International Journal of Advanced Science and Technology
Vol.93 (2016), pp.15-24
http://dx.doi.org/10.14257/ijast.2016.93.02

Design and Finite Element Analysis of Helmeted Head Form in Impact

Suddapalli Praneeth Babu*[1] and Dr. Chandana Srinivas[2]

[1]Mechanical Engineering, R.V.R&J.C College of Engineering
[2]Associate Professor, Mechanical Engineering, R.V.R&J.C College of Engineering
[1]praneethsuddapalli92@gmail.com, [2]srinivaschandana2010@gmail.com

Abstract

This paper is intended to perform finite element analysis by and study the severity of the injury with and without helmet and the impact absorbing polystyrene with different shear modulus. The Impact absorption tests (drop tests) at three different points on head form were performed. The work also compares the deformations, velocities of the head form, accelerations that are obtained during the drop test according on the head form with and without the helmet and protective padding (liner) of different mechanical properties. The work also shows the necessity of different materials with energy absorbing.

Keywords*: Helmet, liner, head form Drop test, impact, Catia, Explicit Dynamics*

Nomenclature:

K.E: Kinetic Energy

EPS: Expanded Polystyrene

EOS: Equations of state

HF: Head form

PLA: Peak Linear Acceleration measured in ‘g’

GFRP: Glass Fibre Reinforced Plastic

PS2: Polystyrene, 2MPA shear modulus

PS3: Polystyrene 3MPA shear modulus

PS5: Polystyrene 5MPA shear modulus

PU: Polyurethane

1. Introduction

Motorcyclists are subjected to accidents more than other motorists. Head is a sensitive part in the human body and is very vulnerable to injury, often with severe ramifications. It is particularly prone to acceleration/deceleration and rotational forces as it is freely movable in three dimensions and is relatively in unstable position, supported only on neck muscles and ligaments [1]. Road accidents are one of the major causes of fatalities in the world. Unlike the other vehicle users having seatbelts and airbags as protective equipment, the effective countermeasures to prevent head injuries in bicycle and motorcycle crashes is the use of protective helmet. The fatalities in the motorcycle crash were high for the non-helmeted when compared to the helmeted. In the early 1900s, with the advent of the motorcycle, the need of a crash helmet arises. Primarily, the helmet

ISSN: 2005-4238 IJAST

purpose is meant to be understood as head protection against skull fractures, and modern helmets are usually efficient in this sense [2]. Another main purpose of motorcycle helmets is the prevention of brain injury caused by the accelerations caused by the relative movement of the brain in the cerebral fluid.

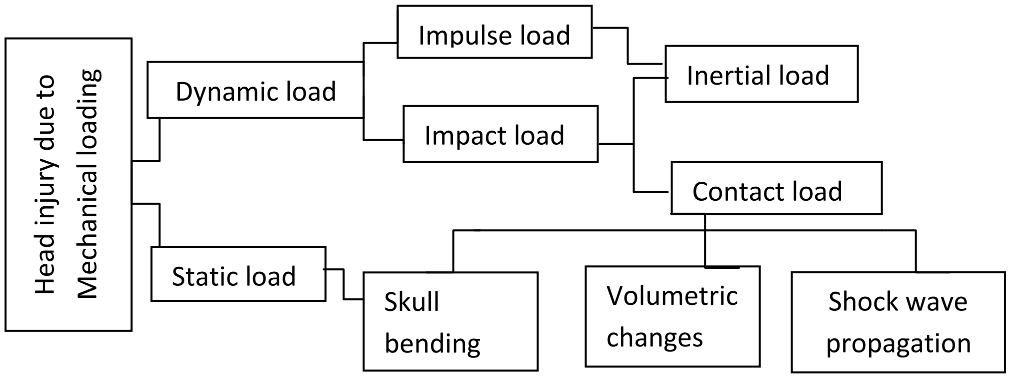


Figure 1. Types of Load Act on Head Subjected to Collision

Thus, the purpose of protective helmets is to prevent head injury by decreasing the amount of impact energy that reaches the head, reducing the severity or probability of injury. They protect the head in case of accident by absorbing the impact and cushion the head to extend the time of impact.

The following are the components of the helmet and their functions

Shell: Protects head from by the dispersing energy

Protective padding: absorbs dispersed energy and reduce accelerations by undergoing crushing and increasing impact time.

Comfort padding: this layer provides comfort in all environmental conditions.

Fastened retention system: this secures the helmet to stick on the head.

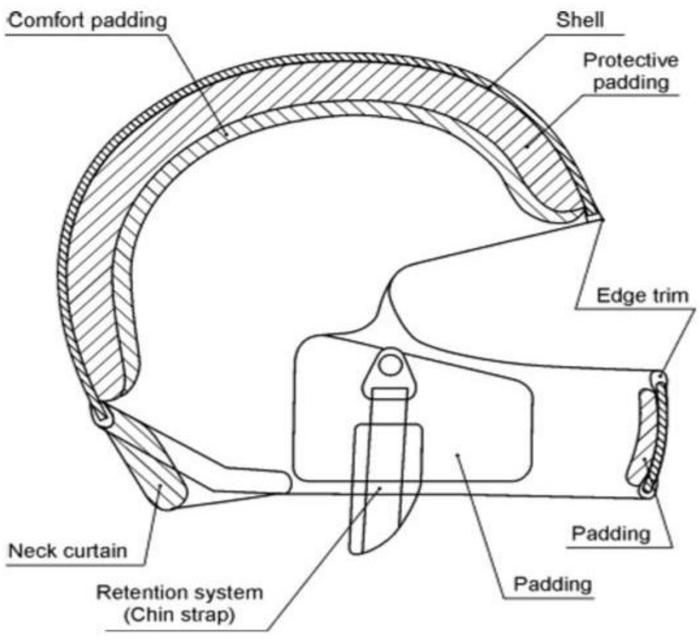


Figure 2. Components of Typical Motorcycle Helmet

2. Methodology

Design of head form and helmet assembly in CATIA

The commercially available helmets in India have the shells with thickness of 5mm and the liner of 20 to 50mm thick and the weight ranges from 0.7kg to 1.4 kg depending on the make, model type and the material used

The following are the design constraints that are considered in our study.

Head form size: G
Thickness of the shell: 5mm
Thickness of the liner: 25mm
Weight of the helmet: 1.1kg

Weight of the helmet is the constituent weight of the shell and that of the liner. The liner is considered to be a single piece component. The helmet is assumed to snugly fit on the head form and any kind of the air gap is not present with the head form and helmet assembly.

Models developed using CATIA V5 software.

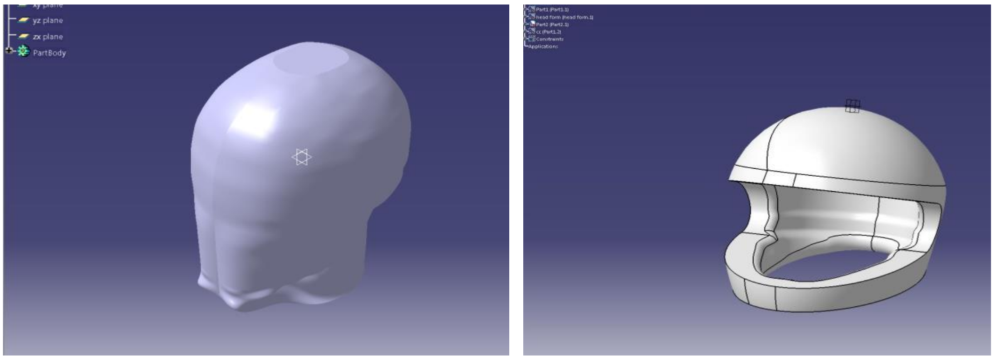


Figure 3. Model Head Form (G) and Model of the Impact Absorbing Liner

Many publications have models that were developed and studied for the strength of the shell ranging from ABS plastic to Carbon fibre composites. Many of them have impact load criteria and adopted the protective padding material to be a foam material.

In our study, we considered that the load is caused by the contact force and the acceleration in which a shock is observed. Hence the material model 'shock EOS linear', available in explicit dynamics module of the ANSYS14.0 workbench material library is considered.

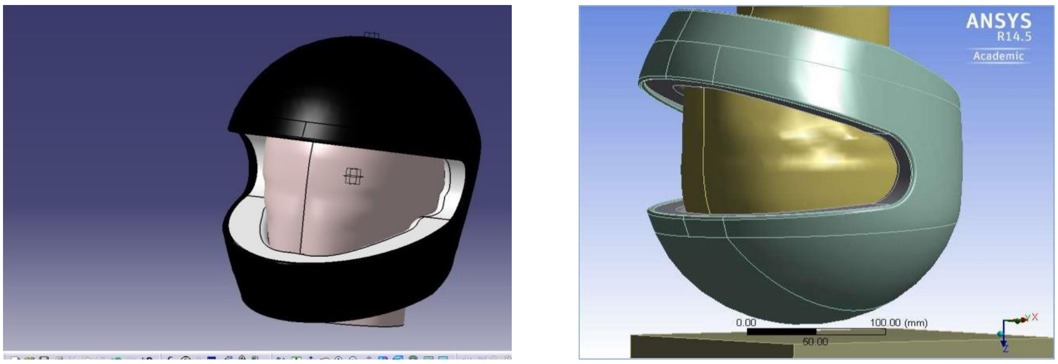


Figure 4. Assembly of Head form and Helmet (Left) and Imported to ANSYS (right)

Table 1. Properties of the Materials used in this Study

Property / Part	Material	Type	Density (kg/m^3)	Young's modulus (MPa)	Poison's ratio	Weight (Kg)
Flat Anvil	Structural Steel	Isotropic elasticity	7850	2E+05	0.3	7.46
Head form	Magnesium K1A	Isotropic elasticity	1740	38000	0.32	4.5
Shell	GFRP	Isotropic Elasticity	2000	80	0.3	1.09
Liner	Low density Polystyrene	Shock EOS linear	35	Shear Modulus 2,3 and 5 MPa	Damping Factor 0.3	0.066
Liner	Polyurethane	Shock EOS linear	75	Shear Modulus 5 MPa	Damping Factor 0.3	0.1

The helmet drop test is a dynamic analysis problem which involves the varying load with time. The helmet is subjected a large impact force and time of the impacts is bound to few milliseconds in which the shock wave propagates in the shell of the helmet first and the liner compresses next to it. Impact absorption capacity is determined by recording against time the acceleration imparted to a head form fitted with the helmet, when dropped in guided free fall at a specific impact velocity upon a fixed steel anvil. This is performed at three different sites namely crown point,peak point and side point (also referred as oblique point at which the central axis of the head form makes 30° with the vertical).

Meshed models

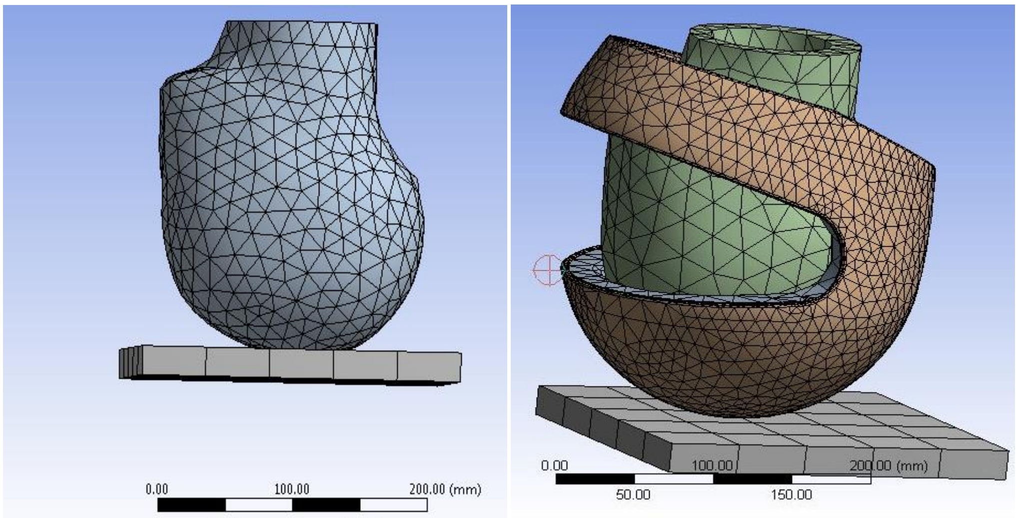


Figure 5. Meshed Model of HF without (left) and with Helmet (right) in Crown Impact

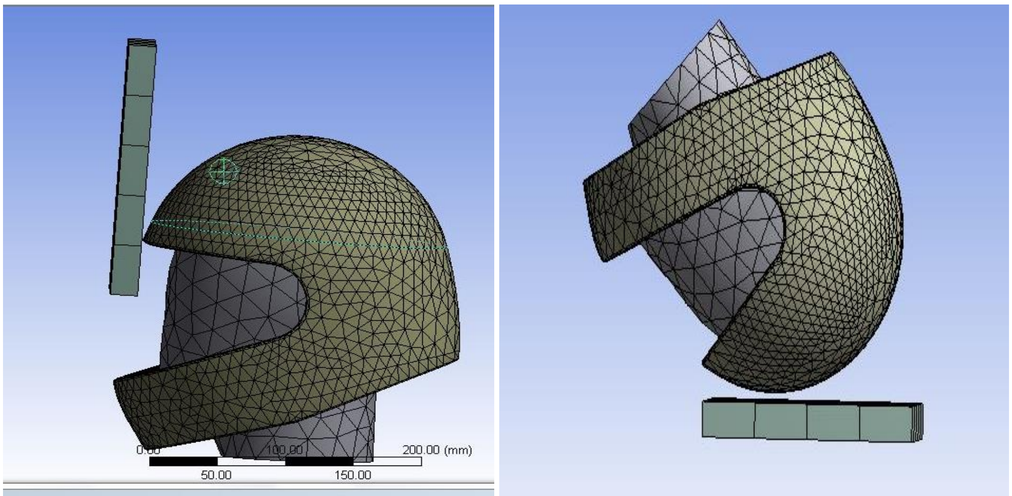


Figure 6. Peak Point Impact and Oblique Point

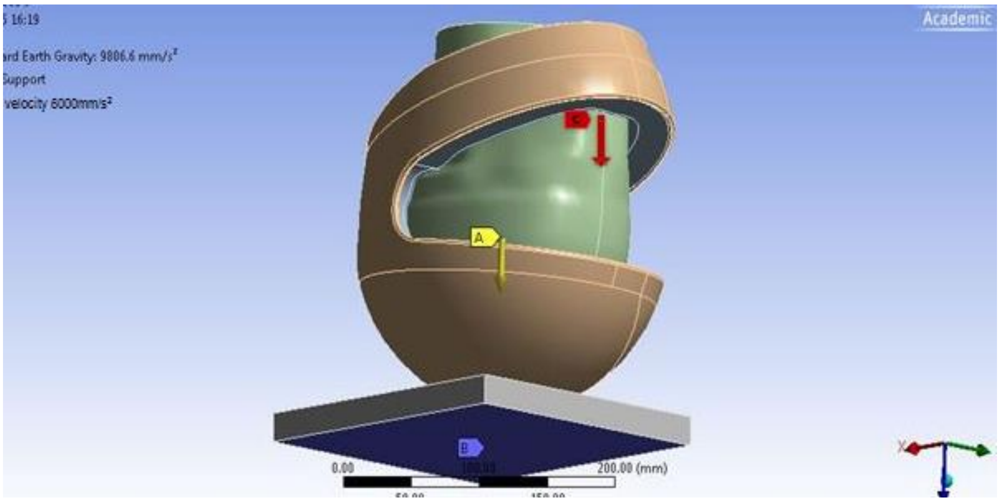


Figure 7. Representation of Forces on HF-helmet Assembly

Initial velocity of head form : 6000mm/s Acceleration due to gravity: 9810mm/s^2
Time duration considered : 9 milliseconds.

3. Observations

The following are the observations made in our study at different impact sites.

Without helmet at Crown Point: The head form experienced a contact force of 713 KN Without helmet. The kinetic energy drop is 22.4%. The head form undergone deformation of 35mm and it was seen at 9mm with the PU liner. The head form which came in contact with the flat steel anvil bounced with larger velocity up to 10m/s. The PLA experienced by head form at centre of gravity is 6000g for duration of 0.001s.

With helmet at Crown Point: The head form experienced a comparatively very low contact force with PS3 liner; it was as low as 16.34kN. The kinetic energy drop is 63 % which is the maximum reduction observed in PU liner. The head form undergone least deformation of 9mm with the PU liner. The helmeted head form with PS2 liner first shown reduction from 6m/s to 1.8m/s during the impact and bounced back with 5.5m/s velocity. The PLA experienced by head form at centre of gravity is 485g for duration of 0.0085s

Crown Point: The model with PS2 liner came into contact with the anvil at 1.8ms and ended at 6.5ms for duration of 4.7ms. The kinetic energy drop of head form is46.8% with PS2 liner, 59.56% with PS3 liner, 60.48% in PS5liner and 63% in PU liner.

Peak Point: As the model considered in our study doesn't contain the visor and retention system (chin strap *etc.*,), the helmet displaced over the head form. As the result of this undesired position, the head form slipped from its position and came in contact with the anvil. However this proved the importance of the retention system in the helmet which secures the head inside the helmet. The head form made of metal as it differs from the actual human head rebound with a high velocity. The kinetic energy drop is very low as 8%. The contact force experienced without helmet is 657KN while it was 221KN with the PS2 liner which the lowest compared to the other three liners.

Oblique Point: It is to be noted that the oblique impact is such an impact where the velocity to the anvil is given and in this position of the head form as the head form undergoes collision with the moving anvil, the rotational forces also exist. Here, oblique point is a point where the central vertical axis of the head form makes an angle of 30º with the vertical axis of the anvil. The duration of impact was seen for 0.0063 seconds. The results were nearly equal to that of the Crown Point impact.

4. Results and Discussions

According to a study made by P. Kelly, T. Sanson, G. Strange and E. Orsay *"The lack of helmet use was found to be a major risk factor for increased severity of injury"*, our study once again proved numerically that the importance of the helmet. The helmeted head form subjected to impact, majority of the force is taken by the helmet making the head form to experience less severity of the injury when compared to that of the head form without the helmet. Majority of the previous studies were done by use of LS-DYNA in which the padding material is taken as foam material, by assuming the impact to be a shock wave propagated, modelling also can be done by the use of the Shock EOS linear material that is available in the ANSYS Explicit Dynamics workbench.

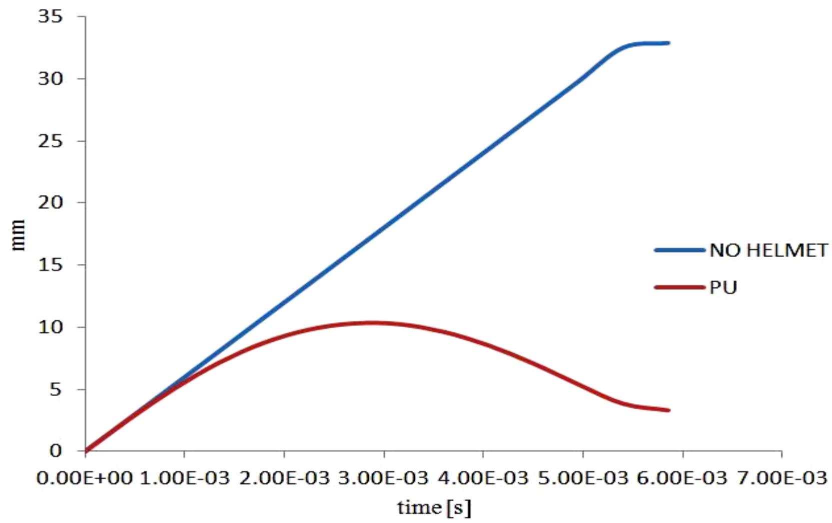


Figure 8. Deformation of Head Form with and Without Helmet

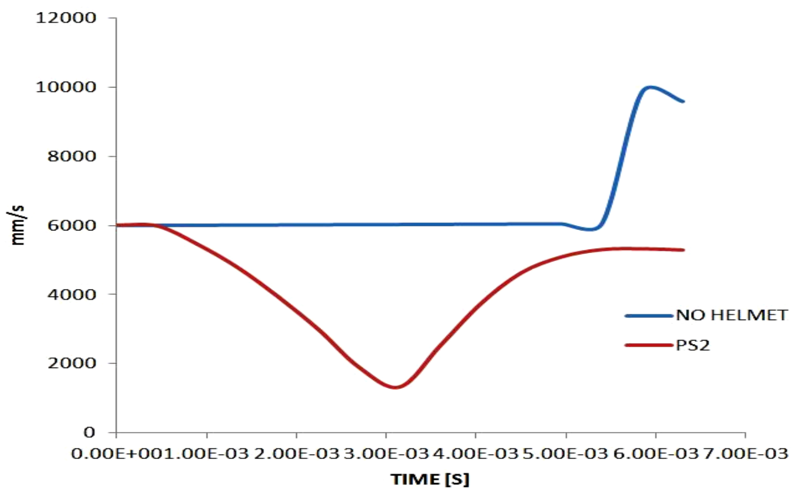


Figure 9. Velocity of Head Form with and without Helmet

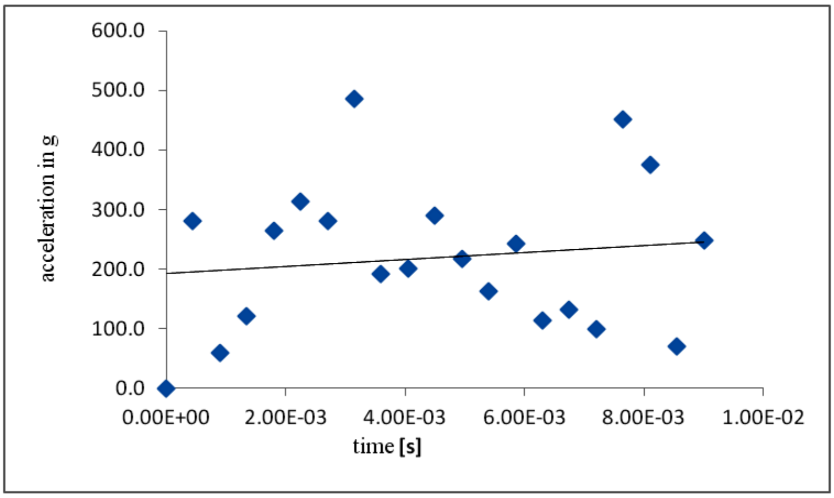


Figure 10. PLA of Headform with PS2 Liner in Crown Impact

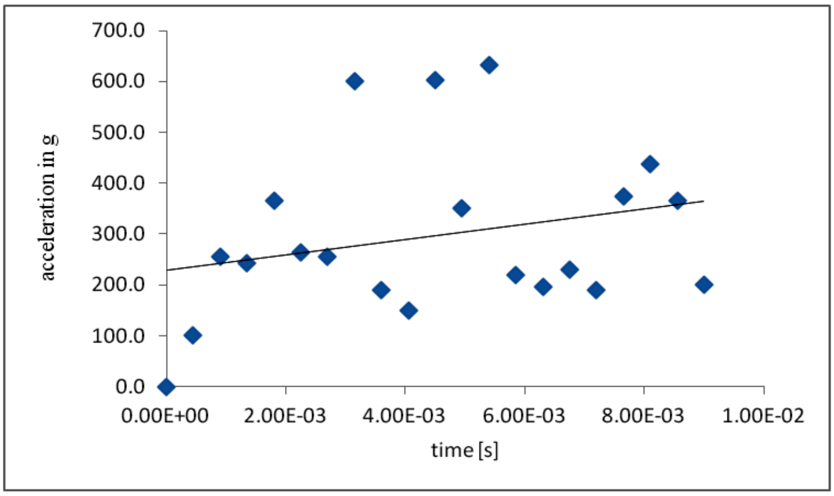


Figure 11. PLA of Headform with PS3 Liner in Crown Impact

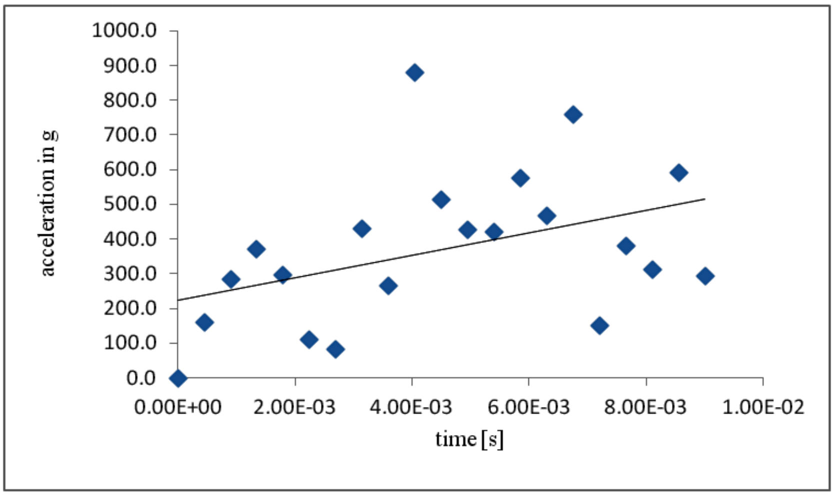


Figure 12. PLA of Head Form with PS5 Liner in Crown Impact

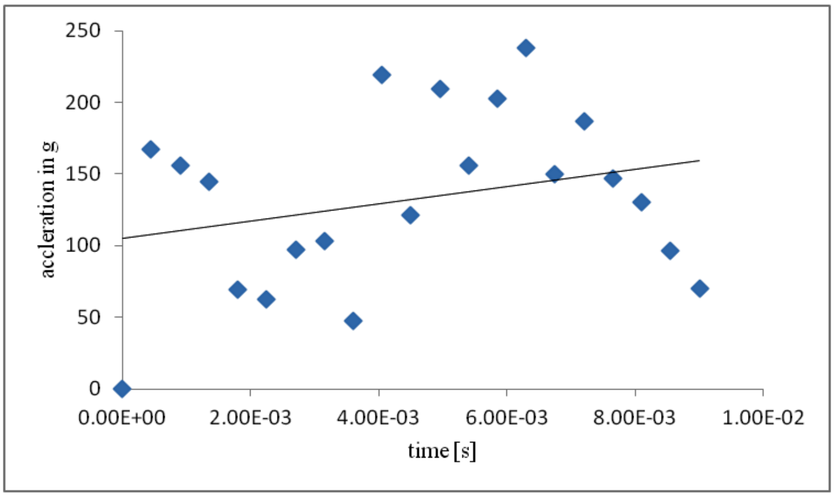


Figure 13. PLA of Head Form with PS2 Liner in Oblique Point Impact

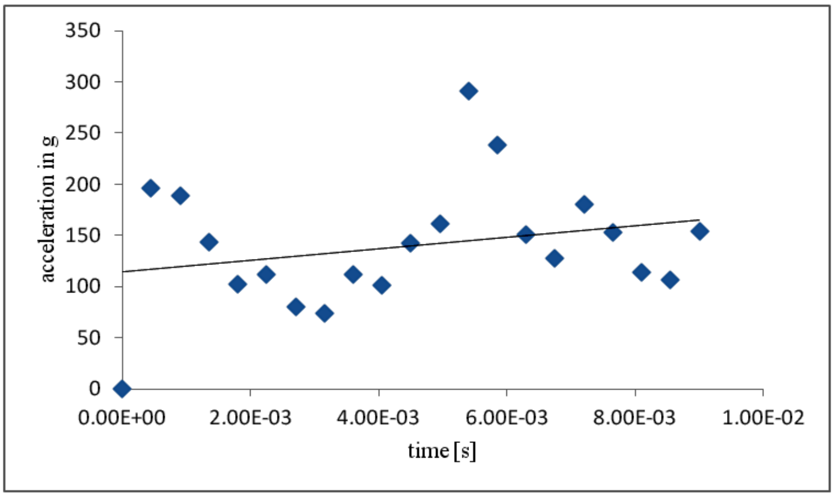


Figure 14. PLA of Head Form with PS3 Liner in Oblique Point Impact

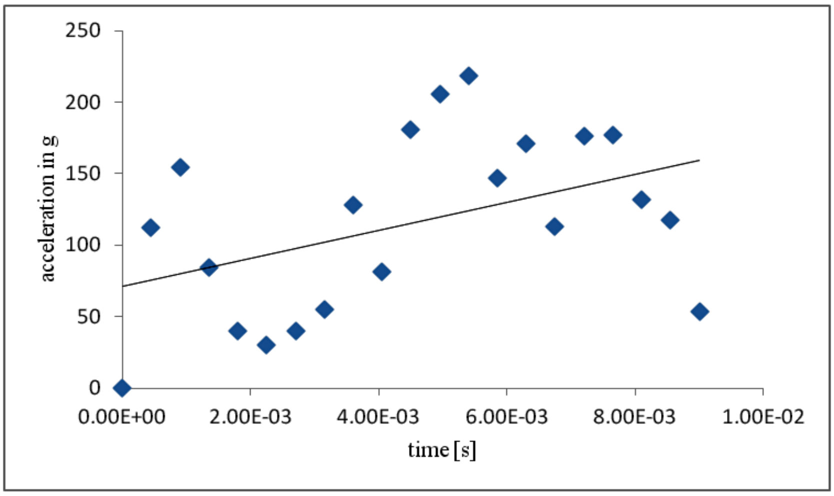


Figure 15. PLA of Head Form with PS5 Liner in Oblique Impact

Figure 8 shows that as the head form without helmet is subjected to impact force and undergone a plastic deformation while the helmeted head form subjected to comparatively less force, regained in the elastic region. Figure 9 the head form without helmet experienced a reaction force of 713KN which resulted in the rebound of the head form with velocities reaching 10m/s, while the helmeted head form(PS2) reached 1.3m/s which is 78.3% less than the initial velocity. However it also regained velocity due to the rebound of the helmet as in a free fall. The PLA observed in head form with helmet is 480g at 3ms while the average is 210g for the duration of the experiment time of 9ms which is in accordance with the helmet laws. Figure 10.PLA of headform with PS2 liner in crown impact is seen as 480g at 3ms and the average PLA of 270g throughout the duration of 9ms. Figure 11.PLA of headform with PS3 liner in crown impact is seen as 631g at 5ms and the average PLA 310g throughout the duration of 9ms. While in Figure 12 gives.PLA of headform with PS5 liner in crown impact is seen as 879g at 4ms and the average PLA 500g throughout the duration of 9ms. It is observed that with the increase in the shear modulus, the PLA also increased. In case of PU liner, the PLA have reached 1000g and even more at certain times in the duration of the study which is an undesired effect. In the peak impact, as the model has no chinstrap or retention system, the shell slipped and rolled out of the headform.Hence realised the importance of the retention system in the helmet. However peak impact was not considered as the helmet slip-off the headform. The point where the central axis of the headform makes an angle of 30° with the vertical, called the oblique point, the impact is called as the oblique point impact. The values obtained are very much low when compared to many of available studies. In PS2 liner the highest linear elastic deformation of the liner observed and it PLA is 237g for 3ms and the average is 142g. The PLA of 290g was observed in PS3 liner at 6ms however the average for the duration of the impact is 138g. The lowest PLA of 218g is seen in PS5 liner at 6ms and the average acceleration during the impact was 139g.

Most of the developments were going in the material properties of liner and overall weight of the helmet where the liner is modelled as single continuous block. But from the results, it is understood that one material cannot justify the at different sites. The liner with different individual small parts with properties suiting the criteria at different impact zones.

References

[1] P. Kumar Pinnoji and P. Mahajan "Finite element modelling of helmeted head impact under frontal loading", Sādhanā, vol. 32, no. 4, **(2007)** August, pp. 445-458.

[2] F. A. O. Fernandes and R. J. Alves de Sousa "Motorcycle helmets—A state of the art review", Journal of Accident Analysis and Prevention, vol. 56, **(2013)** March, pp. 1-21.

[3] A. Cernicchi, U. Galvanetto and L. Iannucci "Virtual modelling of motorcycle safety helmets: practical problems", Proceedings of 6th European LS-Dyna user's conference, **(2007)**, pp. 523-532.

[4] N. J. Mills and A. Gilchrist, "Finite-element analysis of bicycle helmet oblique impacts", International Journal of Impact Engineering, vol. 35, **(2007)** August, pp. 1087-1101.

[5] Bureau of Indian Standards, "IS 4151:1993 Protective Helmets for Motorcycle RidersSpecification"October1993.https://law.resource.org/pub/in/bis/S03/is.4151.1993.pdf

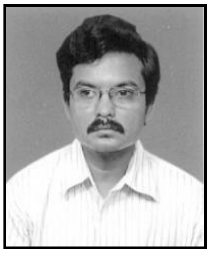
[6] Bureau of Indian Standards, "IS 7692: Specifications For Head forms For Testing Of helmets" May 1993, ftp://law.resource.org/pub/in/bis/S03/is.7692.1993.pdf.

[7] C.-Y. Chang, C.-H. Ho and S.-Y. Chang, "Design of Helmet" A project report, www.academia.edu/9577961/DESIGN_OF_A_HELMET.

[8] Snell Foundation, "Philosophy and concepts of Helmet Testing", www.smf.org/testing, accessed on 27/08/2014.

Authors

Suddapalli Praneeth Babu, is an M.Tech Scholar associated with Mechanical Engineering Department, RVR&JC College of Engineering. India.



Dr. Chandana. Srinivas, PhD, MISTE, is an Associate Professor in the Department of Mechanical Engineering, R.V.R. & J. C. College of Engineering, Chowdavaram, Guntur-522019 Andhra Pradesh, India.

