Design and Analysis of Bicycle Helmet Made of PETg and ABS with Honeycomb Structure Against External Impacts using Abaqus Software

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Abstract: The bicycle helmet has a significant role in reducing and preventing impact because of reducing the deceleration of the skull, spreading the area over which the forces of the impact reach them and preventing direct contact between the skull and the impacting object. Honeycomb structure, due to its elastic properties, extends the energy absorption time of the whole structure and also increases the ability of the whole structure to absorb energy. Therefore, it can be used in the liner designing of a helmet to reduce velocity, energy, and acceleration in impacts. In this paper, intending to identify the minimum stress transmitted to the helmet during an impact, we used Rhino software to model a helmet with honeycomb liner and outer shell and then analyzed it in Abaqus software. Due to the fact that the size of various parts of the head is different in people, so for more comfort and safety, the use of customized-helmet is emphasized. To design and make a customized-helmet, the materials used in designing the helmet are ABS and PETg filaments, which can be used in 3D printing. These two materials have been analyzed with four compositions for the liner and the shell of the helmet. The results show that the best combination of the helmet with Minimum stress transmission and appropriate plastic strain due to impact is the helmet case with honeycomb liner of PETg and a shell made of ABS.

Keywords: Abaqus, Honeycomb, Bicycle Helmet, Stress Analysis

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1 INTRODUCTION

Bicycle-related head in the united states(us) resulted in an estimated 81000 emergency room visits in 2011. and 77% of these patients were diagnosed with Traumatic Brain Injury (TBI). Among children and teenagers, bicycling results in more cases of TBI than any other sport or recreational activity. the number of bicycle-related TBIs have increased steadily over the past fifteen years, despite increased rates of helmet use among cyclists [1]. Traumatic Brain Injury (TBI) is one of the biggest causes of death in adults under the age of 45 and survivors of such injuries can suffer long term neurological disability which has significant public health and societal implications [2]. Among this situation, helmets are the best strategy to protect your head from Traumatic Brain Injury (TBI) [3].

Based on 3D anthropometric data, 3D heads cans were collected with a Philips-scanner at a low dosage, it is possible to create accurate 3D models of the human heads and in an experiment aimed at evaluating helmets designed in the traditional and new method, the researcher understands that the redesigning helmet shell with the new method is smaller in height than the original shell. In the traditional method, without the reference of a 3D head model, it is hard for the designer to accurately control the protection distance, and thus the designer is inclined to design a conservative space between the shell and the head. This may explain why the original shell has such an excessive height. The redesigning helmet weighs 12.8% less than the original. The centroid of the redesigned helmet shell is 10.9mm lower than the original one (z-axis direction), and the moments of inertia of the helmet shell are also obviously decreased. These results imply that stability is also improved [4].

Figure 1 presents the cross-section view of the brain strain for three impact cases. The first row is about head injuries for helmeted impacts. The second row shows the unhelmeted impact and the third row is medical imaging in medical images, the circle indicates the injury. The red areas indicate high strain levels in a first and second row. In all three cases, the area with the highest strain was in the same region for both the helmeted and unhelmeted impacts, but strain levels were reduced in helmeted impacts [5]. Put simply, bicycle helmets (and most other sorts of helmets) aim to reduce the risk of serious injury due to impacts to the head. Serious head injuries can take two forms: skull injuries and brain injuries. While simple fractures to the skull can heal, brain injuries, unlike those to other body regions do not and can lead to long-term consequences. Bicycle helmets perform three functions: 1) reducing the deceleration of the skull and hence the brain by managing the impact. This is achieved by crushing the soft material incorporated into the helmet. 2) spreading the area over which the forces of the impact reach the skull to prevent forces being concentrated on small areas of the skull. 3) preventing direct contact between the skull and the impacting object [6].

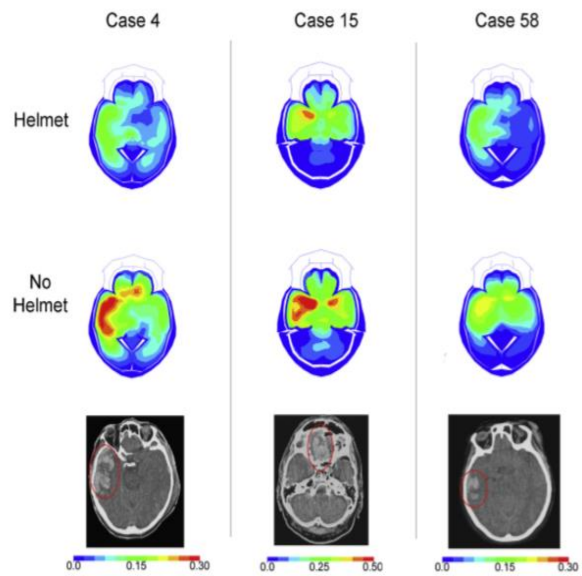


Fig. 1 Comparison of the brain against the three types of impacts (vertical columns) while the target has a helmet (first row), no helmet (second row), a medical image of the injury area [5].

In this paper, intending to identify the minimum stress transmitted to the helmet during an impact, the model of helmet was modeled with honeycomb liner and outer shell and then analyzed. The materials used in designing the helmet are ABS and PETg filaments, which can be used in 3D printing. These two materials have been analyzed with four compositions for the liner and the shell of the helmet.

2 STANDARD OF HELMETS

Standards have evolved and changed over time reflecting the state of knowledge of real crashes and how helmets have failed to provide protection. Given that most of the key requirements in standards are specified in terms of performance in tests, they do not restrict the development and use of new materials nor the skills of the designer [6].

To be sold in the United States, bicycle helmets must comply with the CPSC's Safety Standard for Bicycle Helmets [7], [2].

This bicycle helmet standard was produced by the Consumer Product Safety Commission (CPSC). The standard was developed in conjunction with ASTM and the test procedures are largely similar to the F1447 standard [2].

It has to be remembered that before the publication of the CPSC regulation in the USA, none of the standards was mandatory and it is the main difference between CPSC and ASTM, because ASTM is a voluntary bicycle helmet standard [6]. So in this paper, we also used the CPSC standard to evaluate the helmet performance against the impacts. To confirm helmet protection capability, impact tests should be performed based on helmet safety standards. Generally, these tests involve a series of controlled impacts positioning the helmet on a test head form. The helmeted head form is then dropped in guided falls onto specified test anvils. The impact site and the impact of energy must meet certain requirements for the tests to be valid. This helmeted head form model consists of a head form and helmet models [8]. "Table 1" summarizes the types of CPSC standard tests.

Table 1 Types of CPSC standard tests [9]

Tests	The purpose of the test	How to do the test
Positional Stability (Roll Off)	The standard specifies a test procedure and requirement for the retention system's effectiveness in preventing a helmet from ''rolling off'' a head.	The procedure specifies a dynamic impact load of a 4-kg (8.8-lb) weight dropped from a height of 0.6 m (2 ft) to impact a steel stop anvil. This load is applied to the edge of a helmet that is placed on a headform on a support stand. The helmet fails if it comes off the headform during the test
Retention System	The standard requires that helmets be able to meet a test of the dynamic strength of the retention system. This test ensures that the chin strap is strong enough to prevent breakage or excessive elongation of the strap that could allow a helmet to come off during an accident	The test requires the chin strap to remain intact and not to elongate more than 30 mm (1.2 in) when subjected to a ''shock load'' of a 4-kg (8.8-lb) weight falling a distance of 0.6 m (2 ft) onto a steel stop anvil. This test is performed on one helmet under ambient conditions and on three other helmets after each is subjected to one of the different hot, cold, and wet environments
Impact Attenuation	To ensure that helmets will adequately protect the head in a collision. This test involves securing the helmet on a headform and dropping the helmet. The helmet must provide protection at all points above a line on the helmet that has a specified relation to the headform.	Under the standard, the helmet is tested with three types of anvils (flat, hemispherical, and curbstone),

In this paper, the CPSC standard impact test was used to analyze the stress transmitted to the helmet. In assessing helmets under this standard, helmets on a head form are evaluated in an impact test. The total weight of the set that drops should be from 3.9 to 5 kg [9].

3 THE COMPONENTS OF THE HELMET AND ITS FEATURE

3.1. Shell

One of the main components in the helmets is the outer shell that protects the head against impact and the hanging system of the helmet ensures us about its proper installation and comfortability in use. significant improvement of the fitting comfort in a helmet is also related to its low shell weight, lower inertia moment, lower centroid position and other external shell features [4]. One of the best choices for making a comfortable helmet is custom-designing by using the 3D printing method, since the customized design of safety helmets offers improved wearing comfort and thus better protection for the wearers and it can significantly reduce weight and increase the stability of the helmet.

3.2. Helmet Liner

Impact forces cause both linear and rotational head acceleration. The crushing of the helmet liner prevents or reduces brain injuries by reducing the peak impact force FN to less than 10 kN, thereby reducing the peak head accelerations [10]. Finite-Element Analysis (FEA) was used to consider the improvement of bicycle helmet performance which shows that thicker foam liners of lower compressive yield stress can protect the head against a linear acceleration in 150 J impacts.

Using a two-foam helmet with a single-density liner has a better performance against the impact than a two-foam with dual-density liner and could cope with higher energy impact. However, these limited simulations suggest that a dual-density liner is unlikely to have significant advantages over a single-density liner and we can ignore it [10].

3.3. Honeycomb Structures

Honeycomb structures are widely used in the automotive, aerospace and marine industries [11]. This structure processes a superior energy absorption performance compared to the solid structures with the same consistent materials under the same mass level.

To create specific properties in any honeycomb structure, the desired property can be obtained by changing the hexagonal geometric parameters or other properties. For example, honeycomb construction with less elasticity can reduce acceleration compared to other structures. Hard materials used in this structure can increase acceleration and greater resistance to force. But in general, the choice of materials with high flexibility is preferable. At lower input energy levels, a flexible structure, lower material modulus and lower wall thickness are required, and when the energy input is high, it requires greater depth to avoid bottom out [12].

The example of a helmet made by this method can be named as Wavecel helmet. This helmet is consisted of a thick aluminum honeycomb liner that was elastically suspended between the outer shell and inner liner. This unique cell structure of this particular honeycomb allowed forming the liner into a spherical shape inside the helmet shell while retaining a regular cell geometry. For mitigation of liner acceleration, this honeycomb is served as a non-elastic crumple zone to absorb the normal component of the impact force that was directed perpendicular to the outer helmet shell. To reduce the risk of TBI among helmeted bicyclists, this novel bicycle helmet was developed with Angular Impact Mitigation (AIM) system capable of reducing both linear and angular head acceleration and improving brain injury criteria [1], [13]. The average impact velocity of the honeycomb structure helmet was comparable to other standard helmets. The non-elastic crumple zone of honeycomb structure helmets yielded a 24% lower rebound velocity and a 43% reduction in rebound energy compared to standard helmets. The maximum linear acceleration of the head form during impact was 14% lower with AIM helmets than with standard ones. The corresponding HIC values were 15% lower and the risk of concussion and DIA decreased by 27% and 44% respectively. These helmets also have a maximal liner compression of 67% while the maximum compression of the EPS liner in standard helmets was 31% [1]. Due to the importance of helmet weight loss in its comfort and stability as well as the effect of honeycomb structure on improving the performance of the helmet by the impact, in this article, we also used honeycomb structure to design the liner of the helmet that is covered by a thin outer shell which protects the head from direct impact or contact with outside factors.

4 IMPACT TEST OF CPSC STANDARD

4.1. Selecting of Point for Impact Test

In cyclist crashes influence of impact location and velocity are the two important factors that are effective in risks of head injury. Six locations dispersed around the helmet were selected to assess helmet performance over a range of impact scenarios. The positions are 1 mm apart. Locations were set > 120 mm apart, which the CPSC suggests that it is the sufficient distance to prevent overlap of damage profiles from previous tests [14]. In the normal impact test (linear acceleration), the helmet mass is 5 kg which is attached to the holder of the impact test device at an angle of 45 degrees to apply the impact in front of the helmet [1]. Therefore, in this article, which is based on the CPSC standard, the impact will hit the front of the helmet and the results will be recorded. ("Fig. 2")

Fig. 2 Selected point for impact test [14].

4.2. Selecting of Anvil Type for Impact Test

In the CPSC standard, the helmet is tested with three types of anvils (flat, hemispherical, and curbstone).

Impacts are specified on a flat anvil from a height of 2 meters and on hemispherical and curbstone anvils from a height of 1.2-meter. The helmet dropped on to a flat anvil at 6.2 m/s or a hemispherical or curbstone anvil at 4.8 m/s [15-18]. Among all types of anvils, depending on results obtained by researchers from comparing head acceleration under impacts against flat and curbstone anvil, we noticed that the linear acceleration and head injury for the helmeted head impacting in flat anvil is higher than the curbstone one. In the impact test, the energy-absorbing by the helmet against flat anvil is lower than the curbstone one [19]. In other researches, the researcher often used only the flat anvil, [7-8], [20] since flat impact surfaces are most common in field impacts [21]. Therefore, due to the higher linear acceleration and head injury in impact test against flat anvils than curbstone ones, and considering its importance in other researches, in this paper we have just studied the results of honeycomb helmet impact against the flat anvil.

4.3. Finite Element Simulation using Abaqus Software

Rapid advances in computer technology have enabled applied mathematicians, engineers, and scientists to make significant progress in solving previously intractable problems. The FE method contributes greatly to helmet test modeling. As such, computer simulation is an economical and time-efficient alternative to physical testing. The main advantage of the numerical test model over the physical test model is that it enables researchers to easily investigate the effect of material and geometrical factors of the helmet on head injuries. FE simulations are also indispensable to evaluate Head Injury Criteria (HIC) [8].

According to this, Kholoosia and Galehdari [22] used honeycomb structure to design 4mm thick of polypropylene helmets which were covered by an ABS plastic layer with an inner radius of 9 cm and an external radius of 13 cm. The structure was modeled through Abaqus software and according to the Japanese standard JIS T8133, flat and hemispherical anvils were considered to simulate head impact by initial velocities of 5.8 m/s and 4.8 m/s, respectively. Moreover, the oblique impact by the angle of 60 degrees was studied.

The honeycomb structure of the helmet, based on both the computer simulation and the physical impact test, in addition to meeting the required standard, affects the performance of the helmets and improves it. The computer simulation tests are an economical and time-efficient alternative while also adapting the results of the experimental and physical tests. So in this paper, we used the computer simulation and testing method with Abaqus software to obtain the results that we need.

5 MATERIAL USED

Among the materials available for use in the helmet, the researchers found that nylon material responds better to impact when integrated with ABS plastic bumpers [23]. Divakar et al [24] also conclude that by analyzing ABS plastic with a double layer of glass fiber, the double layer of glass fiber increases the ABS resistance. This paper aims to identify the minimum stresses to be applied to the helmet during the collision, to identify the best material for cycling helmet layers comprising two main body parts with honeycomb structure and integrated shell between the 3D printer filters that ABS and PETg perform with "Table 2" specifications. This has helped us to identify the best way to use this material to design a cycling helmet.

Table 2 ABS and PETg Material Specifications

Material	ABS	PETg
Density(g/cm^3)	1.12	1.25
Young's modulus(GPa)	2.1	1.4
Poisson's ratio	0.35	0.33
Yield stress(MPA)	20	15

Table 3 The helmet material components of defining helmet

D	C	B	A	
PETg	ABS	PETg	ABS	Honeycomb liner
PETg	ABS	ABS	PETg	Outer shell

For this experiment, we considered four components for the helmet cases ("Table 3"), which include the honeycomb and outer shell material. This helmet was tested with falling at a speed of 6.2 m / s from two meters' height, taking into account the gravity of the ground and the impact on the front side of helmets are defined. Customized helmets parts were modeled using Rhino software ("Fig. 3"), the helmet included 1.8mm liner thickness and 2mm outer shell thickness. The stress analysis during the impact was performed using ABAQUS software.

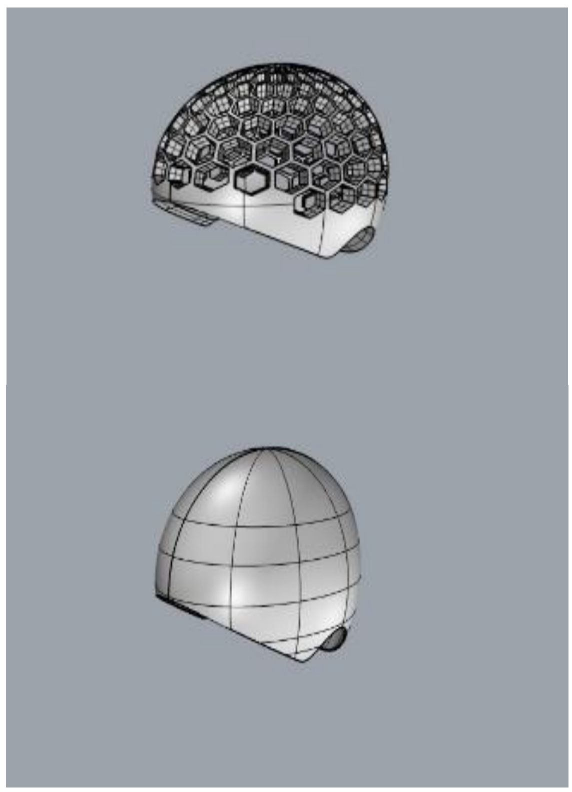


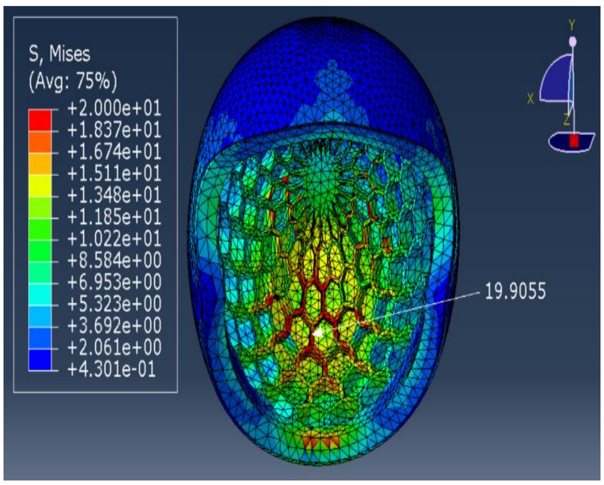
Fig. 3 Helmet designed in Rhino software.

6 RESULTS OF HONEYCOMB HELMET IMPACT TESTING BASED ON CPSC standard

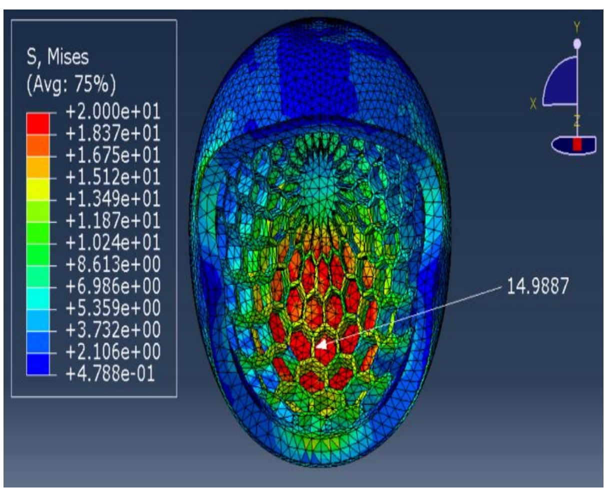
The test was performed according to the fall conditions for the amount of stress entering the cap, which is shown in “Fig. 4” and “Table 4” .

Table 4 The maximum stress transmitted to helmet liner in different cases

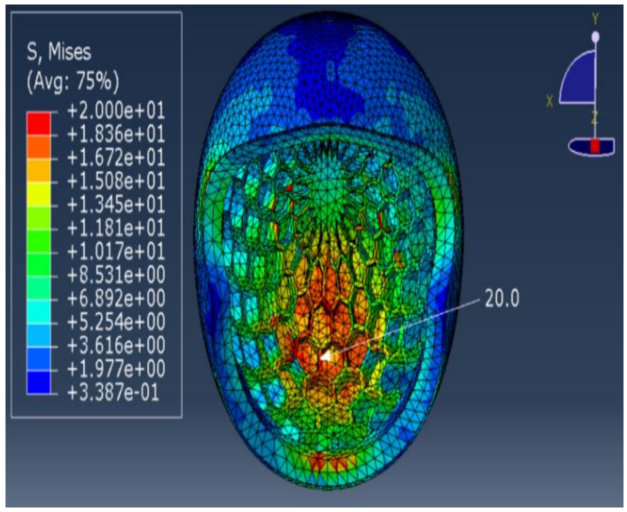
Maximum stress	cases
19.9055	A (ABS+PETg)
14.9887	B (PETg+ABS)
20.0	C (ABS+ABS)
14.9721	D (PETg+PETg)



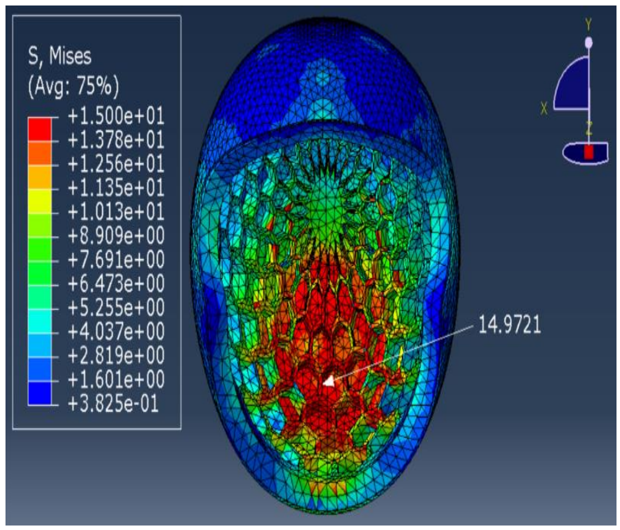
CASE A



CASE B



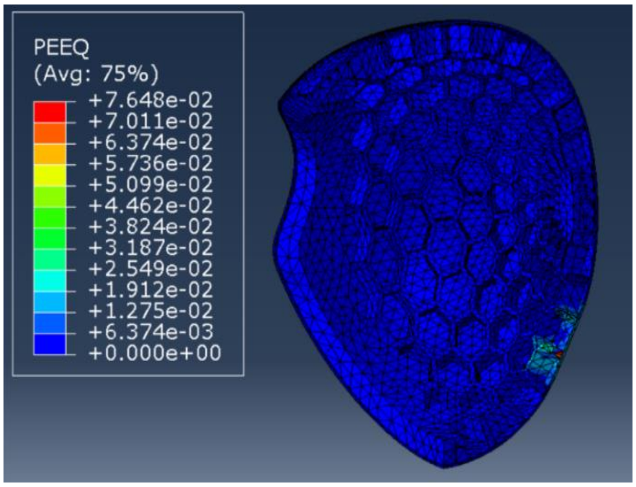
CASE C



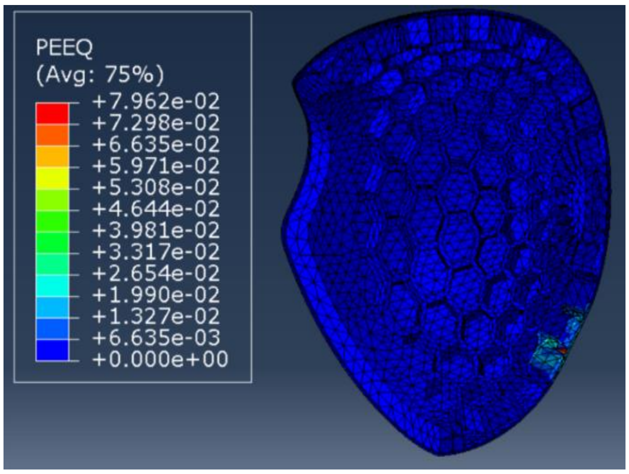
CASE D

Fig. 4 The stress applied to Inside the helmet in case: A, B, C, and D.

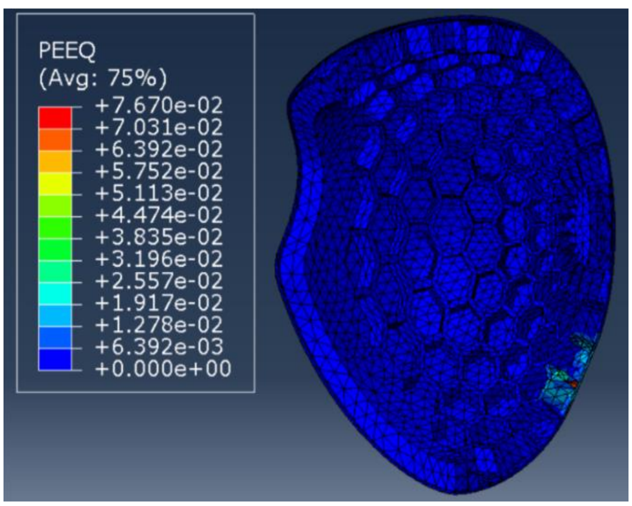
As shown in “Table 4” , the maximum stress applied to the helmet is presented in quadruple cases. The combination of PETg as the inner layer and PETg as the outer shell leads to the least amount of stress applied to the helmet. The PETg composition as the inner layer and ABS as the outer shell, ABS as the inner layer and PETg as the outer shell, and finally ABS as the inner layer and ABS as the outer shell have a higher amount of stress to the liner helmet, respectively. The results of equivalent plastic strain (PEEQ) analysis performed by using abaqus software are also presented in “Fig. 5” .



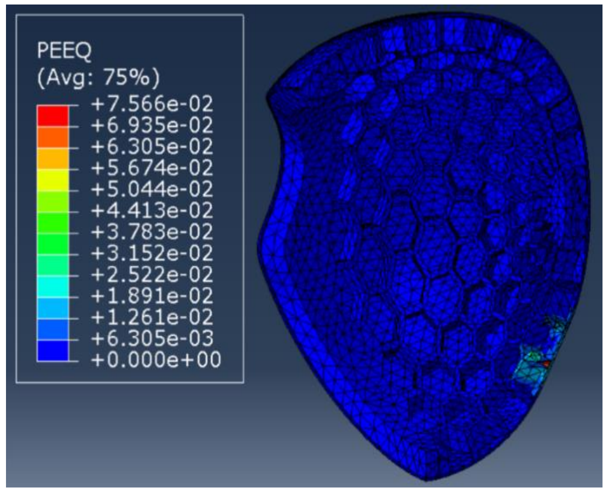
CASE A



CASE B



CASE C



CASE D

Fig. 5 For CASE A (ABS for honeycomb and PETg for the outer layer), for CASE B (PETg for honeycomb and ABS for the outer layer), for CASE C (ABS for honeycomb and ABS for the outer layer), for CASE D (PETg for honeycomb and PETg for the outer layer).

Based on the above results, it is found that the plasticity behavior that is identical in different cases has no significant difference with each other. Since the amount of stress in the helmet liner is very close in D and B cases and there is no significant difference in their plasticity strain, and due to the properties of ABS filament which has a better scratch and moisture resistance among the other filaments, it can be used as an outer shell. So we can recommend case B as the best combination of the helmet.

7 CONCLUSION

Because of the importance of helmet and its effective role in preventing brain injury and the advantage of customizing this type of helmet with 3D printing, this article aims to identify the highest impact resistance to identify the best materials for cycling helmet layers (Including two main body parts with honeycomb structure and integrated shell) between conventional 3D printer filters, which are ABS and PETg, to offer the best use of these materials in cycling helmets. In this regard, two-part helmet modeling was performed using Rhino software and the CPSC standard impact test was performed with a flat anvil on the front of the helmet with no angel. According to this issue that the optimum case occurs when the less stress is transmitted to the helmet liner as well as the less plasticity strain on the helmet.

So, the maximum stress transmitted to the helmet during impact and plasticity strain equivalent (PEEQ) were obtained in Abaqus software using the finite element method. Based on the studies and experiments and the results of comparing the reaction of the materials selected for use in the two parts of the helmet, the best case for use in the manufacture of a cycling helmet with the least amount of elasticity and stress applied to the liner due to impact is case B which is included of a PETg liner and an ABS outer shell.

REFERENCES

[1] Hansen, K., Dau, N., Feist, F., Deck, C., Willinger, R., Madey, S. M., and Bottlang, M., Angular Impact Mitigation System for Bicycle Helmets to Reduce Head Acceleration and Risk of Traumatic Brain Injury, Accident Analysis and Prevention, Vol. 59, 2013, pp. 109–117.

[2] Connor, T. A., Meng, S., and Zouzias, D., Current Standards for Sports and Automotive Helmets: A Review, European Union's Horizon 2020 Research and Innovation Program, 2016, pp. 1–42.

[3] Hoye, A., Bicycle Helmets – to Wear or Not to Wear? A Meta-Analyses of the Effects of Bicycle Helmets On Injuries, Accident Analysis and Prevention, Vol. 117, 2018, pp. 85–97.

[4] Liu, H., Li, Z., and Zheng, L., Rapid Preliminary Helmet Shell Design Based On Three-Dimensional Anthropometric Head Data, Journal of Engineering Design, Vol. 19, No. 1, 2008, pp. 45–54.

[5] Fahlstedt, M., Halldin, P., and Kleiven, S., The Protective Effect of a Helmet in Three Bicycle Accidents - A Finite Element Study, Accident Analysis and Prevention, Vol. 91, 2016, pp. 135–143.

[6] H. Dickinson, H., Towner, J.,Burkes, M., Hayes, M., Dowswell, T., and Towner, E., Bicycle Helmets - A Review of Their Effectiveness: A Critical Review of the Literature, Publication of Department for Transport: London, No. 30, 2020, pp. 96.

[7] Bland, M., McNally, C., and Rowson, S., Differences in Impact Performance of Bicycle Helmets During Oblique Impacts, Journal of Biomechanical Engineering, Vol. 140, No. 9, 2018.

[8] Teng, T. L., Liang, C. C., and Nguyen, V. H., Development and Validation of the Finite Element Model of Helmet Impact Test, Proceedings of the Institution of Mechanical Engineers Part L Journal of Materials Design and Applications, Vol. 227, No. 1, 2012, pp. 82–88.

[9] 16 CFR Part 1203, Safety Standard for Bicycle Helmets, Consumer Product Safety Commission, Vol. 63, No. 46, 1998, pp. 11711–11747.

[10] Mills, N. J., Gilchrist, A., Bicycle Helmet Design, Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications, Vol. 220, No. 4, 2006, pp. 167–180.

[11] Qi, D., Lu, Q., He, C., Li, Y., Wu, W., and Xiao, D., Impact Energy Absorption of Functionally Graded Chiral Honeycomb Structures, Extreme Mechanics Letters, Vol. 32, 2019.

[12] Caccese, V., Ferguson, J. R., and Edgecomb, M. A., Optimal Design of Honeycomb Material Used to Mitigate the Head Impact, Composite Structures, Vol. 100, 2013, pp. 404–412.

[13] Bliven, E., Rouhier, A., Tsai, S., Willinger, R., Bourdet, N., Deck, C, M., Madey, S. M., and Bottlang, M., Evaluation of a Novel Bicycle Helmet Concept in Oblique Impact Testing, Accident Analysis and Prevention, Vol. 124, 2019, pp. 58–65.

[14] Bland, M. L., McNally, C., Zuby, D. S., Mueller, B. C., and Rowson, S., Development of the STAR Evaluation System for Assessing Bicycle Helmet Protective Performance, Annals of Biomedical Engineering, Vol. 48, No. 1,2020, pp. 47–57.

[15] Bourdet. N., Deck, C., Carreira, R. P., Willinger, R., Head Impact Conditions in The Case of Cyclist Falls, Proceedings of the Institution of Mechanical Engineers, Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology, Vol. 226, 2012, pp. 282-289.

[16] Ching, R. P., Thompson, D. C., Thompson, R. S., Thomas, D. J., Chilcott, W. C., and Rivara, F. P., Damage to Bicycle Helmets Involved with Crashes, Accident Analysis and Prevention, Vol. 29, 1997, pp. 555–562.

[17] McIntosh, A. S., Dowdell, B., and Svensson, N., Pedal Cycle Helmet Effectiveness: A Field Study of Pedal Cycle Accidents, Accident Analysis and Prevention, Vol. 30, 1998, pp. 161–168.

[18] Williams, M., The Protective Performance of Bicyclists 'Helmets in Accidents, Accident Analysis and Prevention, Vol. 23, 1991, pp. 119–131.

[19] Milne, G., Deck, C., Carreira, R. P., Allinne, Q., and Willinger, R., Development and Validation of a Bicycle Helmet: Assessment of Head Injury Risk Under Standard Impact Conditions, Computer Methods in Biomechanics and Biomedical Engineering, Vol. 15, 2012, pp. 309–310.

[20] Mills, N. J., Gilchrist, A., Oblique Impact Testing of Bicycle Helmets, International Journal of Impact Engineering, Vol. 35, No. 9, 2008, pp. 1075–1086.

[21] DeMarco, A. L., Chimich, D. D., Bonin, S. J., and Siegmund, G. P., Impact Performance of Certified Bicycle Helmets Below, On and Above the Test Line, Annals of Biomedical Engineering, Vol. 48, No. 1, 2020, pp. 58–67.

[22] Kholoosi, F., Galehdari, S. A., Design and Analysis of a Helmet Equipped with Graded Honeycomb Structure under Impact of Flat and Hemi-Spherical Anvils, Procedia Engineering, Vol. 173, 2017, pp. 1299–1306.

[23] Anil Kumar, K., Babu Suresh, Y., Design and Analysis of Industrial Helmet, International Journal of Computational Engineering Research, Vol. 3, No. 12, 2013, pp. 48–58.

[24] Divakar, H., Nagaraja. R., Puttaswamaiah, S. and Guruprasad, H. L., Mechanical Characterization of Thermoplastic ABS /Glass Fibre Reinforced Polymer Matrix Composites, International Journal of Engineering Research and, Vol. V4, No. 05, 2015.