

3D-Printed Energy-Absorbing Polymer Structures for Reducing Injury Risk from Overhead Impacts to Hard Hats



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Introduction & Hypothesis

- Struck-by accidents (i.e., being hit by a falling object) are a leading cause of traumatic brain injuries (TBIs) and concussions in the construction sector.¹
- Hard hats are the most common protective device for mitigating impact loads to the head, and significantly reduce the chance of both fatal and non-fatal injuries.
- While appreciable advances have been made to protective headgear in various sport settings, similar progress has not been made with hard hats (designs have not changed for decades).
- 3D-printing can be used to quickly and efficiently produce prototype designs. This technology has been to create energy-absorbing lattice structures and improved protective headgear.²
- Accordingly, we seek to:
 - Augment an existing hard hat with 3D-printed energy-absorbing structures (see below), as a proof-of-concept, that could then be efficiently and inexpensively extended to commercial designs.
 - Quantify the impact performance of the new design, as measured by the head injury criterion (HIC).

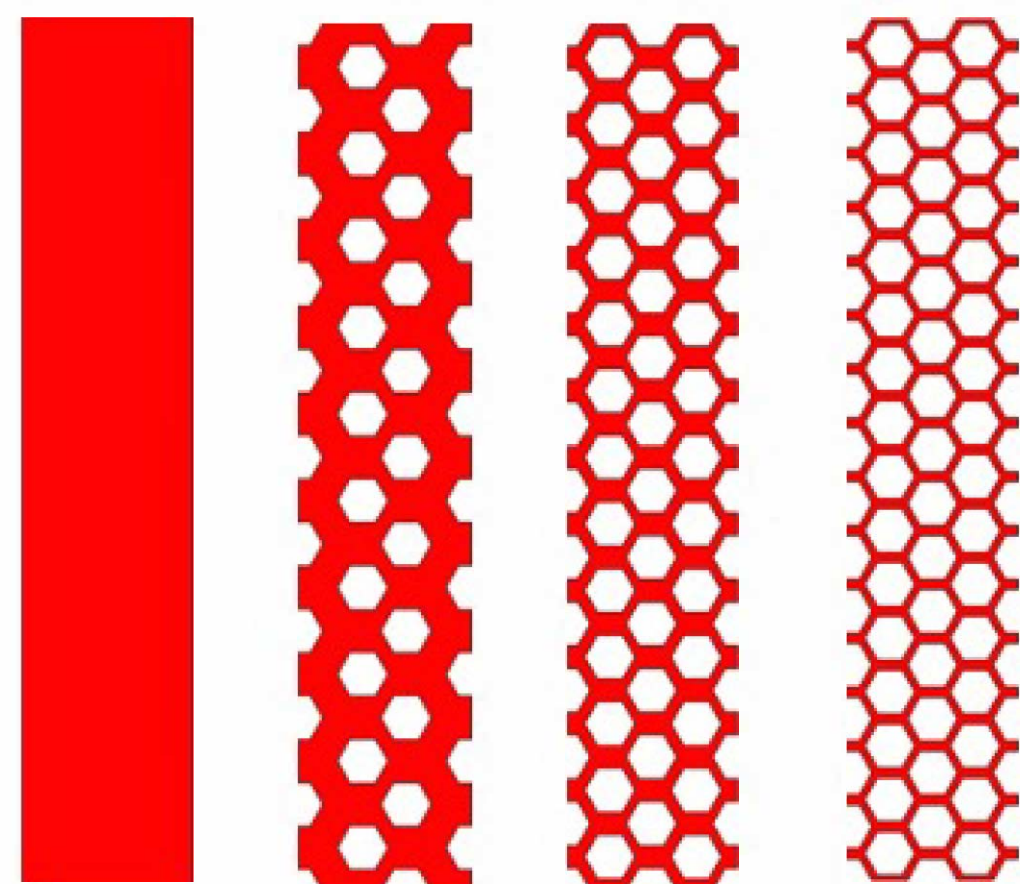


Fig 1: Porosity of inserts (from left to right): 0% (solid), 32.48%, 56.29% and 69.28%.

Hard Hat Design

- MSA V-Gard Helmets were used. The helmets are manufactured with a raised structure, and part of that structure was removed to create a compliant cantilever (Fig. 2).
- Cuboid inserts (app. 10x10x50mm) were 3D-printed using various polymers and porosities (Fig. 1) and inserted under the cantilever.
- Three types of 3D-printable material were used in this study: ABS (Acrylonitrile Butadiene Styrene), HIPS (High Impact Polystyrene), and PLA (Polylactic Acid).

Drop Tests

- A drop test was performed using a 4-lb. steel bar loaded 1.83m above the surface of impact.
- A Hybrid III head form containing accelerometers capable of measuring 6-degree orientation acceleration was outfitted with a hardhat for each test (Fig. 4). N=3 tests were conducted for each condition (i.e., combination of insert polymer material and porosity). A total of 39 tests were conducted.
- Data was collected via a SLICE MICRO data acquisition system (DTS, Seal Beach, CA), which was set to sample acceleration data at 20 kHz with 4 kHz anti-alias filtering for three linear accelerometers and three angular rate sensors (DTS 6DX PRO 2K-18K, Seal Beach, CA).



Fig. 2: MSA V-Gard helmet w/ removal and insert.



Fig. 3: Close-up of insert.



Fig. 4: Head Form model with Control Helmet³

Data Processing and Analysis

- HIC values and Maximum acceleration (a_{peak}) are common metrics used to predict injury risk.
- The data from each impact test was analyzed using a MATLAB script in order to determine HIC and a_{peak} according to the SAE J1727 standard.
- The HIC score using a 15-millisecond interval from t_1 to t_2 performed via algorithms from this code is provided in the following equation shown in Equation 1.

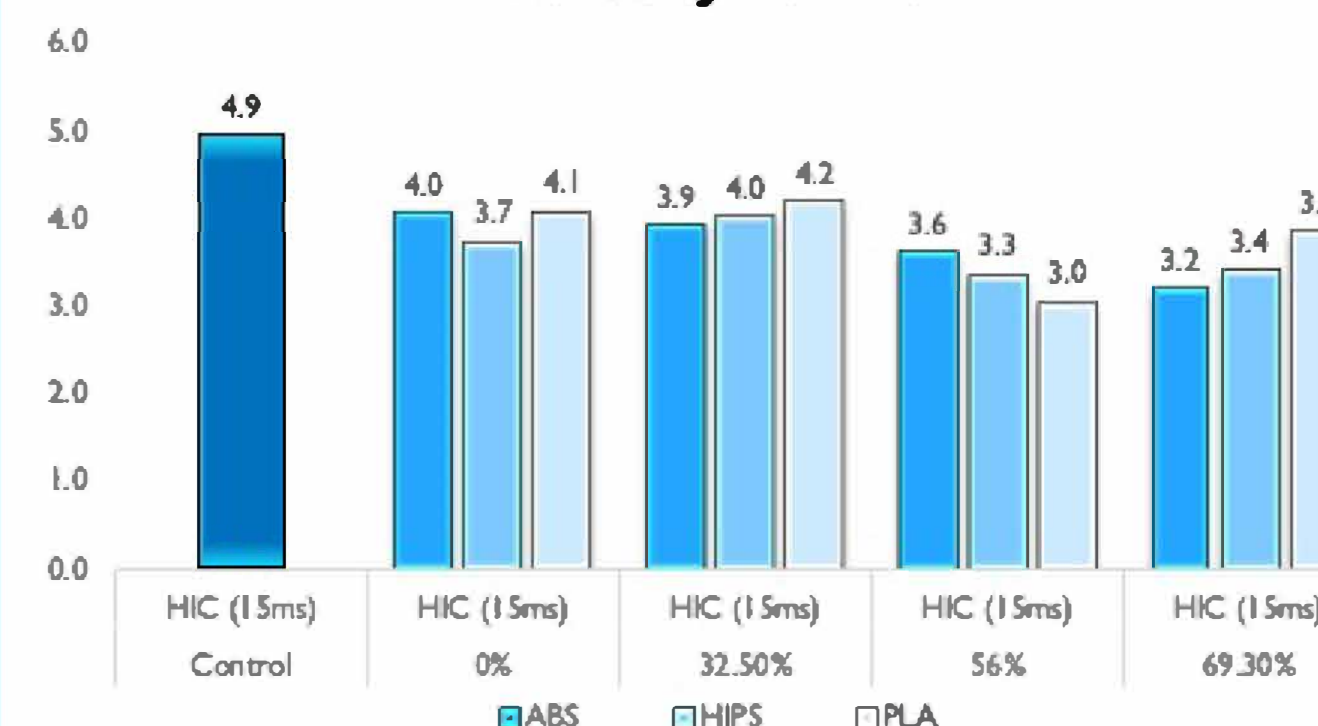
$$HIC = \max \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t) dt \right]^{2.5} (t_2 - t_1)$$

Eq. 1: Max HIC score value equation

- HIC and PLA data for each test condition were compared against results from a control (i.e., unmodified) helmet using ANOVA.

Results

Porosity vs. HIC



Porosity vs. Max. Acceleration

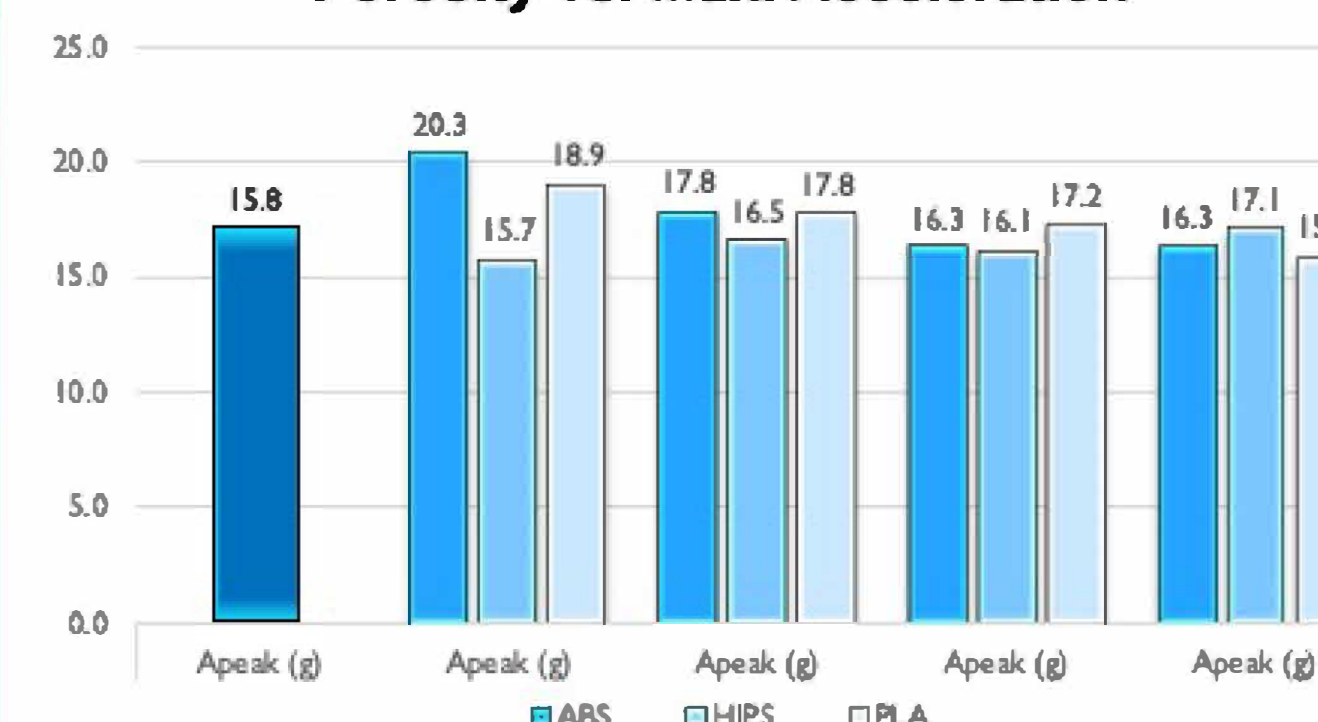


Fig. 5 – HIC and a_{peak} values for each insert type (material & porosity).

Results (Continued)

- ANOVA revealed that HIC was significantly reduced for all lattices with 56% porosity ($p < 0.023$) and for the ABS and HIPS at 69.3% porosity ($p < 0.024$) compared to the control (unmodified) hardhat (Fig. 5).
- The best performing insert (PLA/56%) reduced HIC by 38% compared to the control.
- Maximum acceleration was not significantly changed compared to the control for most inserts, although slight increases were observed for the solid (0% porosity) PLA and ABS ($p < 0.04$).

Discussion and Conclusions

- Inserts reduced HIC by reducing the magnitude of acceleration and the functional time period over which energy was transferred (Fig. 6).
- This data indicates that simple and inexpensive modifications can be made to existing hardhat designs to reduce injury risk from overhead impacts.

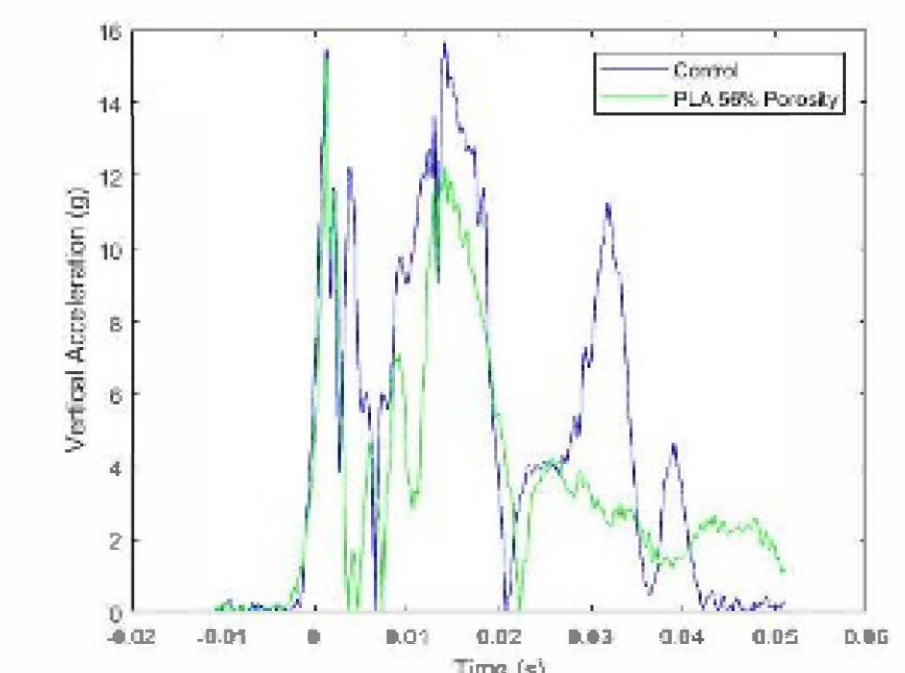


Fig. 6: Acceleration vs. time plots for representative control and insert tests. After initial impact, the insert has lower accelerations that exist for a shorter functional time period.

References

- Coronado, et al. *Trends in traumatic brain injury in the U.S. and the public health response: 1995-2009*. JSR 2012
- Jafferson, et al., *Use of 3D printing in production of personal protective equipment (PPE) - a review*, MTP 2021
- Alves Dos Santos, *Efficacy of Hard Hats in Attenuating Head Accelerations: A Combined Experimental and Computational Investigation*, UNF Thesis 2020

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