International Journal of Computational Research and Development (IJCRD)
Impact Factor: 5.015, ISSN (Online): 2456 - 3137
(www.dvpublication.com) Volume 3, Issue 1, 2018

SAFETY ASSESSMENT OF MOTORCYCLE HELMET USING FINITE ELEMENT ANALYSIS

Varun Agrawal*, Rohit Kumrawat*, Rizwan Sheikh & Sanjay Jain*****

* Undergraduate Student, Department of Mechanical Engineering, IPS Academy, Institute of Engineering and Science, Indore, Madhya Pradesh

** Associate Professor, Department of Mechanical Engineering, IPS Academy, Institute of Engineering and Science, Indore, Madhya Pradesh

*** Head of Department, Department of Mechanical Engineering, IPS Academy, Institute of Engineering and Science, Indore, Madhya Pradesh

Cite This Article: Varun Agrawal, Rohit Kumrawat, Rizwan Sheikh & Sanjay Jain, "Safety Assessment of Motorcycle Helmet Using Finite Element Analysis", International Journal of Computational Research and Development, Volume 3, Issue 1, Page Number 174-181, 2018.

Abstract:

The helmet is protective equipment which is used for the different purposes like by two-wheeler riders, during construction of a building, driving sports cars, etc. for the protection of the head from the injury caused by impact during anaccident. There are various standards and their norms for deciding the safety level of different kinds of thehelmet. In this research work, a motorcycle helmet was designed and then analyzed according to the norms of the standard DOT FMVSS 218. The impact and penetration tests were performed on the helmet assembly as per the safety requirements of this standard. In this work, the helmet was designed using a Computer Aided Design (CAD) software CREO Parametric 3.0 and the meshing on the helmet assembly was completed on the Computer Aided Engineering (CAE) software HyperMesh 13. The dynamic testing was performed on the LS-DYNA which is a product of Livermore Software Technology Corporation (LSTC). To enhance and ensure the impact capacity of the helmet, two different cases based on the thickness of the foam padding in the helmet were simulated. And finally, the case which passed all the tests as per the standard had been suggested.This research work can also assist in the optimization of the helmet by suggesting the different models which would optimize the cost, weight, and helmet size.

Key Words: Motorcycle Helmet, FMVSS 218, CAD, CAE, Impact Testing, Penetration Testing & Safety

1. Introduction:

Helmets are designed to protect the riders from the severe injuries during accidents. The safety of the helmet can be measured in different forms like calculation of the head acceleration during impact or by reducing the Head Injury Criterion (HIC). The experimental setup of testing the helmet is very costly. It can be analyzed by using Finite Element Analysis (FEA) which is also known as Matrix Structural Analysis as it uses the matrix algebra to solve the system of simultaneous equations. In FEA, the complex structures are divided into finite elements which are connected by the nodes. By using different boundary conditions, different parameters like stresses, displacements, temperature distribution, acceleration, etc. can be calculated and the comparison can be made between the results.

Different loading conditions on the motorcycle helmet were simulated by using CAE software ANSYS (Gandhi et al., [1]). For each condition, results of different parameters like von Mises stress, total deformation, and equivalent strain energy were compared with the standard experimental data proposed by the Bureau of Indian Standards (BIS). The chin (retention system) had undergone less strain energy and deformation which lead to a serious head injury during anaccident.

Sadaq et.al, [2] performed the impact tests on the motorcycle helmet using software COSMOS. The helmet was impacted at different speeds and at different positions. The Poly Vinyl Chloride (PVC) material helmet performed well as compared to Acrylonitrile Butadiene Styrene (ABS) helmet when compared on the basis of stresses but ABS material helmet was better than PVC helmet in terms of strain and deformation. Later the same type of testing on thehelmet was performed by (Thomas et al., [3]) in which the material used was fiber reinforced polymer composite. The simulation was performed on ANSYS. The results indicate that the use of fiber composite is viable for helmet application.

FEA on the bicycle helmets making oblique impacts (Mills and Gilchrist [4]) was performed to evaluate the linear and rotational accelerations of the headform. In this study, the effect of helmet rotation on the head was also considered with the interaction of retention strap with the headform. The contributing mechanisms were established by the investigation of peak headform rotational acceleration as a function of the helmet geometry, impact sites and velocities. Later (Mills et al., [5]) performed FEA of the oblique impact of amotorcycle helmet to study the same parameters. It was found out that the peak rotational accelerations were potentially injurious. And the most effective method of reducing the head rotational acceleration could be a reduction in the linear acceleration limit of the helmet standards.

Rueda and Gilchrist [6] performed the design and finite element analysis of the helmet with the variations in terms of different variables other than headform linear acceleration, such as the gap between the liner and shell, ventilation holes, and ridges on the helmet liner to determine the best performing helmet configurations by analyzing there influence on helmet performance.

Work on the different category helmets was also done to study the impact of human skull and brain. Jacob et al., [7] considered construction, bike,and motorcycle helmet and simulated different impact cases using FEA software such as HyperMesh and ABAQUS. The amount of stress absorbed by the skull and brain and the displacements experienced by the whole system during the impact was compared by the use of different materials. The helmets significantly decreased the consequences of damage to human skull and brain.

The motorcycle helmet was also tested by the consideration of no outer shell or with thedifferentlightweight outer shell (Sikri et al., [9]). They performed anexperiment by using different materials for the shell and foam in order to investigate if a helmet could provide thesame protection as conventional helmets. Acceleration of the headform and impact force on the helmet was measured. The helmet weight was reduced by the use of polypropylene foam, foam thickness was reduced in case of polycarbonate shell, and Expanded Polystyrene(EPS) liner foam had only excellent first impact performance. Pinnoji and Mahajan [10] tested the possibility of anouter shell made of metal foam, which has high strength, good energy absorbing capability and lightweight. The authors aimed towards the reduction in weight of helmet without compromising with its impact capacity. The helmet weight was found to be 30% less as compared to ABS helmet.

Advanced Motorcycle Helmet was designed which consists of a lightweight carbon composite shell fitted with an expanded polystyrene liner and a low friction sacrificial outer surface (Mellor and StClair, [11]). The results of the testing were related to the Abbreviated Injury Scale(AIS) scale. The helmet was designed such that it has the capability to reduce AIS 6 injuries to AIS 4 and AIS 5 and 4 injuries to AIS 3.

Sambamoorthy and Halder [12] simulated the FEA modeling of the different foams available in LS-DYNA and the results, HIC and acceleration curves were compared with the physical test results.

Chang et al., [13] presented a report on helmet design method by considering the criteria of designing as the reduction of the risk of mild traumatic brain injury (MTBI), comfort, stability and fit. The helmet design optimization and its solution were explained.

Connor et al., [14] gave a review of various helmet standards and the detailed information of the testing method of all the tests which are performed on different helmets to make them safe as per the norms of the standard.

Department of Transportation (DOT) Federal Motor Vehicle Safety Standards (FMVSS) 218, formed in 1974, developed and enforced by National Highway Traffic Safety Administration (NHTSA), is a well-accepted regulation whose purpose is to reduce fatalities and injuries resulting from the traffic accidents. This standard applies to all the helmets intended for use by motorcyclists and other motor vehicle users. The testing conditions according to this standard [15] are:-

The speed of the helmet assembly in case of impact attenuation testing with hemispherical anvil is 5.2m/s and in case of theflat anvil is 6.0m/s. In case of penetration testing, the mass of the conical impactor is 3 kg.

The requirements of the testing are that in impact testing, the peak acceleration should not exceed 400g and in penetration testing, the striker should not contact the surface of the test headform.

2. Methodology:

In this study, a full face motorcycle helmet had been designed and then tested as per the norms of FMVSS 218. Before the helmet design, a medium headform had been selected for the testing as per the standard and designed in the CAD software CREO Parametric 3.0. Detailed dimensions of the headform are given in figure 1.

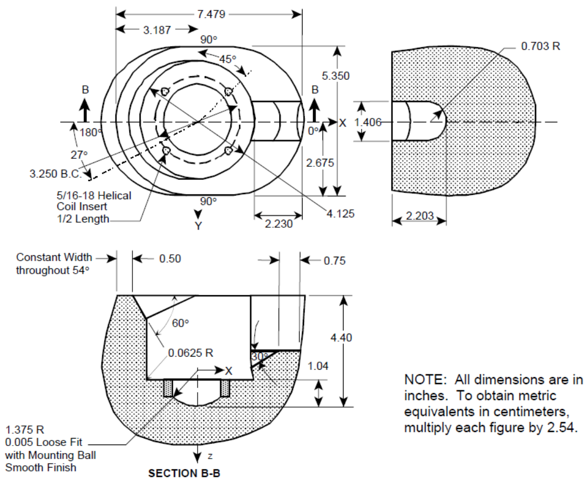


Figure 1: Dimensions of the Medium Headform

2.1 Modeling: The CPSC (Consumer Product Safety Committee) standard dimensions helmet [1] had been designed in CREO Parametric 3.0. The 3D CAD model of the motorcycle helmet is shown in figure 2.

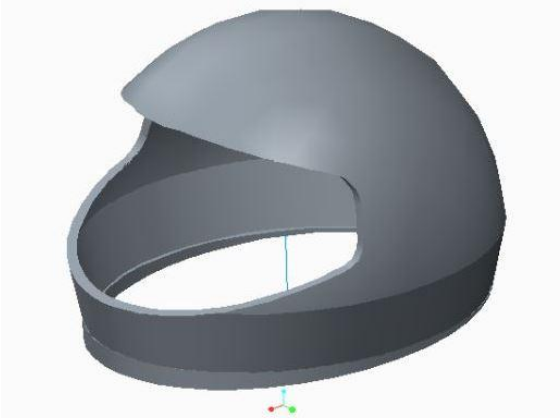


Figure 2: CAD Model of Helmet

2.2 Meshing: CAE software HyperMesh 13 was used to generate the mesh on the helmet assembly. Tetra elements were developed on the headform. FE model of headform is shown in figure 3. Detailed FE model ofthehelmet shell and foam padding is shown in figure 4.

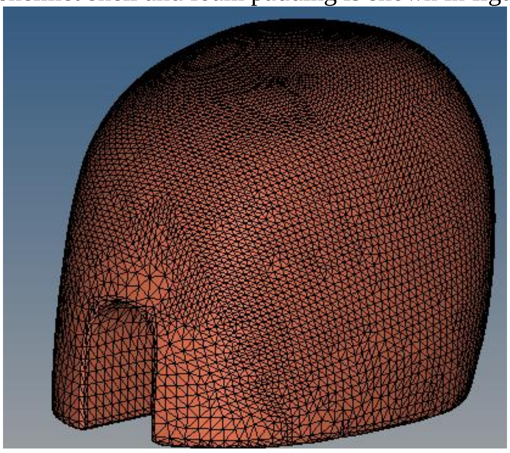


Figure 3: FE Model of Headform

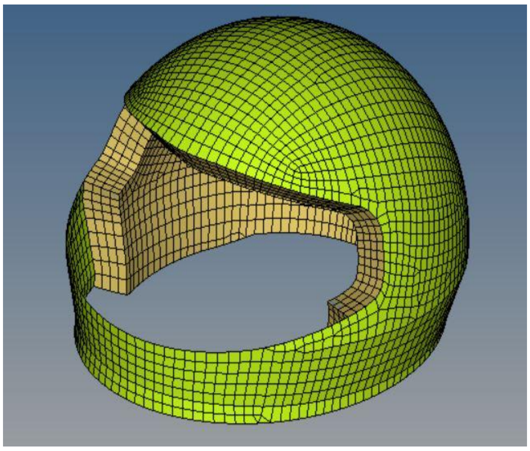


Figure 4: FE Model of Helmet

2.3 Helmet Components and Material Properties: A 1.5mm helmet shell had been given the material properties of the fiberglass reinforced polymer [6]. Foam paddingof 25mm thickness [13] was used as the main impact energy absorbing component and the properties of polyurethane foam [12, 8] were used. The headform used is generally made of magnesium alloy (K-1A) and its properties were retrieved from matweb [16].

2.4 Test Setup: The headform had been fitted in the helmet with the minimum distance from the padding so as to avoid the penetrationof the elements in the model. The helmet assembly is shown in figure 5.

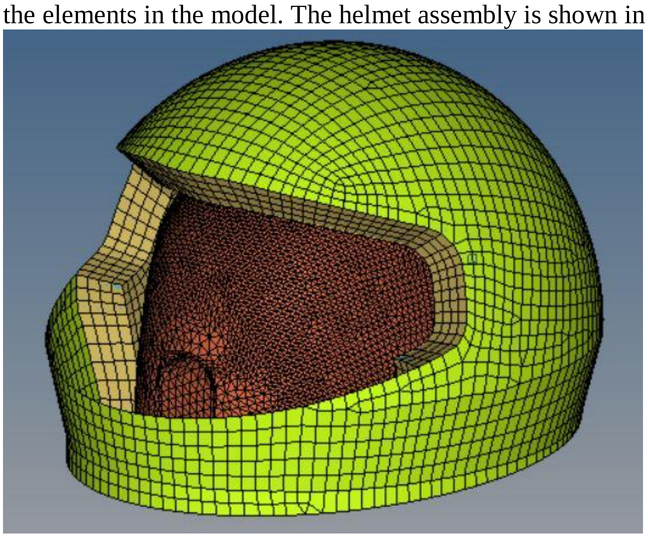


Figure 5: FE Model of Helmet Assembly

The test setup for the impact attenuation testing as per the FMVSS 218 is shown in figure 6 and figure 7 and the same was used in the software for the simulation.

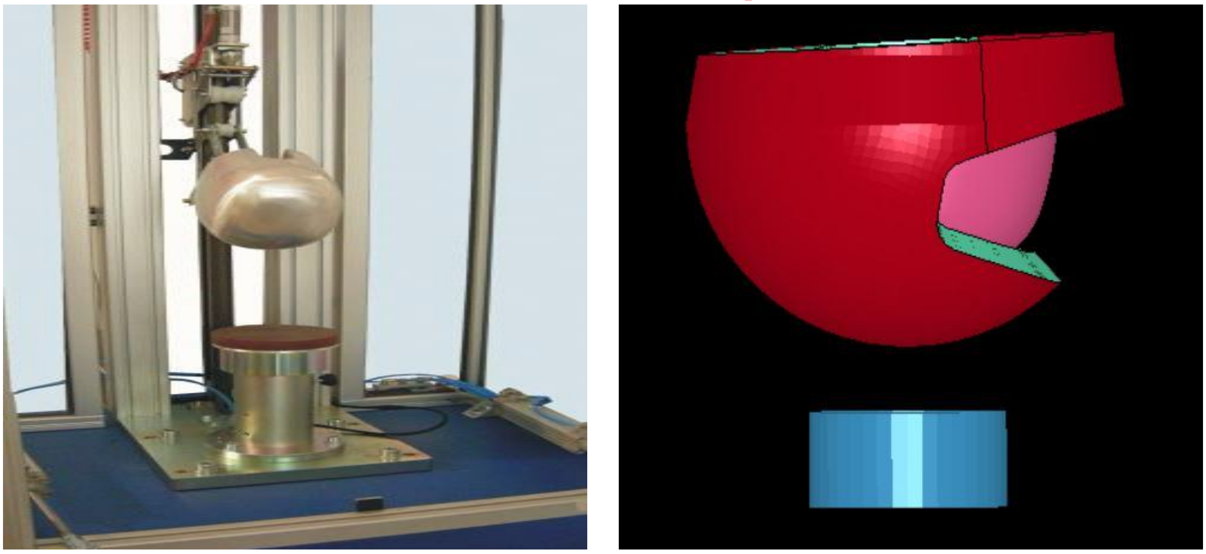


Figure 6: Test Setup for Flat Anvil

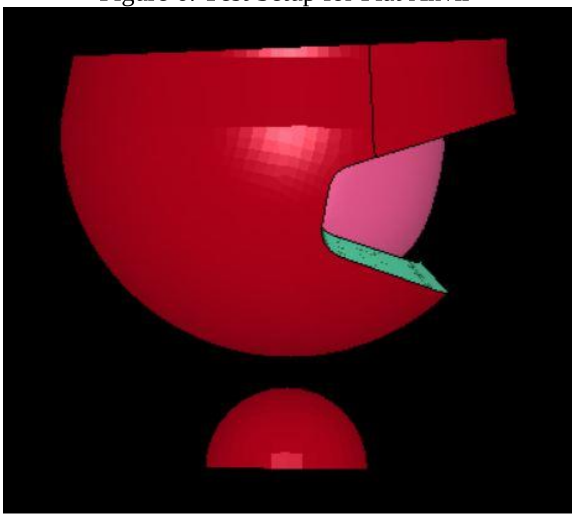


Figure 7: Test Setup for Hemispherical Anvil

Similarly, the penetration test setup is shown in figure 8.

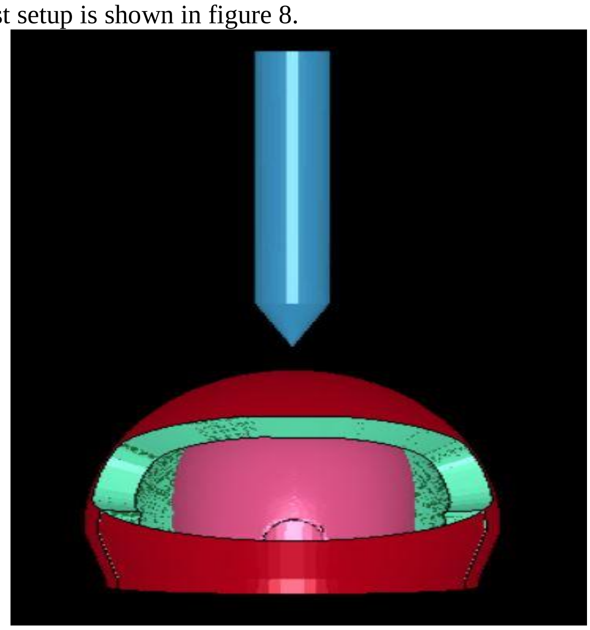


Figure 8: Test Setup for Penetration Testing

The helmet assembly had given the speed of 6.0 m/s in case of theflat anvil and 5.2 m/s in case of thehemispherical anvil.In case of penetration testing, the conical impactor had given the speed of 7.67 m/s. The accelerometer was used in the FE model to get the results with high accuracy.

2.5 Analyses: The analyses were made with the different foam padding thickness. This was performed because as the thickness of the foam padding increases, the peak head acceleration decreases in case of impact [13].

Initially, the helmet assembly was tested on the flat anvil with the 20mm thick foam padding. Figure 9 showscross-sectional view of the helmet assembly of this testing. The peak head acceleration was found to be greater than 400g.

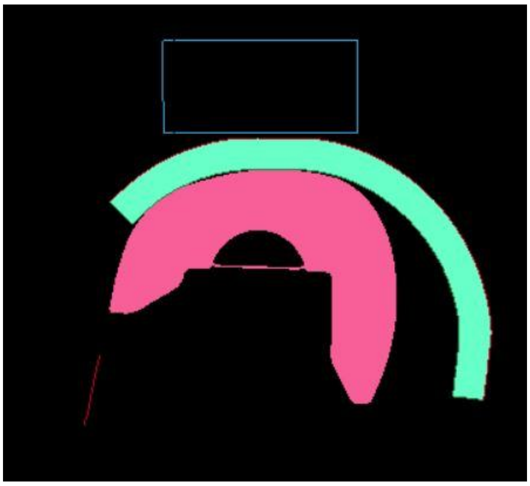


Figure 9: Cross Section of Helmet Assembly and Helmet Deformation with 20mm thick foam

Figure 10 shows the testing of the helmet assembly on the flat anvil with the 25mm thick foam padding. The peak acceleration was found to be less than 400g.

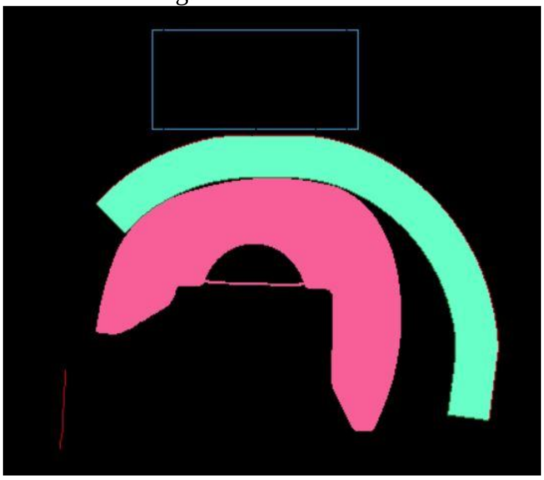


Figure 10: Cross Section of Helmet Assembly with Helmet Deformation with 25mm thick foam

Figure 11 shows the testing of the helmet assembly on the hemispherical anvil with 25mm thick foam padding.

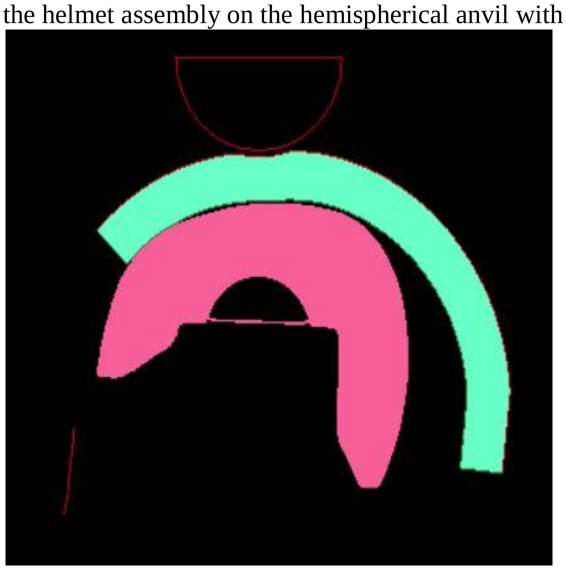


Figure 11: Cross Section of Helmet Assembly and Helmet deformation in case of Hemispherical Anvil

Figure 12 shows the penetration testing of the helmet assembly.

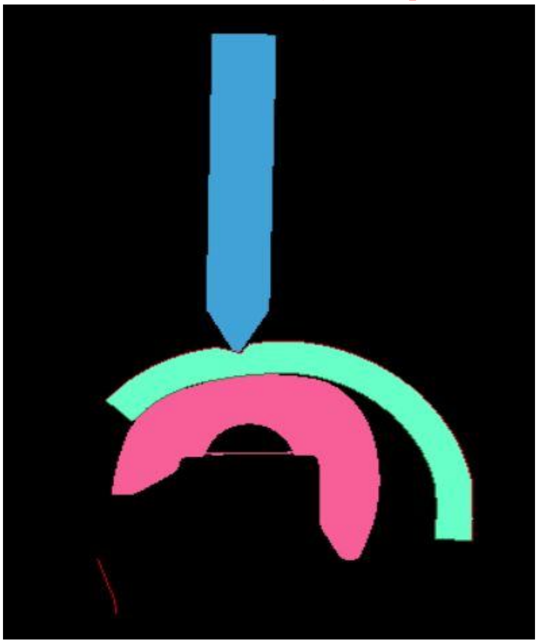
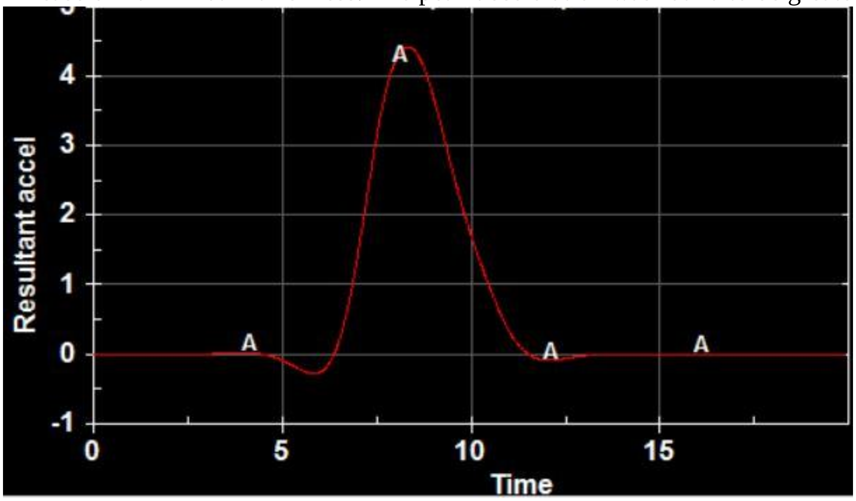


Figure 12: Cross Section of Helmet Assembly and Helmet Deformation in case of Penetration Testing

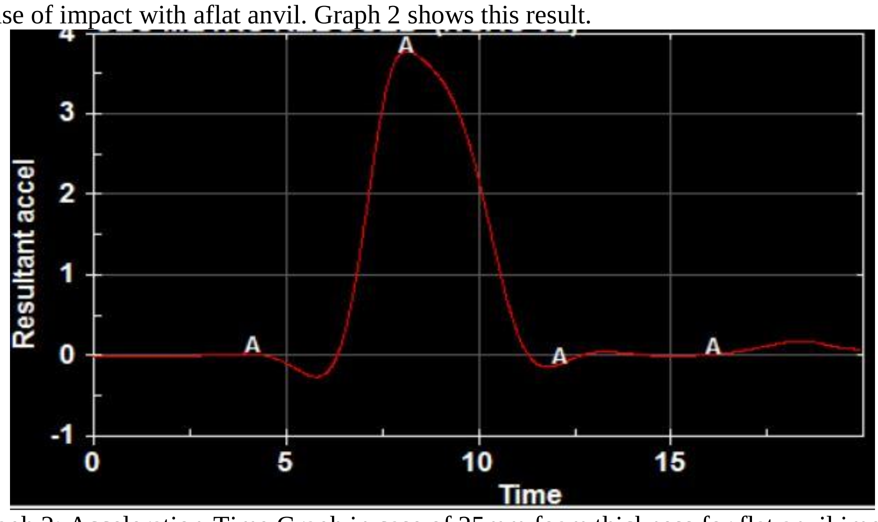
3. Results:

Graph 1 shows the graph of acceleration $(\mathrm{mm/ms^2})$ and time (ms) for the impact of helmet assembly with theflat anvil in case of 20mm foam thickness. The peak acceleration was found to be greater than 400g.



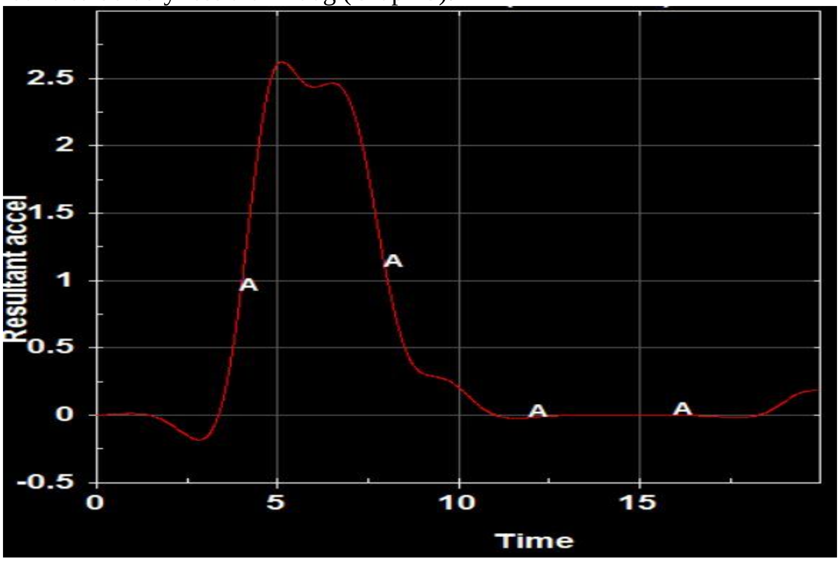
Graph 1: Acceleration-Time Graph in case of 20mm foam thickness for flat anvil impact

In case of 25mm foam thickness, the peak acceleration of the helmet assembly was found to be less than 400g in case of impact with aflat anvil. Graph 2 shows this result.



Graph 2: Acceleration-Time Graph in case of 25mm foam thickness for flat anvil impact

Inthe impact of helmet assembly with thehemispherical anvil in case of 25mm foam thickness, the peak acceleration was found to be very less than 400g (Graph 3).



Graph3: Acceleration-Time Graph for 25mm foam thickness for Hemispherical Anvil Impact

The penetration testing results are shown in figure 12 itself in which the striker had no contact with the surface of headform. The table below summarizes all the results:

Case	Peak Acceleration
Flat Anvil Impact with 20mm foam thickness	450.798g
Flat Anvil Impact with 25mm foam thickness	385.919g
Hemispherical Anvil Impact with 25mm foam thickness	268.121g
In case of penetration testing, striker had no contact with surface of test headform.	

4. Conclusion:

In this research work onfull-face motorcycle helmet, the testing had been performed by using HyperWorks and LS-DYNA and as per the norms of regulation DOT FMVSS 218. The different tests were simulated to ensure the impact capacity of the helmet. The foam thickness played a very important role in the peak headform acceleration. When the foam thickness was increased, then the helmet passed all the tests and met the safety requirements of the regulation.

5. Acknowledgment:

The authors are thankful to Mr. Sumit Sharma of Indore Institute of Computer Aided Engineering, Indore for availing all the software for this research work.

6. Funding:

This research work received no funding from any specific institution or sector.

7. References:

1. Gandhi V C S, Kumaravelan R, et al. (2014) Performance Analysis of Motor Cycle Helmet under Static and Dynamic Loading. Mechanics and Mechanical Engineering, Vol. 18, No. 2, 85-96
2. Sadaq Irfan S, JunaidiMdA R, et al. (2014) Impact Test on Motor Cycle Helmet for Different Impact angles using FEA. International Journal of Engineering Trends and Technology, Volume 12 Number 6.
3. Thomas A, Dr. Suresh P, et al. (2017) Impact Analysis on Composite Helmet by Using FRC and Glass Fiber by using ANSYS. International Research Journal of Engineering and Technology, Volume 04, Issue 03.
4. Mills N J and Gilchrist A (2008) Finite-element analysis of bicycle helmet oblique impacts. International Journal of Impact Engineering, 25, 1087-1101
5. Mills N J, Wilkes S, et al. (2009) FEA of oblique impact tests on a motorcycle helmet. International Journal of Impact Engineering, 36, 913-925
6. Rueda M A F and Gilchrist M D (2012) Computational analysis and design of components of protective helmets. Journal of Sports Engineering and Technology 226(3/4) 208-219, IMechE, doi: 10.1177/1754337112439171.
7. Jacob A,Faria C, et al. (2016)Evaluation of Helmet Protection during Impact of Head to Ground and Impact of an Object to Head Using Finite Element Analysis. Journal of Safety Engineering, 5(1): 8-16 doi: 10.5923/j.safety.20160501.02
8. Burbank S D and Smith L V (2012) Dynamic characterization of rigid foam used in finite element sports ball simulations. Journal of Sports Engineering and Technology 226(2) 77-85, IMechE, doi: 10.1177/1754337112441112.

9. Sikri S, Shishodia B S, et al. (2014) Performance Comparison of Motorcycle Helmet Shells of Different Materials. International Crashworthiness Conference (ICRASH) Malaysia, Aug 25-28
10. Pinnoji P K,Bourdet N, et al. (2008) New Motorcycle Helmets with Metal Foam Shell. IRCOBI Conference Proceedings, 17-19 September 2008 – Bern (Switzerland).
11. Mellor A andStClair V, Advanced Motorcycle Helmets. TRL Limited, United Kingdom, Paper 05-0329
12. Sambamoorthy B andHalder T, Characterization and Component Level Correlation of Energy Absorbing (EA) Polyurethane Foams (PU) Using LS-DYNA Material Models.
13. Chang C-Y, Ho C-H, et al. (2003) Design of a Helmet. ME 499/599 Fall 2003, Final Report.
14. Connor T A, Meng S, et al. (2016) Current Standards for Sports and Automotive Helmets: A Review. Ref. Ares(2016)3151745- 01/07/2016
15. Federal Motor Vehicle Safety Standard No. 218 (49 CFR Sec. 571.218) Motorcycle Helmets.
16. Mat Web: Material Property Data.http://www.matweb.com/.