] (m^{-1})	De Jaeger et al. [27] (m^{-1})	ERG [29] (BET method) (m^{-1})
1	462±35	1062	528	482	709
2	380±30	884	462	403	571
3	860±69	2000	951	860	1299
4	720±58	1549	781	694	1063
5	580±46	1218	669	573	709

Table 2. Surface-to-volume ratio σ_0 results for correlations and model in open literature for the foam samples shown in Table 1.

µCT scan data and numerical model compared with correlations and ERG data

Properties that can be measured through μCT scans are, e.g., porosity (ϕ), surface-to-volume ratio (σ_0), cell diameters (d_1, d_2), pore diameter (d_p) and axial variation of the strut thickness. For five foam samples, the values measured with a μCT scan are reported in Table 1. A_0 is the interfacial strut area as measured in the middle of the strut. The relative experimental uncertainty on the porosity and surface-to-volume ratio is at most 2% and 8%, respectively. The reported properties are also averaged properties, as the μCT scan is performed over 16 cells of the foam sample. The surface-to-volume ratio (σ_0) is calculated via the marching cube algorithm, as described by Lindblad [26]. The interfacial strut area (A_0) is calculated as described in De Jaeger et al. [27].

Note that all uncertainties in this work are expressed as 95% confidence intervals. In Table 2 a comparison is made with the correlations for the surface-to-volume ratio from Calmidi and Mahajan [16] and Fourie and Du Plessis [14]. For this comparison, the porosity and pore diameter from in-house μCT scans are used (Table 1) together with correlations for the surface-to-volume ratio, fiber diameter and tortuosity, as reported in [14] and [15]. Furthermore, a comparison with the work of De Jaeger et al. [27], the so-called hybrid model, is also made in Table 2 together with the values from ERG which you can find on their website [29].

Both Tables 1 and 2 show that the results from correlations show a large deviation from the results obtained through a μCT scan. The correlation of Calmidi and Mahajan [16] is the least accurate with differences up to 233%. The correlation of Fourie and Du Plessis [14] deviates up to 22% from the experimental results of the full μCT data. Furthermore, note that both correlations consistently overestimate the measured surface-to-volume ratio at the 8.5-µm scale. As previously discussed, the surface-to-volume ratio at this scale is actually already an overestimation of the surface-to-volume ratio, which is relevant for the heat transfer and pressure drop. However, these correlations are often used in the open literature [28]. Furthermore, also notice that the comparison made in Table 2 is based on input parameters that are determined through μCT and not according to the common practice as discussed in the paper of Mahjoob and Vafai [11]. As a result, the deviations will be even higher if the uncertainty on the input parameters for the correlations are larger, such as when they are determined through a microscope or the naked eye. This will not only influence the repeatability of the experiments, it will also influence the results. Both in numerical and experimental work, parameters as σ_0 are used as input.

When there is compare to the data from ERG, determined through the BET method as previously explained, the difference between the µCT scans is up to 53%.

Next, the results from the model of De Jaeger et al. [27] show a much better agreement with the μCT scan data. With a relative uncertainty level of 10% [27], the values for σ_0 match the experimental values.

However, μCT scan data are still necessary in the model of De Jaeger et al. [27] as the input parameters (d_1, d_2 and A_0) need to be determined. Hence, the method by De Jaeger et al. [27] requires a great amount of effort. Yet, with the currently available correlations, μCT scans (or the SEM method) are the only way to ensure a relative error that is smaller than 10%.

If future researchers are not able to perform a µCT scan, one should try to determine as much parameters as possible with a microscope. For the surface-to-volume ratio they can use the Fourie and Du Plessis [14] correlation, however, even then they have to do a sensitivity analysis based on the large uncertainty of using this correlation.

Furthermore, the pressure drop of the metal foam can be characterized by the permeability and the inertial coefficient. These quantities in turn are mainly determined by the geometric foam properties that have been discussed so far. Since it has been shown that the uncertainty on these geometrical properties is rather large, it is not surprising that a large discrepancy can be found between the experimental results for the permeability and inertial coefficient in the open literature [8]. Furthermore, the smaller the mass flow rate, the larger the discrepancies.

CONCLUSIONS

For experimental research, the focus should lie on the repeatability of the experiments. Most studies found in open literature do not focus on the characterization of the foam. Generally these studies only report porosity and a number of pores per linear inch (PPI-value). Despite the fact that the PPI is direction dependent, most authors only report one PPI to characterize their foam. Furthermore, this PPI value is frequently used in correlations for macroscopic properties like e.g. the surface-to-volume ratio σ_0. It is shown that the results of these correlations do not stroke with the real values of the macroscopic properties.

In this work an alternative and more profound method for characterization of the foam sample is discussed: using a full characterization of open-cell foam through µCT scans. With this method the complete foam structure can be characterized: all microscopic parameters, but also the macroscopic parameters like σ_0. and porosity. Furthermore, a hybrid model for foam characterization is also discussed, which only requires three parameters measured through µCT scans to make a foam model. With this foam model and/or the full µCT scan, it is possible to calculate the macroscopic parameters for the foam material.

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