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IN APPLICATION

Computation of Full-field Displacements in a Scaffold Implant using Digital Volume Correlation and Finite Element Analysis

Mechanical Behaviour of Materials Laboratory, University of Portsmouth, UK

Introduction

Studies on the relationships between the morphology and the mechanical behaviour of biological tissues and biomaterials are critical to biomedical engineering applications of joint repair and replacement materials. With the recent and rapid progress of micro-focus computed tomography (μCT) combined with the development of in situ experiments, Digital Volume Correlation (DVC) has become a powerful tool to capture 3D strain distributions in solid and cellular materials.

This study demonstrated the excellent capabilities of StrainMaster DVC from LaVision, and also compared performance with another approach by looking at the strain and displacement uncertainty levels of a polymer foam implant undergoing controlled shifts. Micro-finite element computations were also carried out to compare the strain predictions of the foam implant with the DVC measurements. Like other studies taking advantage of DVC, the long term goals of this type of work will be the validation and optimization of an FE model. The only means of quantifying the full volume strain and deformation is through experimental tools such as DVC.

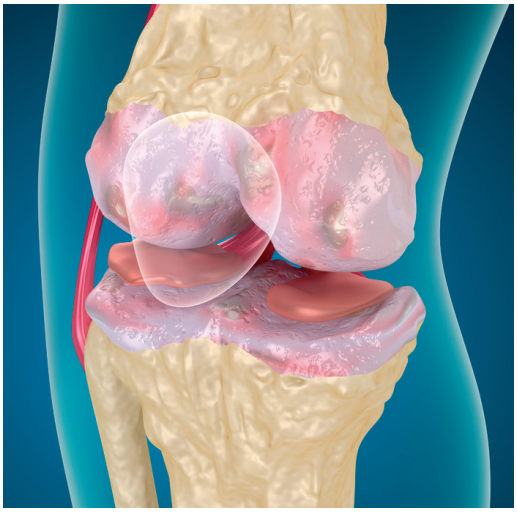

Figure 1: *A pictorial representation of a knee joint*

Experimental Setup

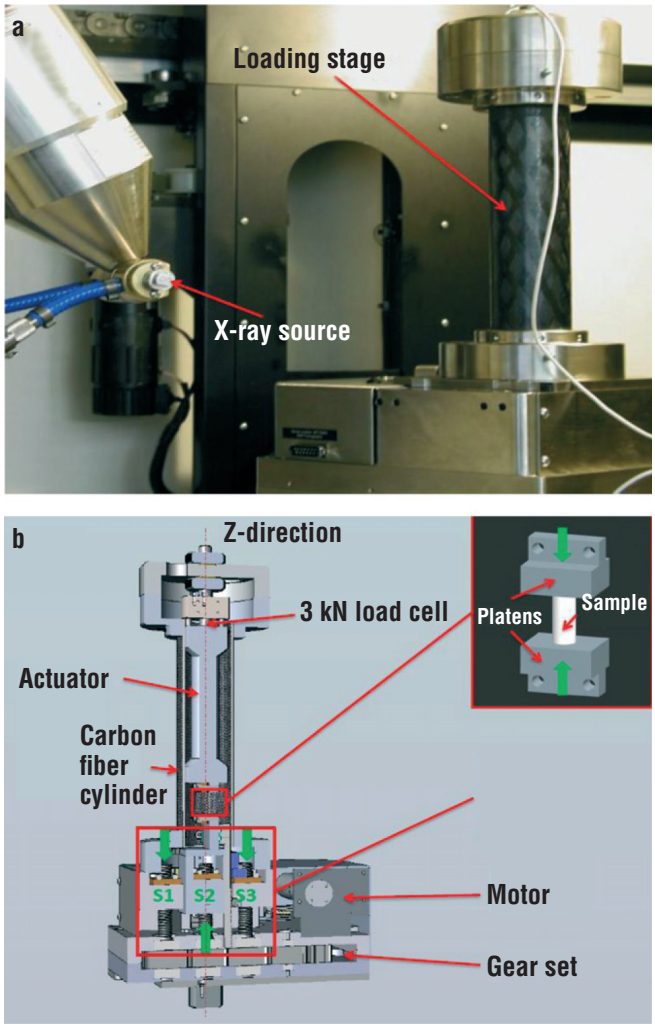

Figure 2: *(a) The micromechanical testing device positioned in the micro-CT chamber and (b) the linear compression applied to the sample is generated through a ballscrew system that drives the jaws symmetrically in opposite directions.*

For further details refer to Madi et al. (2013), Medical Engineering & Physics, 35, 1298-1312.

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A scaffold implant material (Smith & Nephew) was used for this study. The scaffold material was taken from a dual-layer cylindrical implant that mimics cartilage and bone for knee repair purposes. It is made from 85:15 poly(D,L-lactide-co-glycolide). The specimen was 8.57 mm in diameter and 14.7mm in height.
A Nikon XTH-225 X-ray scanner was used at the University of Portsmouth and in this case, with an X-ray tube potential of 60 kV. A resolution of 20 µm per voxel was achieved. The setup is shown in Figure 2 and a 3D reconstruction of the specimen is shown in Figure 3.

Two compression steps were applied to the specimen within a customized micro-mechanical loading device (Deben Ltd, UK) equipped with a 3 kN load cell and microtomography measurements were taken at each stage. DVC calculation settings utilized final sub-volumes of 32 x 32 x 32 overlapping by 50 % after prior passes of 96^3 and 64^3 voxels.

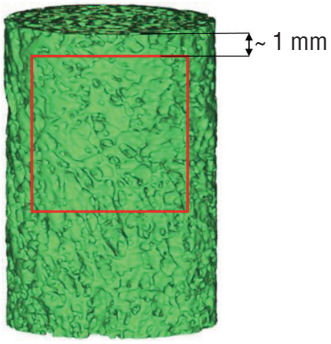

***Figure 3**: reconstruction of the cylindrical specimen*

LaVision's approach to DVC calculations includes the use of a multi-pass approach resulting in displacement uncertainties of less than 0.02 voxel (0.4 µm for the imaging magnification utilized), and strain uncertainties ranging between 60 and 200 µε, with a correlation window of 32 voxels (640 µm).

The excellent displacement and strain accuracy allows the user to identify localization effects in the strain field, and results are available quickly (in less time than a typical scan reconstruction) because of the efficient calculation implementation, making DVC a valuable research tool.

Results

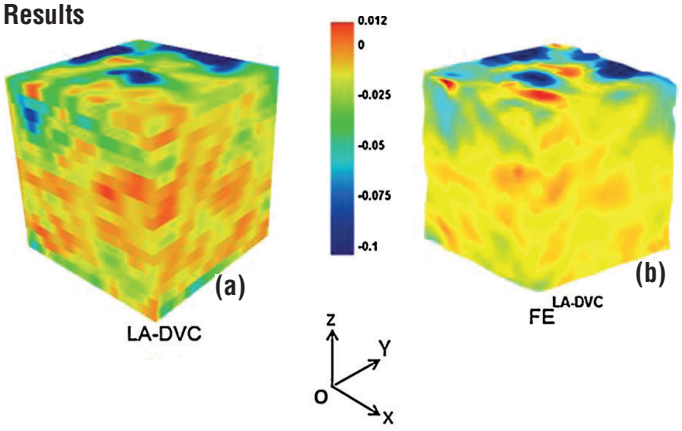

***Figure 4**: 3D visualization of the vertical strain, ε_{zz}, of the VOI (a) LA-DVC (sub-volume size: 0.64 mm with 50% overlap), (b) FE model with boundary conditions applied from LA-DVC (average mesh size: 0.42 mm), The macroscopic strain was applied along (Oz) direction.*

Similar distributions are observed for the LaVision DVC method and alternate approach. The DVC result compared well with the FE result (Figure 4) showing highly localized vertical strain near the top of the specimen. Elsewhere, the strains obtained by DVC seemed to be lower and more continuously distributed.
The strain maps predicted by the FE analysis with an average element size of 0.42 mm were similar to the DVC measured strains.

The 3D full-field DVC calculated displacements in a porous scaffold material compared well with the finite element simulations. The results demonstrate that DVC is applicable to this type of material and that the measured displacements and strains compare well between the two DVC methods. LaVision's DVC approach is able to achieve displacement uncertainties of 0.02 voxel (0.4 µm) and strain uncertainties of the order of 200 µε. DVC provides a displacement and strain measurement technique which has a promising future for a range of applications in biomedical engineering.

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