Contribution ID: **345** Type: **Presentazione orale**

Optimization of density distribution in protective foams for motorcycle helmets

Thursday 3 September 2026 15:00 (15 minutes)

This work investigates the application of variable-density polymeric foams for energy absorption. The study is based on the possibility, developed within a PRIN research project, of controlling the density of a porous component with high flexibility through additive manufacturing technologies: a printing head equipped with a microfluidic nozzle deposits a biphasic "ink"consisting of a polymeric agent and an emulsifier with variable composition.

The case study considered is that of a motorcycle helmet, where the main energy-absorbing layer is typically made of EPS foam with uniform density, usually in the range of 80–100 kg/m³. For homologation purposes, helmets are subjected to multiple impact tests according to the ECE 22-06 regulation, which requires the evaluation of parameters related to the acceleration experienced by the head center of mass.

The material properties were characterized through compression tests at different strain rates on specimens with uniform density. The experimental results were used to calibrate a Crushable Foam constitutive model, with volumetric hardening and strain-rate sensitivity, implemented in tabular form within the Abaqus/Explicit finite element environment. Validation tests were carried out on multilayer specimens with different densities, showing good agreement between numerical and experimental load–deformation curves.

The resulting constitutive model was then used in a numerical procedure aimed at optimizing the density distribution in the liner of a size J motorcycle helmet. The density field was described through 12 shape functions defined in spherical coordinates (radius, azimuthal angle, and polar angle), each associated with a weighting coefficient, along with a parameter representing the average density. The design space was explored using 200 sampling points generated through a Latin Hypercube approach. For each configuration, 7 different impact scenarios against a rigid surface were simulated, and three key performance indicators were evaluated: HIC (Head Injury Criterion), BrIC (Brain Injury Criterion), and MaxG.

The simulation results were used to build a surrogate model based on 21 feedforward neural networks, one for each impact and metric, each with two hidden layers of 10 neurons. The networks were trained using a 75/15/15 split into training, validation, and test sets, with L2 regularization and early stopping to prevent overfitting. The surrogate model was then coupled with genetic optimization algorithms to identify the optimal density distribution configuration. The predicted optimal solution was finally validated through finite element simulations, showing excellent agreement with the surrogate model predictions.

Primary author: SASSO, Marco (Università Politecnica delle Marche)

Co-authors: Dr SABBATINI, Carlo (Università Politecnica delle Marche); Dr ZANDRI, Giacomo (Università degli studi eCampus); Prof. ROSSI, Marco (Università Politecnica delle Marche)

Presenter: SASSO, Marco (Università Politecnica delle Marche)

Session Classification: Xtrema

Track Classification: High Strain Rates