

162 Measurement of cortical bone stiffness using an image-based ultrasonic test

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Abstract. Strain-rate dependence of bone tissue is an important mechanical property relevant to understanding injury of bone, but also for modelling of bone cutting with ultrasonic surgery tools. In this contribution we present an Image-based Ultrasonic Shaking (IBUS) test that has been carried out on a bovine femur bone to identify its elastic properties over range of strain rates (1-100 1/s) and temperatures at 20 kHz excitation.

Introduction

High-power ultrasonic surgery tools offer exciting opportunities for minimal access surgeries as their use require low force while they still provide high precision and preserve soft tissues [1]. To understand the mechanics of bone cutting, often numerical simulations are employed. Modelling requires a good definition of cutting tip motion, but also comprehensive characterisation of bone as a material over a range of strain rates and temperatures [2, 3]. In this contribution, we propose to use the image-based ultrasonic shaking (IBUS) test [4] to identify the stiffness of bone over strain rates in the range of 1-100 1/s.

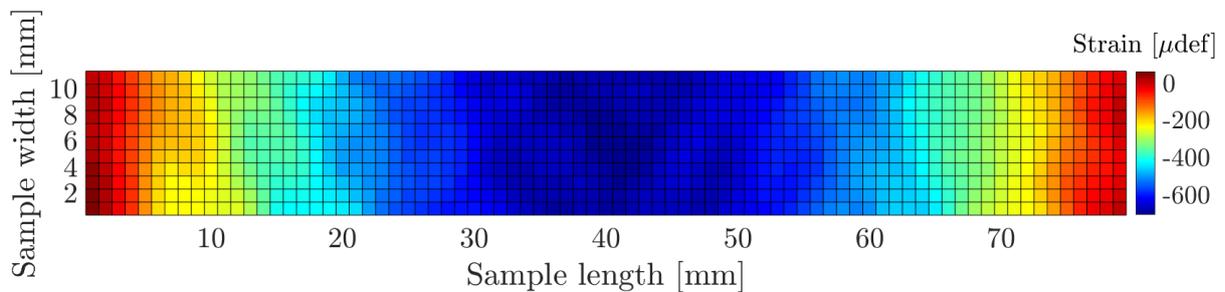


Fig. 1 Heterogeneous state of longitudinal strain across the length of specimen.

Method

The specimens considered here are flat coupons of bovine femur bone (80 x 12 x 2 mm) cut in the longitudinal-circumferential plane, with the length chosen so that the specimen is resonant at 20 kHz. In a real experiment, one of the edges is excited at 20 kHz by an ultrasonic horn leading to heterogeneous states of strain, strain rate and temperature, with the maximum values (anti-node) at the centre and the zero (node) values at the loading and free edges (Fig. 1). The surface of the specimen is printed with a grid that is imaged during the experiment with an ultra-high speed camera (Shimadzu HPV-X) at 0.5 MHz. The images are then used to calculate full-field displacements using the grid method [5]. Simultaneously, the other face of the specimen is imaged using an infrared camera to obtain temperature distribution. The displacement data is used to calculate strain, strain rate and acceleration at each measurement point, which can be used to reconstruct average stress-strain curves over each cross section using the dynamic stress equilibrium [4, 6]. Young's moduli are identified over ranges of strain-rates and temperatures by fitting the stress-strain curves at each cross section. Here, the test was first simulated in a finite element method package (Abaqus) to generate numerical displacement fields that were used to create a set of synthetic grey-level images used with the grid method to identify the stiffness and validate the technique.

Results

The reference stiffness of the specimen in the longitudinal direction was set as 20.00 GPa. The generated grey-level images [6-8] were corrupted with Gaussian noise with standard deviation of 0.5% of the full dynamic range to simulate real experimental conditions. The average Young's modulus identified over the entire length of the specimen was 20.24 GPa (error of 1.2%) giving an accurate measurement of bone stiffness (Fig. 2).

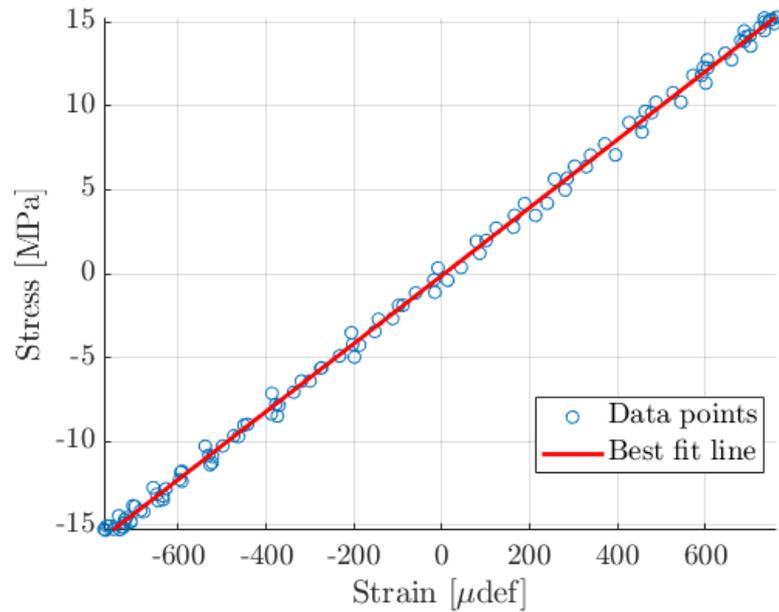


Fig. 2 *Stress-strain curve obtained from a point in the middle of the specimen.*

Discussion and conclusions

The demonstrated method gives a very good measurement of bone stiffness and can be used to obtain Young's modulus over a range of strain rates and temperatures with just a single test, due to the heterogeneity of the response. Experimental results collected from a bovine femur will be presented during the oral presentation.

References

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