Is Cubic + Octet an Ideal Material Geometry for Impact Resistance?

(Technical Report)

Sports Helmet Impacts and their Relationship to Traumatic Brain Injury

(STS Research Paper)

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

The most recent safety debates surrounding football point the finger at the effect of repeated collisions on developing bodies and brains, with concerns spanning from the National Football League all the way down to youth football. A growing concern in safety has caused parents to pull their children from the sport or even vow to never let their kids play football (Bachynski, 2019). For effective impact mitigation, growing research in polymer foams has helped produce improved liners that are implemented in helmet production with the best interest of the safety of each player in mind (Fernandes et al., 2019). My research intends to address the cellular level of polymer foams to determine the best material geometry that facilitates impact mitigation for application in football helmets. To fully understand the effects of helmet safety, further research will address the relationship between helmet safety and the continuous rise of traumatic brain injuries in football.

Despite the direct link between helmet safety and concussions, it is important to identify other factors that contribute to the concussion crisis such as what playing fields are made of and rules recently erected to protect players. A rule change that has gotten a lot of attention has been the emergence of the "Targeting" rule. Targeting is a rule that was implemented that "forbids initiating contact with the crown of the helmet and targeting defenseless players in the head and neck area" (Westermann et al., 2016). Furthering my research will provide a full picture of several actors that need to be improved for the advancement of player safety.

Technical Topic

The thesis question being explored in my technical research is, is the cubic + octet the best foam structure? It is not clear that researchers have decided that a specific material geometry is best that can be implemented or combined with expanded polystyrene. Without knowing which material geometry works best with polystyrene, researchers face the issue of a lack of optimization for foam usage. The six different material geometries identified include cubic, octet, cubic + octet, quasi-random, octet truss, and isotropic truss (Berger et al., 2017). The journal article by Berger et al. (2019) is coauthored by experts within the Materials Science field and acts as the inspiration behind my research question. Cubic + octet was chosen because it is a combination of the first two geometries in order to maximize its material potential. In addition to this, cubic + octet has been characterized to inherit the maximum strain energy storage of the parent geometries, can be isotropic, and can achieve the Hashin-Shtrikman upper bound (Berger et al., 2017).

Different material geometries yield different stress-strain results making certain geometries better at absorbing impacts. To compare the elastic stiffness of these foams, they are characterized by the Young's, Shear, and Bulk modulus. To determine the optimal material properties that can be used for mitigating brain injuries, the methods for testing these polymer foams include testing them against different combinations of yield stress and crushing strain (Begley & Zok, 2013). Expanded polystyrene (EPS) is the type of foam currently used in football helmet liners due to its features of being lightweight, good thermal insulation, moisture resistance, durability, acoustic absorption, and low thermal conductivity (Chen et al., 2015). Chen et al. (2015) is a research article that gives good insight into the current structure of foams being used in helmets and how it's been performing. The shape of this foam is described as a rigid, closed-cell plastic with styrene as its cellular structure. Previous research aims to identify morphological features that are associated with high elastic performance and concludes that a combination of fundamental geometries was able to produce innovative geometries with extremal properties (Berger et al., 2017). Through testing the material geometries of polymer foams, my research intends to establish that the best material geometry to use for impact mitigation applications is the cubic + octet. I will also be using peer-reviewed articles and existing data in order to compare my testing results.

For my technical research, I have chosen to do an independent study under the guidance of Haydn N. G. Wadley. Professor Wadley works in Materials Science & Engineering at the University of Virginia and has done some collaborative work with Matthew Panzer on the use of 3D additive manufacturing for making impact-resistant head gear that appears to reduce the risk of head injury. His lab intrigued me because I saw the previous work he has done regarding polymer foams and a research interest in impact/shock mitigation. I hope to achieve a better understanding of the production of polymer foams, the testing process, and how their different structures affect how well they perform in impact mitigation along with the limitations of certain material geometries. To produce the polymer foam structures, I will be using 3D printing technology in the School of Architectures Fabrication Lab at the University of Virginia. The parameters I will be able to change include topography, density, material, and sample thickness. Once the foam structures have been produced, I will test them in the Center for Applied Biomechanics (CAB Lab) at the University of Virginia.

STS Topic

The constant presence of head injuries within the sport of football has escalated to the issue being coined the "Concussion Crisis". Concussions have been shown to be the leading cause of Chronic Traumatic Encephalopathy (CTE) which is a progressive brain condition caused by repeated blows to the head and repeated concussions (Gardner et al., 2013). According to Collelo et al. (2018), more than 100,000 concussions are reported each year throughout professional leagues such as the NFL, college football, and youth football. While this is the number reported, this doesn't account for concussions that go undiagnosed and unreported. This original article is from the Journal of Neurotrauma by several experts in the Department of Anatomy and Neurobiology and the Department of Biostatics at Virginia Commonwealth University.

The research question I intend to explore with my STS research is what is being done to improve football helmets and standards to make the game safer? And is enough being done? To study this question, I will be exploring methods being used to improve helmet safety, playing field materials, and rules that have been implemented regarding helmet-involved contact/hits to assess what's being done to make football safer. My goal is to use peer-reviewed articles, research articles, and other research-backed statistics in order to identify which area still needs improvement to ensure player safety. Methods being used to determine this include the ranking of helmets after they have been labeled as either a higher-ranked helmet or a lower-ranked helmet (Colello et al., 2018). Collelo et al. (2018) acknowledges that the difference in helmets worn by players can be attributed to the position they play, with centers showing the least variety of helmets worn. As mentioned before, the targeting rule was erected in response to the ongoing issue of concussions. According to Nfl.com (2018), over 50 rule changes have been made since 2002 to reduce the risk of injuries and other potentially dangerous tactics that players tend to do. Another emerging method being used to assess the safety of football in relation to helmets and THI is the type of surface being played on. Traumatic head injuries (THI) impact athletes at any age and the accumulation of THI can lead to lasting neurological issues. Data has shown that artificial surfaces, such as turf, produce greater potential for concussions (Drakos et al., 2013). By assessing the relationship between helmet safety and traumatic head injuries in football, it allows for the reevaluation of safety standards, equipment, and playing surfaces. The overall safety of athletes, amateur and professional, is important to ensure the progression of the sport.

The theoretical framework I will be using in my research is actor-network theory (Roger et al., 2009) to define the relationships between the many actors that make NFL player safety possible. Several actors contribute to player safety which includes the league (NFL) itself, helmet manufacturers, rules and regulations, medical professionals, and the players themselves. There are countless helmet models available and due to NFL safety standards and mandates, it allows players to choose which type of helmet they want to wear that has been approved (Colello et al., 2018). An approved helmet doesn't always mean top-rated in safety. Some players may choose a particular style of helmet because of the look and others may choose based on comfort. The power of choice has led researchers to explore the difference in wearing a new, higher-ranked helmet compared to an older, lower-ranked helmet to see the change in the white matter of the brain (Diekfuss et al., 2021). The average NFL player plays for about 3 years and within that time can accumulate multiple concussions. The effects of this down the line result in medical problems, often neurological, which fall back on the NFL and the safety of its players. This often results in attempts to hold the league legally accountable for athletes that have developed CTE (Eaton, 2020). In Eaton (2020), the legal limitations for CTE lawsuits are defined and explained a statute of limitations that I disagree with for CTE cases. Since CTE is a condition that cannot be diagnosed until death, how can one pinpoint the specific head injury that caused the condition? The piece of equipment protecting these players is their helmets and with the NFL in a concussion crisis, making helmets safer is one step in changing the statistics of concussions and how they affect the game. By addressing helmet safety, football playing surface, and rules of the game, a safer can environment to play football will be fostered from the highest level all the way down to youth football.

Conclusion

The technical research paints a strong case as to why the cubic + octet foam structure is the most effective shape of polymer foam for impact resistant head gear such as helmets. The research done will help further the evolution and optimization of American football helmets which in turn can improve safety standards. Addressing the new rules implemented to protect players allows us to recognize the benefits and the shortcomings of the new rules. Helmets only account for a fraction of the concussion crisis. By including the makeup of football fields and their contribution to the concussion crisis, it allows for a more thorough look into factors that contribute to helmet impacts. Overall, the standards implemented by the NFL should work in the best interest of player safety and that begins with addressing multiple factors contributing to the current concussion crisis.

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