Development Of Advanced Foam Padding For Enhanced Concussion Prevention In Youth Football Helmets

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Abstract

Concussions are a major concern in youth football, with impacts generating linear accelerations of 70-120 g and rotational accelerations of 5,582 to 9,515 rad/s². Research indicates that concussions occur irrespective of the point of impact (Clark et al., 2017). The highest predictive occurrence of concussions has been observed at 96.1 g and 5,582 rad/s² (Brennan et al., 2016). Severe impacts, resulting in subdural hematomas, occur at approximately 316 g (Oeur et al., 2015). To mitigate these risks, this study focuses on the development and testing of various foam materials intended for safer football helmet padding.

To address the problem of concussive injuries in youth football, I developed multiple 3D printed foam materials and subjected them to rigorous testing. Various foam formulations were created, focusing on optimizing their mechanical properties for enhanced energy absorption and impact mitigation. The foam samples were then subjected to compression tests using a mechanical clamp, which applied controlled, uniform pressure to simulate the forces experienced during football impacts. A camera recorded these tests, capturing detailed deformation patterns of the foams. For the analysis of these deformation patterns, we employed MATLAB. Custom scripts were developed to process the images and calculate key mechanical parameters such as Lagrangian strain, X strain, Y strain, XY shear, and Poisson's ratio. This image analysis allowed us to precisely measure the foam's mechanical response under compression. Additionally, detailed finite element models (FEM) of the foam materials were created using COMSOL Multiphysics. These simulations replicated the experimental conditions and provided insights into the internal stress distribution and deformation mechanisms. Key performance indicators included Total Deformation, Total Reaction Force, and Strain Detection.

The simulation and experimental results showed significant variations in the mechanical properties and impact absorption capabilities of the different foam materials tested. Foams with higher energy absorption and optimal deformation characteristics demonstrated a substantial reduction in both linear and rotational accelerations, particularly the foams that have a negative Poisson's Ratio. My Hourglass Foam Prototype showed the best results with the lowest Poisson's Ratio, and lowest amount of deformation out of all foams developed for this project.

Furthermore, these advanced foams exhibited improved durability and maintained their protective properties under repeated impact conditions, suggesting their potential for long-term use in youth football helmets. The development of advanced foam padding using COMSOL Multiphysics has shown promising results in reducing the risk of concussions in youth football. The optimized foam materials significantly decrease both linear and rotational accelerations, thereby enhancing the protective capabilities of football helmets. Future research will focus on real-world testing and the integration of these foams into commercially available helmets. By doing so, we can ensure that young athletes benefit from the highest levels of safety, potentially reducing the incidence of concussions and other traumatic brain injuries in youth football.

Reference

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Figures used in the abstract

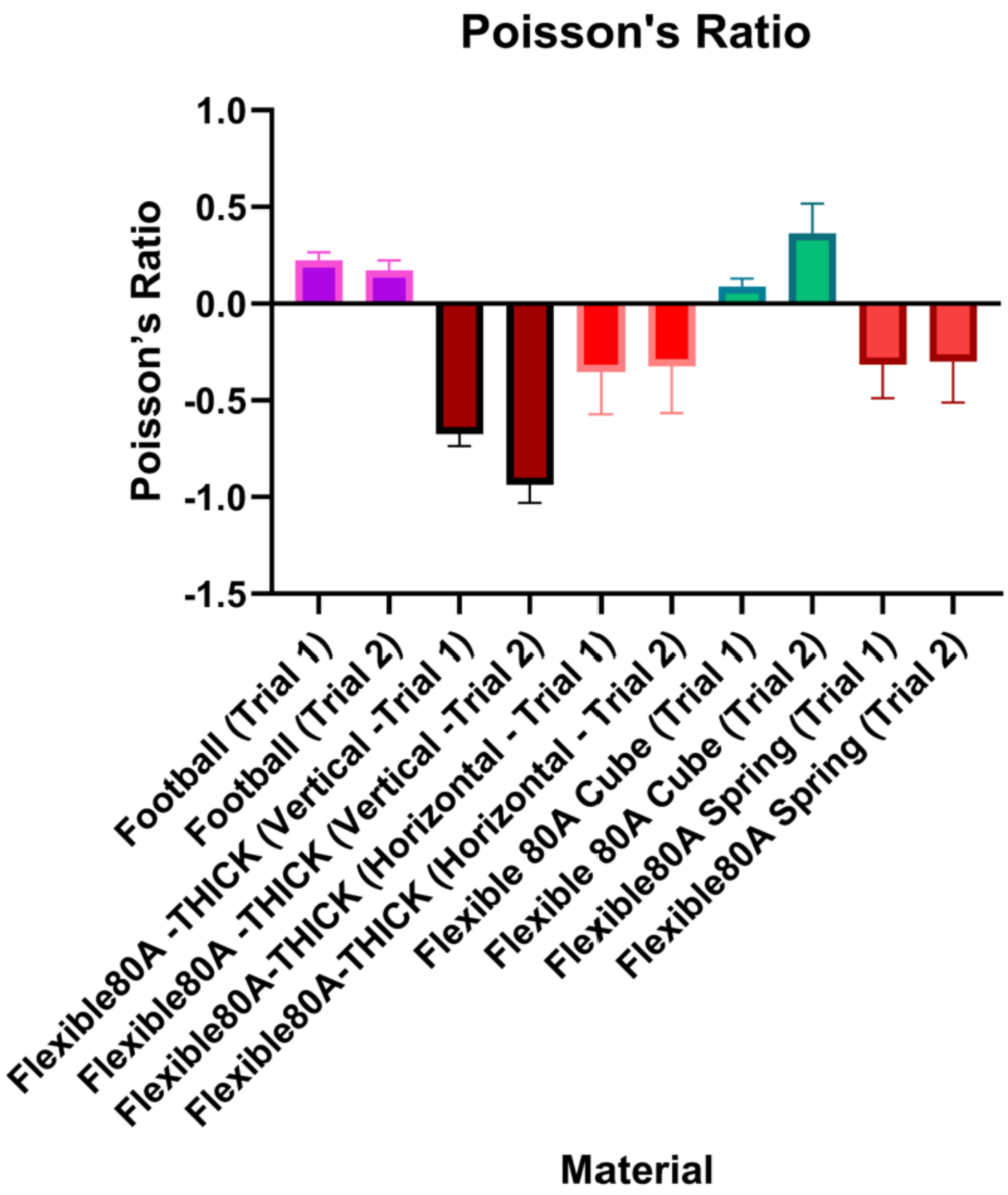

***Figure 1**: Calculated Poisson’s Ratio of all Foams tested Kruskal-Wallis One-way ANOVAs. $p<0.05$*

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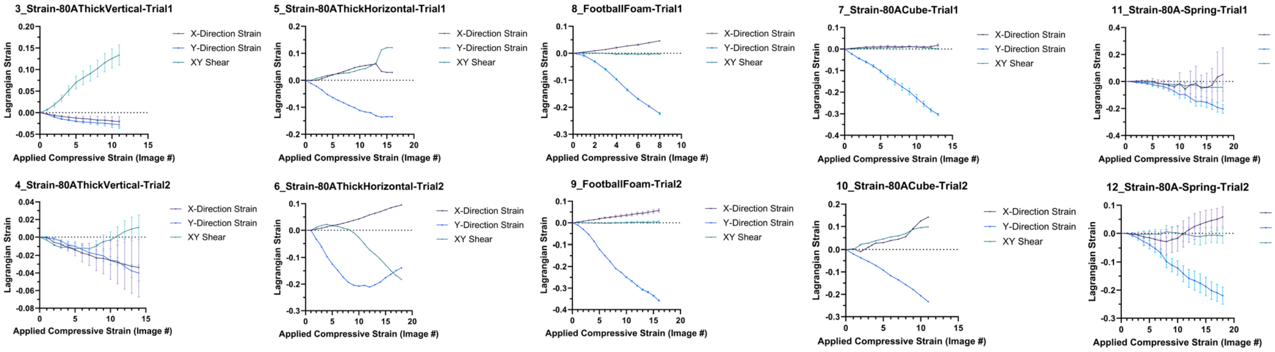

Figure 2: Strain Diagram of Flexible 80A Hourglass Foam– Vertically Oriented (3 & 4), Flexible 80A Hourglass Foam – Horizontally Oriented (5 & 6), Football Foam (8 & 9), Flexible 80A "Triclinic" Cube (7 & 10), Flexible 80A Spring (11 & 12) Kruskal-Wallis One-way ANOVAs. p<0.05

Figure 2 : Figure 2: Strain Diagram of Flexible 80A Hourglass Foam– Vertically Oriented (3 & 4), Flexible 80A Hourglass Foam – Horizontally Oriented (5 & 6), Football Foam (8 & 9), Flexible 80A "Triclinic" Cube (7 & 10), Flexible 80A Spring (11 & 12) Kruskal-Walli

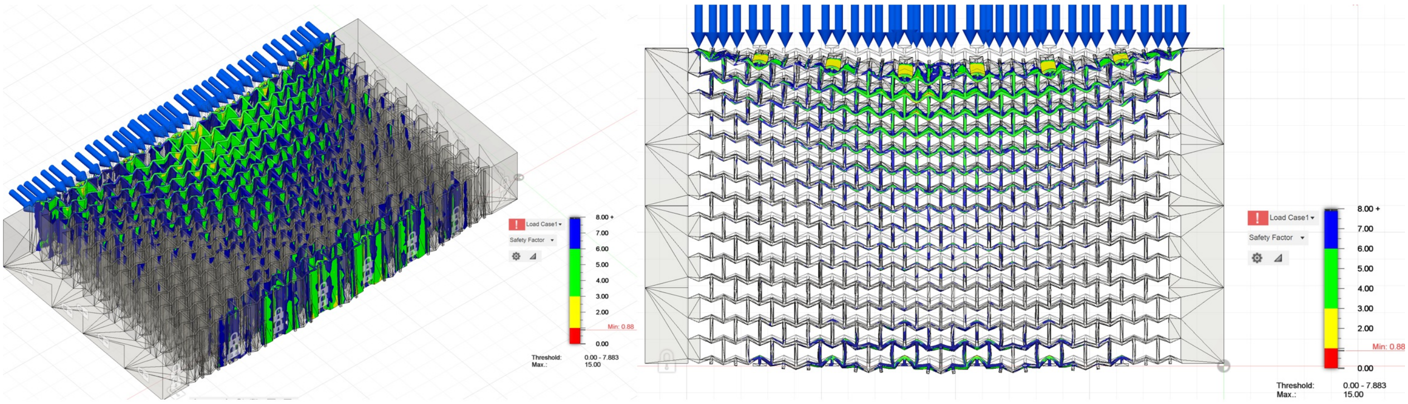

Figure 3: COMSOL Simulated Force Diagram of Flexible 80A Hourglass Foam – Horizontally Oriented. Distributed Load of 1200 N applied at 15 mm depth with the following results: Total Deformation = 1.587 mm, Total Reaction Force = 21.165 N and Little Strain Detected = 0.047

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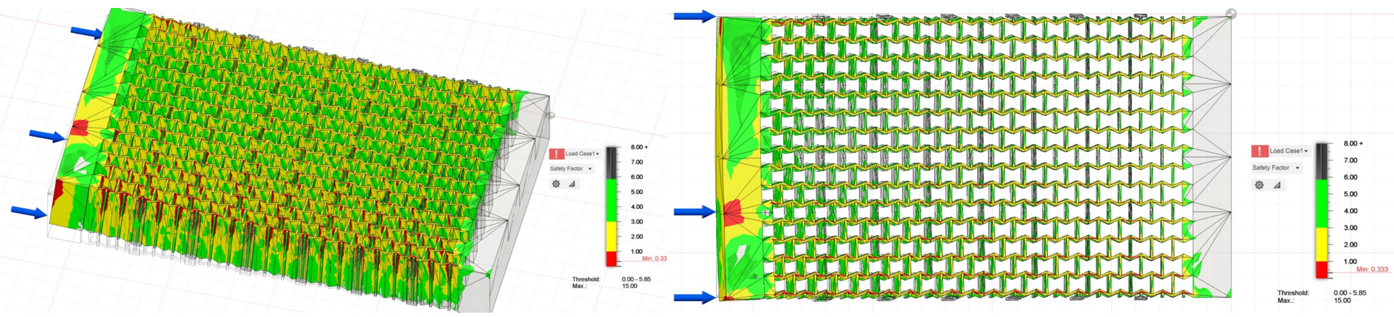

Figure 4: COMSOL Simulated Force Diagram of Flexible 80A Hourglass Foam – Vertically Oriented. Distributed Load of 1200 N at 15 mm depth applied with the following results: Total Deformation = 28.87 mm, Total Reaction Force = 436.972 N and Little Strain Detected = 0.153

Figure 4 : Figure 4: COMSOL Simulated Force Diagram of Flexible 80A Hourglass Foam – Vertically Oriented. Distributed Load of 1200 N at 15 mm depth applied with the following results: Total Deformation = 28.87 mm, Total Reaction Force = 436.972 N and Little Strain D