CJSJ

Evaluation of Plastic Materials for Football Helmet Facemasks Using Finite Element Simulation

Kunwoo Kim

Abstract— **American football reports the highest rate of head injuries including concussion in the United States. Although the use of football helmets has protected players and reduced severe head injuries, the number of concussion incidents has not decreased. A facemask mounted on the front opening of the helmet to protect the face is the second most impacted location of concussions. However, its high-rigidity material such as carbon steel or titanium makes the facemask disadvantageous in absorbing impact. This study aimed to assess the feasibility of using a plastic facemask to absorb impact in order to prevent concussion. Four different plastics, Polycarbonate (PC), Polyetherimide (PEI), Polymethyl Methacrylate (PMMA), and Acrylonitrile Butadiene Styrene (ABS), were selected to make the facemask, and a pneumatic ram impact test was conducted using numerical simulation. A PEI facemask was deformed but withstood the ram impact while preventing the ram from hitting the face. On the other hand, ABS and PMMA facemasks were cracked and failed, and a PC facemask was not cracked but allowed the ram to hit the face. This study indicated that if the plastic material was optimized, a PEI facemask would be feasible for absorbing the severe external impact, and protect players from concussions.**

I. Introduction

American football is the most popular sport in the United States, but it has the highest head injury rate among all sports. Despite the National Football League(NFL)'s tremendous effort, the number of concussion incidents has not decreased since 2015 [1]. Football players wear helmets that consist of an outer shell, paddings, clips, a chinstrap, and a facemask (Figure 1). The structure and material of the outer shell and padding have been studied to improve impact-absorbing performance for a long time: plastic has been applied to the outer shell. The facemask which is for face protection, however, is the second most impacted location of concussion following the side of the helmet according to NFL [2]. little research has been done on facemasks for preventing head injuries. Modern facemasks are made of metal such as carbon steel or titanium. Although a metal facemask is stiff and effective to protect the face from direct contact damage, it can transfer the impact force directly to the head and increase the risk of concussion. The purpose of this study was to evaluate the feasibility of applying a plastic material to the facemask for absorbing impact and preventing concussion by investigating various plastic materials with finite element simulation.

II. METHOD

The NFL requires the test condition of the National Operation Committee on Standards for Athletic Equipment (NOCSAE) for the helmet. One of the test conditions is the pneumatic ram impact test [3,10]. The ram consists of a front plastic cap, foam, and steel rod, and weighs 15.6 kg (Figure 1). Finite element simulation, a method commonly used for impact simulation, was conducted based on this test condition. The ram was set to impact to the front of the facemask at a speed of 7.4 m/s, the threshold impact speed for a concussion in NFL [4].

The NFL provides open-source simulation data of head-neck and football helmet models [5]. The 3-dimensional facemask and ram impactor model were recreated in detail (Figure 1) from the open-source model, in which the facemask was realized as a simplified one-dimensional model. The updated facemask had a circular section of 8 mm diameter. Since actual facemasks are attached to the helmet using clips, clip areas of the facemask were fixed as the boundary condition in the simulation (Figure 1).

Four plastic materials, Polycarbonate (PC), Polyetherimide (PEI), Polymethyl methacrylate (PMMA), and Acrylonitrile butadiene styrene (ABS), were selected for the simulation. PC and ABS are currently used for the helmet outer shell due to their excellent ductility. PC has the best ductility with 110 % elongation at break. PEI is famous for ultra-performance engineering plastic and exhibits the highest strength (110 MPa) with the second-best elongation of 50 %. PMMA, also known as Acrylic, is a common plastic material has the best stiffness equivalent to PEI, and the second-highest strength (67 Mpa). The stress-strain curves of each material were acquired from CAMPUS Plastics (Figure 2) [6,7,8,9]. These stress-strain curves were entered into the simulation to realize nonlinear material behavior.

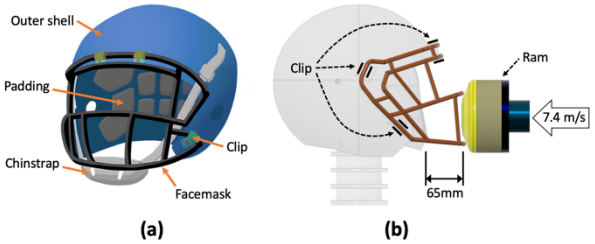

Figure 1. (a) Football helmet composition (b) Ram impact test condition and simulation model (Facemask and ram)

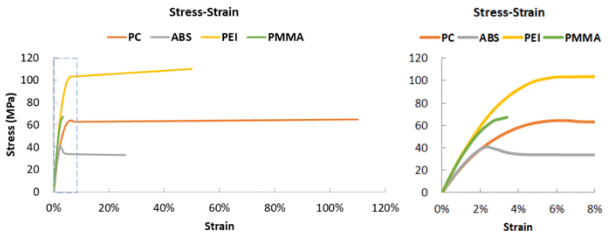

Figure 2. Stress-stain curve (Right curve: Strain from 0 to 8%) - Represent the material behavior against external force

Impact simulation was conducted with an impact event time of up to 0.025 seconds when the ram almost stopped. The contact condition between the facemask and the impactor was defined with zero friction. In the finite element simulation setting, a second-order element option was used for higher accuracy, and elements that reached the maximum tensile strain of the material during the event and were not able to resist against force set to be deactivated to realize crack propagation.

III. RESULTS AND DISCUSSION

It was required that the facemask was not broken by the ram impact and it prevented the ram from hitting the face during the event of the impact. So, the facemasks were examined for cracks until the ram slowed down sufficiently, and the ram velocity and displacement over time were measured from the simulation (Figure 4).

Figure 3 shows the deformation of the PEI facemask for up to 0.025 seconds when the ram was almost stopped (Figure 3,4). The facemask did not break and prevented the ram from touching the face. On the other hand, ABS and PMMA facemasks cracked at 0.014 and 0.002 seconds and failed to protect the face (Figure 5). The ABS facemask could not fully absorb impact energy even with a good ductility of 26 % elongation due to the lowest material strength. The PMMA facemask showed the worst result due to its brittleness of 3.4 % elongation despite its excellent stiffness. The PC facemask was not cracked like PEI facemask, but was deformed by more than 65 mm, allowing the ram to hit the face slightly due to its lower stiffness than PEI (Figure 4.5). These results in failure mode or deformation indicate that the performance of the facemask to absorb impact and protect the face was highly dependent on the material properties.

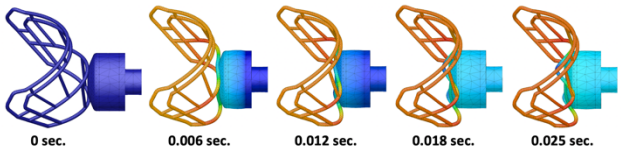

Figure 3. Deformation of PEI facemask over time

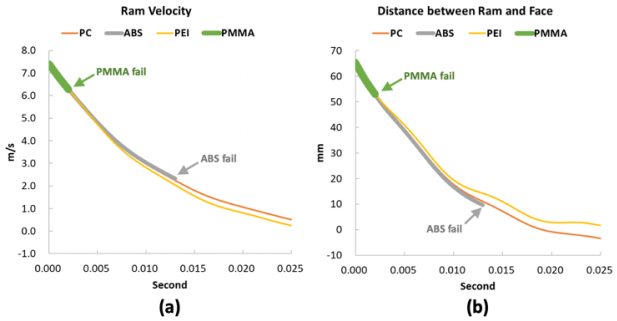

Figure 4. (a) Ram velocity (b) Distance between ram and face

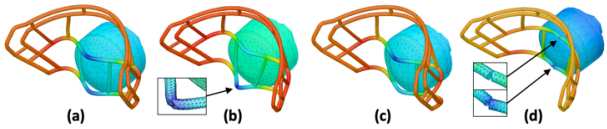

Figure 5. (a) max deformation of PC facemask (b) failure of ABS facemask (c) max deformation of PEI facemask (d) failure of PMMA facemask

IV. CONCLUSION

The facemask on a football helmet is the second most impacted position causing concussions in professional football, but the current facemasks have a metal frame structure that is too stiff to absorb the impact and gives direct impact to the head. Therefore, extensive simulations were conducted to evaluate plastic materials for the facemask to mitigate the risk of concussion. Plastic is flexible and absorbs impact better than metal, so four different plastic materials, PC, ABS, PEI, and PMMA, were validated using simulation based on the ram impact test condition of 7.4 m/s ram impact velocity, the concussion threshold speed. ABS and PMMA facemasks cracked and failed, while a PC facemask didn't fail but was too deformed to protect the face. A PEI facemask was deformed as it absorbed the impact, but it succeeded in protecting the face. This study suggested that a PEI facemask endured a harsh ram impact condition while absorbing the impact more than a metal facemask, and this indicates that a plastic facemask is feasible for an actual helmet to mitigate the concussion risk if the plastic material and frame structure design are further optimized for different ram attack angles and speeds

V. REFERENCES

[1] G. O National Football League (NFL). (2021). Injury data since 2015. https://www.nfl.com/playerhealthandsafety/health-and-wellness/injury-data/injury-data

[2] National Football League (NFL). (2018). Video review webinar. https://www.nfl.com/photos/video-review-webinar#9921dfe5-489e-4632-867e-23a6e24d2b37

[3] National Operation Committee on Standards for Athletic Equipment (NOCSAE). (2019). Standards Performance Specification For Newly Manufacture Football Helmets, NOCSAE Doc (ND)002-17m19.

[4] Pellman, E., Viano, D., Withnall, C., Shewchenko, N., Bir, C., Halstead, P. (2006). Concussion In Professional Football: Helmet Testing To Assess Impact Performance - Part II. Neurosurgery, 58, 78–96.

[5] National Football League (NFL). (2018). Finite Element Models: New Tools for Innovation in Football Helmet Design, from

https://www.nfl.com/playerhealthandsafety/equipment-and-innovation/engineering-technology/finite-element-models-new-tools-for-innovation-in-football-helmet-design
[6] CAMPUS®. 2020. Makrolon® 2405, from https://www.campusplastics.com/campus/en/datasheet/Makrolon%C2%AE+2405/Covestro/22/986598f8
[7] Dundar, M. (2017). Strain Rate Dependence And Impact Behavior Of Abs (acrylonitrile-Butadiene-Styrene) Amorphous Thermoplastic [Doctoral dissertation, Wayne State University].
[8] CAMPUS®. 2020. PLEXIGLAS® 6N, from https://www.campusplastics.com/material/pdf/133627/PLEXIGLAS6N?sLg=en
[9] GE Plastic. 2003. ULTEM PEI Resin Product Guide.
[10] Gunnarsdóttir A. (2019). Evaluation of Test Methods for Football Helmets Using Finite Element Simulations [Degree Project in Medical Engineering, KTH Royal Institute of Technology]