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Biomechanical Simulation Human Head Helmet for Reducing Traumatic Brain Injury

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ABSTRACT

In human beings, head is one of the most important parts. Injuries in this part can cause serious damages to overall health. In some cases, they can be fatal. The present paper analyses the deformations of a helmet mounted on a human head, using finite element method. It studies the amount of von Mises pressure and stress caused by a vertical blow from above on the skull. The extant paper aims at developing new methods for improving the design and achieving more energy absorption by applying more appropriate models. In this study, a thermoplastic damper is applied and modelled in order to reduce the amount of energy transferred to the skull and to minimize the damages inflicted on human head.
KEYWORDS: Head Helmet, Simulation, Finite Element Analysis, Biomechanics

1. INTRODUCTION

Head is the most critical area of the body and most of the injuries in that area can lead to long-term disabilities or even death. A research revealed that about one million Americans experience traumatic brain injury (TBI) each year.
Vehicular accidents, violence, falling down, sports injuries and industrial accidents may lead to TBI [1]. HIC is the most common and most widely used measure for predicting head injury. The formulas 1, 2 and 3 are utilized to obtain the amount of HIC. So far, researchers have conducted many studies regarding human head injuries caused by blows to the head and therefore observed the fractures appeared on the skull. Clinical observations indicated that 80% of patients suffer from concussion which is usually accompanied by slight fracture on the skull surface. It can also be caused by a linear acceleration applied to the head [2]

$\Delta V_{HIC} = \int_{t_1}^{t_2} a dt$ (1)
$\Delta T_{HIC} = (t_2 - t_1)$ (2)
$HIC = (\Delta HICV)^{2.5}/(\Delta T\ HIC)^{1.5}$ (3)

Thousands of people can be saved from other damages, disabilities and even death by minimizing head injuries. The behaviour of materials simulated by finite elements method (FEM) is achieved by conducting experiments. The device that is designed to reduce the amount of damages done to head should be compatible with head and the places affected by the blow (force). A helmet is a device designed for performing this act. Helmets and other dampers alike not only protect the skull from injuries, but considering their structure, they can also damp the impact forces transferred through them. The first extensive use of hard helmets corresponded to hoover dam project [3].
It should be mentioned that all helmets and other safeguards are solely in charge of a small part of the protecting job. Their diversity happens because parameters such as protective characteristics, ergonomics and weight are considered in the design. The designers require different methods to be able to estimate the damping capability of the helmet. Finite elements method is an appropriate model for anticipating the amount of damages caused by the impact. Therefore, it could be a proper method in designing these helmets (dampers).
This study models the hard tissue of the skull and suggests a model for the helmet used in this study[4, 5, and 6].

2. Modeling

Figure 1 displays a 3D view of a human skull. In order to achieve this model, CT images of human skull were brought into the solid works environment and after some modifications became ready to inter the Abaqus software.

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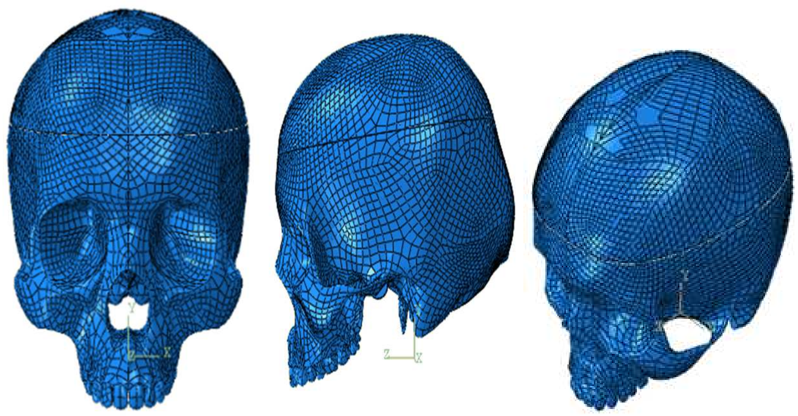
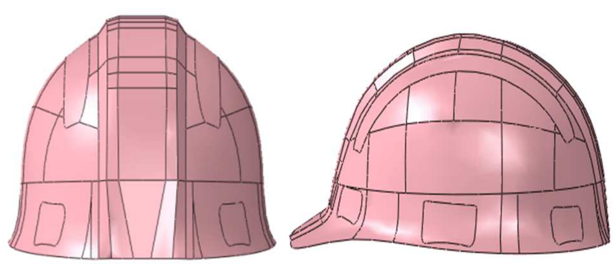


Figure 1. Finite element model images (FEA) of human skulls

Here is a model of human skull perfectly designed using Solid Elements (3D deformable) model. It is meshed volumetrically in Abaqus software version 6.13. The modelled skull has a homogeneous structure and consists of 134874 linear tetrahedral elements and 32803 nodes.The remaining components of finite elements model are related to an industrial hard helmet (mineral helmet)[4]. This model can be meshed and organized using solid works software and being prepared in order to be used in Abaqus software as shown in Figure 2.In Abaqus software this helmet is modelled by applying shell elements. Helmets' shell is modelled using 11163 linear triangular elements and 5671 nodes.



(b): Image Side b): Image Side

Figure 2. Image of the front side of the helmet

Another part of this simulation is a 2kg cylinder which is modelled using discrete rigid – 3D model With 546 nodes and 533 elements that are meshed using linear quadrilateral elements.

4. Methodology

The model used in this paper is a 3D model of human head. In this simulation, only the properties of hard tissues of head (the skull) are taken into account. The Skull is considered to be elastic, isotropic, homogeneous and deformable. Considering these features, the mechanical properties of the skull, are displayed in Table 1 [6].

Table 1. Material properties of the human head [7]

	Material Type	P(kg m^{-3})	E(M Pa)	V	K (MPa)
Scalp	Elastic	1130	16.7	0.42	N/A
Skull	Elastic	2100	6000	0.21	N/A
Brain	Viscoelastic	1140	0.675	N/A	5.625

Where: V = Poisson's ratio; K = Bulk Modulus; E = Young Modulus; ρ = Density

Hard helmet is modeled in Abaqus by applying shell elements. The helmet is homogeneous and isotropic and is modeled using 3D - deformable shell elements. The corresponding mechanical properties are listed in Table 2.

Table 2. Helmet properties [8]

	Material Type	ρ (kg m-3)	E (M Pa)	V	σY (M Pa)	ƐF (m m-1)
Helmet Shell	Piecewise Linear Plastic	1210	3000	0.3	68	0.8

The helmets' shell is considered to have been made from Ultem. ATX100 which is a thermoplastic material. The Data collected from experiments and the corresponding properties for Ultem can be found in sabic webpage [9].

5. Boundary conditions

The jaw is considered to be fixed at the lower part of the skull and has no individual translational or rotational movements in the x- y- z plane. This assumption simplifies the complications in the analysis, because in the case of impact, the skull will not experience any kind of bending forces. Figure 3 indicates that the cylinder hit the central point of upper hemisphere of the Helmet (damper) vertically from the above. It is quite clear that that the x and y components of velocity vector equal zero. The z component of cylinder velocity is increased from 5 up to 20 m/s in different stages of simulation. The information corresponding to the data collected in this model is represented in Table 3.

6. RESULTS

The computer used for simulating this model consisted of these parts: VGA: NVIDA GEFORCE 740M, 6GB of RAM(DDR3), and Intel core i7-3527U-2.0 GH processors. The simulating process lasted approximately between 12 to 14 hours. As with the impact, a 2kg steel cylinder hit the helmet from the above and various impact velocities are examined in periods of 1 to 5ms.The impact velocity increases to the point in which the damages done to the head passes the head injury criteria. Based on HIC tables, serious injury and fractures on the skull surface occurs only when the HIC factor goes further than 1000. Figure 3 indicates the cylinder-helmet collision from different perspectives [10].

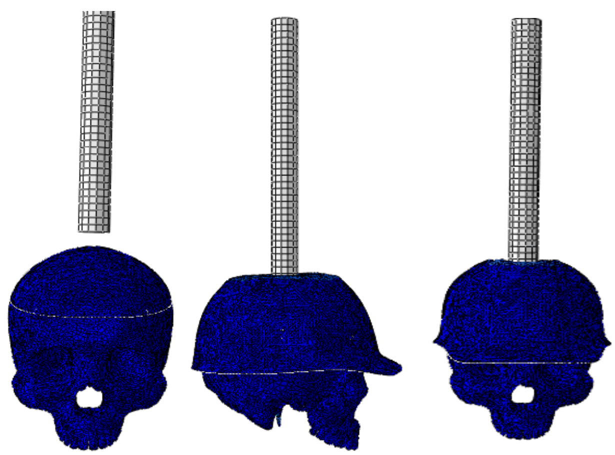


Figure 3. Indication of cylinder-helmet collision from different perspectives

Table 3. The results of the impact of a 2kg cylinder to a helmet from the above in a 3ms period

V_1(m/s)	σ_{VM}(Mpa)	U_s(J)	HIC score	Max HIC
5	150.3	92	21	182
7.5	180.76	226	66	216
10	233.5	365	164	290
12.5	295.45	566	358	437
15	354.1	834	594	614
17	405.4	1050	826	826
19	470.22	1307	1080	1080

Where:V_1=Impact Velocity; σ_{VM}(Mpa) = Skull Von Mises stress; U_s(J) = Skull Strain Energy

Note: Inthe simulation, the catastrophic fractures of the helmet cannot be seen.

The results of this simulation reveal that the impact of a 2kg cylinder with an approximate velocity of 10 m/s will probably cause a minor injury to the head. They also displays that in 15-18 m/s impact velocities will lead to severe damages to the head along with fractures on the skull. In these cases the HIC factor rises up to 1000 or more.

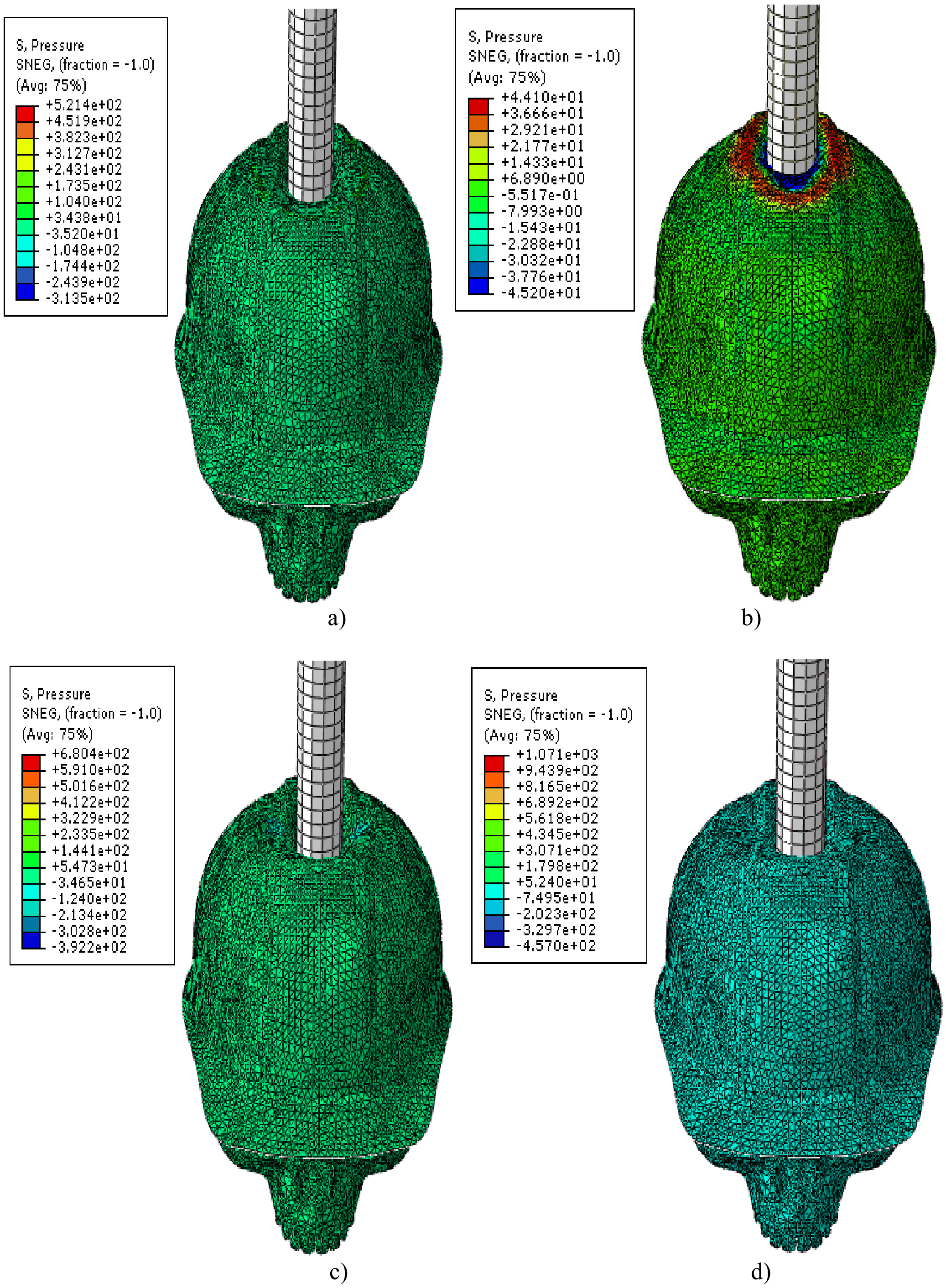


Figure 4. The pressure distribution on the front side of a helmet caused by the impact of a 2kg object with initial speed of 5m/s [a :(2ms); b :(3ms); c :(4ms); d :(5ms)]

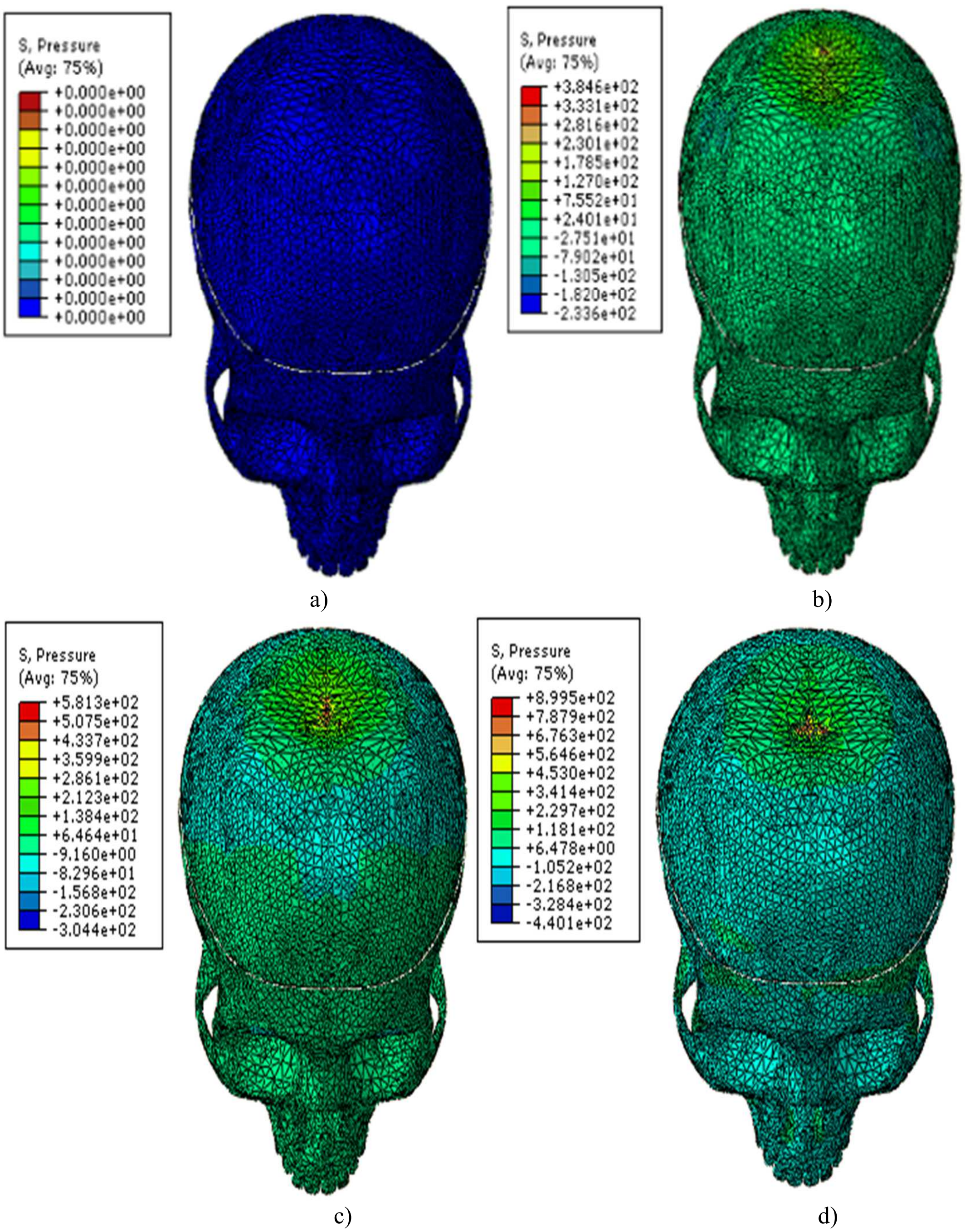


Figure 5. The pressure distribution on the skull caused by the impact of a 2kg object with initial speed of 5m/s [a :(2ms); b :(3ms); c :(4ms); d :(5ms)]

7. CONCLUSION

The ULP model developed by Willinger confirms the model suggested in the present study [11,12,13].In this study a human head along with an industrial helmet are simulated in details in order to display the behavior of a thermoplastic material.

Simulation using software such as Abaqus enables us to explore different materials and assess their impacts on the development of TBI scenarios.

Taking into account the fact that the damping shell of the helmet is made of thermoplastic materials, increasing its thickness (and taking into account the weight factors) leads to increase in the overall efficiency and damping capabilities of the helmet. Adding a foam layer to the inner wall of the helmet has the same effect and reduces the amount of damages and forces transferred to the skull.
The present paper studied the impact of such improvements in reducing the amount of head injuries. Therefore, future studies are better to be focused on more optimized and accurate designs so that they achieve better results in different TBI scenarios.

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