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

Andrew Miceli, Grant Bevill Ph.D., Jutima Simsiriwong Ph.D.
University of North Florida

UNF
College of Computing, Engineering and Construction

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:
  1. 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.
  2. Quantify the impact performance of the new design, as measured by the head injury criterion (HIC).

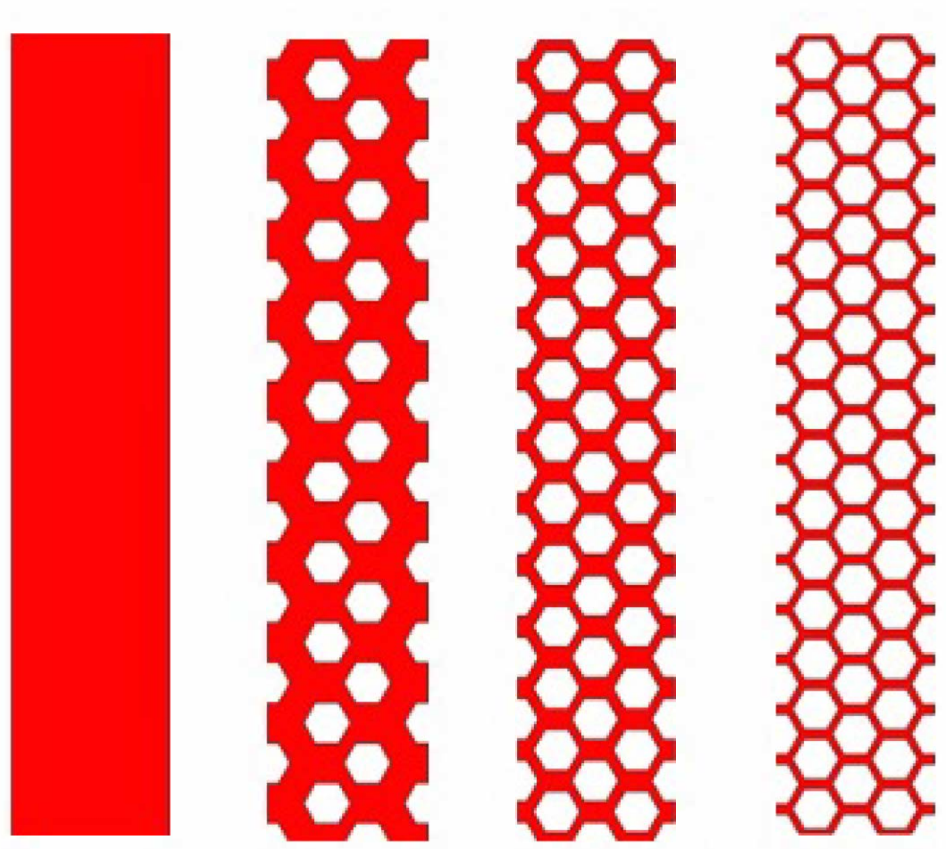

Fig 1: Porosity of inserts (from left to right): 0% (solid), 32.48%, 56.29% and 69.28%.

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.

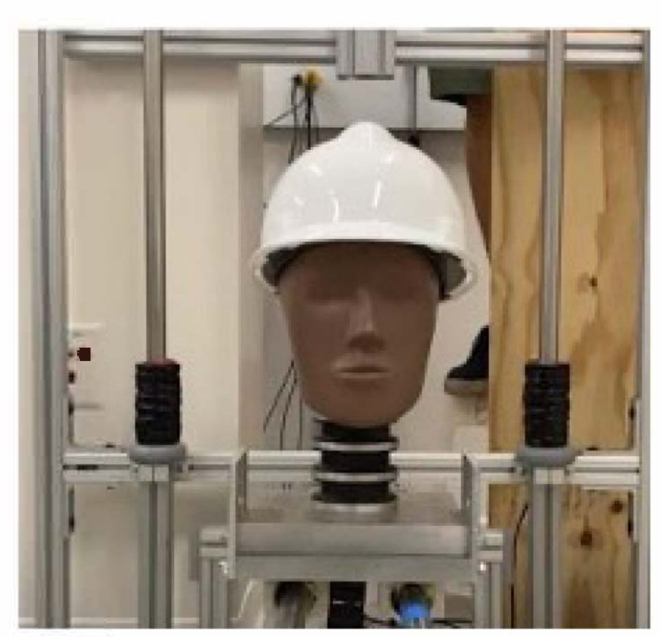

Fig. 4: Head Form model with Control Helmet[3]

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.

$$HIC = \max\left[\frac{1}{t2-t1}\int_{t1}^{t2} a(t)dt\right]^{2.5}(t2-t1)$$

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

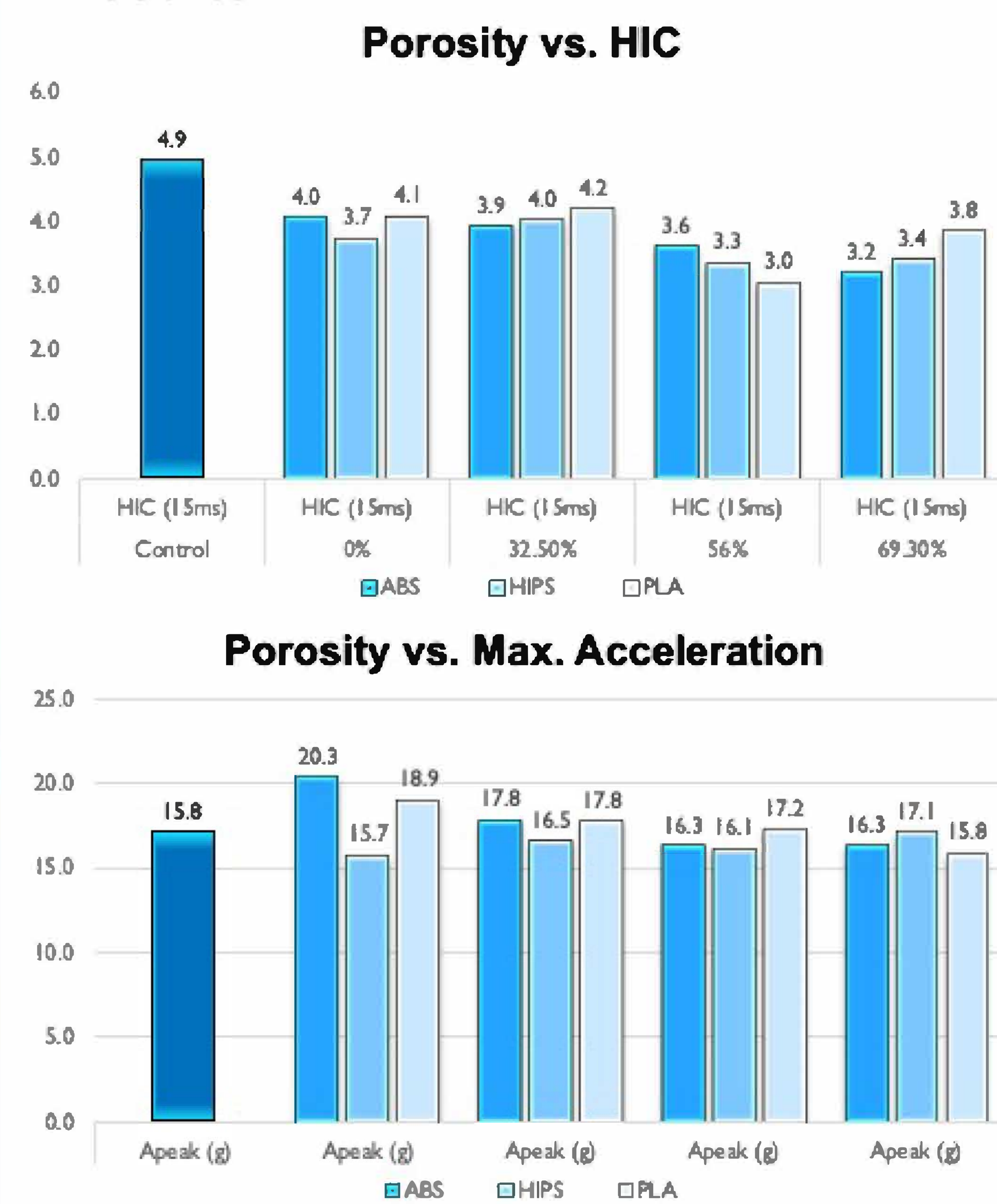

Fig. 5 – HIC and a_{peak} values for each insert type (material & porosity).

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.

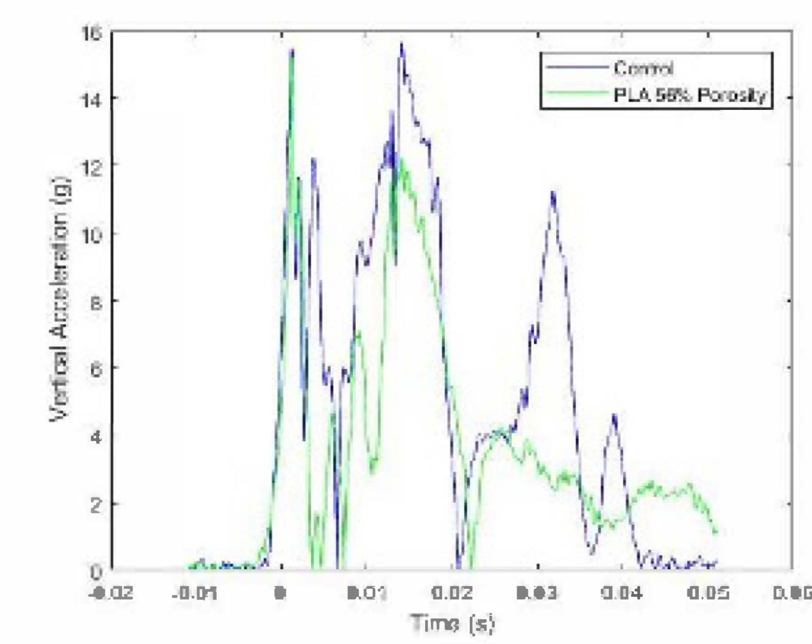

Fig. 6: Acceleration vs. time plots for representative control and insert tests. After initial impact, the insert has lower accelerations that exist for a shorter functional time period.

References

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

Acknowledgements

- UNF Foundation Board.