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Enhancing Tangential Impact Protection in Helmets: A Numerical and Experimental Evaluation of the O-DAMP System with Shear Thickening Fluids

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1. Introduction

Rotational accelerations resulting from oblique impacts are widely recognized as a primary cause of traumatic brain injuries (TBI) (Bourdet, Deck, Tinard, & Willinger, 2011) in motorcyclists. Unlike linear accelerations, which are effectively mitigated by traditional energy-absorbing liners, rotational forces induce shear stresses within the brain, contributing to diffuse axonal injuries and concussions. Despite recent updates in safety standards, helmet designs still struggle to protect against such dynamic loading conditions.

To address this gap, O-DAMP was developed as an innovative anti-rotational system aimed at reducing the transmission of tangential accelerations to the head. O-DAMP is both the commercial name of the product and the name of a university spin-off based at the University of Bologna. The technology is protected by an Italian patent, currently undergoing international extension in Europe and the United States. A second patent application is currently pending. The system exploits non-Newtonian shear thickening fluids to dissipate energy and mitigate brain injury risk.

Unlike existing commercial solutions, which are typically optimized for the velocity ranges defined by regulatory tests, O-DAMP leverages non-Newtonian fluid-based dampers to adaptively dissipate energy across a wide range of impact conditions. This distinctive feature provides enhanced rotational protection even in off-normative scenarios, marking a significant advancement over current state-of-the-art systems.

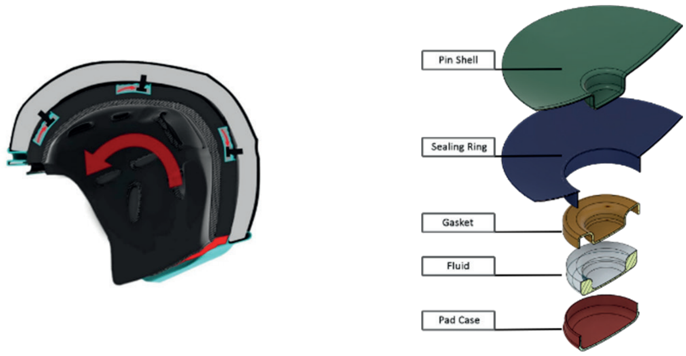

Figure 1. Operating principle of the O-DAMP system and its main components

2. Methods

The numerical campaign was carried out using the explicit solver Radioss, replicating tangential impact conditions defined by the ECE 22.06 regulation. The study followed a stepwise approach, progressively increasing model complexity while maintaining connection with previous experimental data.

Initial simulations on helmet segments, impacted at 7.5 m/s, were used to calibrate material behavior and contact interactions among internal components, the anvil, and striker. This configuration was transferred to a full-helmet model without O-DAMP and validated against experiments.

The focus then shifted to the non-Newtonian fluid in the O-DAMP system. Sub-models simulated the rheological response of single damper elements. To support

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the calibration process, a dedicated test procedure was developed to compare tangential force transmission across various fluids. Experimental force-time and displacement curves enabled matching the numerical model with physical energy dissipation.

After defining helmet and damping components, the complete O-DAMP-equipped helmet model was subjected to tangential impact simulations. Particular attention was given to the integration of damping units, their mechanical coupling with surrounding materials, and dynamic interactions during impacts. Boundary conditions and contact algorithms matched the validated experimental setup.

3. Results and Discussion

Experimental impact tests, conducted at a certified laboratory, compared the baseline helmet with prototypes equipped with O-DAMP technology. The inclusion of the system resulted in a 17.1% reduction in the Brain Injury Criterion (BrIC), a 7.9% decrease in the Peak Rotational Acceleration (PRA), and a 12.5% reduction in peak angular velocity. These values will serve as reference targets for validating the numerical simulations, allowing a direct comparison between standard and O-DAMP-equipped configurations.

Simulations without O-DAMP showed high fidelity with experimental responses, supporting the accuracy of calibration and contact definitions. The fluid sub-models reproduced expected energy dissipation mechanisms under dynamic loading.

The simulation framework enables a deeper understanding of how internal components contribute to energy absorption under oblique loading. Local deformation patterns, stress distributions, and interaction forces typically inaccessible through experiments can now be assessed with high spatial and temporal resolution.

This environment also provides a reliable platform for design analysis and parameter optimization based on validated results.

4. Conclusions

O-DAMP demonstrated clear potential in reducing rotational injury metrics in certified experimental tests, and the numerical environment successfully replicated these trends. The developed simulation protocol supports ongoing validation and future design optimization efforts.

Conflict of Interest Statement

None.

Contributor Roles

Daniel Colombo: corresponding author, experimental and numerical analysis; Nicolas Bailly: numerical Analysis; Giuseppe La Fauci: experimental Analysis; Maria Federica Parisi: material caracterization; Martino Colonna: material caracterization.

Data, software, code availability

Altair Hyperworks, Radioss.

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