Energy Absorption Capacity of Rigid Polyurethane Foam under Impact Load

Kedir Mohamedraja Seid

Abstract: ***Vehicles has multiple safety mechanisms such as air bags, sit belts and ABS brakes to protect lives of occupants. Also, road safety and management offers various solutions like speed breakers and road side barriers to supplement and minimize damages of errand vehicle crashes.***

This thesis work presents mainly finite element analysis of a rigid polyurethane foam under impact loading. Energy absorption capacity of a rigid polyurethane foam was quantified both under impact load of a drop hammer; and a passenger car with mass of 1200 kg and 2000 kg and approach speed 30km/hr. and 50km/hr. scenario. In the absence of field crash tests principle of energy conservation were used to validate developed finite element models.

FEA results showed road side barrier designed with an equivalent design static force of 377 KN and a rigid polyurethane foam thickness of 60.5 cm offers a forgiving road side barrier scenario by absorbing energy and re-directing impacting passenger car into inward lanes. Also, FEA results revealed thickness of a rigid polyurethane foam affects energy-absorbing capacity of a rigid polyurethane foam. For 50 km/hr. impacting speed, as thickness of a rigid polyurethane foam decreased by 33%, the material energy absorption capabilities lost by 100% whereas 33 % thickness increment resulted in 33 % additional energy absorption capacity.

Key word; Rigid polyurethane foam, LS-DYNA, Energy absorption, Vehicle impact

I. INTRODUCTION

Many research works has been conducted on the energy absorption performance of anti-collision facilities as a consequence of the increasing car accidents. There are several types of anti- collision devices that have been developed through time, and each type has its own characteristics and operating conditions. Steel fenders are more commonly used types than other types of anti-collision devices, but this fender has major drawbacks, such as poor corrosion resistance, high initial costs, and high maintenance requirements [1].This type of anti-collusion device is also common in Ethiopia.Vehicle companies make different effort & modifications to make drivers & vehicles safe by introducing different works such as seat belts and air bags , by which impact injuries reduces. But this efforts are on the manufacturer side, on the road safety and management side additional works should be done to reduce injuries.

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This efforts may contain construction of different types of speed breakers, different barriers such as cushions, steel & wire rope barriers etc. even though different efforts are made on the side of road and traffic management professionals as stated above more innovations and modifications are needed in order to reduce and minimize further vehicle and human injuries.The main objective of this paper is studying energy absorption capacity of rigid polyurethane foam under impact load. Which can be practically used in front of different rigid structures including rigid road side barriers, concrete poles, bridge piers and split walls etc.

II. METHODOLOGY

The material considered for detail study under impact load here is rigid polyurethane foam with density of 192 kg/m3.Detail study was made on this material including displacement, force reaction & energy absorption capacity.

A. MAT_CRUSHABLEFOAM (MAT-063)(FOAM MATERIAL)

This is Material Type 63 which is dedicated to modeling crushable foam with optional damping and tension cutoff. Unloading is fully elastic. Tension is treated as elastic perfectly- plastic at the tension cut-off value. A modified version of this model, *MAT_ MODIFIED_CRUSHABLE_FOAM includes strain rate effects.

The material selected for this study is rigid poly urethane foam with known parameters and mat-63 is found suitable for simulation of this material using LS-DYNA pre- post.

Table- 1 Detail material properties of foam sample for impact testing machine and foam [20].

Material type	density	Poisons ratio	TS	Young's modulus	contact	damp	MAT type
Rigid polyurethane foam	192 kg/m3	0	0.1	66.09	Automatic general	0.1	63(Crushable foam)

B. MAT_RIGID (DROP WEIGHT MATERIAL OR VEHICLE MATERIAL USED)

This is Material 20. Parts made from this material are considered to belong to a rigid body (for each part ID). Also, the coupling of a rigid body with MADYMO and CAL3D can be defined via this material. Alternatively, a VDA surface can be attached as surface to model the geometry, e.g., for the tooling in metal forming applications. Also, global and local constraints on the mass center can be optionally defined. Optionally, a local consideration for output and user-defined airbag sensors can be chosen.

C. MAT_ELASTIC {OPTION}-001(support material)

This is Material Type 1. This is an isotropic hypoelastic material and is available for beam, shell, and solid elements in LS-DYNA. A specialization of this material allows the modeling of fluids.

Table 2. Material properties for mat rigid

Material type	density	Poisons ratio	Young's modulus	DA	DB	Not used
Steel Mat-elastic-001	7.8e-9	0.3	2.1e+5	0	0	0

D. FEA analysis of drop hammer with different thicknesses and support conditions

In this step modeling and analysis of rigid poly urethane foam with density of 192 kg/m3 was used in modeling and analysis for different speeds with mass of 50 kg.

E. FE analysis of impact with 1200 kg and 2000 kg mass

In this part the selected foam material was studied for different parameters such as-energy absorption capacity force of Reaction, Displacement, Acceleration and Velocity of the sample under impact of 1200 kg and 2000 kg masses

Table-3 Units used for all analysis

Mass	Length	Time	Force	Stress
Ton	mm	sec	N	Mpa
Energy	Density	Youg's	Velocity	Gravity
N-mm	Ton/mm3	Mpa	mm/sec	9810

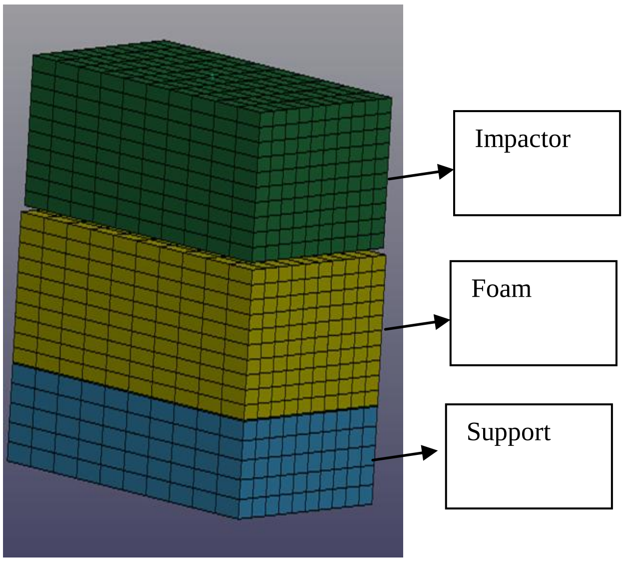

Fig.1. Model of foam material for impact testing and vehicle with rigid support

III. RESULTS AND DISCUSSIONS

Analysis and modeling of foam sample are performed using FE software against impact of different masses .This analysis and modeling work is mainly to know and observe energy absorption capacity of the foam material which is rigid polyurethane foam.

A. FEA OF THE FOAM MATERIAL AGAINST 50 KG MASS

To estimate impact capacity of rigid sponge we can model the machine by simplifying the pendulum type impact testing machine as drop weight impacting machine on ls dyna. In this case since most of the machines are similar is modeled as drop weight impacting instrument with drop weight mass of 50 kg and height of 1.37 m which is equivalent to 18 km/hr.
Based on the data provided on table 7 foam sample material is modeled with different thickness starting from 10 cm up to 40 cm by 10 cm interval by considering for each section 15 kmhr,20kmhr,25 km/hr and 30 km/hr with end time of 0.015 sec.

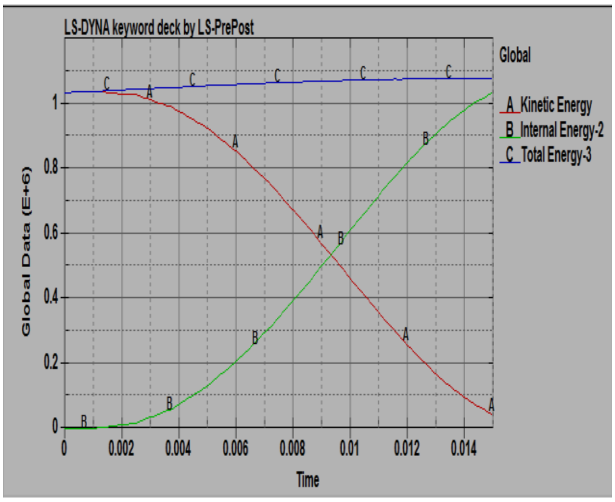

Fig 2 Energy graph for 15 km/hr

As clearly observed from the energy graphs above fig 2, internal energy is increasing with increase of velocity.this shows energy absorption capacity of the foam material with increease of velocity.time is set to .015 sec for all thicknesses and velocities to clearly observe the energy absorption capacity of the polyurithane foam material.

B. Displacement

From figure 3, as velocity increases displacement of the foam material also increases. For 15, 20, 25 & 30 km/hr velocities 32, 40, 52 & 65 mm displacement is observed respectively.so we can say as velocity increases displacement also increases.

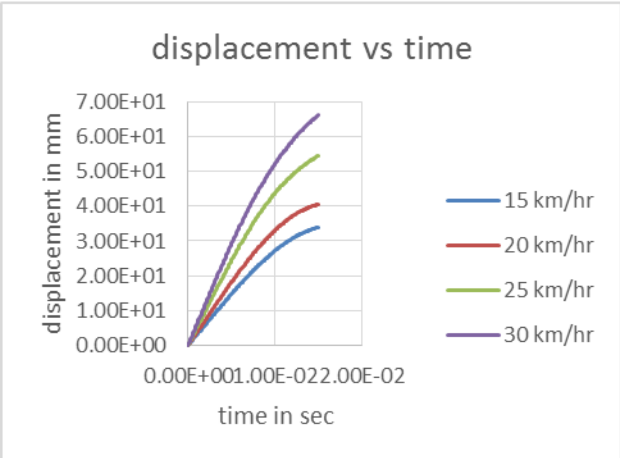

Fig 3 Displacement vs. time graph for different velocities for 10 cm thick

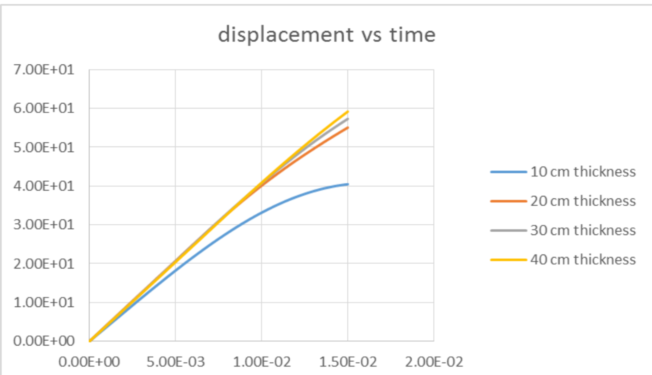

Fig 4 Displacement vs time graph of 30 km/hr for different thickness

From table 4, all energy graphs with thicknesses of 10, 20, 30 & 40 mm thick polyurethane foam we can clearly observe that more energy can be absorbed as thickness of foam increases as the same time by increasing velocity by increasing end time from 0.015 sec. in every energy graphs that we observe end time should be adjusted beyond 0.015 sec to get the exact and proper energy absorbing capacity of the sample we selected. Here the energy absorption capacity is found from internal energy.

But for the sake of clear analytical observation mass and end time was set to be constant which is 50 kg drop height mass and 0.015 sec end time.

Table-4. Summary of different results for 10, 20, 30 & 40 cm foam blocks

no	Foam height	velocity	Displacement (mm)	Force (KN)	Internal energy (J)
1	10 cm	15 km/hr	32	28	1000
		20 km/hr	40	34	1500
		25 km/hr	52	34	3000
		30 km/hr	65	35	4000
2	20 cm	15 km/hr	40		1500
		20 km/hr	55		1700
		25 km/hr	65		2500
		30 km/hr	80		3000
3	30 cm	15 km/hr		13	600
		20 km/hr	58	25	1500
		25 km/hr	68	20	1700
		30 km/hr	80	40	2500
4	40 cm	15 km/hr			650
		20 km/hr	60	28	1500
		25 km/hr	70	52	1700
		30 km/hr	82	62	2500

C. FEA of the foam material against vehicle impact load

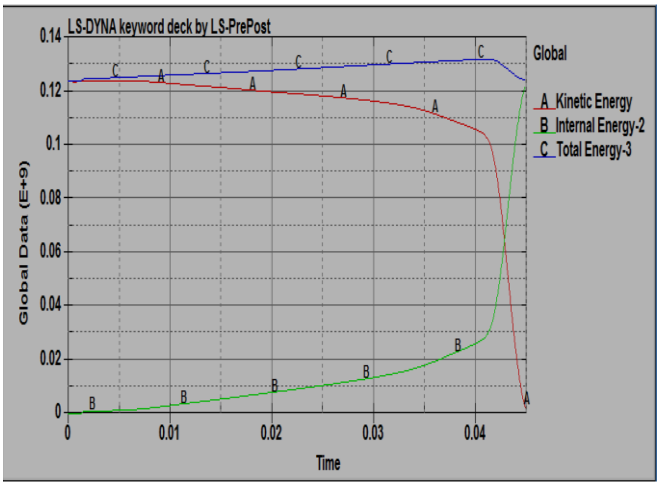

Figure.5.Energy graph for 1200 kg mass & 50 km/hr velocity

For 1200 kg mass vehicle case and 50 km/hr velocity all the total energy is absorbed completely which is 120000 J out of total energy 120000 J .So from this it is concluded that the used thickness of the foam material can resist and redirect any kind of impacts and collusion that may come from masses of such vehicles with the specified velocity.

Fig 6 Displacement graph for different velocities of 1200 kg mass

D. 2000 kg vehicle and 50 km/hr

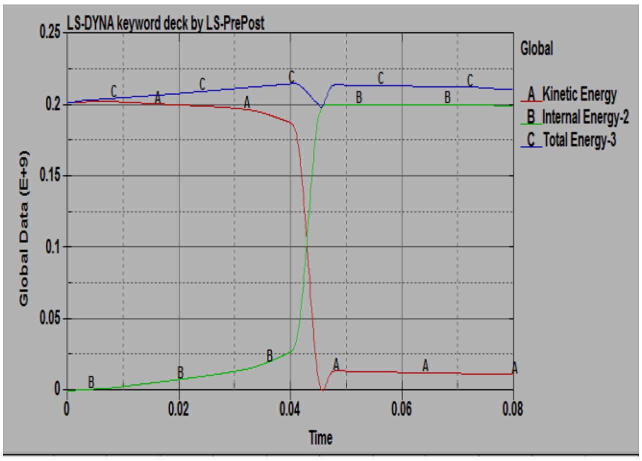

Figure.7.Energy graph for 2000 kg mass & 50 km/hr velocity

The same is true for the above two energy graphs of 2000 kg mass vehicle .as we can see all the total energy released is completely absorbed.

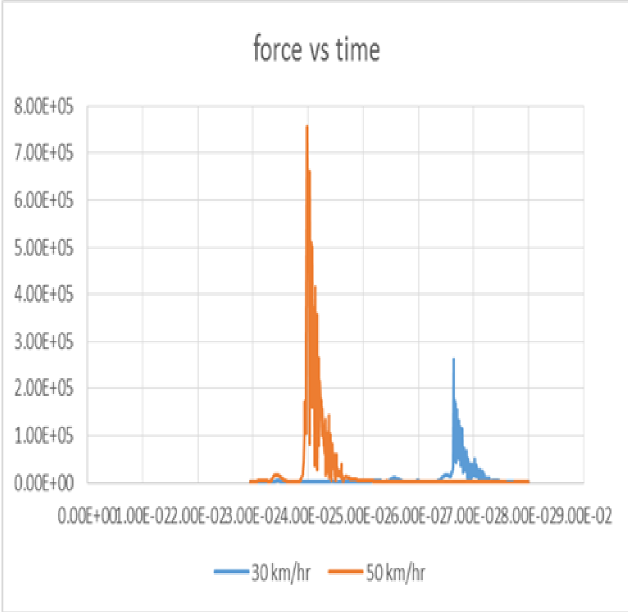

Fig 8 Force graph for different velocities of 2000 kg mass

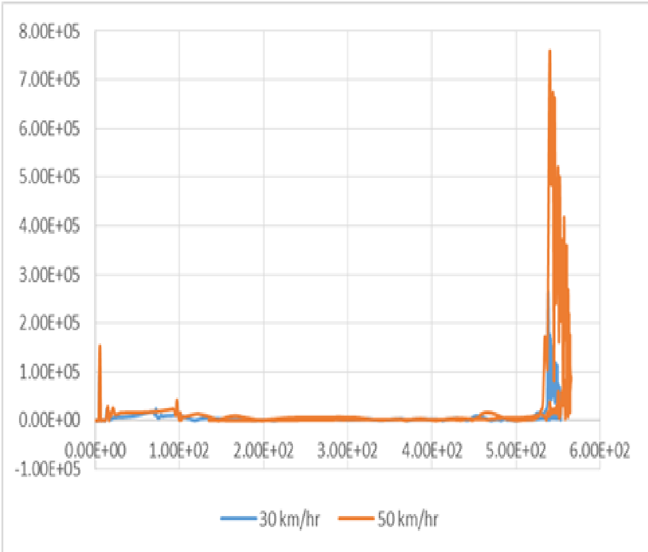

Fig 9 Force vs displacement for velocity of 30 & 50 km/hr of 2000 kg mass

Table 5.Summary of different results for 1200 and 2000 kg mass

no	Vehicle mass	velocity	Displacement mm	Force KN
1	1200 kg	30 km/hr	550	50
		50 km/hr	580	240
2	2000 kg	30 km/hr	580	225
		50 km/hr	600	775

From table 5 displacement and force of reaction increases for both cases as velocity increases.

IV. GLOBAL EQUIVALENT STATIC FORCE

The global equivalent static force (GESF) is obtained by the averaged integration of the instantaneous impact force over the whole collision process, that is: $\int_0^t p(i)\,di/t$…….(1)
Where, p is impact force and t (time where maximum impact force happens)
Integral value from time 0 to t is total duration of time [23].

Table 6-Impact force with thickness reduction (18-33) % and thickness increment (18-33) %

Impact force	**Thickness (mm)**	**Velocity**
		50 km/hr
PDF	40	1.3e+5 N
ESF		203 KN
PDF	50	1.3e+5 N
ESF		650 KN
PDF	60.5	2.4e+5 N
ESF		285 KN
PDF	70	2.2e+5 N
ESF		220 KN
PDF	80	6e+5 N
ESF		500 KN

From table 6 the average equivalent static force on a velocity of 50 km/hr and with 1200 kg mass of vehicle is 377 KN. Since the vehicle is slowed down when brake is 50 km/hr velocity is selected.

Impact of thickness on energy absorption capacity
For specific observation purpose mass of 1200 kg and velocity of 30 km/hr & 50 km/hr is selected.

Table 7-Energy absorption capacity 50 km/hr velocity with different thickness

	thickness in cm	**Change of thickness in percent**	**energy absorption capacity**	**Change in energy absorption in %**	**Remark**
Original thickness	60.5	0	5e+7	**-**	control
decrement	40	33	5e+7	0	No change
	50	17	4.5e+7	10	Decrease
increment	70	17	5e+7	0	No change
	80	33	8e+7	60	increases

General observations

What can be observed from all the above analysis is with same density of foam material as thickness increases energy absorption capacity also increases. For the case of 1200 and 2000 kg mass thickness of the foam material selected was 60.5 cm .if we observe from the beginning of this analysis results, as can observed for mass of 50 kg impactor as the thickness increases for the same mass, energy absorption capacity increases, but as mass increases for even increased thickness the absorption capacity decreasese.so we can conclude from this, if the expected impacting mass is higher thicker foam thickness should be used in order to absorb the coming impact load from the larger mass.in this case specially if we want to use it on road side as the thickness of the foam increases the space for vehicle movement gets smaller & this may cause to happen high traffic jams on areas we apply foam energy absorbers.

Better practice that might be followed here is rather than increasing foam thickness in order to absorb the energy properly we can rather use foam with higher density and limit the thickness that might be used on road side.

V. CONCLUSION AND RECOMMENDATION

This thesis work presents mainly finite element analysis of a rigid polyurethane foam under impact loading. Energy absorption capacity of a rigid polyurethane foam was quantified both under impact load of a drop hammer; and a passenger car with mass of 1200 kg and 2000 kg and approach speed 30km/hr and 50km/hr scenario. In the absence of field crash tests, baseline principle of energy conservation were used to validate developed finite element models. Next, briefly, conclusions and recommendations inferred from FEA is presented.

A. CONCLUSIONS

- FEA results of a 10 cm thick foam sample absorbed 1000, 1500, 3000 and 4000 J energy under impacting velocity of 15 km/hr, 20 km/hr., 25 km/hr and 30 km/hr respectively. This results indicated foam samples with full rigid support can absorb high amount energy.
- FEA results revealed thickness of a rigid polyurethane foam affects energy-absorbing capacity of a rigid polyurethane foam. For 50 km/hr impacting speed, as thickness of a rigid polyurethane foam decreased by 33%, the material energy absorption capabilities lost by 100% whereas 33 % thickness increment resulted in 33 % additional energy absorption capacity. Similarly, respective values for 30 km/hr impacting speed were 0 % loss and 60 % gain in energy absorption capacity.
- FEA results showed road side barrier designed with an equivalent design static force of 377 KN and a rigid polyurethane foam thickness of 60.5 cm offers a forgiving road side barrier scenario by absorbing energy and re-directing impacting passenger car into inward lanes.

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