Abstract

Automobile crashes and blunt trauma often lead to life-threatening thoracic injuries, especially to the lung tissues. Finite element (FE) human body models are used to simulate and predict these resulting injuries. However, these models rely on an accurate estimation of the material properties to simulate crash and trauma scenarios. Moreover, the existing finite element models of lung tissue are considered as homogeneous, which may be computationally efficient but fail to capture the true dynamics of lung tissue.

To model the heterogeneous lung model, it is important to ascertain the material properties of individual lung tissue (i.e. parenchyma and bronchi). These tissues are strain rate dependent and their material properties corresponding to blunt impact loading need to be determined. The aim of this study is to develop the heterogeneous lung model with the strain rate dependent material parameters of parenchyma and bronchi.

Quasi-static and dynamic compression studies were performed on the human and porcine parenchyma tissue to determine its strain rate dependent material properties. A UMAT bilinear material model was utilized to model the strain stiffing and strain rate behaviour of the tissue. The FE model of the parenchyma sample was modelled in LS Dyna, using its average sample dimensions from the experimental tests. The bilinear material properties were then optimized by integrating the inverse FE and genetic algorithm (GA). The normalized root mean square error between the experimental and the FE load time responses were minimized. The quasi static and dynamic tensile experimental studies were performed on the porcine bronchi tissue and using the similar optimization methodology the tensile material properties were optimized. Strain and strain rate variation in both parenchyma and bronchi samples were analyzed to understand the attainment of dynamic equilibrium in the sample.

For human parenchyma, with an increase in loading rate from 1 mm/s to 5 m/s, the maximum engineering stress (for 50% strain) increases from 1.27 to 141 kPa. With the strain rate varying from 0.1 to 500 s^{-1}, the elastic modulus increases from 11.6 to 158.8 kPa, and the toe strain decreases from 0.4 to 0.31. For porcine bronchi, as test speed increases from 0.5 to 2 m/s, the maximum tensile stress increases from 1.26 to 2.39 MPa and the failure strain decreases from 0.66 to 0.54. The optimized bilinear properties of bronchi show that the elastic modulus of the bronchi tissue increases from 6.2 to 3960 MPa, and the toe strain decreases from 0.19 to 0.11.

A heterogeneous lung tissue, with both parenchyma and bronchi, was tested using the dynamic compression setup. Before testing, the heterogeneous lung sample was scanned using the micro-CT machine to generate the exact CAD model of the test sample. Later the CAD model was used to generate the corresponding FE model using HyperMesh. The optimized bilinear material properties of parenchyma and bronchi were then incorporated to the generated heterogeneous FE model. The developed heterogeneous model was then validated by the comparing the experimental and the simulated load time responses.

Finally, the full organ lung model was then simulated for the frontal and side impact loading condition. The strain and strain rate variation in the full organ lung model was analyzed, since these parameters are considered as the injury metrics in the soft tissue. The strain and strain rate variation in the heterogenous lung was compared with the homogeneous lung model (model with pure parenchyma) and identified the stress wave amplification at the vicinity close to bronchi. This enhances the probability of injury in the parenchymal tissue, which signifies the need and necessity of heterogeneous lung model during impact loads.