HAL
open science

A new numerical scheme for the measurement of strain fields in cellular micro-structures without pattern

Ali Rouwane, Robin Bouclier, Jean-Charles Passieux, Jean-Noël Périé

To cite this version:

Ali Rouwane, Robin Bouclier, Jean-Charles Passieux, Jean-Noël Périé. A new numerical scheme for the measurement of strain fields in cellular micro-structures without pattern. Photomechanics IDICS Conference, Nov 2021, Nantes, France. hal-03424512

HAL Id: hal-03424512

https://hal.science/hal-03424512v1

Submitted on 10 Nov 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Photomechanics
IDICS Conference
19-22 October 2020
NANTES – FRANCE

A new numerical scheme for the measurement of strain fields in cellular micro-structures without pattern.

Ali Rouwane[1,2], Robin Bouclier[1,2], Jean-Charles Passieux [1], Jean-Noël Périé[1]

[1] ICA, Université de Toulouse, UPS, INSA, ISAE-SUPAERO, MINES-ALBI, CNRS, 3 rue Caroline Aigle, F-31055 31400 Toulouse, France
[2] IMT, Université de Toulouse, UPS, UT1, UT2, INSA, CNRS, 135 avenue de Rangueil, F-31077 Toulouse Cedex 04, France

Abstract — One of the experimental tools that could contribute to a better understanding of the mechanical behavior of cellular materials is the full-field measurements using Digital Volume correlation (DVC). When dealing with micro-structures that do not exhibit sufficient gray-levels, traditional Digital Image Correlation (DIC) algorithms do not allow to measure accurate local deformations. In this critical situation, one of the efficient methods for reducing measurement uncertainties especially in DVC is the use of a mechanical regularization of the underlying optimization problem. Following this approach, we construct an automated fairly-priced image based mechanical model that accurately describes the behavior of a cellular material and use it as a regularization of the DIC problem.
Keywords — Digital Volume Correlation, elastic registration , B-splines, fictitious domain methods, image based models, cellular materials.

Introduction With the recent advances in imaging techniques such as Computed Micro-Tomography (μ-CT), it is possible to acquire voxel representations of the micro-structure of complex heterogeneous materials in an non-invasive way. A particular interest is put on the full-field measurement in cellular materials such as foams. DVC in complex micro-structures presents multiple changes and challenges when compared to 2D DIC. For instance, in most two-dimensional cases, a speckle pattern can be deposited onto the sample in order to introduce sufficient gray-level gradient values in the images. However, for DVC, the only information available is the intrinsic gray-level values of the material. That is why it seems that conventional DVC algorithms can only be applied when materials exhibit a natural speckle pattern (for instance graphite nodules [1]). We aim at developing a DIC algorithm in order to capture local deformations in the micro-structural scale using only the natural texture of the studied material. To do so, we suggest constructing an automated digital image-based mechanical model and using it to regularize the ill-posed problem of DIC.

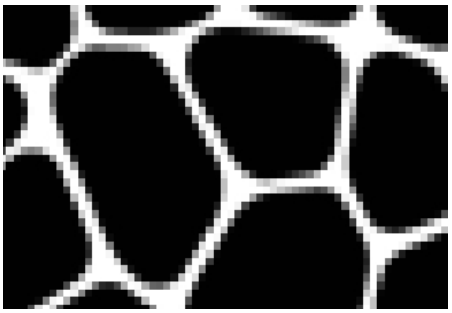
Methods Given two images of a cellular specimen resulting from a mechanical test, we consider solving the classical DIC problem using a penalization of the elastic forces [2]:

$$\arg\min_{\mathbf{u}} \frac{1}{2}R(\mathbf{u}) + \frac{\lambda}{2}||\mathbf{K}\mathbf{u}||_2^2 \tag{1}$$

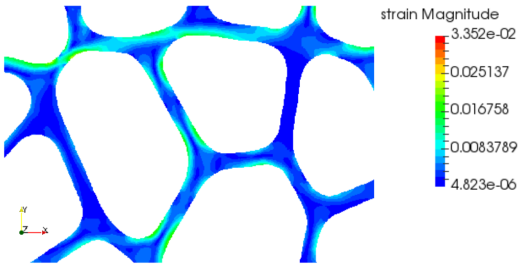
where R is the discrete sum of squared differences between the initial and the advected images, $\mathbf{u}$ is the displacement vector at the control points of a cubic structured B-spline grid defined over the region of interest and $\mathbf{K}$ is an elastic rigidity operator that simulates the mechanical behavior of the texture being observed. Our contribution concerns the automated construction of a fairly priced image-based model that allows to obtain $\mathbf{K}$. To do so, we use a high order fictitious domain method using a level-set representation of the materials boundary [3, 4]. We mean by fairly priced the fact that our model's parameters (mesh size and degree of approximation) are set such that the error made on the mechanical solution is insignificant compared to the geometric errors related to the image-based geometry approximation. In

contrary to boundary-fitted meshing techniques, the degrees of freedom of the fictitious domain method are defined over all the specimen's region (including the empty black region in Fig. 1a). We emphasize that **K** is defined only at the degrees of freedoms on which the elastic forces are known.

Results In order to validate our method, we consider measuring the strain field on a planar specimen representing a two-dimensional synthetic cellular material (see Fig. 1a). Fig. 1b shows that the suggested mechanical regularization allows to measure accurate strain fields compared to traditional low order interpolation schemes and this using only the natural texture of the specimen.



(a) Poorly resolved image of a cellular specimen (4 pixels in the micro-structure's thickness (of length equal to 0.6*mm*). The image gradient is either small (black region) or has a dominant direction (white regions).



(b) Local bending observed at the microscopic scale when using the mechanical regularization without a speckle pattern.

Figure 1: Strain measurement at the microscopic scale for a cellular specimen.

Discussion and Conclusion High order basis functions such as B-splines, allow to capture non-rigid and smooth displacements in the contrary of low order registration techniques. This method was validated in two dimensions for synthetic images. Its generalization to real foam specimens will be done in the future and we assume that the three-dimensional generalization is only related to the computational complexity and efficiency. However, multiple challenges are still open concerning the elaboration of an *in-situ* mechanical test using micro-tomography. In fact, in order to acquire sufficiently resolved images, we need to consider small volume samples. This constraint obliges us to design adapted mechanical testing machines so as not to disturb the tomography acquisition system [5].

References

[1] Hugo Leclerc, Jean-Noël Périé, Stéphane Roux and François Hild. Voxel-scale digital volume correlation. *Experimental Mechanics*, 2011.

[2] Julien Réthoré, Stéphane Roux and François Hild. An extended and integrated digital image correlation technique applied to the analysis of fractured samples. *European Journal of Computational Mechanics*, 2009.

[3] Dominik Schillinger and Martin Ruess. The finite cell method: A review in the context of higher-order structural analysis of cad and image-based geometric models. *Archives of Computational Methods in Engineering*, 2015.

[4] Clemens V Verhoosel, GJ Van Zwieten, B Van Rietbergen, and René de Borst. Image-based goal-oriented adaptive isogeometric analysis with application to the micro-mechanical modeling of trabecular bone. *Computer Methods in Applied Mechanics and Engineering*, 2015.

[5] Aurélie Benoit, Sandra Guérard, Brigitte Gillet, Geneviève Guillot, François Hild, David Mitton, Jean-Noël Périé, and Stéphane Roux. 3d analysis from micro-mri during in situ compression on cancellous bone. *Journal of Biomechanics*, 2009.