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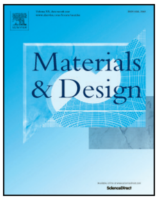

The influence of pore size variation on the pressure drop in open-cell foams

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ABSTRACT

The paper concerns pressure drop in open-cell foam structures in correlation with variation in size of pores. The foam structures with different coefficients of variation of the pore volume CV(V) were designed using procedure based on Laguerre–Voronoi tessellations (LVT). Geometry of the generated structures was compared with the geometry of alumina foam filters used for casting. Pressure drop was calculated for structures with various pore volume distributions using the finite volume method (FVM).

Validation of the LVT algorithm was performed by comparing the pressure drop obtained for modeled structures with the pressure drop of commercial alumina foam filters for aluminum casting. Two of the designed set of porous structures were printed using fast prototyping with the selective laser melting process (SLM). The pressure drop for these structures was measured experimentally and compared with the modeling results.

The results show that the pressure drop is strongly related with the distribution of pore volume. Furthermore, for the investigated range of the coefficients of pore volume variation, a relationship was found between CV(V) and pressure drop.

1. Introduction

Open-cell foam structures have numerous commercial applications due to their unique properties such as high specific strength, low density and high permeability [1]. The list of applications includes lightweight high-strength structures, mechanical energy absorbers, pneumatic silencers [1–3]. Foam structures improve heat transfer in highly endothermic and exothermic reactions, and are used in filters [4,5], heat exchangers, catalytic reactors, waste and exhaust gas purification systems [6–10].

The use of foams in fluid flow applications requires a thorough understanding of the pressure-drop generated by the porous structures. Extensive work has been done in this field — see for example [11]. Geometrical models have been proposed based on the assumption of equal volume of pores of different shapes [12–17]. On the other hand, experimental observations show that foams exhibit a distribution of pore size [18]. Good approximations of these pore size distribution functions can be obtained using the Laguerre–Voronoi algorithm [19,20], where tessellations are performed on a set of spheres with pre-determined size distribution as reported in [21].

In commercial practice foams are very frequently manufactured with narrow pore size distributions. Consequently, permeability of commercially available structures has been primarily investigated in terms of the pressure drop dependence on the porosity and the average pore/cell size [22–29]. The effect of pore and strut shape has been also analyzed in [30,31]. Studies of the influence of pore size variation on the pressure drop are scarce and incomplete. A thorough literature review and description of most commonly used relationships for pressure drop and structural parameters of porous materials can be found in [32].

In order to obtain further insight into the pressure drop phenomena, the aim of the present study was to investigate a possible effect of diversity in the size of pores. To this end a set of porous model structures with different coefficients of variation CV(V) of the pore size was generated using Laguerre–Voronoi tessellations. Pressure drop for these structures was computed using the finite volume method (FVM) and their permeability was estimated using Darcy's law. Validation of the LVT algorithm was performed by comparing the pressure drop obtained for the modeled structures with values calculated for commercial alumina foam filters for aluminum casting. Two of the structures were manufactured using the selective laser melting (SLM)

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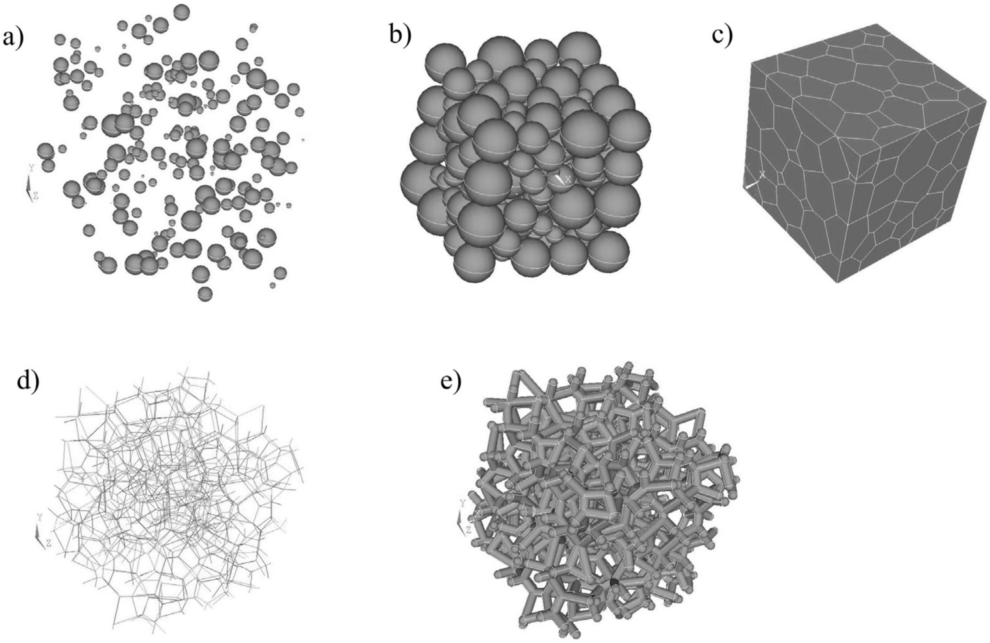

Fig. 1. Schematic illustration of the LVT algorithm developed for generating foam structures: a) spheres of pre-determined volume distribution, b) spheres after packing into low-overall-volume aggregate, c) cellular structure obtained using Laguerre–Voronoi tessellations, d) triple edges of the cellular structure, and e) foam structure with cylindrical struts.

fast prototyping technique. The pressure drop of fluid flowing through the structure was measured experimentally and compared with the modeling results.

2. Methods

2.1. Modeled structures

Foam models were obtained by the Laguerre–Voronoi tessellations method [21] applied to a set of spheres, with specified size distributions, packed in a cube. The foam struts were generated by placing cylinders with defined radius along the cell edges.

The algorithm for the modeling of foam structures employed in the present study consists of the following five steps:

1. Generation of spheres with a defined size distribution (in the computation log-normal distribution of volume was adopted with a pre-selected average value, and the variation coefficient)
2. Packing of the spheres,
3. Performing Laguerre–Voronoi tessellations,
4. Defining the triple edges of the cellular structure, and
5. Generation of struts along the triple edges.

A schematic of the LVT procedure used here is shown in Fig. 1, and a detailed description can be found in [21].

A set of 15 structures with coefficient of pore volume variation CV(V) ranging from 0.45 to 2.0 was developed. Coefficient of pore volume variation was set using a selected range of sphere diameters in the first step of LVT procedure described above. The values of CV(V) for each structure were calculated as CV(V) for LVT cells (Fig. 1c). Each structure was limited by a bounding box of cubic shape and consisted of 200 pores. According to the literature data [33,34] this is expected to be sufficiently high number of pores to study their effect on the properties of the structures in question. Strut diameters values were varied from 0.5 to 2.0 mm, which resulted in porosity ranging from 73.8 to 97.9%. The strut diameter 1.5 mm was used to generate structures representative for 10 ppi commercial foam filters — see Table 1.

Commercially available alumina foams VUKOPOR A (hereinafter called “real structures”) were used as a reference for the designed structures. The real structures with 10 pores per inch (ppi) were studied. Structural parameters of commercial foam filters were studied using X-ray computer tomography (CT), a method commonly used for characterization of such materials [33,35,36]. Digitalized geometries of the foams were obtained using high resolution X-Radia XCT-400 made by SkyScan under acceleration voltage of 150 kV and current of 50A, which assured a voxel resolution 40 μm/voxel.

A three-dimensional reconstruction of the sample was generated by collecting a series of absorption radiographs of the cellular material. A total of 900 projections of the 2D radiography images were reconstructed using XCT-reconstruction software. This process resulted in a set of 256-level grayscale bitmap-format tomograms. In order to recover the actual geometry of the specimen, this dataset had to be filtered and binarized, i.e., each pixel had to be prescribed with a value 0 or 1 (black or white) denoting void or solid phase. Both processes were performed using SkyScan cTAN software. First, a median filter was used to remove the noise. This filtering procedure has an additional advantage of smoothing the solid-porous boundaries. Then, an appropriate threshold level for binarization was chosen. Finally, the internal porosity was

Table 1
Comparison of real foams and modeled structures.

Structure	10 ppi No. 1	10 ppi No. 2	10 ppi No. 3	LVT CV = 0.458	LVT CV = 0.478	LVT CV = 0.484
Porosity [%]	78.30	77.02	78.96	81.40	81.54	83.61
Mean pore diameter [mm]	2.56	2.56	2.56	3.19	3.10	3.01
Mean strut diameter [mm]	1.43	1.39	1.45	1.5	1.5	1.5
Mean pore volume [mm^3]	8.78	8.78	8.78	16.99	15.60	14.28
Surface to volume ratio [1/mm]	696.45	705.12	680.74	577.91	575.41	571.77