Characterization of Sawbones Polyurethane Foam for Finite Element Analysis

Molly Walker[1], Andrea Gonzalez[2], Nicole Mattson[2], Scott Grindy[2], Nick Vasios[2], Sean Teller[2], Xiangyi (Cheryl) Liu[1]
[1]Stryker, Mahwah, NJ, [2]Veryst Engineering, Needham Heights, MA
molly.walker@stryker.com

INTRODUCTION: Closed cell polyurethane (PU) foam, or Sawbones materials (Sawbones), is a common biomechanical alternative testing medium for human bone. When formed into anatomical models, composite bones can offer more consistent and repeatable testing conditions than human cadaveric bone and have been used as bone analogue to demonstrate the use of orthopaedic implants or instrumentation. Likewise, finite element (FE) analysis is a common biomechanical alternative to physical testing. *In silico* testing conducted with FEA models can be used to efficiently iterate implant concepts, surgical techniques, and testing parameters. In order to accurately simulate the physical testing that involve the use of PU foam, the material state and structural responses of PU foam need to be captured in the FE model. For example, during the processes of bone preparation and implant seating, the PU foam may undergo compaction and viscoplastic deformation. If the state of the PU foam and its reponse are not captured accurately beyond the current level of compaction and viscoplastic deformation, the subsequent micromotion testing simulation will be unlikely to yield results equivalent to the physical testing and, therefore, limit the validity of the micromotion simuation. A suitable material model with calibrated material parameters that captures these complex behavior is required to accurately represent PU foam in FE models. However, there is limited literature on calibrated material model for closed cell PU foam which can be used to represent the compaction and viscoplastic behavior of the material in FE models. Therefore, the objective of this work was to create a robust calibrated material model for PU foam at varying material densities which can be used to create FE models which represent the compaction and viscoplastic nature of PU foam.

METHODS: Three closed cell PU foam densities, at 15, 20, and 30 pounds per cubic foot (PCF), were subjected to a battery of tests to characterize important mechanical properties. Test coupons (n=3) for PU foam went through cyclic compression at $-0.01s^{-1}$, monotonic uniaxial compression at $-1s^{-1}$, shear at $0.01s^{-1}$ and $1s^{-1}$, and plane strain testing. Deformation and strain for shear and plane strain testing were measured through digital image correlation. Results from cyclic compression, monotonic uniaxial compression and shear testing were used to calibrate a material model using MCalibration (PolymerFEM). The PolymerFEM Three Network Viscoplastic (TNV) model was selected as the ideal material model to represent the damage accumulation, hysteresis, and nonlinearity of the material. This particular TNV model consisted of two parallel networks, one hyperfoam model with power-law flow and one hyperfoam model without a flow element. Quality of fit was measured using normalized median absolute deviation (NMAD). The material model was then validated by comparing FE model behavior against the results from plane strain testing.

RESULTS SECTION: Three TNV models were calibrated, one for each density of PU foam. The calibrated NMADs were $8.8MPa^2$ for 15 PCF, $8.2MPa^2$ for 20 PCF, and $9.7MPa^2$ for 30 PCF PU foam. Predictions contained all relevant features of the material, including compaction, yielding behavior, material stiffness, and the yield stress. Following successful calibration, the calibrated models were verified against plane strain testing results. As the friction coefficient was unknown, the simulation results were reported for two coefficient of frictions, one frictionless and one where the coefficient of friction was set to 0.1. The plane strain results fell between the two simulation results, with a NMAD of $8.7N^2$ for 15 PCF, $21N^2$ for 20 PCF and $15N^2$ for 30 PCF PU foam.

DISCUSSION: Excellent agreement was observed between calibrated results and the validation data set. This provides confidence that the material models will accurately predict material behavior when used in FE models. It is important to note that these models can only represent compressive and shear behavior of the material. Any FE simulations which require tensile properties should use this calibration with caution. Yield of the material was also accurately captured. However, yield behavior in cyclic compression was underpredicted for all foam densities. Despite these limitations, results are ideally suited to model material compaction, compression, and shear. Therefore, this work satisfies the original objective, providing a robust material model for use in FE studies with closed cell PU foams.

SIGNIFICANCE/CLINICAL RELEVANCE: (1-2 sentences): This work provides the first calibrated material model for compressive behavior of closed cell PU foam at various densities and strain rates. This material model accurately captures material compaction, yield, and viscoplasticity, making it an ideal model for use in FE models containing closed cell PU foams.

Figure 2: Plane strain experimental setup used for material model validation.
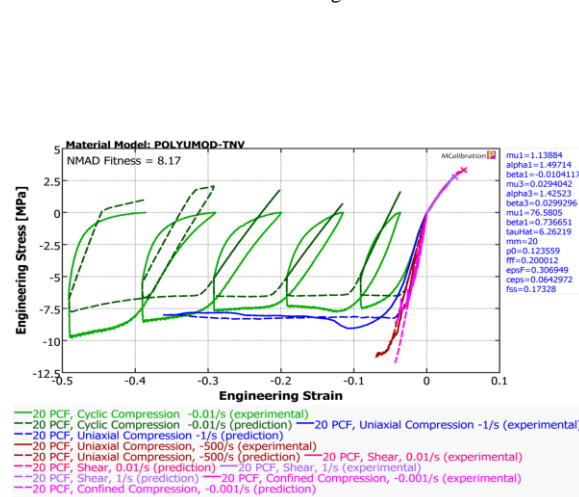

Figure 1: Experimental measurements (solid) and predictions (dashed) of engineering stress and strain in mechanical tests used to calibrate the 20 PCF material model.
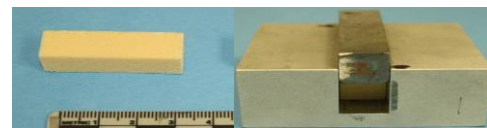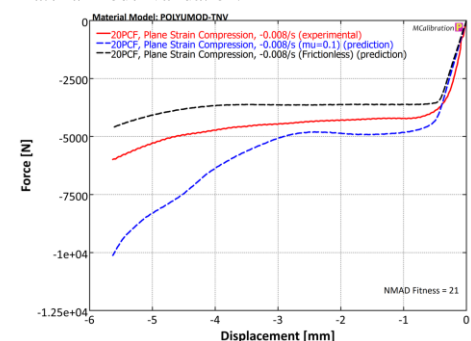

Figure 3: Validation of the material model using plane strain and two coefficients of friction.