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CHARACTERIZATION OF REGIONAL MECHANICAL PROPERTY ANOMALIES IN TENSILE TEST SPECIMENS

**G. Wayne Brodland
Caleb R. Horst
Jim H. Veldhuis
Matthew McDonald**

Department of Civil and Environmental Engineering
University of Waterloo
Waterloo, On
CANADA

SUMMARY

This study demonstrates that regional mechanical property anomalies can be identified in tensile specimens using high-resolution, multi-point tracking and suitable analysis software. Identification of such regions is important for test validation and for accurate interpretation of force-displacement data. Biaxial tensile tests on bovine peritoneum showed that regional strains can vary by a factor of 3 within a single specimen, and analyses that ignore such variations are shown to produce stress-strain graphs that are substantially in error.

INTRODUCTION

Tensile tests provide one of the standard methods for measuring the mechanical properties of biomaterials. Typically, specimens used in these tests are cut so as to avoid regions with visible inhomogeneities, and stress and strain are assumed to be sensibly uniform throughout the specimen. Recent studies have shown that attachment details can introduce significant stress and strain variations [1,2], and here we consider how regional material property variations due to localized structures such as blood vessels might affect such tests. This information is important for the design and interpretation of tensile tests and it provides clues about how localized property variations might be incorporated into statistical materials descriptions.

METHODS

Seven by seven mm specimens of fresh bovine peritoneum were cut and mounted in a BioTester 5000 (CellScale Biomaterials Testing, Waterloo, Ontario) biaxial test system using a BioRake mounting system (Fig. 1A). The specimens were lightly sprinkled with powdered talc (Baby Powder, Johnson & Johnson Inc.) before being lowered into a temperature-controlled bath consisting of physiological buffered

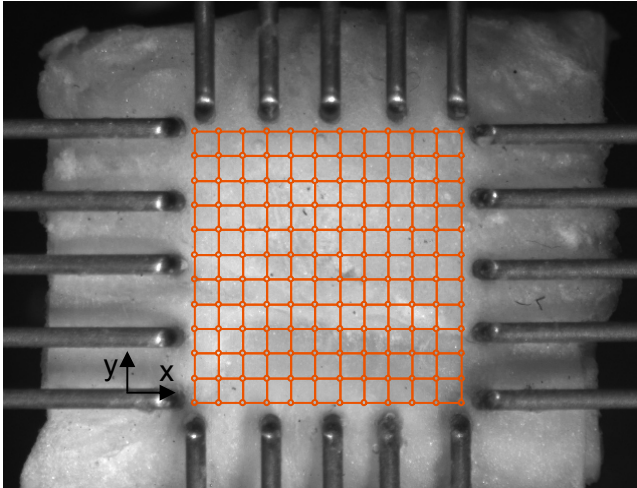
saline solution at 37°C. The specimens were then strained equibiaxially to 30% at a rate of 1.5%/s.

When each test was completed, software that comes with the BioTester system was used to place a grid of points on the starting image (Fig. 1A). Points at the grid intersections were tracked from image to image, and regional strains in each of the now deformed squares of the grid calculated [3]. Tracking accuracy was estimated to be ± 0.5 pixels. The images were 1280 by 960 pixels, and there were 129 pixels/mm. Each of the deformed grid squares was then coloured based on its maximum principal stress, and an elliptical representation of its strain tensor was added using the software (Fig. 1B).

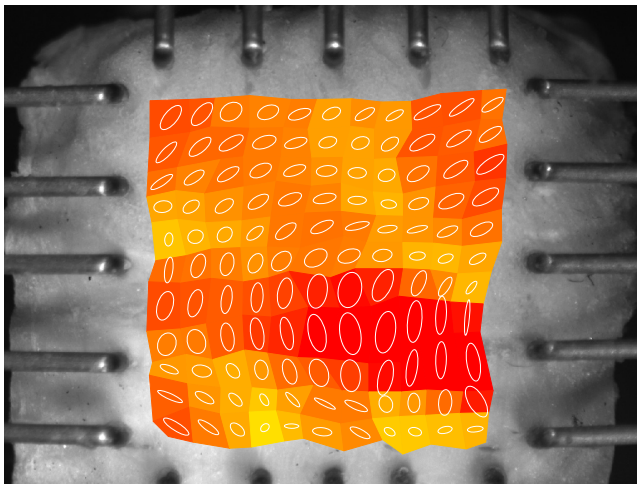
RESULTS

Figure 1 shows the initial and maximally-stretched geometries of a typical specimen. If the strain had been uniform, each square would have been identical in colour and would have contained a circle of the same diameter. In the test shown, colour varies with position and the ellipses have varying size, aspect ratio and orientation. A visual inspection showed that the strains along a band near the lower edge of the specimen are different than elsewhere. Post-test analysis revealed that a blood vessel ran through this area.

Figure 2 shows how the strain in the y-direction varies with position along the vertical midline, and that it is nominally three times as high along the center of the vessel as it is away from the vessel. Because the vessel runs essentially transverse to the y-direction, one can infer that its stiffness in the y-direction is approximately one third that of the balance of the tissue. Because the vessel area is so flexible, much of the total specimen elongation in the y-direction occurs in this area, and the y-strain in the balance of the specimen material is substantially less than it would otherwise be, as suggested by the dashed line in Fig. 2.



(A) Initial Configuration



(B) 30% equibiaxial strain

Figure 1. A typical biaxial test

Figure 3 shows stress-strain curves for the y direction for tissue in the area of the vessel (solid curve) and for tissue away from the vessel (dashed curve). Clearly the two regions exhibit quite different mechanical characteristics. If the properties of the tissue had been based on the assumption that stress and strain are uniform over the specimen, the dotted curve would have been obtained. Note that the x-dimension of the strain ellipses is nearly the same in all regions of the specimen, indicating that the x-strain was nearly uniform. Again, this can be attributed to the anomalous region being essentially parallel to one of the edges of the specimen. Stress in the x-direction, however, would not have been uniform because of x-y coupling effects, like those described by Poisson's ratio for linear materials. Tests on additional specimens having anomalies parallel to either the x- or y-axes produced comparable deformation patterns.

Tissues almost invariably contain vessels, nerves, fascia, scars or other inhomogeneities, and advanced materials models would include their effects either explicitly or implicitly. The present study suggests a way to quantify the mechanical effects of these localized structures so that they can be properly incorporated into such models.

In general, estimation of regional properties is substantially more challenging than in the present case. The mathematical inverse

problem associated with extracting regional properties from strain maps is complex and not well posed. However, as this study shows, regional strain data can be obtained provided that the anomaly is suitably oriented with respect to the test apparatus.

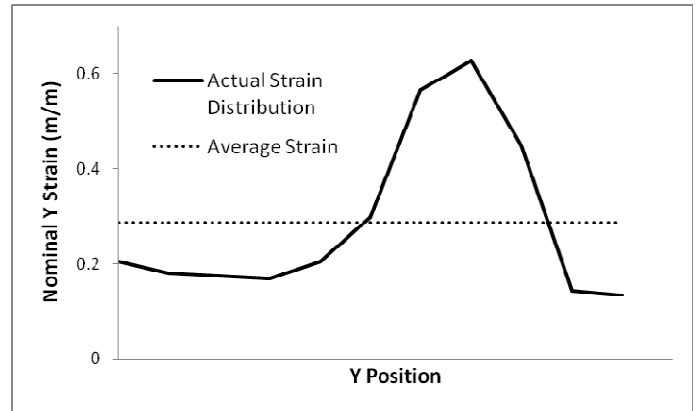


Figure 2. Strain profile

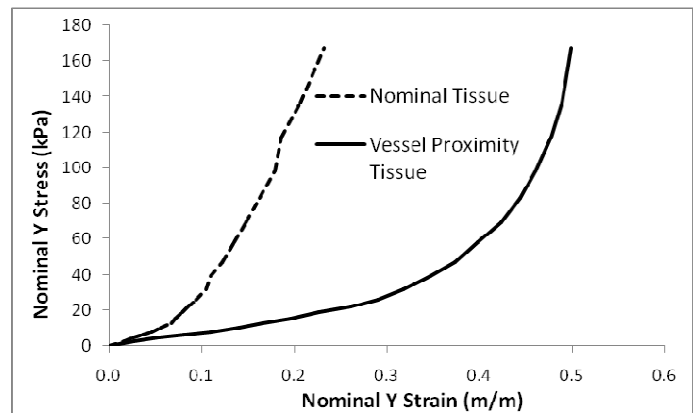


Figure 3. Stress-strain graphs

CONCLUSIONS

By tracking a grid of points on a tensile specimen, it was possible to identify regional material property variations and to quantify their mechanical effects. Material property estimates based on the assumptions of uniform stress and strain over the specimen would have yielded substantially erroneous values.

REFERENCES

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