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Geometry Simplification for Modeling of Porous Materials

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Abstract Porous and lattice materials have become ever-present in applications such as medicine, aerospace, design, manufacturing, art, entertainment, robotics, material handling, etc. However, their application is impeded by the uncertainty of their mechanical properties (elongation, torsion, compression moduli, etc.). Computational Mechanics of poorus materials is also hindered by the massive geometric data sets that they entail, if their full geometric representations are used. In response to these limitations, this article presents a truss simplification of a porous material. This simplified representation is usable in computer simulations, instead of the full triangle- or freeform-based Boundary Representations (B-Rep), which produce intractable problems. This article presents the simplification methodology, along with results of estimation of the stress - strain response of porous material (in this case, Aluminum). Our methodology presents itself as a possible alternative in contrast with impossible processing when full data is used. Follow up work is needed in using the truss methodology for calculating macro-scale equivalent Young or Poisson moduli, with applications on mechanical design.

Keywords Porous Materials · Geometric Simplification · Computational Mechanics

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1 Introduction and Literature Review

The following references model the micro-structure of the Foam by using pre-defined cells (e.g. Kelvin, Voronoi, etc.). However, none of these references mentions geometric simplification of the data. The refs reviewed (e.g. [1]) use a Computer Tomograph of Foam as basic data. [2] model the Foam with 14 pentagonal face cells, conducting experimental work for the property validation. [3] uses Laguerre-Voronoi cells, creating tetradecahedron (14 faces) cells. [4] uses directly CT slices, binarized, to apply a FEA method for prediction of Bulk Properties (e.g. Young Moduli). [5] computes walls within the foam, carrying SVD on the microCT data. [6] conducts CFD simulations on CT data, computing permeability and effective thermal conductivity. [7] uses a collection of implicit functions to model struts, passing through Marching Cubes, Triagulations and Surface Meshes. We present a geometric simplification that enables otherwise intractable mechanical computations with CT-sampled Foams.

2 Methodology

The geometry of porous materials is obtained and simplified as follows.

2.1 Processing of Computer Tomograph (1) Computer Tomography (CT) of the porous domain $\Omega = 400 \times 400 \times 400\ mm^3$ (Fig. 2(a)). (2) Execution of a Marching Cubes algorithm on the scalar field CT to produce a triangle - based Boundary Representation (B-Rep) or mesh $M = (T, V)$ of the foam surface.

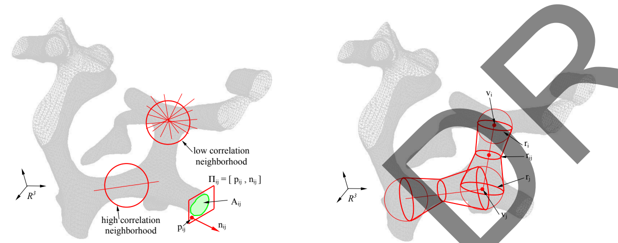
2.2 Generation of Boundary Representation (1) Assurance of Topological correctness of M, to ensure 2-manifold properties. (2) Triangle size and shape homogenization. (3) Decimation controlled by curvature, to lower the number of triangles. (4) Fitting of Quadrangular patches to mesh M. (5) Construction of a borderless Boundary Representation (B-Rep).

2.3 Node vs. Bar Detection By combination of visual and Principal Component Analysis (Fig. 1): (1) Identification of low correlation point cloud sub-sets (truss nodes). (2) Identification of high correlation point cloud sub-sets (truss bars).

2.4 Truss Topology (1) Determination of Graph structure of the node - bar graph $G = (V,E)$ (V= node set, E=bar set). (2) Representation of bar $e_k = \overline{v_i, v_j}$ ad a truncated cone (radii r_i, r_j) (Fig.1(b)). (3) Replication of Truss extents using symmetry plane $\Pi = [p_v, \hat{n}]$. (4) Topology Index set consolidation.

2.5 Automatic Generation of Finite Element Analysis Automatic generation in MATLAB of a FEA script to: (1) Generate the Topology and Geometry of the Truss. (2) Force - charge a subdomain Ω_F of the full domain Ω. with $\mathbf{F} = F.\hat{u}$ = direction prescribed according to the parameter sought (E_x, E_y, E_z, μ_{xy}, G_x,...). (3) Kinematically restrict nodes in a subdomain Ω_U of the full domain Ω. (4) Execution of the FEA Simulation.

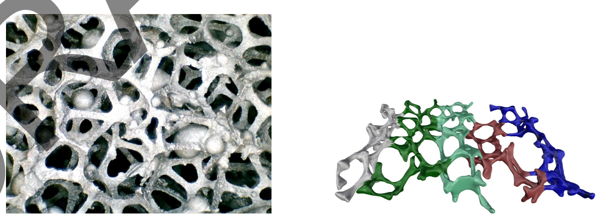
2.6 Estimation of Bulk Deformations of the Foam Structure. (1) Longitudinal Deformation. (2) Angular Deformation, (3) Poisson Deformation (expansion normal to force). (4) Statistical determination of Young Moduli, Torsion Moduli, Poisson coefficients.



(a) Statistical Identification of Nodes vs. Bars. (b) Truss Bar with Double-cone Geometry.

Fig. 1 Statistical Criteria for Identification of Nodes and Bars in Foam Material.

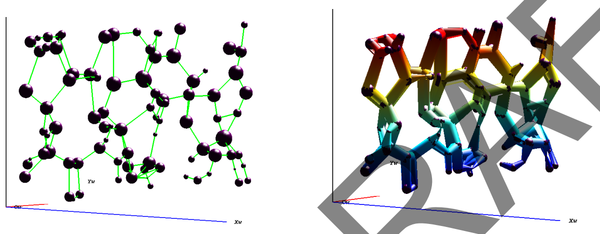
3 Results



(a) Porous material (Aluminum foam). (b) Eight-th Portion of Domain Ω with Layer Colors.

Fig. 2 Porous Material and Voxel - based Model.

Fig. 2(a) presents the CT input data, which undergoes the process in section 2, to reach a full B-Rep model (Fig. 2(b)). However, even basic FE generation is impossible with this small data set. In contrast, FEA using Truss (Nodes+Bars, Fig. 3) representation, allows not only the meshing but the conclusion of the simulations.



(a) Foam Nodes (b) Foam Connectivity with Cylindrical Bars

Fig. 3 Simplification of Half Domain

4 Conclusions and Future work

Geometric simplification proved to enable the FEA simulation for non-trivial Foam domains. Ongoing work is required to process the FEA results (basically point sets) into meaningful sample deformations, and to generate bulk equivalent Young, Poisson, and Torsion Moduli. The verification of a reasonable precision by using the simplifyied geometry is also required.

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