EFFECTIVENESS OF COUNTERMEASURES IN RESPONSE TO FMVSS 201 UPPER INTERIOR HEAD IMPACT PROTECTION

Arun Chickmenahalli
Lear Corporation
Michigan, USA
Tel: 248-447-7771
Fax: 248-447-1512
E-mail: achickmenahalli@lear.com

ABSTRACT

Analysis and development of countermeasures in meeting vehicle upper interior free motion headform (FMH) impact safety requirement (FMVSS 201) has become an important aspect for engineers. FMVSS 201 safety regulation stipulates that the Head Injury Criterion, HIC (d) should be less than 1000 when a FMH is impacted at a speed of 15 mph. The interior components of a vehicle generally do not generate high HIC (d) numbers by themselves but the steel structures behind them to which they are attached do so. The gap between the interior component and the steel structure makes a provision for the introduction of some countermeasures which can absorb the kinetic energy of the FMH in the form of internal energy so that the acceleration response of the FMH does not generate high HIC (d) and Peak G force.

This paper discusses a methodology in developing a countermeasure for automotive interior components to comply with FMVSS 201 requirements. The effectiveness of introducing a countermeasure between the headliner and the steel structure or the body in white (BIW) is evaluated through Finite Element Analysis using a dynamic finite element tool, LS-DYNA. Several geometric configurations of the countermeasure have been studied to ascertain its suitability in absorbing the kinetic energy of the FMH. Parametric studies have been carried out by varying the thickness of the countermeasure to see the effect on the injury parameters, HIC (d) and Peak G. Finite element analysis results are compared with the test results as per the FMVSS 201 regulations to deduce concrete conclusions about the effectiveness of the countermeasure.

Keywords: Countermeasure, Safety Plastic, Initial Thickness, Damage, FMVSS 201

INTRODUCTION

Federal Motor Vehicle Safety Standard (FMVSS) 201 upper interior head impact protection specifies the requirements to afford impact protection for occupants. This standard applies to passenger cars and to multipurpose passenger vehicles, trucks, busses with a GWR of 10,000 pounds or less. The criterion for compliance to FMVSS 201 is based on Head Injury Criterion (HIC (d)) which is calculated from the center of gravity of the head resultant acceleration. The performance criterion set by FMVSS 201 is that the HIC (d) shall not exceed 1000 when calculated in accordance with the formula:

HIC (d) = 0.75446 (free motion headform HIC) + 166.4.

The free motion headform HIC is calculated in accordance with the following formula:

$$\left[\frac{1}{(t_2 - t_1)}\int_{t1}^{t2} a\,dt\right]^{2.5}(t_2 - t_1)$$

Where the term '*a*' is the resultant acceleration expressed as a multiple of the acceleration of gravity, and t_1 and t_2 are any two points in time during the impact which are separated by not more than a 36 millisecond time interval.

Finite Element Analysis (FEA) is an effective tool which is used to study and develop new concepts and reduce prototyping costs. By the use of FEA, many alternatives could be tried and parametric studies can be easily carried out. The main objective of this study was to analyze, compare and summarize the FMVSS 201 correlation study done on some countermeasures. The main aim was to compare the finite element analysis results to the test results as per the FMVSS 201 specifications in terms of HIC(d) and Peak Acceleration values and also to develop a methodology for simulating safety plastic accurately in computer simulations using a Finite Element Codes. In this study, a baseline model was simulated and then the effectiveness of introducing a countermeasure was evaluated. A cone shaped polypropylene countermeasure with varied geometric configurations with varied thickness was simulated. Different heights of the cone, which represents the gap between the body-in-white and the headliner, are studied. The tests were conducted with the free Motion Headform (FMH) pendulum set up and results were correlated with the FEA results.

FTSS HYBRID III HEADFORM MODEL

FMVSS 201 stipulates that a deformable HYBRID III headform shall be used for the analysis and testing. The headform is given an initial velocity of 15 mph as per NHTSA standards. The main aim of study here is to see that the kinetic energy of the headform is absorbed by the countermeasure as internal energy. The center of gravity node of the headform is taken as the reference for all the simulation characterization. The acceleration response of the center of gravity node is plotted to calculate the HIC(d) and also the Peak G. The reduction in velocity for the rigid headform is intended to account for the energy dissipation caused by the skin of the deformable headform. For saving the computational time, a rigid finite element representation of the headform is used in the analysis. The outer surface of the headform is defined by finite elements which is used to define the contact between surfaces and will come in to importance for the activation of contact forces.

GENERAL MODEL DESCRIPTION

Finite element modeling was done by using HYPERMESH as the pre-processor and the analysis was done by using LS-DYNA dynamic solver. The post processing was done using LS-POST. The countermeasure was modeled with shell elements. The cones of the countermeasure were modeled in such a manner that the top, side and the base could be assigned different thickness. Material model with plasticity and damage was introduced to simulate the correct behavior of the countermeasure in reality. Finite Element Simulations were done for the following configurations:

1. Baseline model with a hat sectioned 15-gage sheet metal.
2. 20 mm cone height with the initial thickness of the countermeasure being 0.04 inches.
3. 14.5 mm cone height with the initial thickness of the countermeasure being 0.04 inches.
4. 10 mm cone height with the initial thickness of the countermeasure being 0.04 inches.
5. Parametric studies for 20 mm, 14.5 mm and 10 mm cone height with varying initial thickness of the countermeasure.

This paper provides the results and discussions for the above mentioned configurations.

BASELINE MODEL

The baseline model had a hat section which simulated the in-car scenario. The edges of the hat section were fixed at the corners and the free motion headform impacting to the center of the hat section. Free Motion Headform was impacted with a 10 degree inclined 15-gage sheet metal (Figure 1) with an initial velocity of 15 mph. Efforts were made to estimate the HIC (d) and the peak acceleration values. Finite Element Analysis results were compared with the test results. It is evident from Table 1 that the results of the finite element analysis match with the test results. Also, Figure 2 shows the plot of the acceleration versus time for the center of gravity node of the headform for the analysis and test, which are in acceptance with each other. Figure 3 shows the energy balance during the impact.

INCORPORATING THE COUNTERMEASURE TO THE BASELINE MODEL

Safety Plastic: It is a multiple cone shaped, thermoformed polypropylene countermeasure for head impact, developed by Oakwood Group, which has a good energy absorbing capability during an impact (Figure 4).

Initial Thickness: The thickness of the polypropylene sheet before it is thermoformed.

Table 2* shows the percentage improvement in the HIC (d) values by using safety plastic in-place of conventional foam. In order to analyze the effectiveness of safety plastic as a countermeasure, to the baseline model, safety plastic was incorporated (Figure 5).

**Reference: Oakwood Group Data*

Analysis of 20 mm cone height with 0.04 inch initial thickness

Free motion headform was impacted with the safety plastic and the background being the 15-gage sheet metal inclined at 10 degrees. The headform was given an initial velocity of 15mph. The simulation results were compared with the test results in terms of HIC (d) and peak acceleration values. From Table 3, it is evident that the simulation and test results correlate well. The comparison of acceleration versus time graph shown in Figure 6, indicates that the simulation curve matches the test curve. Figure 7 shows the energy balance in the impact process.

Parametric study of 20 mm cone height

A parametric study was done by varying the initial thickness of the safety plastic and to study the effect of the same on the HIC (d) and peak acceleration values were studied. Table 4 gives the results of the parametric study. The HIC (d) and the peak acceleration values reduced as the thickness was increased from 0.04 inches to 0.05 inches but did not improve for a higher initial thickness of 0.06 inches. So it is evident that, with a 20 mm cone height, increasing the initial thickness more than 0.06 inches may not help in reducing the injury parameters.

Analysis of 14.5 mm cone height with 0.04 inch initial thickness

Free motion headform was impacted with the safety plastic and the background being the 15-gage sheet metal inclined at 10 degrees. The headform was given an initial velocity of 15mph. The simulation results were compared with the test results in terms of HIC (d) and peak acceleration values. From Table 5, it is evident that the simulation and test results match very closely. The comparison of acceleration versus time graph shown in Figure 8 indicates that the simulation curve matches with the test curve. Figure 9 shows the energy balance in the impact process.

Parametric study of 14.5 mm cone height

A parametric study was done by varying the initial thickness of the safety plastic and the effect of the same on the HIC (d) and peak acceleration values were studied. Table 6 gives the results of the parametric study. The HIC (d) and the peak acceleration values reduced as the thickness was increased from 0.04 inches to 0.05 inches and further to 0.06 inches. Unlike in the case of 20-mm cone height for 0.06 inches initial thickness, the injury parameters showed a decline. This shows that the use of a higher thickness for a lower cone height helps in reducing the injury parameters to some extent. But for a initial thickness of 0.07 inches, the injury parameters increased.

Analysis of 10 mm cone height with 0.04 inch initial thickness

Free motion headform was impacted with the safety plastic and the background being the 15-gage sheet metal inclined at 10 degrees. The headform was given an initial velocity of 15mph. The simulation results were compared with the test results in terms of HIC (d) and peak acceleration values. From Table 7, it is evident that the simulation and test results match very closely.

Parametric study of 10 mm cone height

A parametric study was done by varying the initial thickness of the safety plastic and the effect of the same on the HIC (d) and peak acceleration values were studied. Table 8 gives the results of the parametric study. The HIC (d) and the peak acceleration values reduced as the thickness was increased from 0.04 inches to 0.05 inches but did not improve for a higher initial thickness of 0.06 inches. So it is evident that, with a 10 mm cone height, increasing the initial thickness more than 0.06 inches may not help in reducing the injury parameters.

PHYSICAL TESTING

Free Motion Headform pendulum tests were conducted at the Lear facility in Southfield, Michigan. Ten tests were conducted and the repeatability of the results was found to be good. Free motion headforms launched from a height by the use of pendulum, were given an initial velocity of 15 mph. The headforms were impacted with a rigid fixture to simulate the real in-car situation.

CONCLUSION

From the correlation study, it is very clear that Finite Element Analysis and especially the dynamic explicit solver LS-DYNA is a good tool for accurately simulating head impact and the safety plastic. Also it can be deduced that safety plastic can be an effective countermeasure. A good correlation is achieved with the finite element analysis results and the test results in terms of HIC (d) and Peak Acceleration values. Also the acceleration versus time curves from the analysis match very closely with the test curves.

From the parametric studies of the 20mm cone height without the headliner for varying thickness, it is evident that the increase in initial thickness of the safety plastic does not necessarily decrease the injury parameters. For each configuration an optimum thickness does exist to have a desirable and safe design to achieve reasonable injury parameters in accordance with FMVSS 201. For a cone height of 20mm and 0.04-inch initial thickness with the headliner, the HIC (d) value is in accordance with the FMVSS 201 standards.

Table 9 gives the percentage improvement in HIC (d) values of the safety plastic model without the headliner for various initial thickness over the baseline model. This shows that safety plastic could be an effective countermeasure for reducing the injury parameters. Figure 10 shows the internal energy absorbed by the safety plastic material during the impact process. As the safety plastic absorbs some energy during the impact process, we can infer that by incorporating safety plastic countermeasure we can reduce the injury parameters to a considerable extent in accordance with FMVSS 201 requirements.

For a given cone height, by using an appropriate initial thickness of the safety plastic, the injury parameters can be reduced to a large extent.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the help extended by the Lear Corporation Test Lab engineers and technicians and also the co-operation by the Oakwood Group engineers.

REFERENCES

A. Deb, S. Calso, N. Saha, “Effectiveness of Countermeasures in Upper Interior Head Impact”, SAE Technical Paper Number 970391, Detroit, Michigan.

S. D. Barbat, P. Prasad, “Finite Element Modeling of Structural Foam and Head Impact Interaction with Vehicle Upper Interior”, SAE Technical Paper Number 950885, Detoit, Michigan

NHTSA, Laboratory Test Procedure for FMVSS 201 Upper Interior Head Impact Protection (TP-201U-01, 1998)

Amoco Product Guide, Amoco Polymers, 4500 McGinnis Ferry Road, Alpharetta, Georgia- 30005.

H. A. Rychlewski, P. M. Miller II, “A General Discussion on Interior Design Alternatives in Response to FMVSS 201 U- Upper Interior Head Impact Protection”, SAE Technical Paper Number 982348.

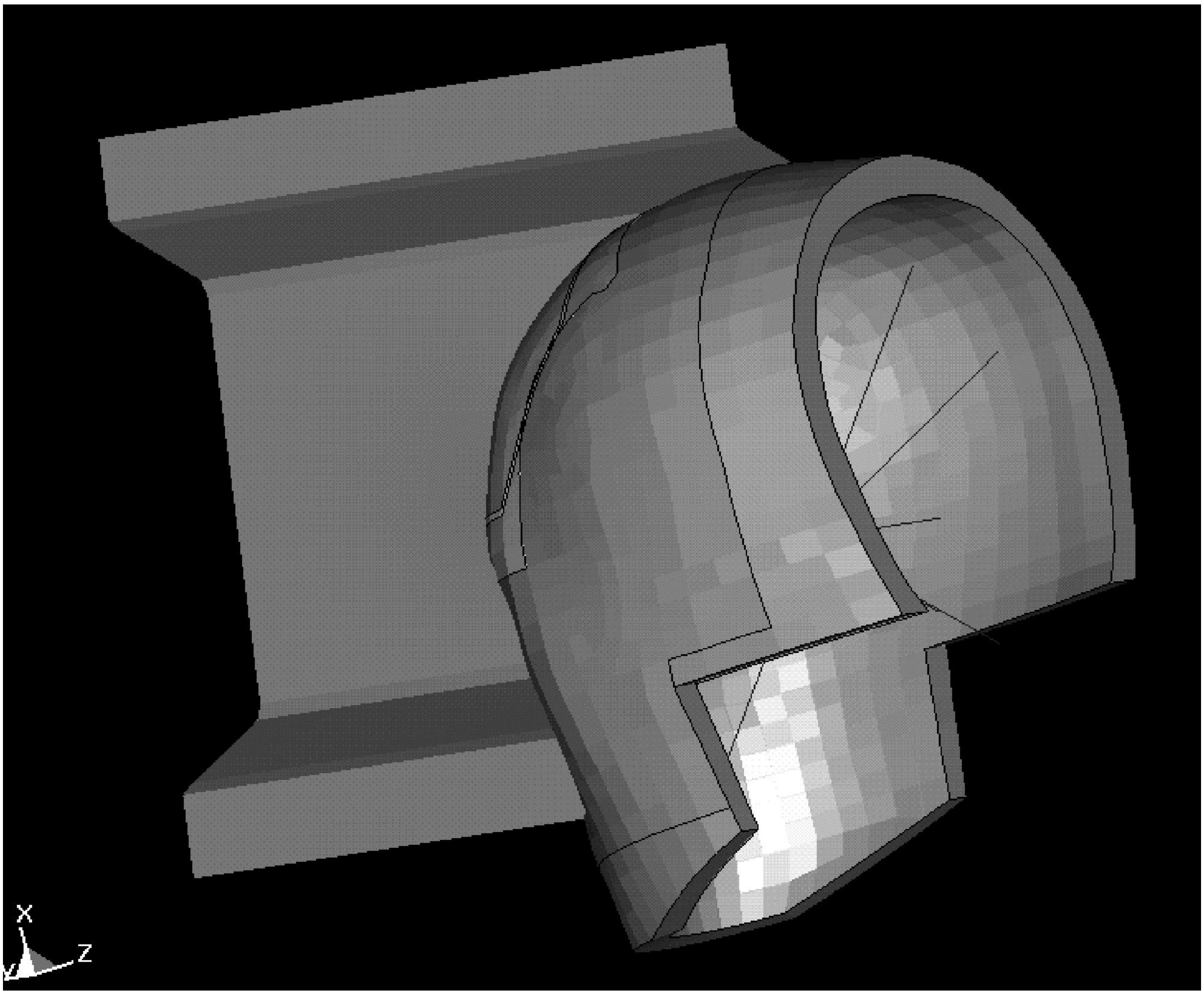

Figure 1: Baseline model with the Free Motion Headform impacting the hat sectioned sheet metal

Table 1: Comparison of results for a headform impact with a 15 gage sheet metal

	TEST	FEA
HIC (d)	1772	1775
PEAK ACC, G's	253	245

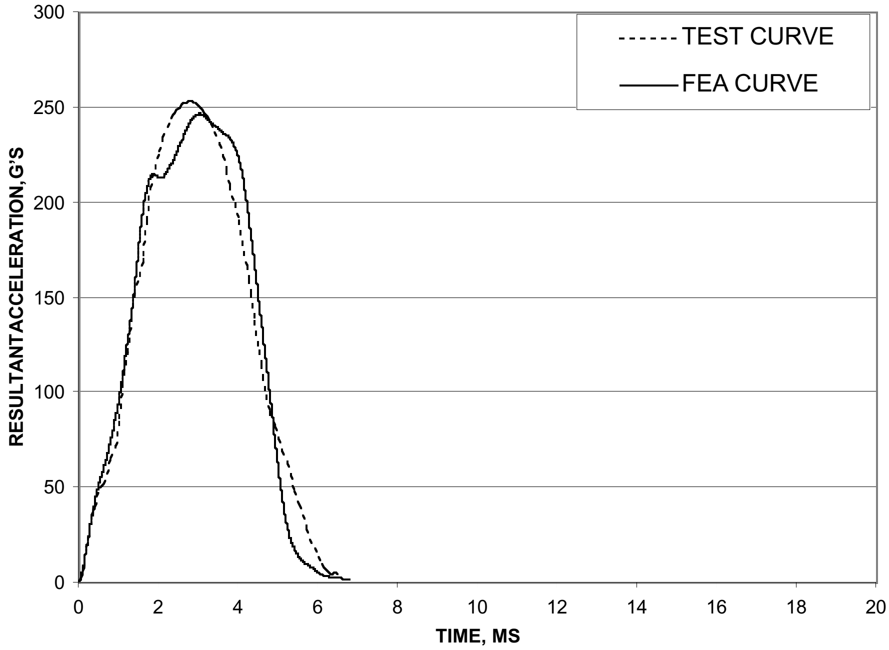

Figure 2. Comparison of acceleration Vs time curves for the baseline model.

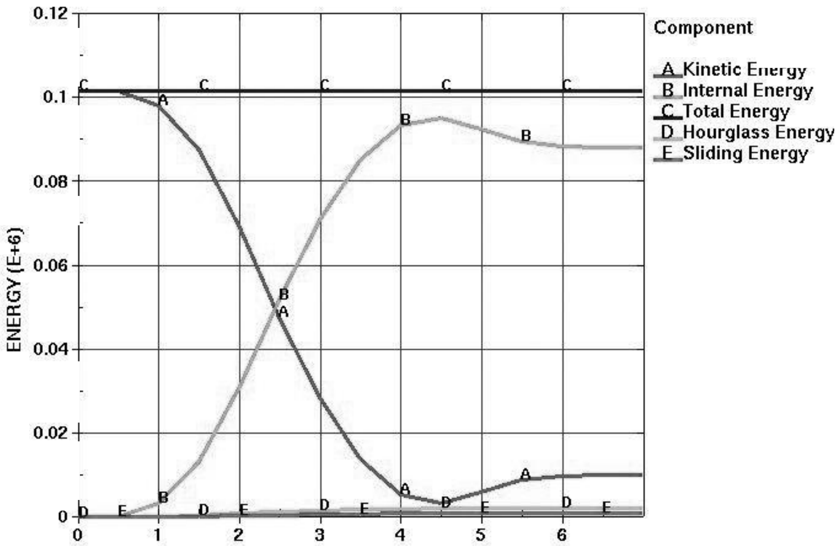

Figure 3: Energy balance plot for the baseline model.

Table 2: Comparison of the HIC(d) values for safety plastic and foam.

SAFETY PLASTIC	FOAM	%IMPROVEMENT
766	820	7%

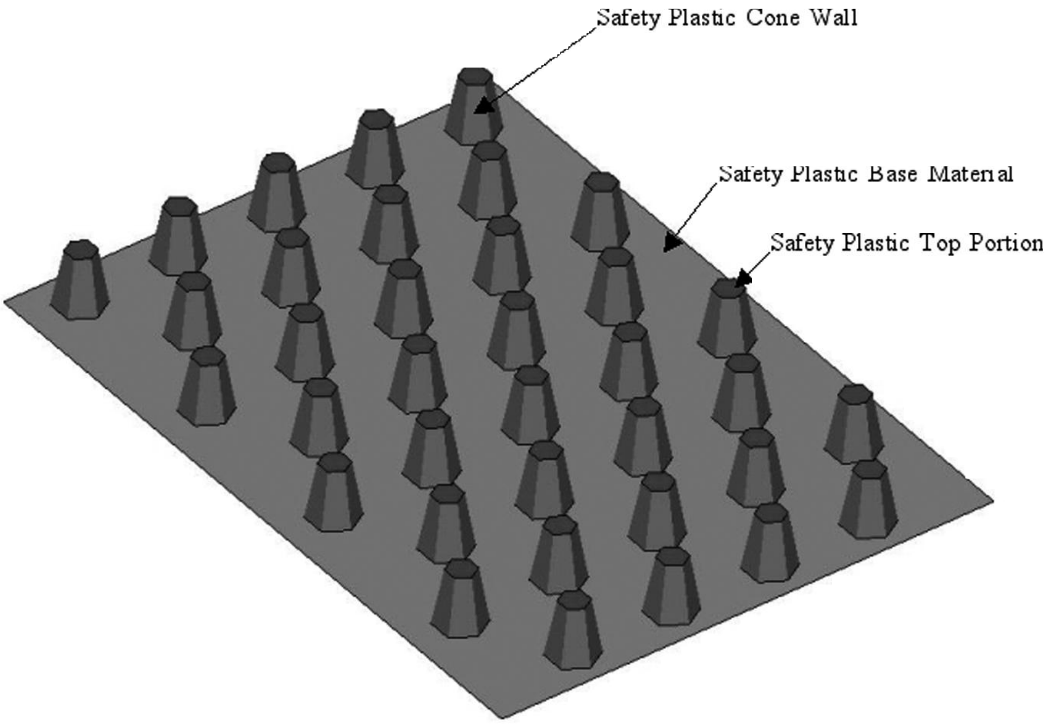

Figure 4: Diagram of a Safety Plastic

Table 3: Comparison of test and FEA results for 20 mm cone height and 0.04 inch initial thickness of the safety plastic.

	TEST	FEA
HIC (d)	1075	1081
PEAK ACC, G's	195	198

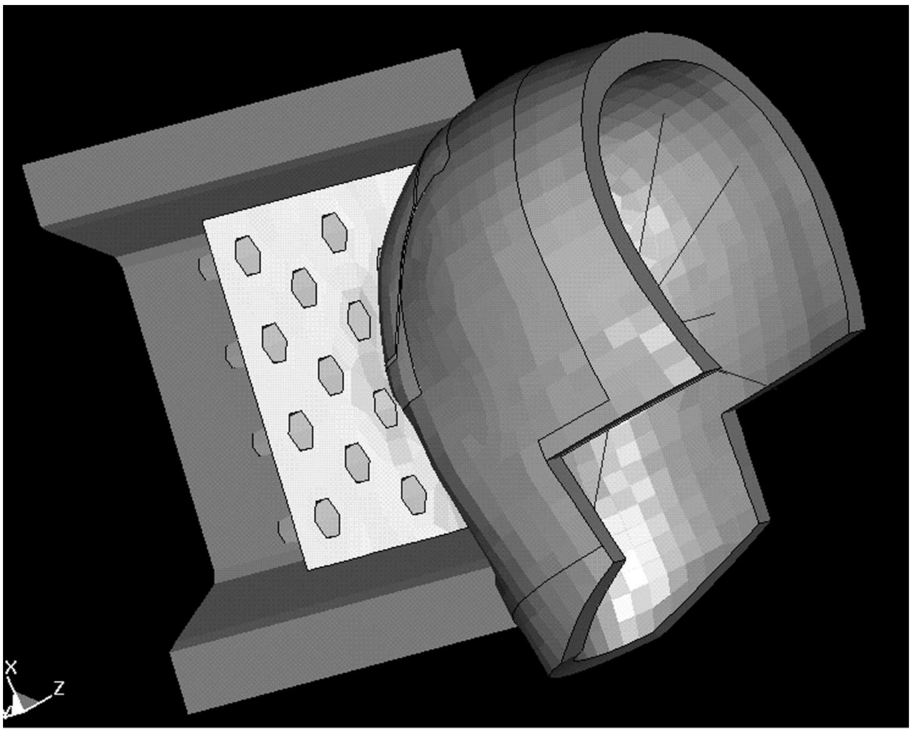

Figure 5: Diagram showing the introduction of safety plastic countermeasure.

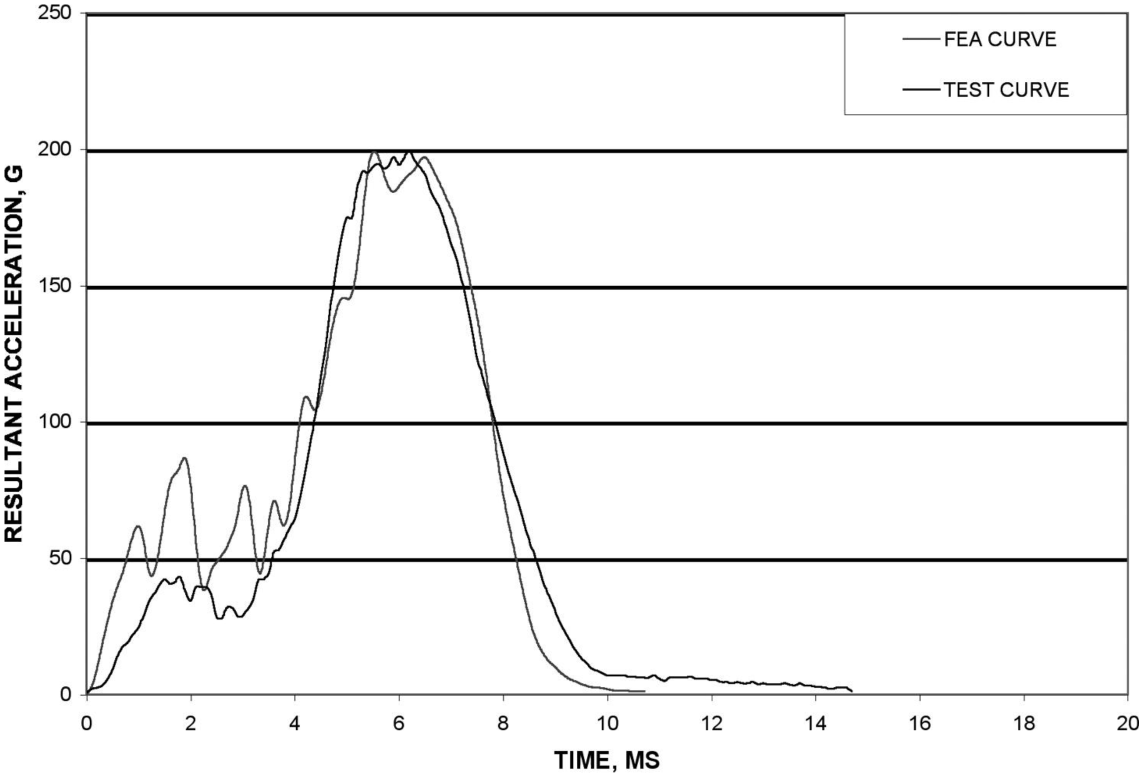

Figure 6: Comparison of acceleration Vs time curves for 20 mm cone height and 0.04 inch initial thickness of the safety plastic.

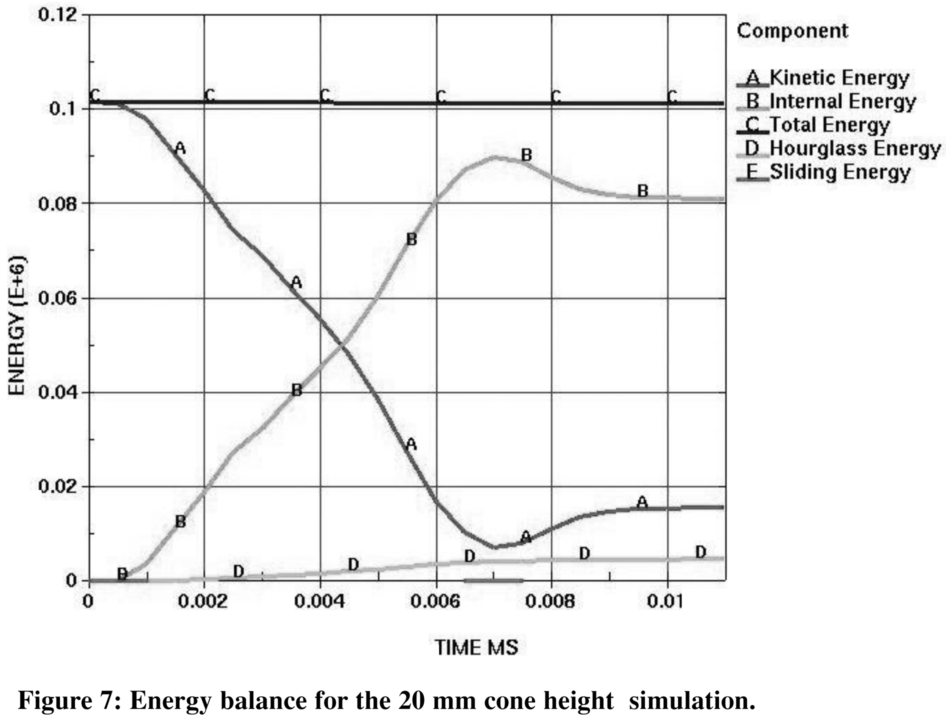

Figure 7: Energy balance for the 20 mm cone height simulation.

Table 4: Parametric study results for 20 mm cone height with varied initial thickness

HEIGHT OF THE CONE,	MMINITIAL THICKNESS, INCHES	HIC(d)	PEAK ACC IN G's
20	0.04	1081	198
20	0.05	795	160
20	0.06	843	164

Table 5: Comparison of results for 14.5 mm cone height and 0.04 inch initial thickness.

	TEST	FEA
HIC (d)	1280	1289
PEAK ACC, G's	225	224

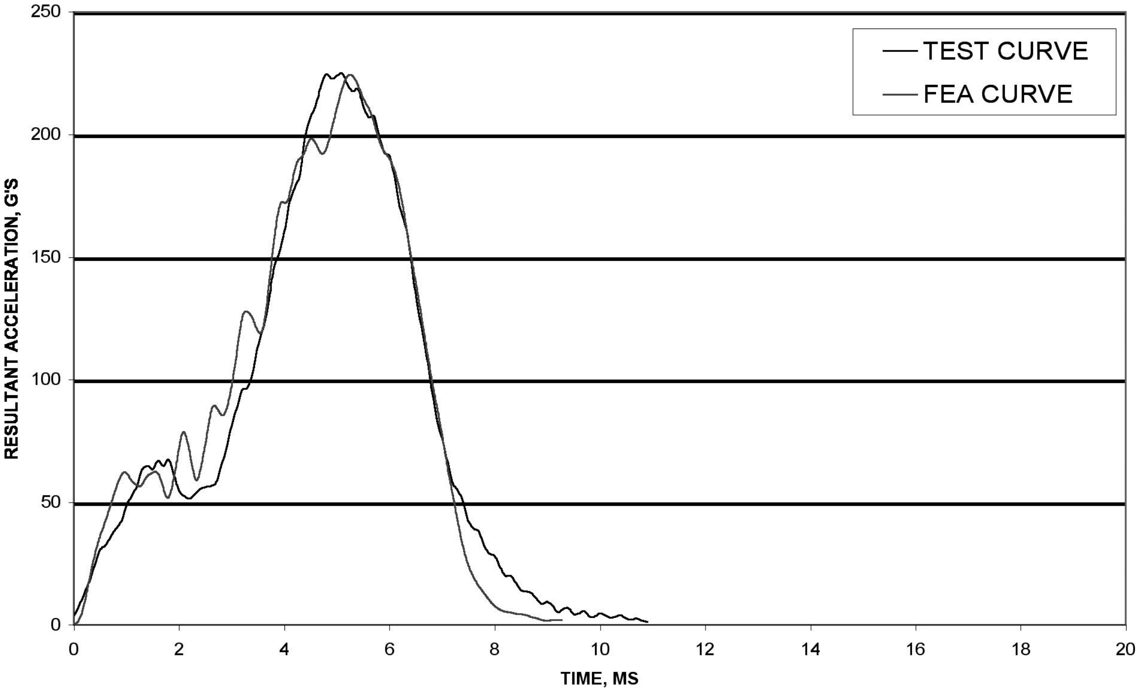

Figure 8: Comparison of acceleration Vs time curves for 14.5 mm cone height with 0.04 inch initial thickness of the safety plastic.

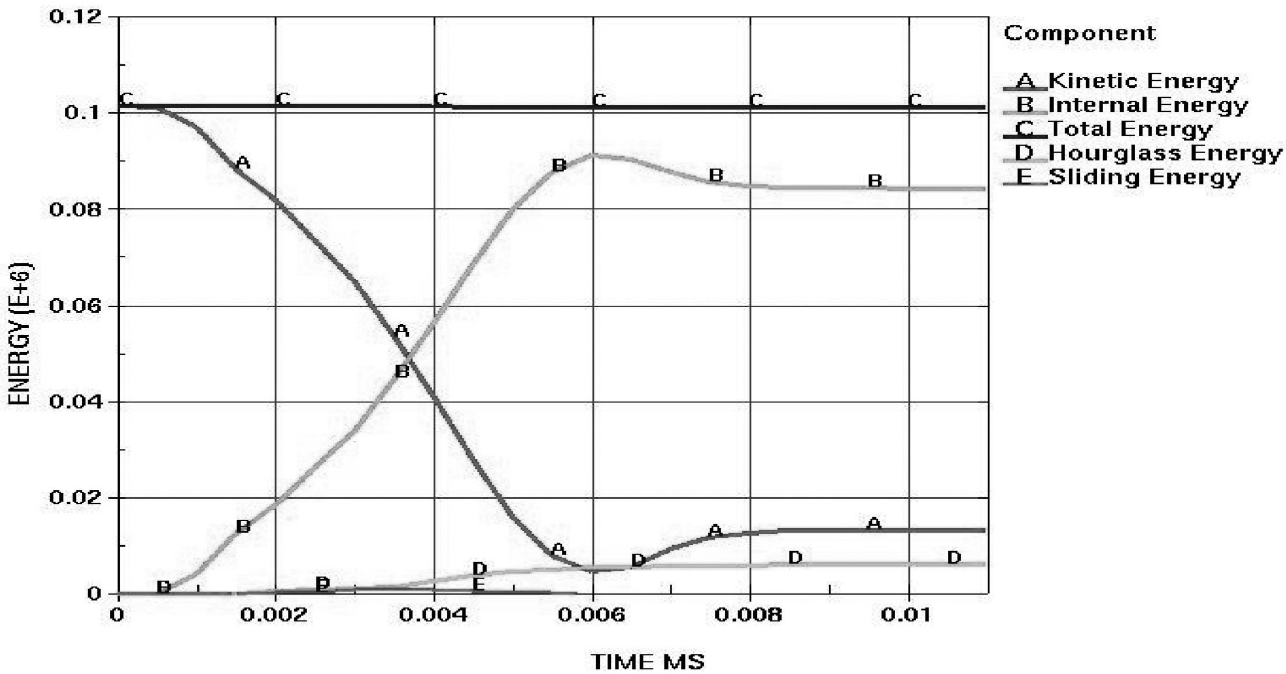

Figure 9: Energy balance plot for 14.5mm cone height

Table 6: Parametric study results for 14.5 mm cone height with varied thickness

HEIGHT OF THE CONE, MM	INITIAL THICKNESS, INCHES	HIC(d)	PEAK ACC IN G's
14.5	0.04	1289	224
14.5	0.05	1089	196
14.5	0.06	988	155
14.5	0.07	1067	183

Table 7: Comparison of test and analysis results for 10 mm cone height with 0.04 inch initial thickness of the safety plastic.

	TEST	FEA
HIC (d)	1300	1201
PEAK ACC, G's	202	210

Table 8: Parametric study results for 10 mm cone height with varied thickness.

HEIGHT OF THE CONE, MM	INITIAL THICKNESS, INCHES	HIC(d) G's	PEAK ACC IN
10	0.04	1201	210
10	0.05	1146	193
10	0.06	1314	191

Table 9: HIC(d) percentage improvement of the safety plastic model over the baseline model.

THICKNESS IN INCHES	20 MM	14.5 MM	10 MM
0.04	39%	27%	32%
0.05	55%	38%	35%
0.06	52%	44%	26%

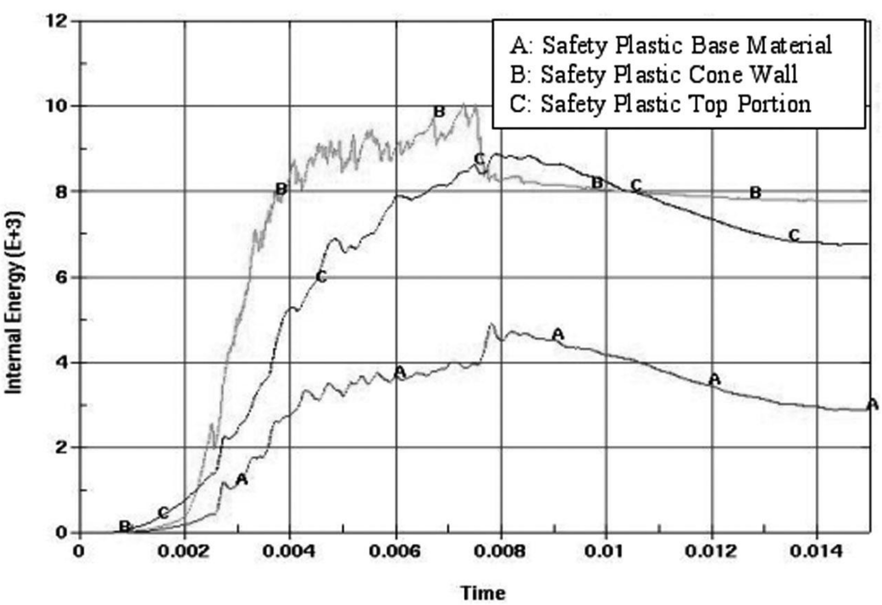

Figure 10: Internal Energy plot for 20mm cone height with 0.04 inch initial thickness.