MatchID
Metrology beyond colors

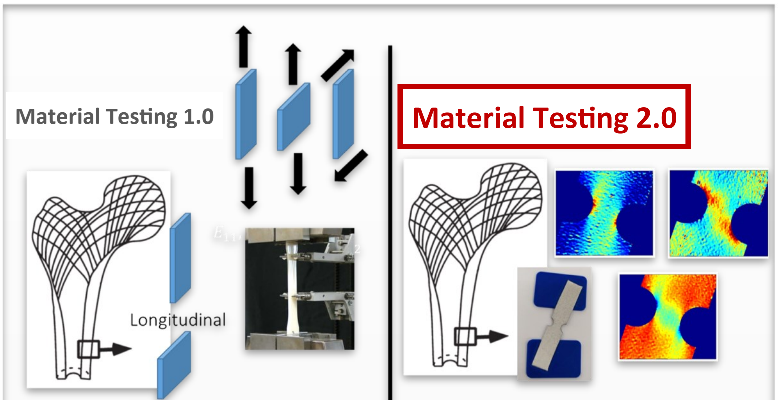
UNIVERSITY OF Southampton

Application Note

Material Testing 2.0 for human cortical bone

Case Description

This application note demonstrates how the new paradigm in mechanical testing of materials called 'Material Testing 2.0' can be applied to human bone testing*. Traditional testing methods (Material Testing 1.0) require several coupons to obtain the orthotropic stiffness components of cortical bone. This work designed an innovative test that allowed for the full set of stiffness components to be identified in a single test. It involved back-to-back 2D DIC measurements and identification with the Virtual Fields Method. Convincing results were obtained.



*PhD work by Dr Panagiota Tavianatou, supervised by Dr Lloyd Fletcher and Prof. Fabrice Pierron

Experimental Setup

- ✓ **Cameras:** FLIR Blackfly 24.5 MPix (5320 x 4600)
- ✓ **Type:** Back-to-back 2D DIC
- ✓ **Field of View:** 21.3 mm x 18.4 mm
- ✓ **Material:** Human cortical bone specimens cut from femurs and tibias of two female donors
- ✓ **Speckling:** use of PDMS stamps with 20 to 40 µm features

Analysis

- ✓ **Back-to-back strain averaging** to remove effects of bending and out-of-plane movements
- ✓ **Virtual Fields Method** with piecewise noise optimized virtual fields
- ✓ **Digital Twin using image deformation** to create individual twins for each specimen, producing individual uncertainty quantification

Results

- ✓ **Full set of orthotropic stiffness components** obtained for each specimen, tested multiple times
- ✓ **Successful results**, in line with literature values but obtained with **a single test on a single specimen**
- ✓ **Digital Twins** showed significant scatter related to the speckle patterns

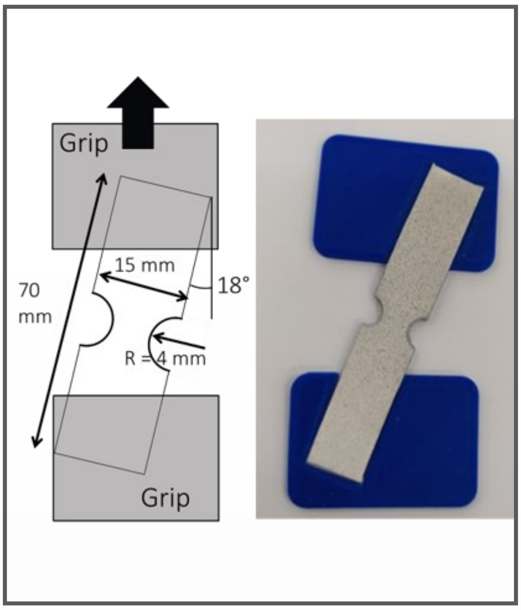
Why MatchID

- ✓ Powerful **performance analysis module** auto-determines optimized DIC settings
- ✓ **Higher-order shape functions** for more accuracy
- ✓ **Virtual Fields Method (VFM) module** relying on MT2.0, Strain 59(3) 2023.
- ✓ Digital Twin with FEDEF module for **synthetic image deformation**

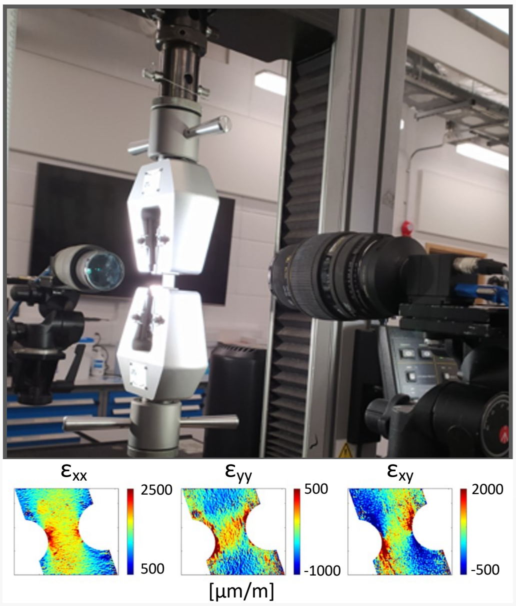
Test design

Current testing of human cortical bone relies on several uniaxial tests to obtain the full orthotropic stiffness components. Specimen preparation is time-consuming and studies on patient variability of bone properties is impaired by the fact that a lot of tissue is necessary to obtain just one set of properties.

The present study applies the concept of “Material Testing 2.0” to this problem. An innovative test specimen was designed that takes into account the geometrical constraints of cutting such a specimen from a human femur or tibia. Also, since specimens cannot be cut ‘off-axis’ because of the same constraints, it is the whole specimen which is set up off-axis in the test machine to enrich the stress state. Notches have been added to enhance stress heterogeneity further.



Experimental setup



Since the test is nominally 2D, a back-to-back camera arrangement was used. Strains are measured independently on each face and averaged between the two faces. This has the advantage of removing both the effect of out-of-plane movement and out-of-plane bending. Because the cameras have very high spatial resolution, a specific procedure to apply speckle patterns was designed. Moulds were manufactured by laser engraving and were ulteriorly used to produce PDMS stamps. They were inked and applied to the samples to produce the patterns. Difficulties in ink transfer led to local defects in the pattern which had an impact on identification (see below). This is the main feature in the procedure that needs improvement. Finally, the specimens were loaded in their linear elastic range to ensure that they could be retested several times to explore inter-test variability.

Identification, DT and results

The identification was performed using noise optimized piecewise virtual fields. It was observed that the identified stiffness components were very stable with load step apart from the very first images where the signal to noise ratio was poor. Consistent properties were found, for instance, the shear modulus (on the right) was constant over the whole set of samples. It was possible to conclude this thanks to the error bars produced by Digital Twins (DT) obtained for each specimen using image deformation with the actual speckle pattern on each side. This opens up the way for much more efficient testing of human bone for which samples are very valuable. It also allows for more accurate sampling of property heterogeneities within a femur or tibia.