IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 12, Issue 2 Ver. IV (Mar - Apr. 2015), PP 17-27
www.iosrjournals.org

Design and Analysis of an Automotive Front Bumper Beam for Low-Speed Impact

Maheshkumar V. Dange[1], Dr. Rajesh. B. Buktar[2], Dr. Nilesh. R. Raykar[3]
[1.2.3.] *(Department of Mechanical Engineering, Sardar Patel College of Engineering/ Mumbai University, India)*

Abstract: *Automotive bumper beam assembly plays very important role in absorbing impact. In this paper, the most important parameters of an automotive front bumper beam such as material, shape and impact condition are to be studied to improve the crashworthiness. The simulation of bumper beamis done under low-velocity impact as per the standards of automotive stated in E.C.E. United Nations Agreement, Regulation no. 42, 1994. The strength of the bumper beamin elastic mode is investigated with energy absorption and impact force in maximum deflection situation. Similar bumper beams made of different materials are simulated to determine the deflection, impact force, stress distribution and energy-absorption behavior, these characteristics are compared with each other to find best choice of material. The results show that a M220 material can minimize the bumper beam deflection, impact force and stress distribution and also maximize the elastic strain energy. In addition, the effect of passengers in the impact behavior is examined. The time history of the calculated parameters is showed in graphs for comparison.*

Keywords *-Bumper beam, Impact, low velocity, LS-Dyna.*

I. Introduction

Car accidents are happening every day. Most drivers are convinced that they can avoid such troublesome situations. Nevertheless, we must take into account the statistics – ten thousand dead and hundreds of thousands to million wounded each year [1]. These numbers call for the necessity to improve the safety of automobiles during accidents. Automotive bumper beam is one of the key systems in passenger cars. Bumper beam designed to prevent or reduce physical damage to the front or rear ends of passenger motor vehicles in collision condition. They protect the hood, trunk, grill, fuel, exhaust and cooling system as well as safety related equipment such as parking lights, headlamps and taillights, etc. [2]. A good design of car bumper must provide safety for passengers and should have low weight [3]. Different countries have different performance standards for bumpers. Under the International safety regulations originally developed as European standards and now adopted by most countries outside North America, a car's safety systems still function normally after a straight-on pendulum or moving-barrier impact of 4 Kmph (2.5 mph) to the front and the rear, and to the front and rear corners of 2.5 Kmph (1.6 mph) at 445mm above the ground with the vehicle loaded or unloaded. In North America (FMSS: Federal Motor Vehicle Safety Standards), Canada (CMVSS: Canadian Motor Vehicle Safety Standards) and E.C.E. United Nations Agreement, Regulation No. 42, 1994[4]. This regulation is accepted by ARAI India, so it is used for this study.

II. Literature Review

Hosseinzadeh et al. [2] studied the structure, shape, and impact condition of glass mat thermoplastic (GMT) bumper by using LS-DYNA pre solver and the results are compared with conventional metals like steel and aluminium. GMT showed very good impact behavior compared with steel and aluminium, which all failed and showed manufacturing difficulties due to strengthening ribs or weight increase due to use more dense materials.

Andersonet al. [5] has discussed that to increase crash performance in automotive vehicles it is necessary to use new techniques such as use of energy absorber and materials. Components linked to crash safety should transmit or absorb energy. The energy absorbing capability of a specific component is a combination of geometry and material properties.

Evans D and Morgan T [6] have studied that as vehicle manufacturers continue to become more aggressive with the styling of new vehicles, bumper system technologies will be required to find new solutions that fit into the reduced package spaces while continuing to meet the vehicle performance and cost requirements. It was suggested to introduce new and innovative Expanded Polypropylene (EPP) foam technologies and techniques.

Bautista et al.[7] studied the different impact standards and for the specific material they optimized the shape of bumper beamby performing the software simulation. They also studied the effect of metallic energy absorber in bumper system.Maximum stress and deformationwere used as design criteria. They have complied many international standards for bumper beam design.

From above published work it is clear that different countries have different standards but few are accepted globally. For this study E.C.E. United Nations Agreement, Regulation No. 42, 1994[4] selected. Design criteria selected as follows.MaximumVon-Mises stress should be less than the yield strength and deformation should be less than the specified limit which depends on gap space available in the design. For this paper deformation limit is 40mm.

III. Impact Mechanics

Investigators [3, 6, 7, 8] have recommends following procedure for finding energy dissipated during impact, and find the vehicle velocity after impact. The impacting phenomenon between barrierand the front bumper beam in a low-speed full crash could be very complicated, since transient and nonlinear analysis are involved. But, in designing the front bumper beam, automobile manufacturers insist that the bumper system should not have any material crash or failure. Therefore, up to that point, the total energy is conserved throughout the impact duration.

Since the barrier is assumed to be rigid and the bumper beam was made of metallic material and shock absorber is a relatively low stiffness material, the distribution of the impact load is irregular along the contact area and over the contact region of the bumper, the bumper beam subjected to the impact load undergoes a constant deformation $\delta_{max.}$

A principle of energy conservation in the elastic impact is used[3]; The kinetic energy before impact is conserved and converted to elastic energy and the kinetic energy of the barrierand the automobile at its maximum deflection, i.e.,

$$\frac{1}{2} M_A V_A^2 = \frac{1}{2} K_{eq} \delta_{max.}^2 + \frac{1}{2} M_A V_0^2 + \frac{1}{2} M_B V_0^2 \qquad (1)$$

Where M_A is the mass of the barrier, M_B the mass of vehicle,$V_A$the velocity of the barrierbefore impact and V_0 the final velocity of the barrierand vehicle in maximum deflection point. $K_{eq}$the equivalent impact stiffness of a bumper and is obtained by the relationship of displacement and reaction forces from beam analysis.

An important consideration of momentum is that it can be neither created nor destroyed. Thus, the momentum before an impact is equal to the momentum after the impact. At the moment of its maximum deflection, a principle of momentum conservation before and after impact can be ex- pressed as follows:

$$M_A V_A = (M_A + M_B) V_0 \qquad (2)$$

From equations (1) and (2) the maximum deflection δ_{max} is obtained as follows:

$$\delta_{max.}^2 = \frac{1}{Keq} \frac{MaMb}{Ma+Mb} V_A^2 \qquad (3)$$

After separation point, energy and momentum conservation equations can be expressed as follows:

$$\frac{1}{2} M_A V_A^2 = \frac{1}{2} M_A V_{A2}^2 + \frac{1}{2} M_B V_{B2}^2 \qquad (4)$$

$$M_A V_A = M_A V_{A2} + M_B V_{B2} \qquad (5)$$

Where V_{A2} and V_{B2} are the final velocities of the impactor and vehicle, respectively in separation point.

In the elasto-plastic impact, the principle of linear momentum conservation satisfies, since impact forces are equal and opposite.

$$M_A V_A + M_B V_B = M_A V_{A2} + M_B V_{B2} \qquad (6)$$

In this case, the velocities after impact may be determined with the coefficient of restitution (e). The coefficient of restitution (COR) is the ratio of speed of separation to speed of approach in a collision.

$$e = (V_{B2} - V_{A2}) / (V_A - V_B) \qquad (7)$$

An object with a COR equals to 1 collides elastically, while an object with a COR of 0 will collide inelastically, effectively sticking to the object it collides with, not bouncing at all. The coefficient of restitution is a number which indicates how much kinetic energy (energy of motion), remains after a collision of two objects. If the coefficient is high (very close to 1), it means that very little kinetic energy was lost during the collision. If the coefficient is low (close to 0), it suggests that a large fraction of the kinetic energy was converted into the heat or was otherwise absorbed through deformation.

The Eq. (8) can be used to find the energy dissipated, E_D during an impact. This is found by subtracting the kinetic energy of the two masses after impact, and the kinetic energy of the impactor before impact.

$$E_{Plastic} = \frac{1}{2} M_A V_A^2 + \frac{1}{2} M_B V_B^2 - \frac{1}{2} M_{A2} V_{A2}^2 - \frac{1}{2} M_{B2} V_{B2}^2 \qquad (8)$$

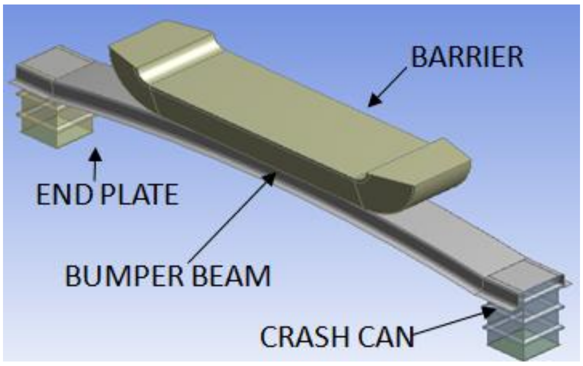


Figure 1.Isometric view of impact layout

IV. Finite Element Modeling

The bumper beam dimension are measured from local passenger car.From the measured dimension generate the 3D Bumper beam is generated in ANSYS workbench 14.5. The analysis “Nonlinear explicit” type. Bumper beam generated is surface model. The Barrier is made as per the ECE R42 standards [4] this barrier acts as rigid component. The bumper beam is attached to two semi-cubic plastic polypropylene (PEP) holders as shown in Fig.1. In this study to reduce the simulation time bumper beam is replaced with spring having stiffness equal to the stiffness of the crash can. These springs areattached to end plate, and the complete assembly is attached to car body. In this model half of car weight (with passenger) is applied to each end plate as point mass.Weight of the barrier is also equal to weight of car (with passenger).All the degree of freedom are restricted for end plates and barrier, exceptthe degree of freedom in the direction perpendicular to barrier

Bumper beam is meshed by shell element whereas barrier and end plate is meshed with rigid solid element. Material used for bumper beam is martensitic steel and for the barrier and end plate it is structural steel.

Barrier was modeled according to dimensional drawings from E.C.E. standard [4]. Fig. (1) Shows the model of bumper beam and barrier. As shown in the figure barrier impacts on bumper beam in straight and perpendicular direction. Frictionless contact was assumed between barrier and bumper beam surface and the car was taken to be lying on a flat and frictionless surface. Barrier velocity was 4kmph for straight impact as stated in E.C.E standard [4]. Table (1) shows the FEM characteristics of each component in the modelling.

Table 1FEM characteristics of the models.

Part of model	Material	FEM element	Thickness or weight
Bumper beam	Steel, Mg, Al, M220	Shell	4 mm
Crash can	PEP	spring	4 mm
Car		Mass	1300 Kg 1600 Kg with passenger
Barrier	Str. steel	Solid	1300 Kg

V. Bumper Beam Material

To find out the effect of bumper beam material on the impact behavior, two parameter are studied here: modulus of elasticity and yield strength.

5.1 Modulus of elasticity

To study the effect of modulus of elasticity three material are considered having their yield strength nearly equal and different moduli of elasticity. Mechanical properties of the material are given in table 2 [9, 15].

Table 2Material properties of the models.

Material	**E(GPa)**	**Y (MPa)**	**υ**	**ρ (Kg/mm^3)**
Str. Steel	**200**	**250**	**0.3**	**7850**
Aluminium alloy 6060-T5	**69.5**	**243**	**0.33**	**2700**
Magnesium alloy	**45**	**193**	**0.35**	**1800**

Other material properties of the model such as crash can, barrier, etc. are constant for all other case studies. The barrier impacts the bumper beam perpendicularly with 4 Km/h velocity.The deformation amongst the three bumper beam material measured at a height 445mm above the ground level as per the E.C.E standard [4] where the maximum impact occurs in most of cases [10].

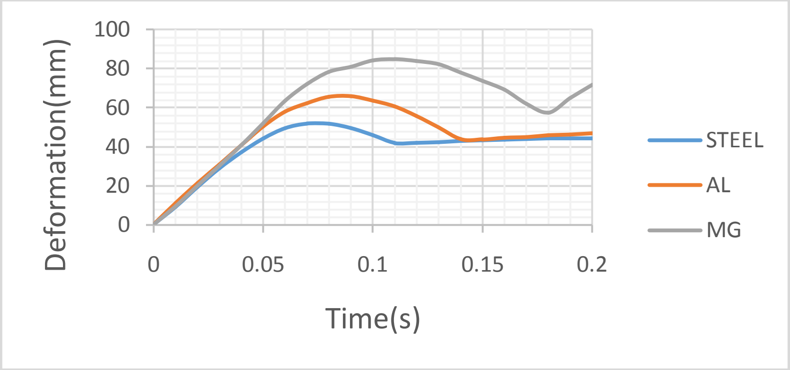


Figure 2. Magnesium, aluminum and steel bumper deflections

The bumper beam separates from barrier at 0.180, 0.127 and 0.108 s, for magnesium, aluminum and steel respectively.This may be seen in the deflection vs. time diagram in Fig.5.1, where the deflections become constant.The maximum deformation point also occurs at 0.055, 0.090 and 0.075s; with the deflections 87.46, 64.24 and 52.12 mm, for magnesium, aluminum and steel respectively. From this it is clear that the steel stiffness is higher than the aluminum and the aluminum stiffness is higher than the magnesium.

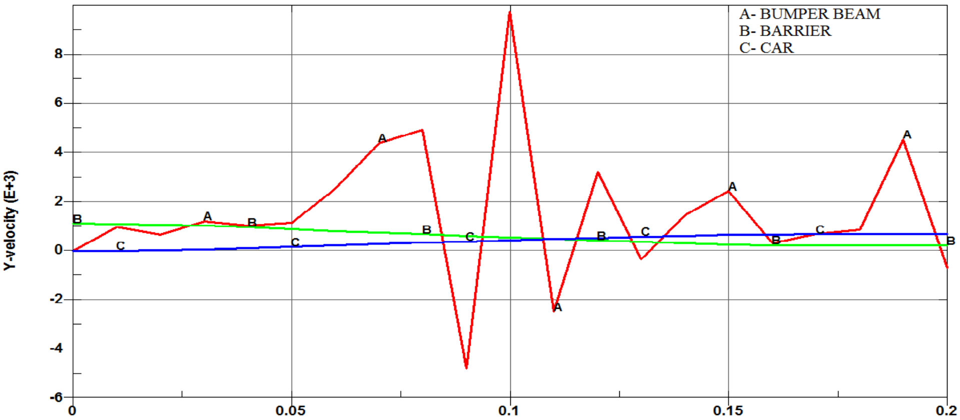


Figure 3. Kinetic energy transfer in Magnesium bumper.

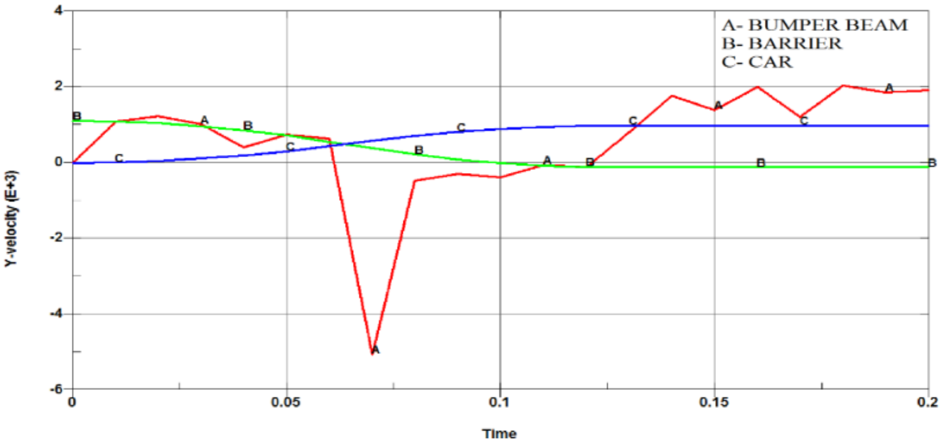


Figure 4. Kinetic energy transfer in Aluminum bumper.

Fig. 3-5 clearly shows that there is difference in impact velocities among the steel, aluminium and magnesium bumper beam. In magnesium bumper beam difference between barrier velocity and vehicle velocity after impact is higher than the steel and aluminium. It means in magnesium bumper beam more kinetic energy transfer from barrier to vehicle. As COR of magnesium is lower than the steel and aluminium maximum KE loss in deformation which results the deformation of Mg bumper beam is higher than other.

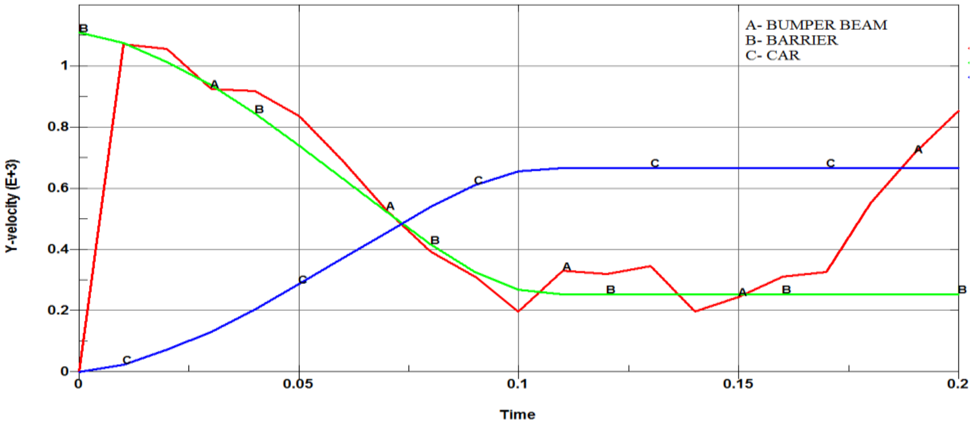


Figure 5. Kinetic energy transfer in Steel.

To compare the differences among impact forces, the impactor inertia force in three states was defined as a common criterion. According to Fig. 6, the impact force in magnesium bumper is the lowest. This phenomenon is due to lower rigidity of magnesium.Withhigh impact force barrier decelerate quickly it is clear from energy graph.

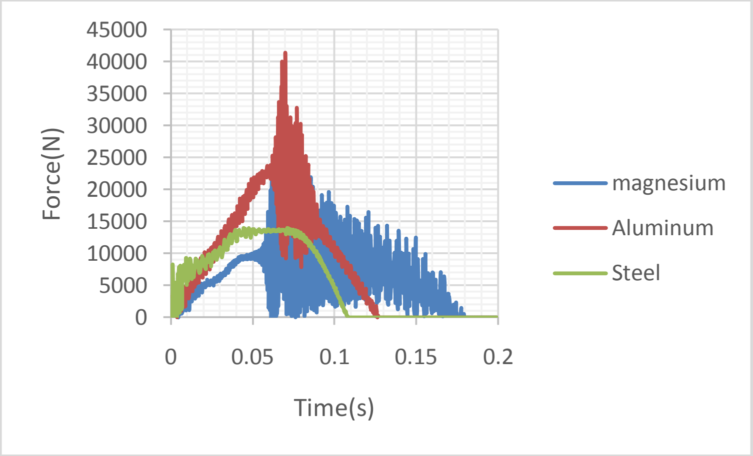


Figure 6. Impact force in steel, aluminum alloy and magnesium alloy bumper beam.

Table 3 shows the comparison of three material only the steel is nearer to fulfill the required condition i.e. stress should be less than the yield stress and deformation of bumper beam less than 40mm but this condition is not satisfied by any material.

Table 3. Comparison of stress and deformation for three materials

Material	Von Mises stress	Yield stress	Max Deformation	Limiting deformation
Magnesium	212.02	193	84.76	40
Aluminum alloy 6060 T5	256	243	65.92	
Steel	25.71	250	51.92	

5.2 Yield strength.

To study the effect of yield strength on bumper beam three different aluminium alloys are considered. Mechanical properties of these aluminium alloys are given in table4.

Table 4. Mechanical properties of the various aluminum alloy [11, 12].

Material	E(GPa)	Y (MPa)	υ	ρ (Kg/mm^3)
A6111-T4	68.35	170	0.33	2700
A6060-T5	69.5	243	0.33	2700
A20204-T351	71	363	0.33	2700

Fig. 7 demonstrate that maximum deformation and plastic deformation after impact less in A2020-T351.Compare to others because it has high yield strength than others. The maximum deflection also occurs early in high strength material. For different aluminum bumpers, difference between vehicle and impactor velocities afterimpact increasesby increasing the yield strength.

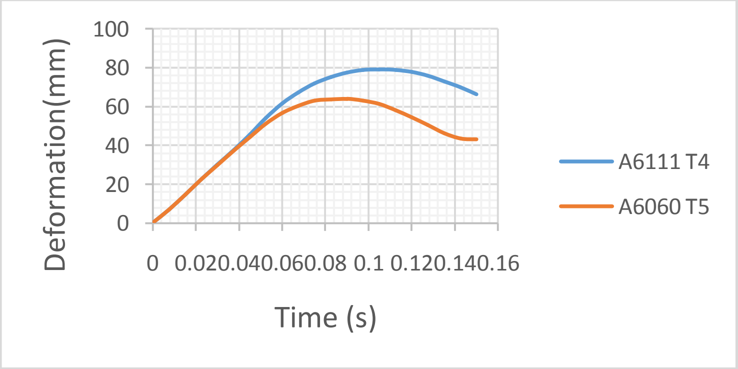


Figure 7. Various aluminum bumper beam deformations

Accordingly, more kinetic energy transfers to the vehicle and as a result lesser energy dissipates. This can be clearly shown in Figs. 8, 9 and 10. According to these figures, the velocity of barrier is not reduced to zero. As plastic deformation is more in bumper beam so maximum energy is dissipated in deformation and remaining in heat.

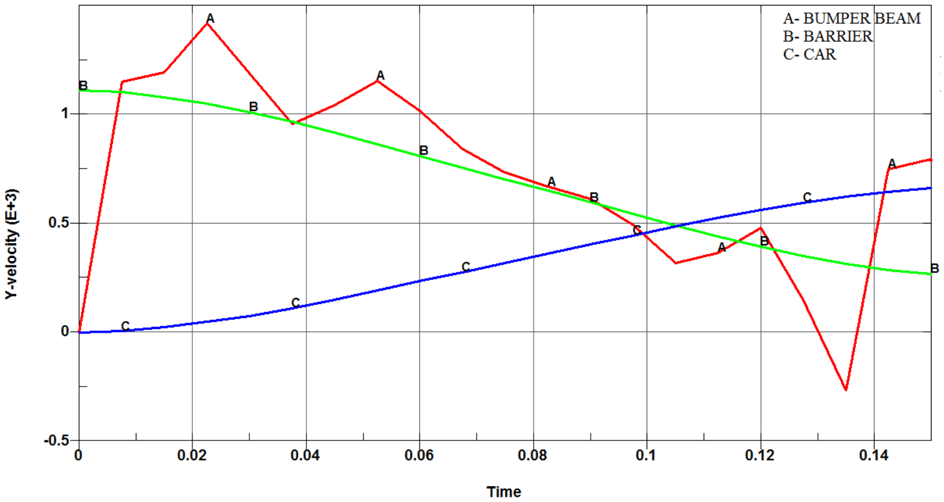


Figure 8. Kinetic energy transfer in aluminum 6111-T4 bumper.

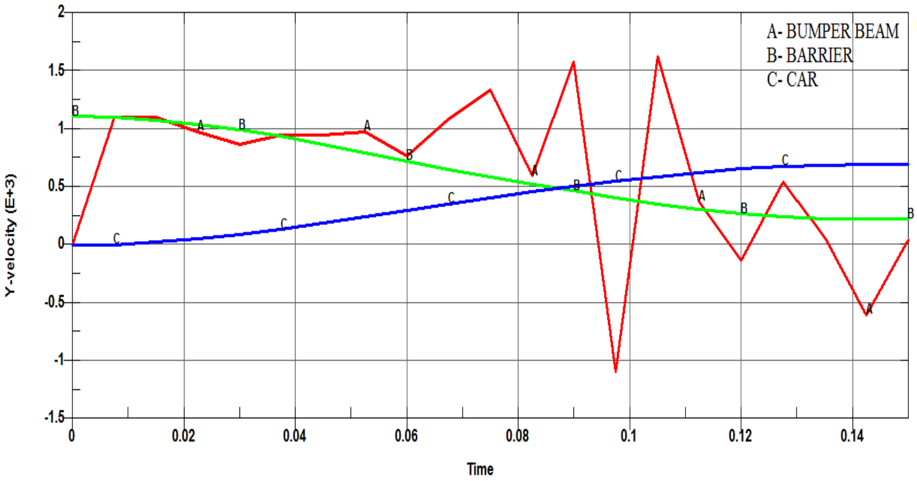


Figure 9. Kinetic energy transfer in aluminum 6060-T5 bumper.

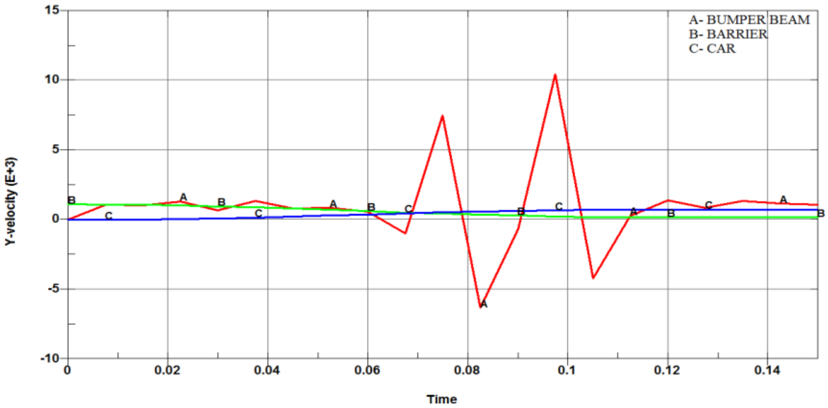


Figure 10. Kinetic energy transfer in aluminum 2024-T351 bumper.

When bumper beam is in contact with the barrier middle point of bumper will gain the same velocity as that of barrier and when it is separates from barrier starts vibrating to adjust its velocity to that of car.

In fig.11 impact forces of different aluminum alloy are shown. It is observed from fig.11 that the impact force decreases by decreasing the aluminium strength. It is also observed that for high strength aluminium maximum deformation occur early.

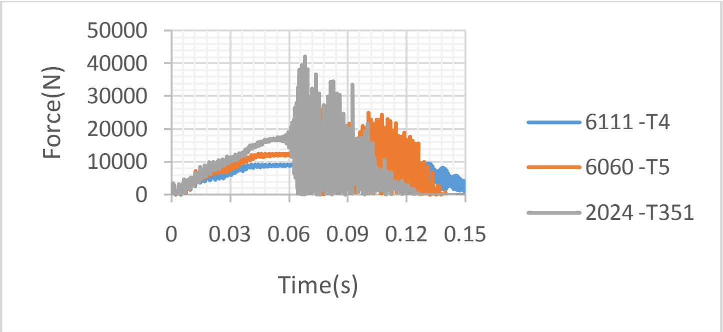


Figure 11. Comparison of impact force for three different aluminum alloy.

Fig. 12 shows the conversion of energy. As barrier loses the kinetic energy at the same time bumper beam starts gaining the strain energy, bumper is not able to gain all the energy transferred by the barrier because some of energy loss in plastic deformation. So due to plastic deformation bumper not able to reach the barrier velocity 4 km/h.

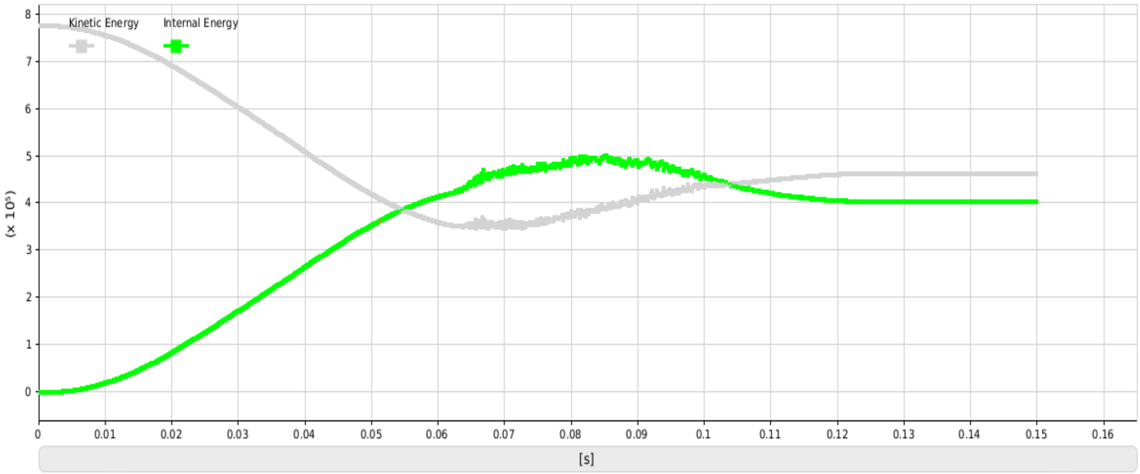


Figure 12. Kinetic energy converts to strain energy 2024- T351.

From the table 5 it is clear that all the aluminum alloy are not able to fulfill the criteria [2, 3]. It is observed that with high strength material maximum deformation is less also it absorbs the more energy.

Table 5. Comparison of stress and deformation for three materials.

Material	Von Mises stress	Yield stress	Max Deformation	Limiting deformation
A6111-T4	192.4	170	79.07	40
A6060-T5	253.52	243	64.04	
A20204-T351	365.89	363	53.97	

VI. Martensitic Steel.

Martensitic steel having high modulus of elasticity and also it has high yield strength [13] this type of steel are used for the manufacturing of the bumper beam [14]. Material property of the M220 given in table.

Table 6. Mechanical properties of M220 [16]

Material	E(GPa)	Y (MPa)	υ	ρ (Kg/mm^3)
M 220	200	1350	0.3	7890

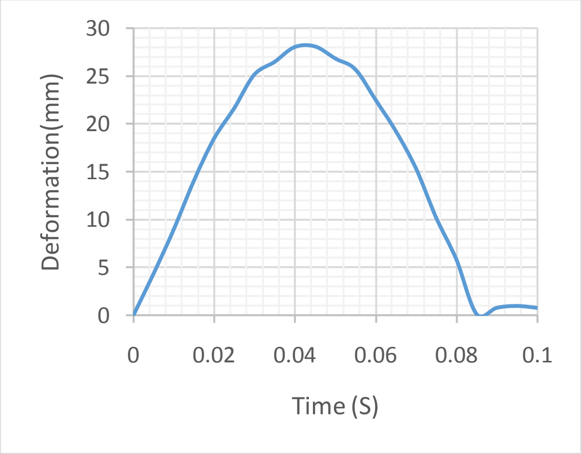


Figure 13. Deformation of bumper beam for M220.

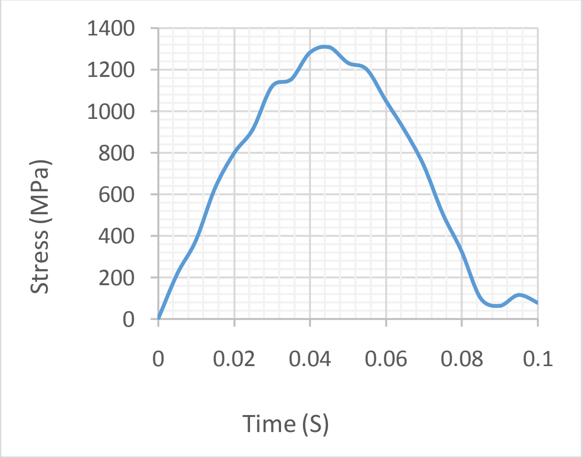


Figure 14. Stress of bumper beam for M220.

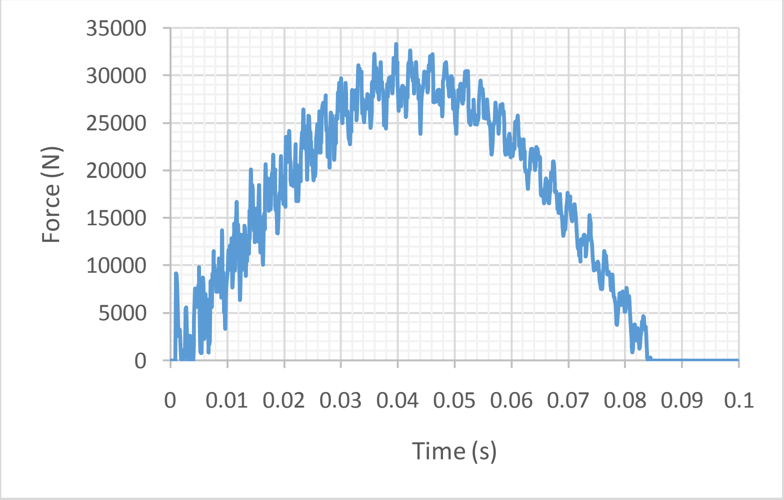


Figure 15. Impact force of bumper beam for M220.

With bumper beam Material as M220 once again model is tested and the result are plot.The maximum deformation of the bumper beam for M220 material is 28.10mm which is well below the permissible limit 40mm, also the maximum stress value is 1308.8 MPa which is less than the yield strength of the material 1350MPa. The maximum impact force is 33313.8N which is more than the aluminum alloys. Fig.15 shows that the force absorbing capacity of the M220 material is higher than the all other material studied in this paper.

Fig. 16 shows the Von-Mises stress distribution in bumper beam. Maximum stress is induced at the middle portion of the bumper beam as it is less than the yield stress of material so the bumper beam is safe.

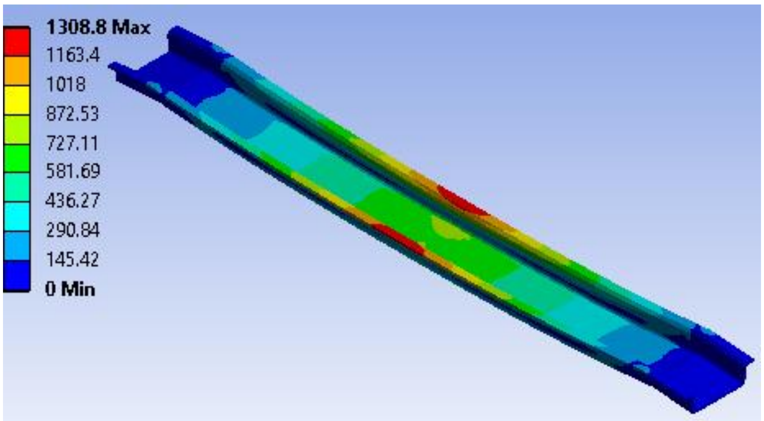


Figure 16. Von Mises stress distribution in M220 bumper beam.

VII. Effect of Passenger.

The effect of presence of passenger on impact behavior with martensitic steel is investigated by considering the passenger's weight as point mass elements which is applied on end plate. There are two conditions studied here first car weight with passenger and second case car without passenger. For the simplification, in case of car with passenger, distribution of passenger is not considered here. For this study four occupants are considered as per the standard.

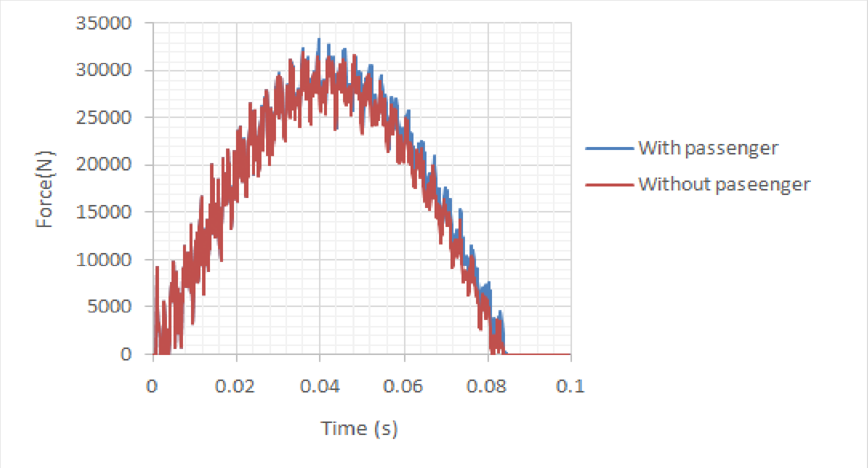


Figure 17. Comparison of impact force for two case studies.

The impact force with and without passenger are calculated and plot in fig.17. It shows that impact force with passenger is 6% more than the without passenger. Fig. 18 shows the deformation comparison for with and without passenger. The effect of without passenger is not much compare to with passenger.

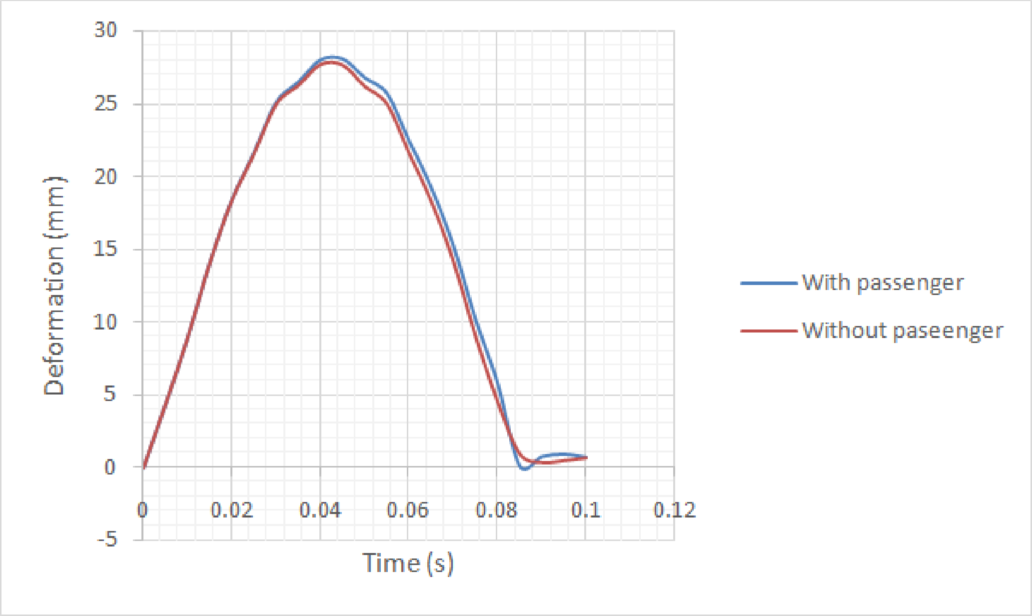
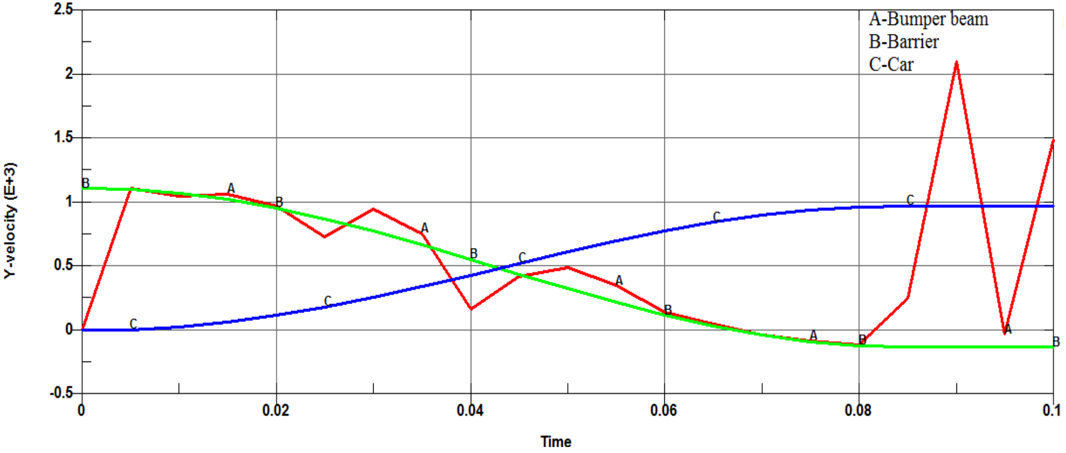


Figure 18. Comparison of deformation for two case studies.

Figure 19. Kinetic energy transfer in M 200 bumper beam with passenger



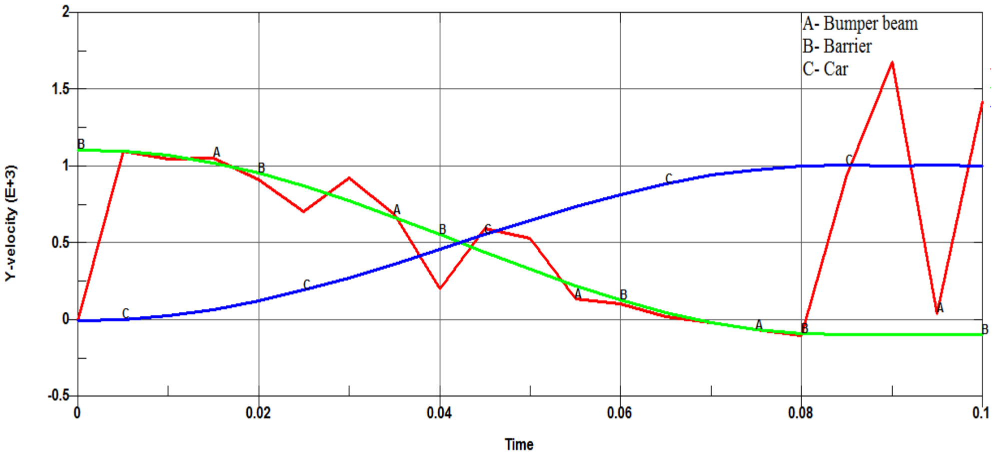


Figure 20. Kinetic energy transfer without passenger.

Kinetic energy and linear momentum conservation is observed in Figs. 19, 20. The difference between barrier velocity and car is different for bumper beam with and without passenger. Barrier velocity goes in negative direction because the barrier is not able to transfer its complete momentum to a bumper beam. In case of bumper without passenger barrier goes less in negative direction compare to with passenger. The COR < 1 means barrier impacted on bumper beam inelastically. COR with passenger bumper beam is 0.9 and 0.98 for without passenger.

From the above study it is clear that if the bumper beam is tested considering effect of mass, itis critical case nearer to actual case. If this is safe then it is definitely safe for the case without passenger.In the second place, any plastic deformation of the bumper beam should be avoided as much as possible in low-speed mode. Maximum deformation of bumper beam should be within the acceptable limit which in this study is 40mm limit is considered. The maximum stress of the bumper must be below the yield stress.

From the material study it is conclude that bumper beam material must have high yield strength and high modulus of elasticity.

VIII. Conclusion

In order to design the front bumper beam, two major factors considered. First the internal absorbed energy by the bumper beams should be kept high by using material having high yield strength and high modulus of elasticity.In the second place, any plastic deformation of the bumper beam should be avoided as much as possible in low-speed mode. Maximum deformation of bumper beam kept within the acceptable limit. The maximum stress of the bumper is also below the yield stress of material.

From the study of passenger it is clear that if bumper is safe for with passenger then it is definitely safe for without passenger. From the above study it isconclude that material M220 is good for the manufacturing of bumper beam.

IX. Acknowledgement

I take this opportunity to express my gratitude to the people who have been instrumental in the successful completion of this work. At the outset I articulate my overwhelmed feelings towards my guide and **head of mechanical engineering Dr. Rajesh B. Buktar**for being my teacher and providing confidence to carry out my research work.

I express my deep sense of appreciation to **Prof. N. R. Raykar** for his unrelenting help and moral support throughout the research work. I thanks to my parents for giving me the innate abilities that I have. I wish to recognize the moral support, proof reading and lively cooperation of my lovely friends.

References

Journal Papers:

[1]. Umar R.. Update of road safety status in Malaysia. University Putra Malaysia. 2005.
[2]. Hosseinzadeh RM, Shokrieh M, and Lessard LB, "Parametric study of automotive composite bumper beams subjected to low-velocity impacts", Composite Structures 68 (2005) 419–427, Elsevier Ltd.
[3]. Marzbanrad J M, Alijanpour M, and Kiasat MS, "Design and analysis of automotive bumper beam in low speed frontal crashes", Thin-Walled Structures 47(2009) 902–911, Elsevier Ltd.
[4]. United Nations agreement, Uniform provisions concerning the approval of vehicles with regards to their front and rear protective devices (bumpers, etc.), E.C.E., 1994.
[5]. Andersson R, Schedin E, Magnusson C, Ocklund J, "The Applicability of Stainless Steel for Crash Absorbing Components", SAE Technical Paper, 2002.
[6]. Evans D and Morgan T, "Engineering Thermoplastic Energy Absorbers for Bumpers", SAE Paper, 1999.
[7]. BautistaGarret, HardinChad, TaylorBen, "Best-In-Class Global Bumper Reinforcement Beam", AISI 123-129.California Polytechnic State UniversitySan Luis Obispo2009
[8]. Vincent W. Antonetti, "Estimating the Coefficient of Restitution of Vehicle-to-Vehicle Bumper Impacts", SAE 980552.
[9]. D. Al Galib, A. Limam "Experimental and numerical investigation of static and dynamic axial crushing of circular aluminum tubes", Thin-Walled Structures 42 (2004) 1103–1137, Elsevier Ltd.
[10]. Williams DA, Parkin CC, European new car assessment programme (Euro NCAP), Testing protocol, Transport Research laboratory, version 2, May 1999.
[11]. Samer Mahmoud, Kevin Lease, "Two-dimensional and three-dimensional finite element analysis of critical crack-tip-opening angle in 2024-T351 aluminum alloy at four thicknesses", Engineering Fracture Mechanics 71 (2004) 1379–1391, Elsevier Ltd.
[12]. Wonoh Lee, Kyung-Hwan Chung, "Experimental and numerical study on formability of friction stir welded TWB sheets based on hemispherical dome stretch tests", International Journal of Plasticity, 25 (2009) 1626–1654, Elsevier Ltd.
[13]. Pocket book of steel: Your reference guide to steel in the automotive industry. Corus Automotive. (2009, Dec).
[14]. Carrie M. Tamarelli, "The Evolving Use of Advanced High-Strength Steels for Automotive Applications", Materials Science and Engineering University of Michigan, 48075, 2011.

Websites:

[1] www.ansys.com
[2] http://www.ispat.com
[3] https://www.araiindia.com
[4] http://www.nhtsa.dot.gov/cars/testing/procedures/TP-581-01.pdf
[5] http://www.autooutlet.es/MS0101330.