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Finite Element Analysis of the Motorcycle Helmet Material against Impact Velocity

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Abstract: A motorcycle helmet is the best protective headgear for the prevention of head injuries due to direct cranial impact. A finite element model based on realistic geometric features of a motorcycle helmet is established, and explicit finite element code is employed to simulate dynamic responses at different impact velocities. Peak acceleration and Head injury criterion values derived from the head form are used to assess the protective performance of the helmet. We have concluded that the dynamic responses of the helmet dramatically vary with impact velocity, as well as the mechanical properties of the outer shell and energy- absorbing liner. At low velocities e.g. 8.3 m/s, the shell stiffness and liner density should be relatively low to diminish head- contact force. At high velocity e.g. 11m/s, a stiffer shell and denser liner offer superior protection against head injuries. Different tests were performed in ansys explicit dynamics solver by taking different materials and calculating PLA, Head Injury Criteria, K.E, P.E, contact energy etc. The results obtained for different materials were then compared with easy other to draw the necessary conclusion's.
Keywords: Peak Linear Acceleration (PLA), Head Injury Criteria.

I. INTRODUCTION

Motorcycles and scooters are popular and provide an important means of transportation in both developing and developed countries. Approximately, 50% the population owns a motorized two- wheeled vehicle. Therefore, it is notsurprising that 45% of all traffic accident fatalities involve motorcyclists, with most deaths resultingfrom head injuries. Although patterns of motorcycleusage in other countries differ from India, head injury of the rider remains a significant health problem.

Wearing a motorcycle helmet is the best way to prevent head injuries from traffic accidents. To ensure protective performance, shock absorption test codes have been established in many countries. In most of these standards, the peak acceleration of a magnesium alloy head- form within the helmet should not exceed 300G (G= 9.8m/s^2) and theHead Injury Criterion should be less than 2400 withthe impact energy ranging from 80- 150 J. Therefore, commercial helmets structures are principally designed to meet the specifications set out in these standards. In general, a motorcycle helmet consists of a hard outer shell, an energyabsorbing liner and inner comfort foam,

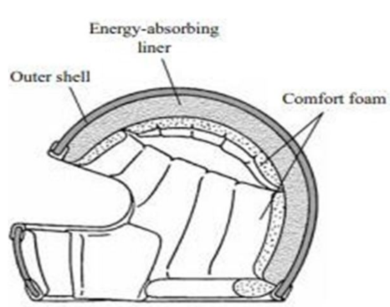

Fig. 1.1: A typical cross-section view of motorcycle helmet [1]

Than an attempt to define the conditions experienced. The outer shell serves mainly to distribute contact forces, while the polystyrene linerabsorbs the impact energy. The comfort foam distributes the static contact forces to avoid headaches.

Many studies have been conducted to evaluate the protective performance of helmets during direct head impact, with constant – rate compression and drop- impact tests which are typically used to investigate the protective the protective contributionof individual helmet components.

A finite element model is used to study the influences of construction material on helmet performance. In these simulation studies helmet geometry is simplified with either spherical or regular shapes adopted. In addition most of these studies utilized impact velocities ranging from 5.6-7.7 m/s, as required by the various helmet standards. However, the impact velocity adopted for a particular standard probably reflects an underlying economic rationale rather in real accidents. At higher velocities, the dynamic response of the helmet and the influenceof material on helmet performance are seemingly unclear.

Since in four wheelers, we have other sources of protection equipment like seatbelts and airbags but in motorcycles we don’t have this much luxury for the protection of our body parts, only thing which protects our most vital organ (brain) on a motorcycle is the helmet. There is a much risk of fatality rate for a rider, if he rides a motorcycle without helmet and this rate gets reduced by around 60% when rider wears a helmet. Helmets are must needed for a rider to prevent injuries of vital organs like skull, brain and other delicate parts of a rider’s head. Helmets can be used for many other purposes like protection against the brain injury due to the accelerations by the relative moment in cerebral fluid of the brain.

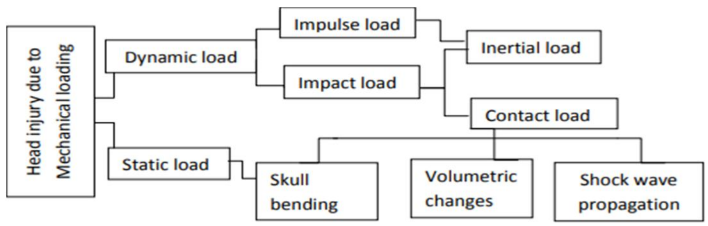

Fig1.2: Types of load act on head subjected to collision [4]

Basically, helmet protects the various brain parts after a collision by absorbing the huge amount of impact injury before reaching the brain parts, thus reducing the chances of injury. The inner liner present in the helmet plays a very vital role in absorbing the impact energy caused after thecollision and it also provides cushion to extend the impact time.

The following are the components of the helmetand their function

1) *Outer Shell:* This helps in distribution of impact energy to the whole helmet surface.
2) *Inner Liner:* this absorbs the impact energy caused by the collision before reaching to the brain parts.
3) *Inner Comfort foam:* It provides the comfort to riders head against all environment conditions.
4) *Fastened Retention System:* It helps in keeping the helmet to stay on the head after a collision.

Thus the objective of this study is therefore to establish a

a) Finite Element (FE) model based on realistic geometric features of a motorcycle helmet and known material properties and,
b) To assess the protective performance of the helmet with respect to head injuries at different impact velocities with and without the helmet and inner liner (padding) ofdifferent mechanical characteristics.
c) To show the necessity of different materialswith energy absorbing capabilities

II. MATERIALS USED AND MATERIAL PROPERTIES

For construction of the helmet, step wise procedureis followed:

A. Construction of rigid outer shell
B. Perfect selection of material for impactabsorbing liner
C. Fitting the comfort liner for ensuring thecomfort and perfect fit for the rider.

Various material from which helmet shellmade of are:

1) Acrylonitrile butadiene styrene(ABS) or plastic
2) Reinforced material like (Fiberglass)
3) Carbon fiber
4) GFRP
5) Polycarbonate

Helmets can be made while using one ormore of these materials together, which are usually known as composite helmets.

For outer shell of the helmet, the selected materials are:

- Plastic/ABS
- GFRP(fiber-reinforced plastic)
- polycarbonate

Material	Type	Density (kg/ m^-3)	Young's modulus (pa)	Poisson's ratio
ABS	Isotropic elasticity	1030	1.628e+ 009	0.40 89
GFRP	Isotropic elasticity	2000	8.e+007	0.3
polycarbon ate	Isotropic elasticity	1800	1.0e+00 9	0.30

For inner impact absorbing liner, the selectedmaterials are:

- PU foam(polyurethane)
- Polystyrene(5MPa, 3MPa, 2MPa)

III. DESIGNING

The head foam and the assembly were designed in SOLIDWORKS. There are some standards for commercial helmets in India. The outer shellthickness must not increase 5mm. The inner liner must have thickness of 18- 48mm. The overall weight of the helmet must be in the range of .7 to 1.2 kg. This weight depends on the type of material and method used in construction of a helmet.
The **Bureau of Indian Standards** (BIS) have madeit compulsory for the weight of the helmet to not exceed a weight of 1.2 kg

The designed helmet consists of the following parts

A. Outer shell
B. Inner foam
C. Head foam

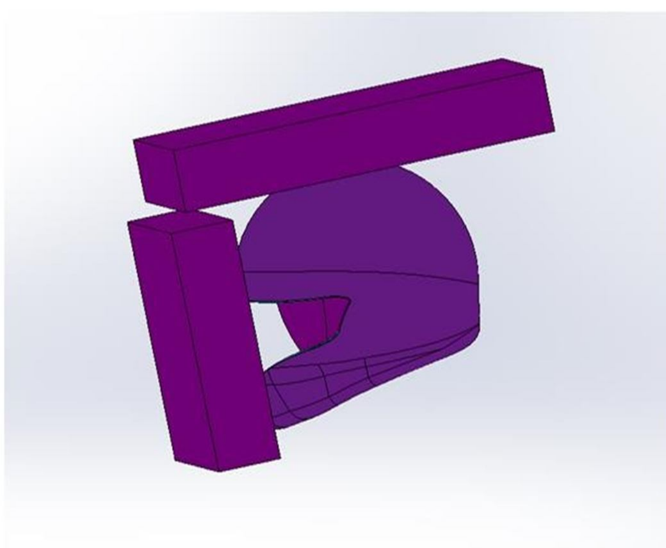

Fig 1.3: Assembly of head form and helmet

Material	Type	Densit y	Young's modulus	Poisson's ratio
PU	Isotropic elasticit y	75	4.7e+00 5	0
Polystyrene	Isotropic elasticit y	35	Shear modulus 2,3,5 MPa	Dampin g factor of 0.3

Many publications and journals have studied for thestrength of various materials like polycarbonate, fiberglass, carbon fibre, ABS. They had chosen the method for this study which is also known as impact load criteria and they had considered inner liner as a protective padding as a foam. In our studywe had conducted a drop test in which a helmet is released from some height and given some differentinitial impact velocities. The material model for the outer shell is considered 'isotropic elastic' and inner liner as 'shock EOS linear' in the ANSYS workbench.

IV. METHODOLOGY

Now after designing the assembly and assigning thematerials it is important that a proper method must be specified. A finite element tetrahedral mesh is assigned to the assembly. To stimulate the impact between the helmet and the wall the type of contact between head foam and the helmet was taken as free.

The drop test carried out on the helmet has a varying load acting on it with the varying time.Firstly the helmet was released with an initial impact velocity of 6m/s. The solution time was considered as 9 milliseconds and in this few milliseconds, after an impact shock wave travel through the inner liner and compresses it. The amount of impact absorbed is calculated by Comparing with the rebound velocity obtained from different materials for different velocities.

PROPERTIES	INNER FOAM	HEAD FOAM	OUTER SHELL
LENGTH X	0.36345 m	0.27837 m	0.19784 m
LENGTH Y	0.39682 m	0.32336 m	0.40857 m
LENGTH Z	0.41046 m	0.30256 m	0.4189 m
VOLUME	2.9561e-003 m^3	8.4592e-003 m^3	9.5551e-004m^3
MASS	0.10346 kg	As per standards	1 kg
NODES	1236	2991	2373
ELEMENTS	3853	14700	6699

The test will be performed in two differentpositions:

- First the impact of the helmet against the topwall at crown position and
- The impact of the helmet against the top wall

We will be using the explicit dynamics analysis system in the Ansys workbench and our solution time will be restricted to 9 milliseconds (9ms).

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The impact time or solution time= 9 millisecond

A. Finite element mesh

Due to the large relative size of the geometry an intermediate sized mesh is provided on the geometry to limit the no of elements and nodes in the geometry.

Total elements- 27137

Total nodes- 9120

De-featuring size- .005m

Multi-zone mesh is provided on the wall to get hexadominant mesh elements on the wall.

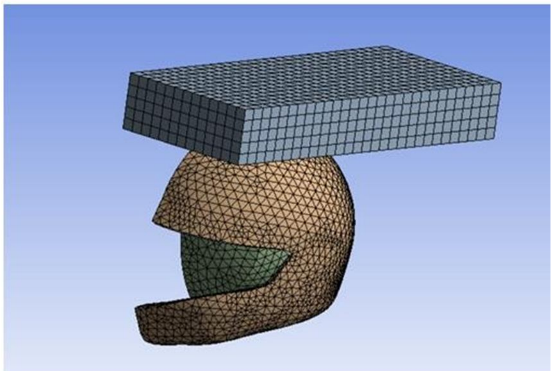

Fig 1.4: Meshed model of HF with Helmet

B. Analysis Settings

The initial impact velocity is taken as **6m/s** in the y direction and provide to the whole helmet geometry.The surface C of the wall is kept fixed for the impact to happen between the helmet and wall. The surface C and A are provided with a displacement=0 in the x direction but free to move in the y and z direction. This was done to get accurate results as only half portion of the geometry is considered. By applying the constraints of zero displacements in the X direction the results obtained for the one half can be applied to other also due to symmetry

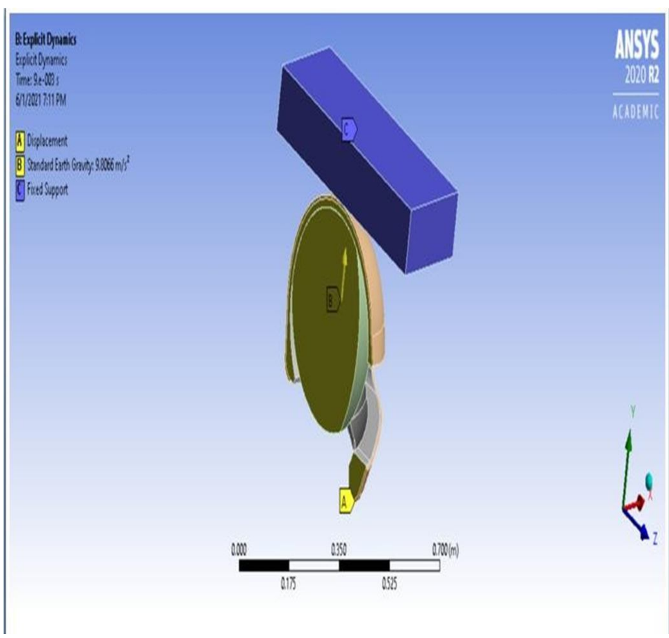

Fig 1.5: initial analysis settings

V. RESULTS

A. Impact Without Helmet At Crown Point

1) *Head:* The head foam is assigned asmagnesium K1A.
2) *Helmet:* Helmet is assigned GPRF.
3) *Wall:* wall is assigned as concrete.

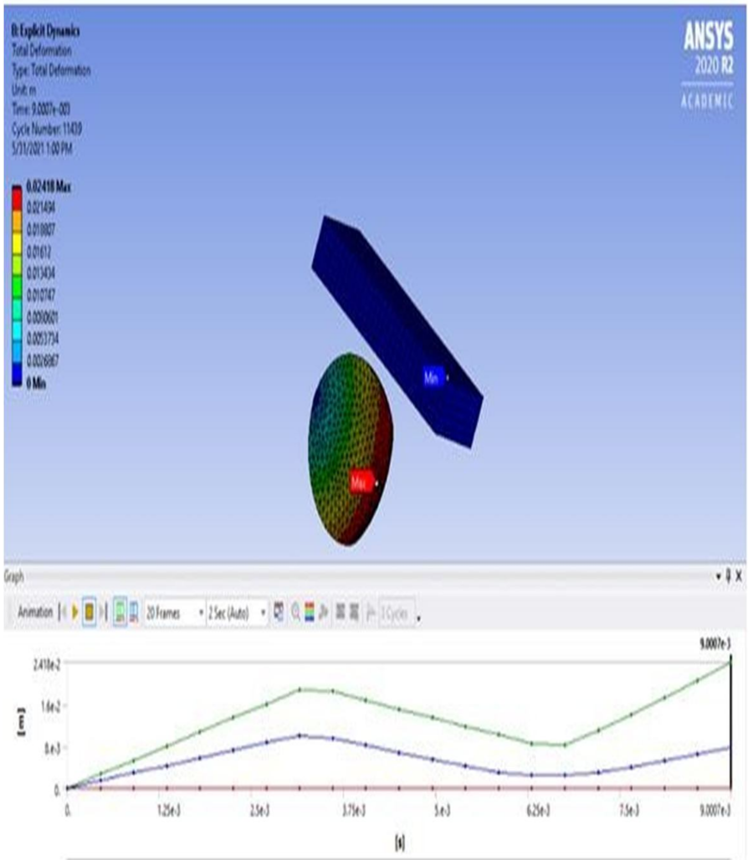

Fig 1.6: points of max and min deformation

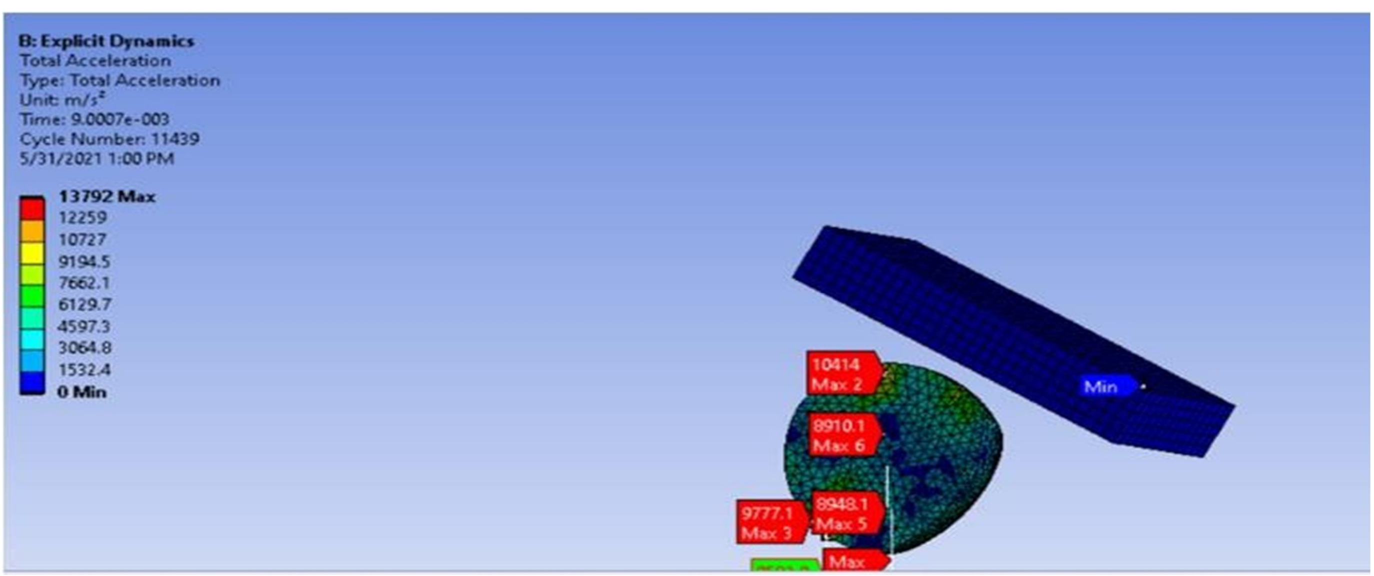

Fig .1.7: points of diff accelerations of head form

B. Impact with Helmet at Crown Point (5MPa)

1) In this analysis, the impact between the wall andhelmet is carried with rider wearing a helmet.
2) The connection between the head foam andhelmet is assumed to be frictionless for our easy.
3) Following materials are assigned to the helmetgeometry
 a) *Head:* Magnesium K1A
 b) *Inner foam :* Polystyrene (shear modulus- 5MPa)
 c) *Outer shell :*GPRF
 d) *Wall:* Concrete

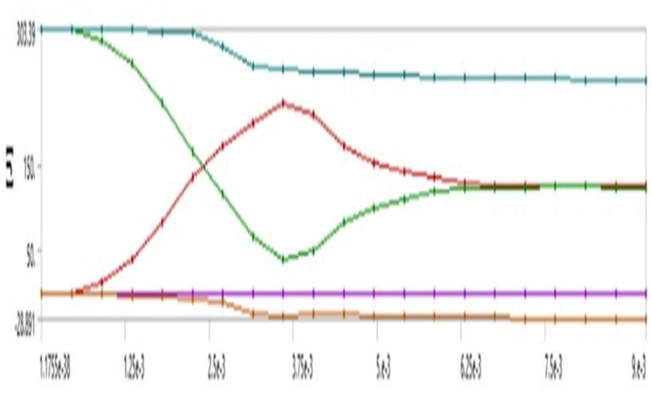

Fig 1.8: Energy probe at frontal lobe point

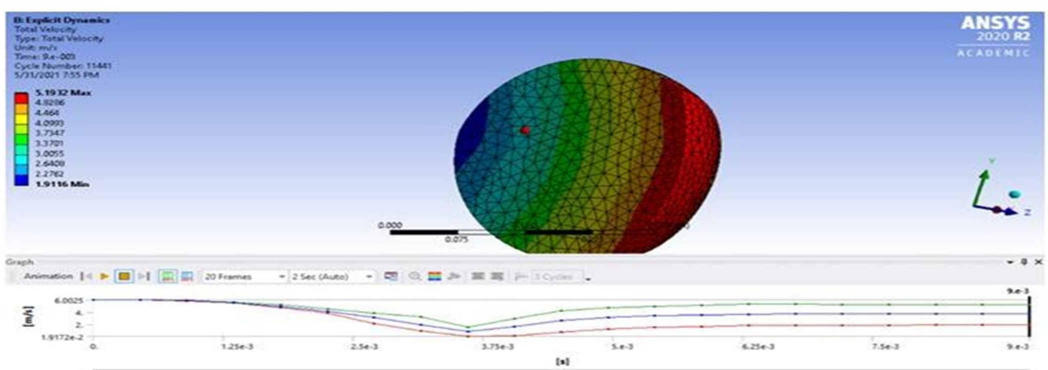

Fig 1.9: Total velocity probe

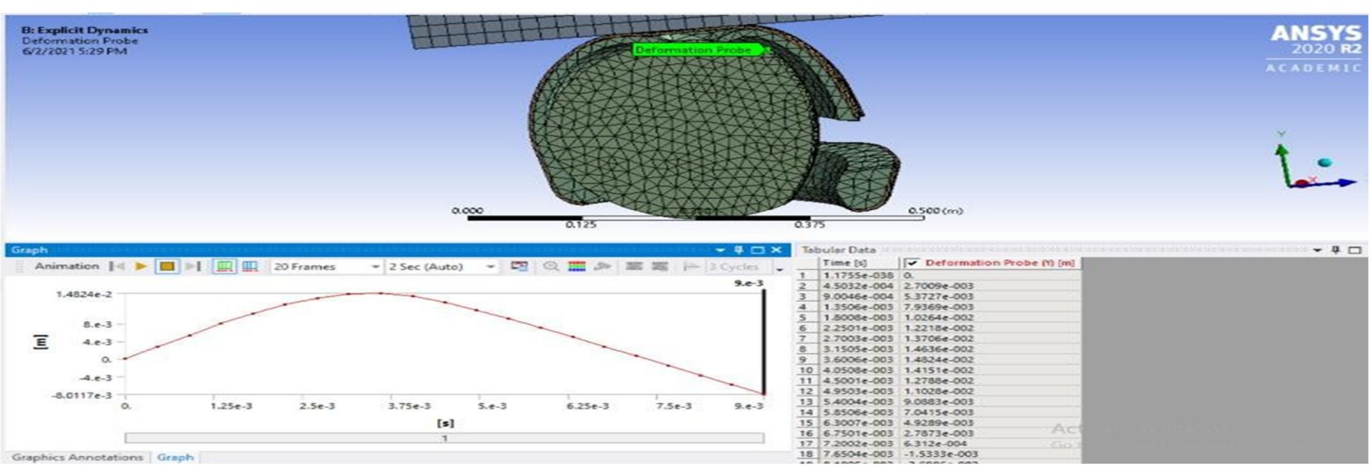

Fig.1.10: Deformation probe with helmet

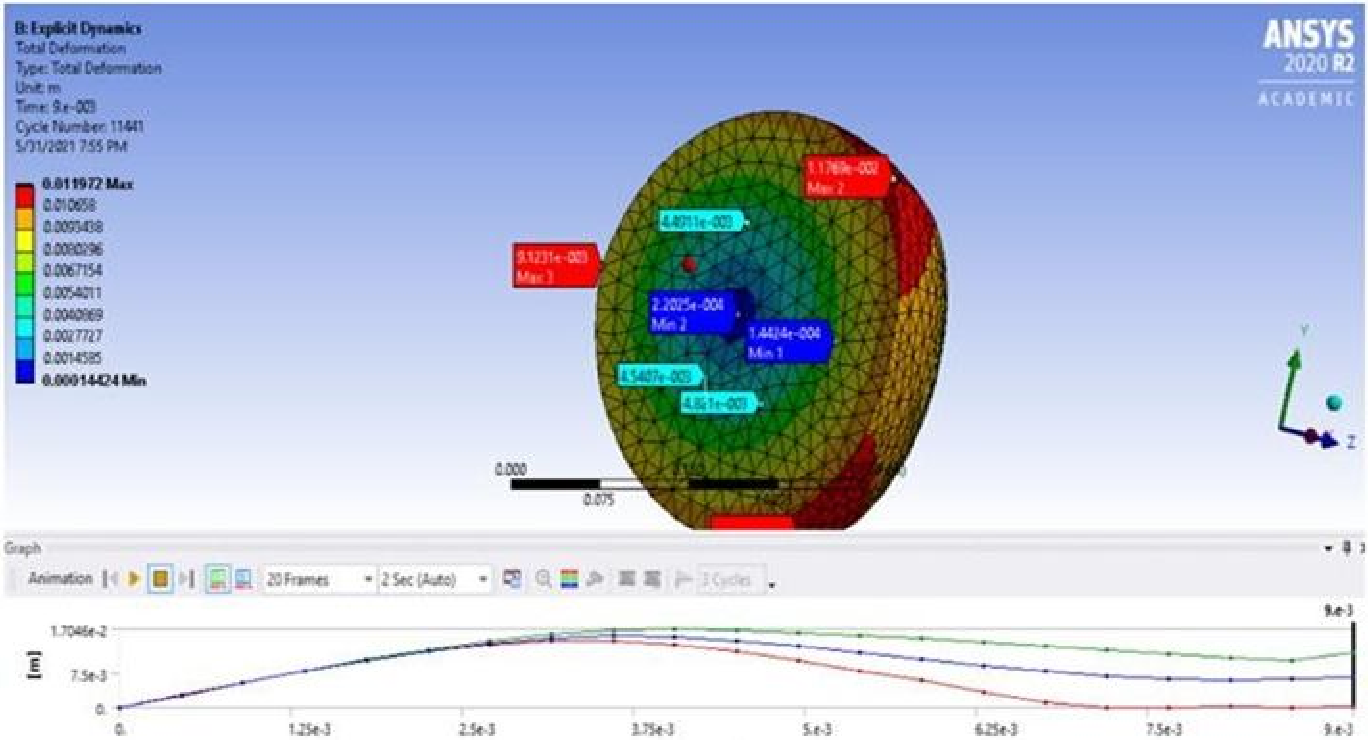

Fig 1.11: Total deformation of head foam

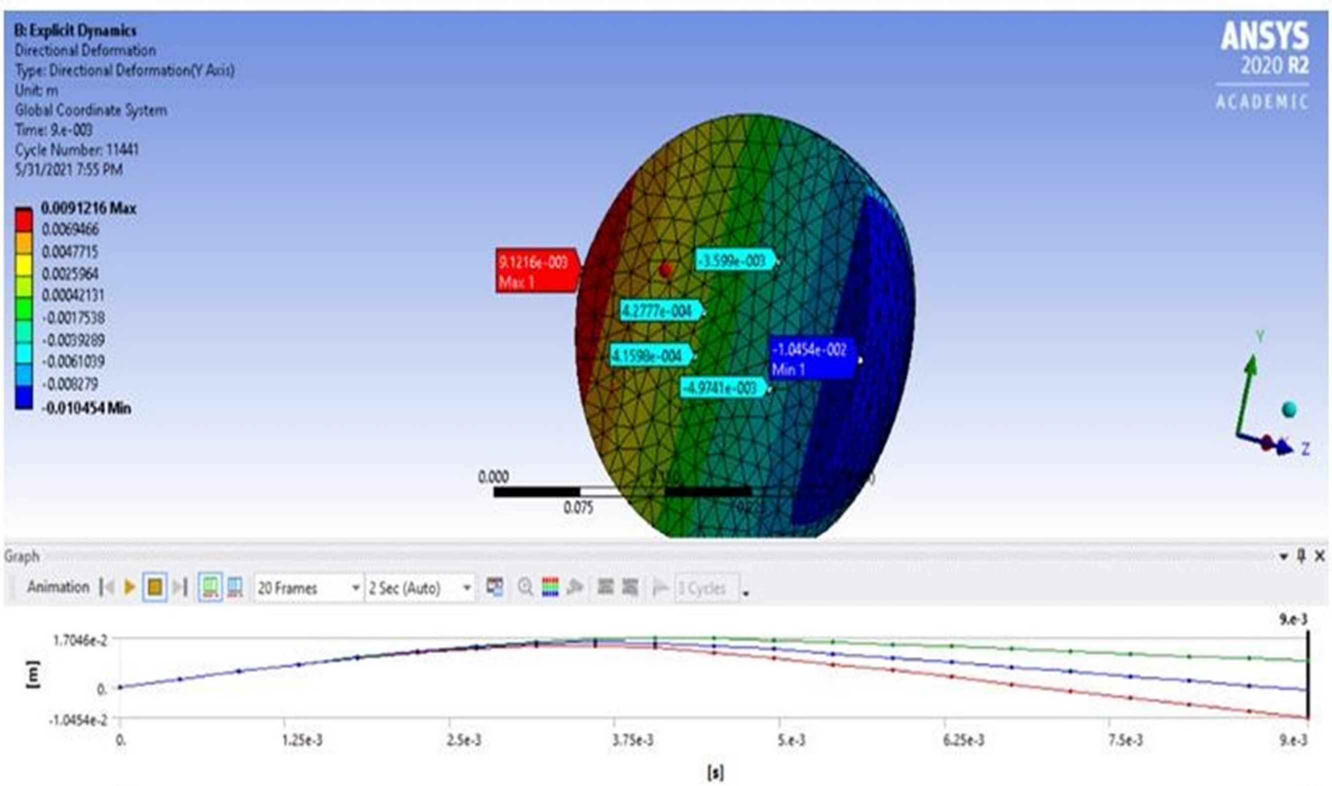

Fig 1.12: Directional deformation at y axis

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C. Impact with Helmet at Crown Point (FOR3MPa)

The same tests were performed by assigningfollowing material:

1) *Head*- Magnesium K1A
2) *Inner Foam*- Polystyrene (shear modulus –3MPa)
3) *Outer Shell*- GPRF
4) *Wall*- Concrete

Tabular Data

	Time [s]	Minimum [m]	Maximum [m]	Average [m]
1	1.1755e-038	0.	0.	0.
2	4.5032e-004	2.7013e-003	2.7024e-003	2.7023e-003
3	9.0046e-004	5.3894e-003	5.3952e-003	5.3927e-003
4	1.3506e-003	8.0212e-003	8.0464e-003	8.0333e-003
5	1.8008e-003	1.0518e-002	1.06e-002	1.0558e-002
6	2.2501e-003	1.2798e-002	1.2998e-002	1.2894e-002
7	2.7003e-003	1.4746e-002	1.5171e-002	1.4951e-002
8	3.1504e-003	1.5908e-002	1.6803e-002	1.6339e-002
9	3.6005e-003	1.5809e-002	1.7573e-002	1.6659e-002
10	4.0507e-003	1.4493e-002	1.7509e-002	1.5948e-002
11	4.5e-003	1.2363e-002	1.6884e-002	1.4545e-002
12	4.9502e-003	9.8717e-003	1.6011e-002	1.2836e-002
13	5.4003e-003	7.2609e-003	1.5057e-002	1.1025e-002
14	5.8505e-003	4.5987e-003	1.4068e-002	9.1704e-003
15	6.3006e-003	1.9161e-003	1.3066e-002	7.2992e-003
16	6.7508e-003	-7.7419e-004	1.2055e-002	5.4201e-003
17	7.2001e-003	-3.4564e-003	1.104e-002	3.5429e-003
18	7.6503e-003	-6.1285e-003	1.002e-002	1.6689e-003
19	8.1004e-003	-8.7791e-003	8.9975e-003	-1.9434e-004
20	8.5506e-003	-1.1403e-002	7.9719e-003	-2.0448e-003

Fig 5.13: showing variation of total velocity

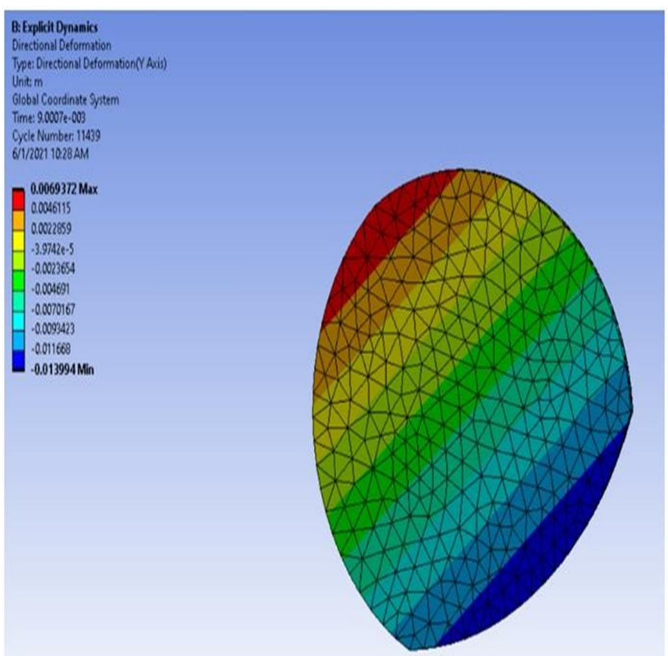

Fig 1.14: Directional deformation in y direction

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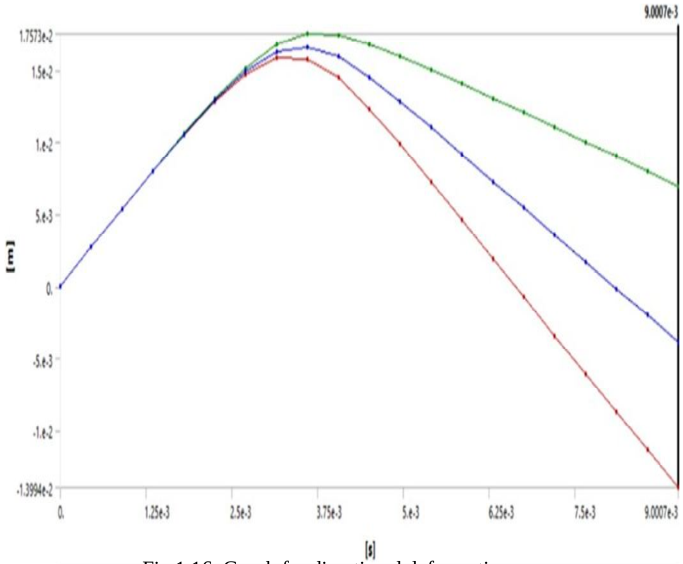

Fig 1.16: Graph for directional deformation

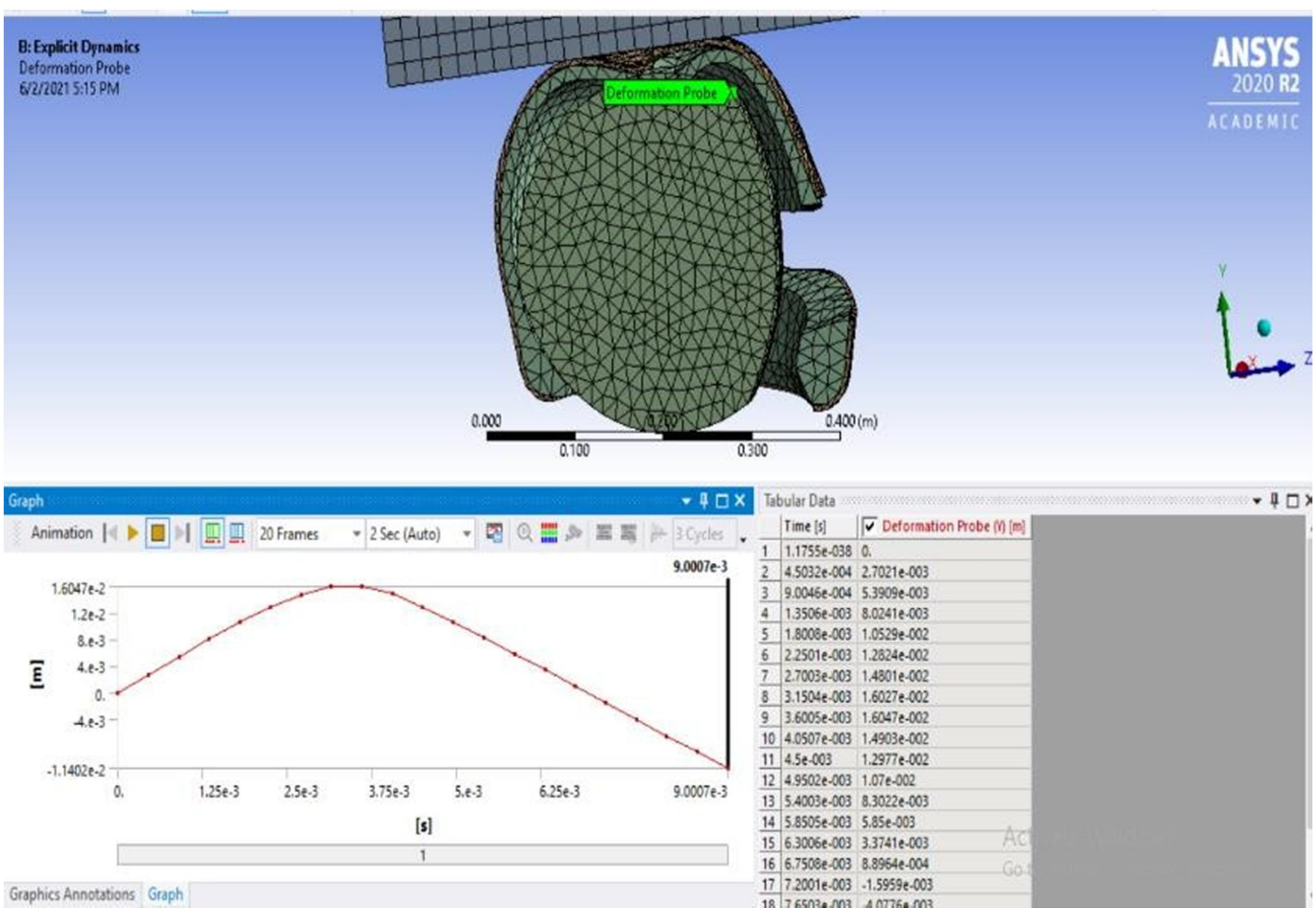

Fig 1.17: Deformation probe with helmet (for S.M of 3MPa)

Max directional deformation observed at 0.009s =6.9mm
These readings represent the deformation of headfoam at vel. of 6m/s in the y direction.

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A maximum velocity of 5.7689 was observed at theface region at the end time of 9ms.

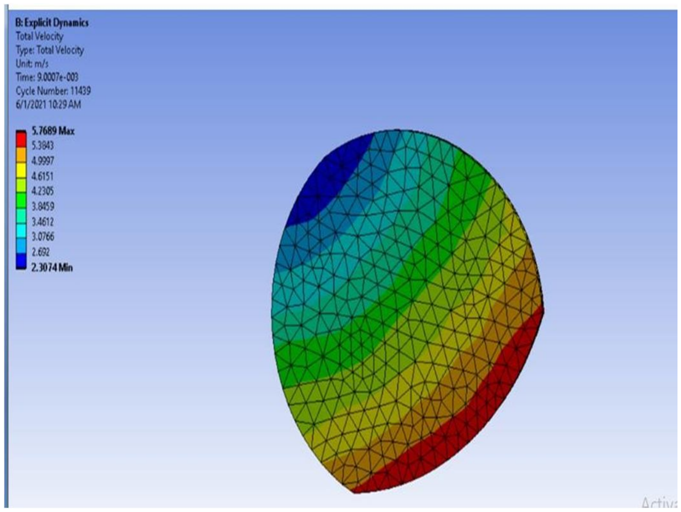

Fig 1.18: Total velocity

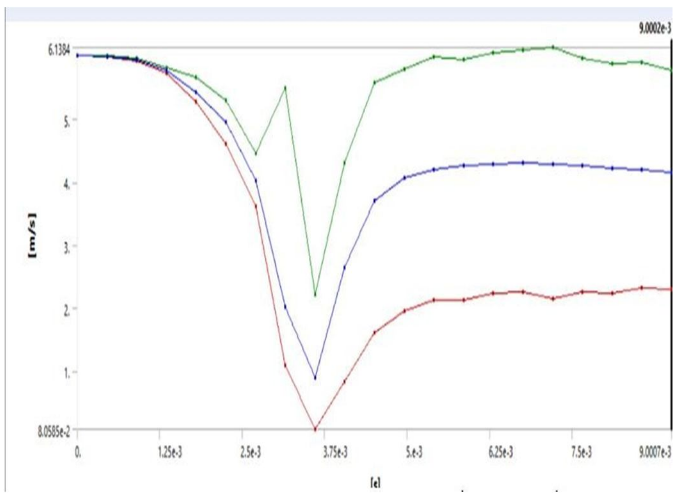

Fig 1.19: showing variation of total velocity

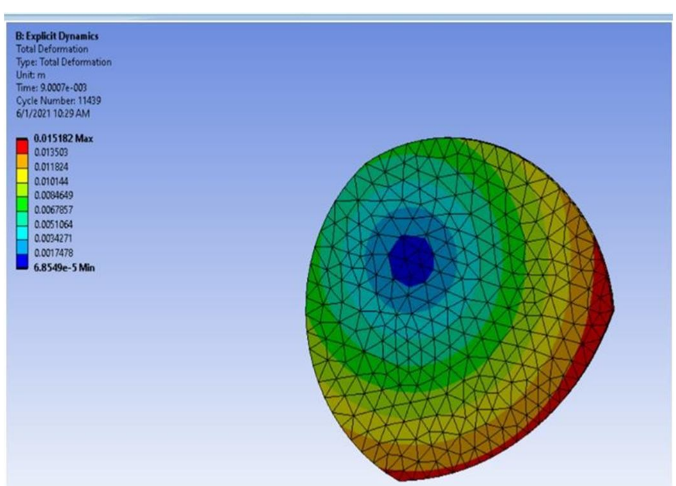

Fig 1.20: Total deformation

	Time [s]	Minimum [m/s²]	Maximum [m/s²]	Average [m/s²]
1	1.1755e-038	0.	0.	0.
2	4.5032e-004	-7130.5	5078.6	-42.986
3	9.0046e-004	-3461.5	3562.9	-303.65
4	1.3506e-003	-6312.6	16242	-413.38
5	1.8008e-003	-80921	1.8272e+005	26.175
6	2.2501e-003	-98311	94714	-694.97
7	2.7003e-003	-73670	56001	-3921.2
8	3.1504e-003	-6.5672e+005	6.736e+005	-1424.3
9	3.6005e-003	-1.5581e+005	1.9352e+005	-2479.3
10	4.0507e-003	-2.5732e+005	2.2768e+005	-2556.4
11	4.5e-003	-1.5577e+005	1.7922e+005	-2585.7
12	4.9502e-003	-2.6889e+005	1.6489e+005	1995.8
13	5.4003e-003	-95445	1.053e+005	142.31
14	5.8505e-003	-1.8302e+005	1.7284e+005	3372.4
15	6.3006e-003	-1.4748e+005	70096	-2264.9
16	6.7508e-003	-1.7612e+005	5.3455e+005	175.3
17	7.2001e-003	-45172	60642	4142.8
18	7.6503e-003	-49421	42627	294.23
19	8.1004e-003	-41490	39465	1324.8
20	8.5506e-003	-24408	51835	2490.2
21	9.0007e-003	-40475	42297	842.56

Fig 1.21: Data showing min, max and avg. acceleration attained

From the above analysis, it is possible to see that PEAK LINEAR ACCELERATION (PLA) exist between 2.5 and 3.75 milliseconds.

The average acceleration line always remains below 350g.

From the tabular data it can be seen that the averageacceleration of the head form always remain withinthe permissible limit (i.e. less than 350G).

These are the results calculated were in accordancewith the ISI certification.

This shows that using polystyrene (having shearmodulus of 3MPa), the PLA of the head form remains below 350G.

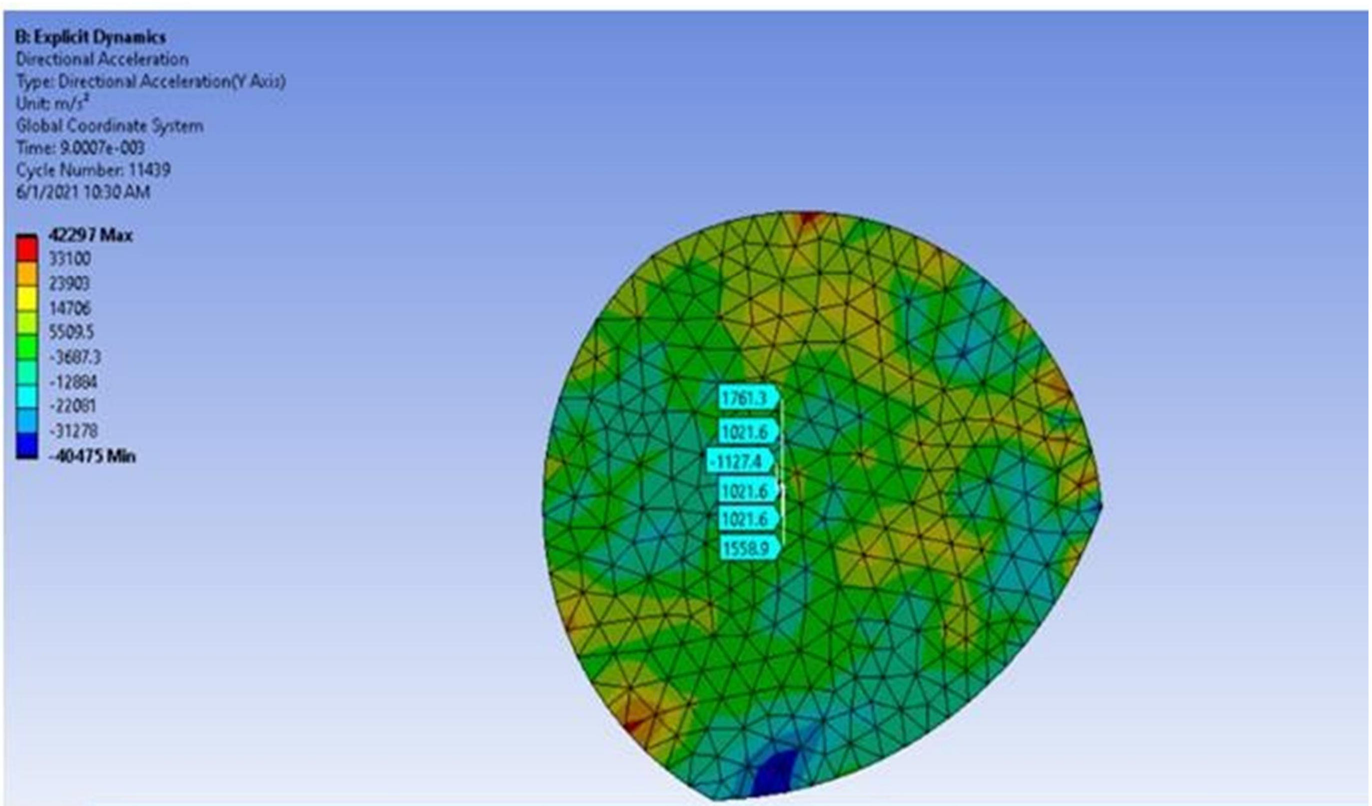

Fig 1.23: values of directional acc. near the centroid

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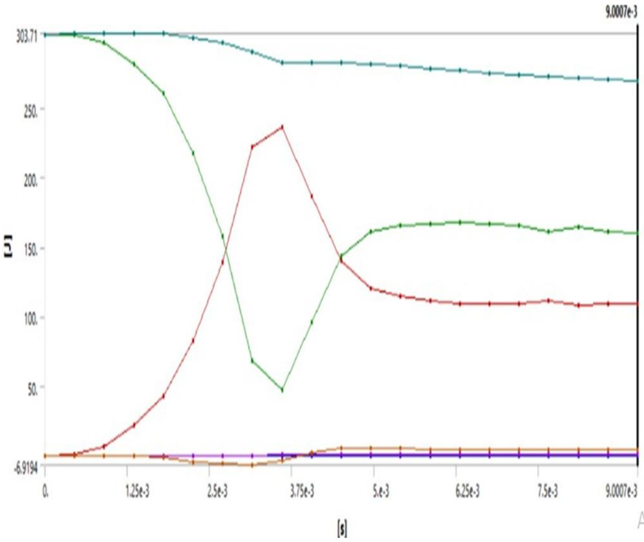

Fig 1.22: graph showing variation of diff energies

VI. OBSERVATIONS

The following are the observations made in our study for different impact velocities and sides:

1) *When head form falls at Crown Point without Helmet:* The head form experienced a maximum deformation of 24.18mm. And kinetic energy drop is 63.3%. The total deformation with polystyrene foam is 11.97mm. The head form after collision with the wall rebounded with larger velocity up to 7.5179 m/s. The peak linear acceleration experienced by the head form at C.G is 3077.1g forduration of .009s.
2) *When Head Form Falls At Crown Point with Helmet:* The head form experienced a very low deformation of11.97mm with polystyrene foam having shear modulus of 5mpa. The K.E drop is 87.15% which is greater than maximum reduction observed in Polyurethra foam of 84.17%. The helmeted head form with PS3 liner first shown reduction from 6m/s to 4.0967m/s during the impact and bounded back with the percentage reduction in velocity of 31.7%. The PLA experienced by the head form at center of gravity is150g.

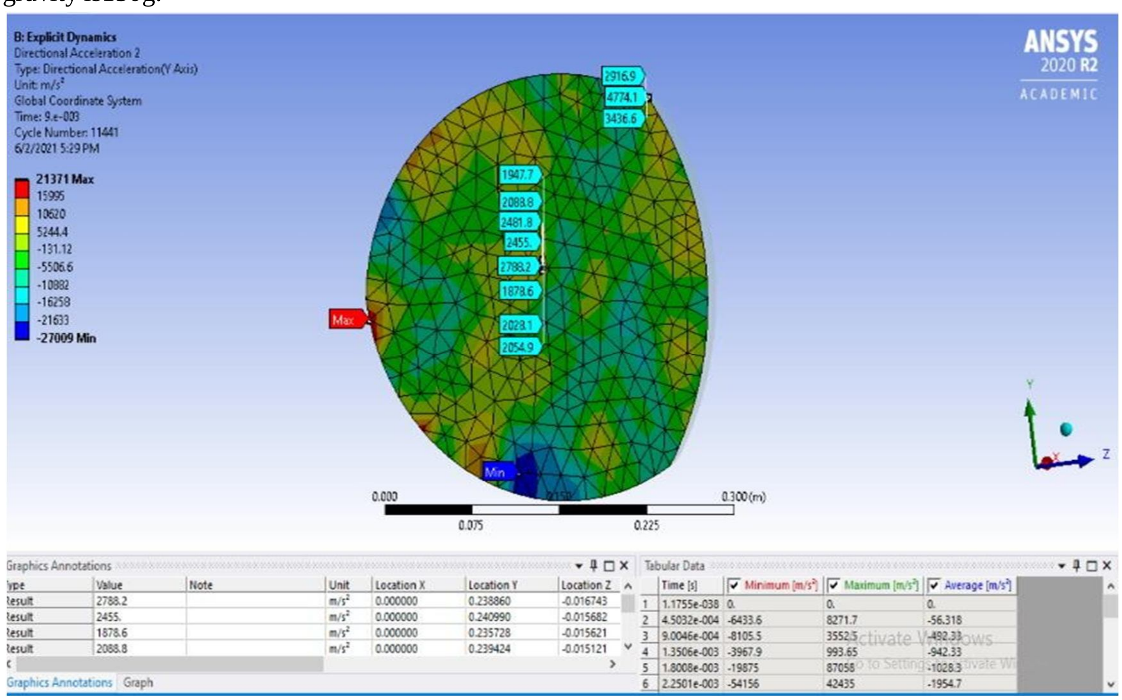

Fig 1.24: PLA of Polystyrene having shear modulus of (5Mpa)

3) *Crown Point:* The kinetic energy drop of headform is 84.5% with polystyrene liner having shearmodulus of 3Mpa and 87.15% with polystyrene liner having shear modulus of 5Mpa.

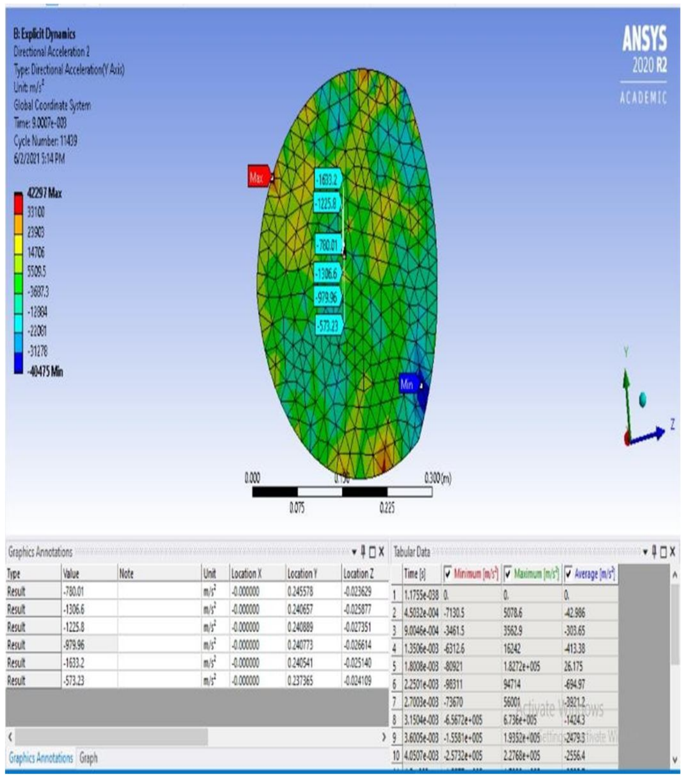

Fig 1.25: PLA of polystyrene having shear modulus of 3Mpa

From the above analysis, the PLA of head form with PS3 liner is 130 g, whereas the PLA of head form with PS5 liner is in the range of 200g - 250g(approx. 240g at center of gravity)

NOTE-This shows that PLA of helmet formincrease with increase in shear modulus of polystyrene foam.

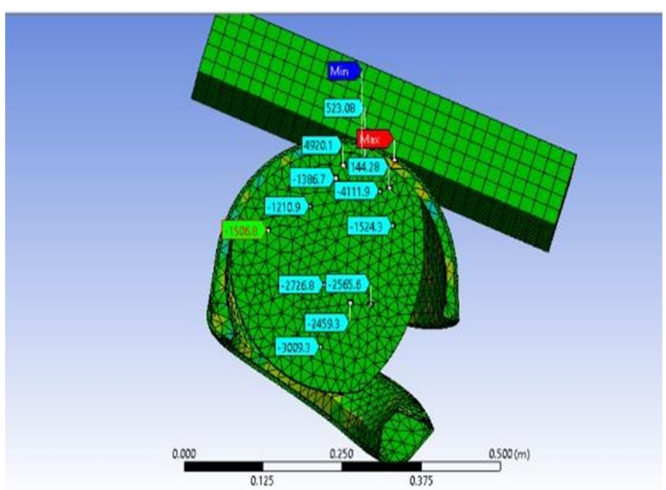

Fig 1.26:Values of directional acc. for polyurethra foam

Moreover the PLA for head foam in case of polyurethra foam was higher than that of the styrene form. So polystyrene proves to be a better material (PLA in the range of 275g to 310g). In case of PU liner, the PLA have reached 500g andeven more at certain times in the duration of the study which is an undesired effect.

The peak acceleration (G) of the head form for avariety of shell stiffness's and liner densities

	ABS	ABS	Carbon fiber
Liner density=	44kg/m^3	57 kg/m^3	57 kg/m^3
6m/s	118g (2.5 to 3.5 ms)	173.93 g (2.8 to 3.2ms)	197.8 g (3.15 to 4 ms)
8m/s	168.83 g(3.1 to 4.05ms)	566 g(2.6 to 3ms)	570 g (2.7 to 3.6)
10m/s	307.3 g	636 g (.8 to 1.2 ms)	670g
12m/s	Approx.350	901.06 (1.2 to 1.6 ms)	not preferable

A. Calculated HIC Values

IMPACT VELOCITY	ABS	ABS	CARBON FIBER
6m/s	151.25	159.5	467
8m/s	351.84	3048	6981.19
10m/s	1655.4	4080	8133.3
12m/s	-	7311.4	-

Once the average acceleration for the various timeintervals t1 to t2 of the crash have been calculated,one calculates the quantities

$$(t2-t1)*(a)^{\wedge}2.5 = (t2-t1)*[1/t2 - t1\int_{t1}^{t2} a(t)dt]^{2.5}$$

Head Injury Criteria (HIC) $_1$ = (t2-t1) * (a) $^{2.5}$ = 10^{-3} *(118)$^{2.5}$ sg$^{2.5}$

VII. CONCLUSION

Varying liner density significantly altered the peak acceleration and HIC, with both values increasing as liner density increased, regardless of shell stiffness and impact velocity varied.

Some points to be worth noting is that ABS is much stiffer (i.e. can take large load) whereas carbon fiber has less stiffness and very high strength and brittle nature. Due to this reason carbon fiber absorbs more impact energy as compared to ABS for same stress and more has high scratch resistant and more durable as compared to ABS. In terms of weight carbon fiber is much lighter as compared to ABS. Due to its high cost carbon fiber helmet is not used much commonly as compared to ABS(now a days properties of both carbon fiber and ABS are used toget highly optimized helmets).

From the tabular data it can be seen that the Peak acc. of the carbon fiber is slightly more as compared with ABS this is due to the reason that carbon fiber is weak in compression and strong intension therefore during impact slightly higher

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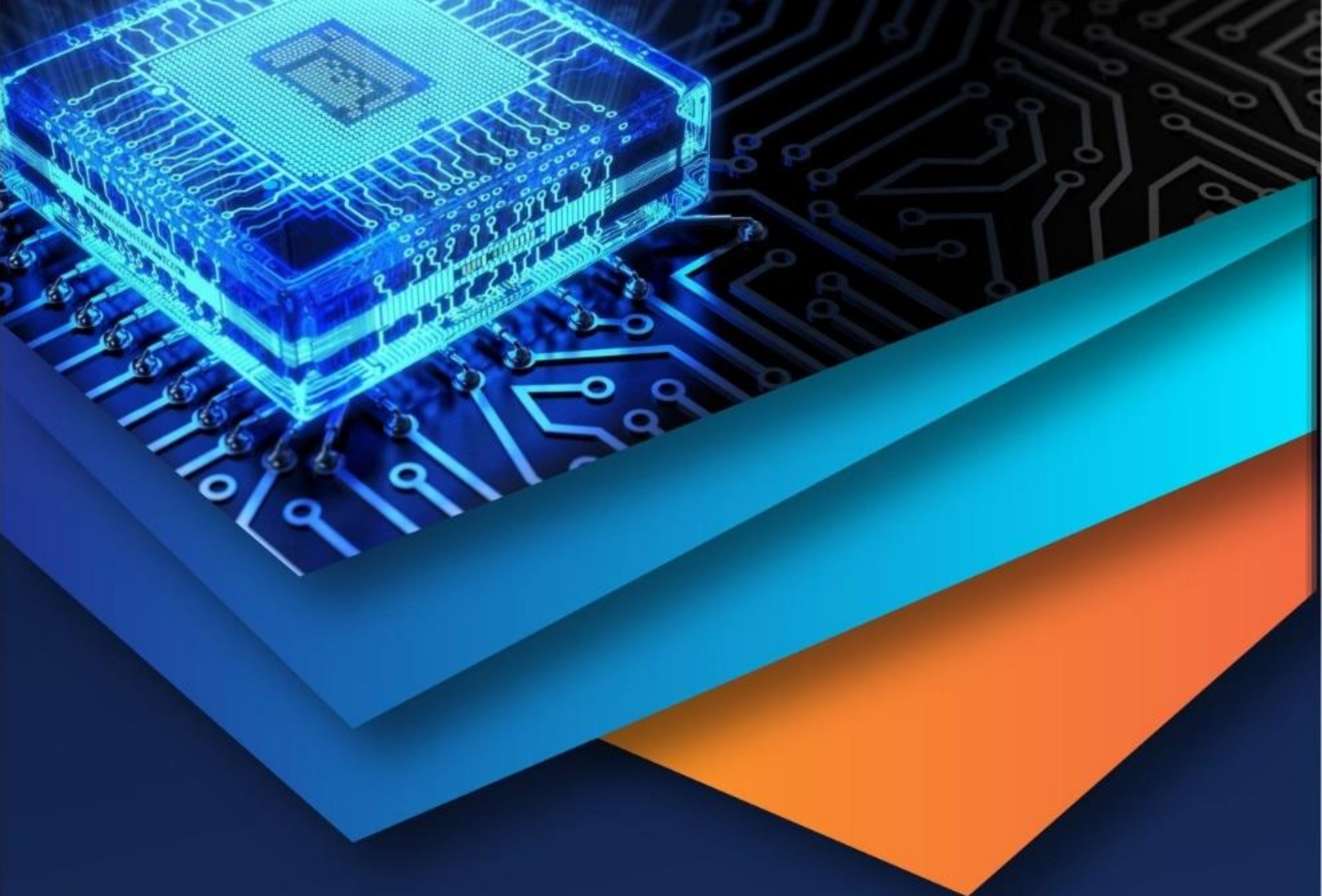

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IMPACT FACTOR: 7.429

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