FEA Based Slotted Tube Performance Emulators for Design Specification Development

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Introduction: Slotted tubes play an important role in the medical device industry as the mechanical backbone for various guidewire and device delivery system designs. Setting dimensional tolerances on these slot cut-patterns experimentally can be difficult due to manufacturing constraints and modeling limitations. This study explores the ability of virtual modeling to predict the functional performance of slotted tubes using a calibrated emulator in tandem with a discrepancy emulator for cut-pattern dimensional tolerancing applications.

Materials and Methods: A combination of SolidWorks®, ANSYS®, and Abaqus™ software packages were used to create 140 unique FEA models to simulate bending of a slotted tube segment. Each model contained 19 pairs of slots and had a unique set of five dimensions used to define the cut-pattern (Example in Figure 1). A modified Latin hypercube approach determined the sampling of the five-factor design space. The output of the FEA simulations, specifically the maximum equivalent plastic strain (PEEQ) and the bending stiffness, were used to create continuous response emulators in SmartUQ® software. FEA predicted PEEQ values were translated to fatigue performance (cycles to failure) using the Coffin-Manson low-cycle fatigue relationship. The emulators were calibrated via a Bayesian technique within SmartUQ® software, using data from 16 unique batches of units in fatigue and stiffness bench tests. The calibration not only tuned parameters, but also modeled the discrepancy between the prediction and bench test across the design space. To assess the accuracy of the calibrated emulators, a leave-one-batch-out cross-validation approach was utilized.

Results and Discussion: Adding the results of the calibrated prediction emulator and the discrepancy model led to highly accurate prediction emulators with a leave-one-batch-out cross-validation RMSE values of 0.179 log cycles and 0.000142 in²-lbs for the fatigue and stiffness emulators respectively. The experimental vs. prediction curves from the leave-one-batch-out cross-validation can be found in Figure 2.

Translational Impact: The FEA based, calibrated emulators coupled with the discrepancy emulators exemplified high prediction accuracy of complex miniature geometrical interactions. This makes them a powerful tool to use for slotted tube design development.

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