Effect of Cortical Bone Material Asymmetry Using a Three-Point Bend Test Simulation

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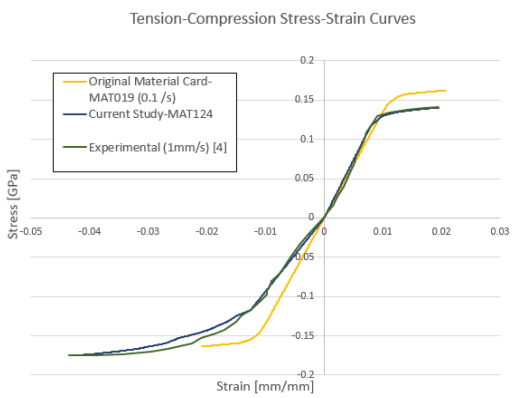
I. INTRODUCTION

An important step in applying finite element (FE) modelling for musculoskeletal injury analysis is the evaluation of response and failure of hard tissues. Cortical bone is known to be anisotropic, asymmetric and strain rate dependent [1-6]. However, the Global Human Body Models Consortium 50th percentile male (M50) femur model uses an isotropic plasticity material model (MAT019) for cortical bone [7] (Fig. 1). A previous study evaluated asymmetry and rate dependency properties for a femur FE model under three-point bending [5], but did not discuss the predicted fracture pattern, which is an important aspect of model validation and failure response. Under bending, failure initiates from tensile loading [6][8-9], leading to "butterfly" or tension wedge fractures [6][9], which are more likely to occur when for loading at the mid-span of the diaphysis [8]. The aim of this study was to apply a detailed finite element model to evaluate cortical bone fracture with a femur model using asymmetric material properties in a quasi-static three-point bending load case.

II. METHODS

An asymmetric plasticity constitutive model (MAT124, LS-Dyna R6.1.1) was investigated in this study [10] (Fig. 1). The asymmetric stress-strain data for cortical bone (1 mm/s) were digitized from experimental data [4] and verified using single element simulations (Fig. 1). Compression and tension failures were defined based on principal strain values, and element erosion was disabled when the compression principal strain was reached.



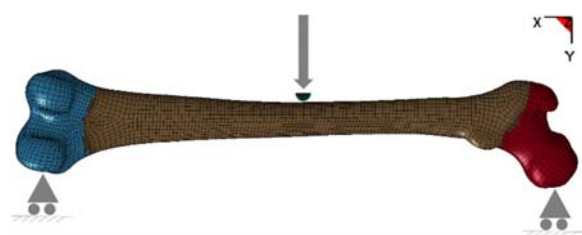


Fig. 1. Cortical bone properties [4] and constitutive models. Fig. 2. Femur Model Boundary Conditions.

A three-point lateral-to-medial bending model of the M50 femur was developed, reproducing an experiment by Kerrigan *et al.* where the ends of the bone were potted in bone cups and the point of contact of the impactor was on the centre of the mid-diaphysis of the femur [11]. The proximal and distal ends of the femur (Fig. 2) were confined in the vertical y-direction and allowed to rotate freely around the z-axis. The impactor was modelled as a deformable steel semi-cylinder with a prescribed velocity of 0.25 m/s in the lateral-medial direction of the long bone (y-axis).

III. INITIAL FINDINGS

The initiation of fracture in the femur occurred at the site of the impactor on the compression side of the femur shaft with the symmetric plasticity model (Fig. 3 (a)), but occurred on the tension side of the femur shaft with the implemented asymmetric plasticity model (Fig. 3 (b)). With the asymmetric plasticity model, the fracture propagated towards the mid-sagittal line into the compressive region, cracked along the maximum shear plane and then transversely through the bone (Fig. 3 (b)). The failure forces and displacements of the femur model using

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the plasticity and asymmetric plasticity models (Fig. 4) were in good agreement with the experimental data [11].

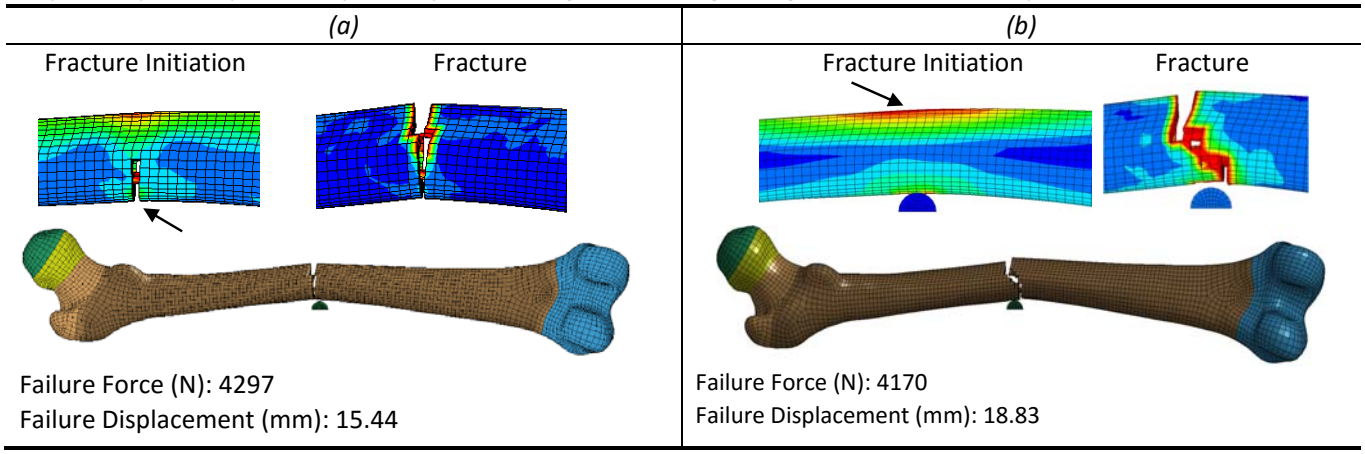

Fig. 3. First principal strain contour plots showing fracture (a) Isotropic and (b) Asymmetric Plasticity models.

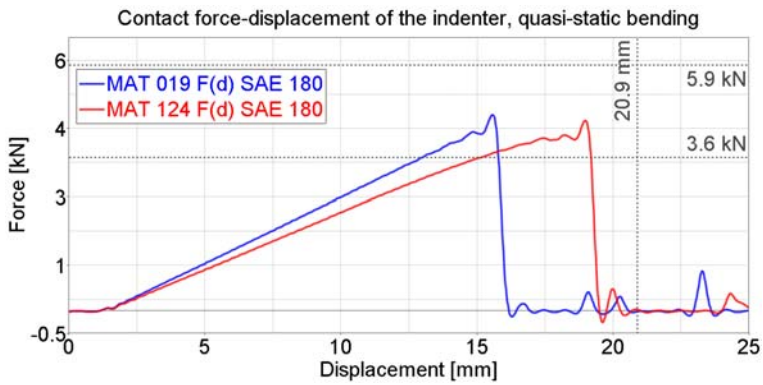

Fig. 4. Force-displacement response of both models with experimental data in dotted lines. Average experimental failure force: 4354.5N (range=3613N-5994N, n=4); failure displacement: 20.9 mm [11].

IV. DISCUSSION

For the symmetric model, fracture initiated and propagated from the location of load application. Although a small amount of compressive damage was noted at the load location for the asymmetric model, the fracture initiated on the top (tension side) of the bone and propagated transversely across the bone, as reported in the literature. In addition, an angled fracture pattern was observed for the asymmetric model as opposed to a transverse fracture pattern using the original plasticity model (Fig. 3). The angled fracture pattern was in good agreement with literature that suggests that as the fracture propagates towards the compression side, it will crack along the maximum shear plane at an angle of 45 degrees [6][9]. However, the fracture did not bifurcate and form the “butterfly” fracture pattern. It is possible that mesh refinement and anisotropy will result in the ideal fracture pattern, but this will be the focus of future studies. The three-point bending experiment that this simulation was based on was performed under a dynamic load rate. In the same study, one quasi-static bending test performed on the tibia gave a failure load of 3549N, which fell within the range of the failure loads of the other dynamic load rate bending tests of the tibia [11]. Future work will involve the inclusion of anisotropic, rate dependency properties and further mesh refinement.

V. REFERENCES

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