Design and Analysis of an Automotive Frontal Bumper Beam for Low-Speed Crashes

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Abstract— In low-velocity impact test, the main parameters like material, shape, thickness and impact conditions are considered generally for modeling and analysis of an automobile bumper for better crashworthiness. Analysis of bumper beam under the conditions of impact is considered to the respective low-velocity standards of automotive mentioned in E.C.E. United Nation's agreement, Regulation no. 42, 1994. The crash analysis is performed on bumper by considering aluminum and composite materials in order to compare the deflection and Von-mises stresses in order to know the behavior of impact. In maximum deflection situation, under the elastic mode the strength is investigated with impact force and energy absorption. Designing a bumper beam of automotive should be good enough in order to provide the safety of passengers, which should also be of low weight to improve the efficiency of the passenger car. Apart from the safety factor, gas emission and fuel efficiency regulations are also considered importantly which gives the advantage to the manufacturer in weight reduction of automotive.

Keywords—Front Bumper beam; Finite element model; Low-speed; Impact analysis.

I. INTRODUCTION

In this study, a bumper beam is modeled and by considering three materials: high strength sheet molding compound (SMC), glass mat thermoplastic (GMT) and aluminum are examined by impact test in order to measure the impact forces, deflection, energy absorption and stress distribution behavior. The above parameters are compared to decide the best selection of thickness, shape and material. In the end, we can say that the modeled SMC bumper can reduce the stress distribution, deflection and impact force along with increase in the elastic strain energy. The studied characteristics are represented in graphs at regular interval of time for comparison between different materials. Furthermore, by suing SMC material we can achieve some other advantages like weight reduction, more economical by using less cost composite materials and flexibility in manufacturing because of eliminating ribs.

Marzbanrad et al. (2009) considered critical parameters, which includes impact conditions, shape and thickness in order to get a better design and analysis of a bumper to develop crashworthiness for low-speed collision impacts. In order to provide good impact strength for automotive, bumper is one of the important structures, which need attentive design and production (Cheon et al., 1995; Reid, 2000). In order to absorb the energy when collision occurred, bumper is the important part, which has to be considered (Maeda et al., 1994). Since, for a product like bumper, the impact strength should be suitable (Cheon et al., 1997; Cheon et al., 1999). In order to design a light-weight bumper beam, a commercial bumper is chosen in the project for designing and impact test by introducing safety, crashworthiness and automobile safety legislation are considered as initial conditions (Feng and Feng, 2002).

By using composite materials and metallic sheet consists of high strength which is of a small thickness material, weight of the automobile bumper can be reduced (Jambor and Beyer, 1997; Yuxuan, 2004). To design the bumper as similar to the reality, so many efforts are taken. Thus, the created model is directly imported in to LS_DYNA pre-processor and meshing of the bumper, such that the model is precise. Modeling of the bumper beam is done based on the conditions given in E.C.E. United Nations Agreement, Regulation no. 42, 1994 (1994). For these kinds of conditions, the passenger car must be situated on a flat surface on releasing the break and gear and impact test is performed on side and front directions (Hosseinzadeh, 2005). Simplified assumptions are considered since, for the practical low-speed test mentioned in the referred agreement needs lab equipment in order to produce the possible finite element modeling. However, the consequence of this concept adoption is that when a bumper impacts any rigid body, this kind will happen generally in accident while parking or in low-velocity impact pendulum test (Lee and Lee, 1996), such that the bumper frontage alone may need not be adequately stiff enough to resist the impact.

Overall, the main objective of this study is to improve an automotive bumper beam made of different materials (Sheet Molding Compound, Glass Mat Thermoplastic and Aluminum) which satisfies the requirements as follows:

1. Shape simplification by eliminating the strengthening ribs of bumper beam, which indirectly helps in easy manufacturing.
2. Using composite materials of low-cost is always economical.

3. When compared to metallic bumpers, these materials achieve reduction in weight.
4. Improved or at least similar impact behavior can be achieved when compared to the present metallic structure.

Even latest surveys based on SMC composites, are proving that suitable SMC materials can replace GMT (Das, 2001; Automotive Composite Alliance (ACA), 2000; Busch, 2000).

II. METHODOLOGY

A. *Finite Element Modeling*

A commercial Bumper beam of an automotive passenger car is considered and efforts were kept on re-modeling it by using CATIA v5 (2012) with the help of different modules like surface modeling, part modeling as shown in the Fig. 1.

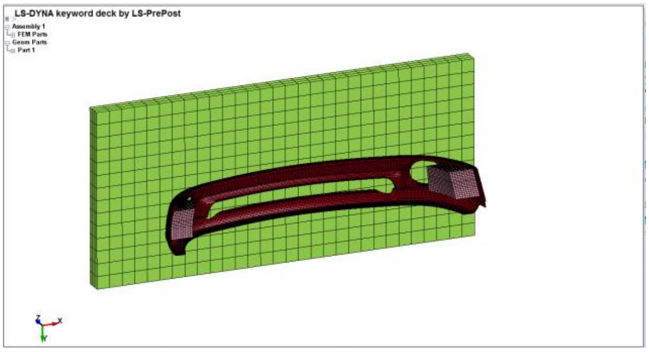

Figure. 1Finite Element Model of Bumper beam

B. *FEM Characteristics of the Models*

Different materials are considered for different parts in this impact mechanism. Parts and its parameters are tabulated as shown in Table.1. Materials and their properties are tabulated as shown in Table. 2

Table. 1 Characteristics of the Models

Part	Material	Element type	Thickness/weight/ density
Bumper beam	GMT, SMC, Al	Shell	4 mm
Car (Mass elements)	–	Mass	1500 kg
Impactor	Rigid body	Solid	$7.8{*}e^5$ kg/m^3

Table. 2 Material Properties

Material	Young's Modulus, E (GPa)	Poisson's ratio, ν	Yield stress, S_y (MPa)	Density, ρ (Kg/m^3)
GMT	12	0.41	230	1280
SMC	20	0.33	309	1830
Aluminum 3105-H18	73.1	0.33	248	2840

C. *Impact Mechanism*

This kind of research on impact tests, the important point to be noted is the type of impact that we obtain elastic or plastic impact. Negligible quantity of energy will be losing in elastic impact in between two impacting bodies. Impact between two billiard balls can be considered as an example. Considerable amount of energy dissipation will be taking place in plastic impact. Impact between two automotive vehicles or at least between a rigid body and an automotive vehicle in which the vehicle gets crumple on an impact. It is also an example of an elasto-plastic impact. Schematic diagram of a low-speed impact test is shown in the Fig. 2.

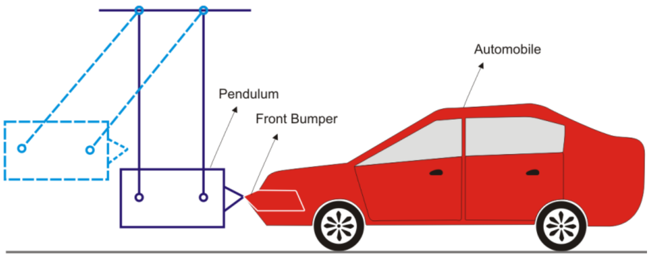

Figure. 2 Low-Speed Impact test

Since the impact between the front bumper and an impactor is nonlinear and transient analysis are involved, this phenomenon can be very complicated in low-speed crashes. Therefore, the automobile manufacturers insist that material failure or crash should not occur in bumper system while designing the bumper. Such that the total energy will be conserved throughout the duration of impact.

Here, the impactor is considered as rigid body and the font bumper is made of composite and metallic materials, the load of the impact distributed irregularly along the connecting area over the connecting region of the bumper beam. When the bumper is subjected to impact loading, it always undertakes a constant deformation $\delta_{\max}$.

In the elastic impact, energy conservation principle is considered here; kinetic energy is conserved before the impact and again converted to elastic energy. Kinetic energy of automobile and the impactor during its maximum deflection can be expressed as follows:

$$\frac{1}{2}m_1v_1^2 = \frac{1}{2}K_{eq}\delta_{\max}^2 + \frac{1}{2}m_1v_o^2 + \frac{1}{2}m_2v_o^2 \qquad (1)$$

where v_1 is the velocity of impactor before the impact and v_o is the final velocity at maximum deflection point of the vehicle and the impactor, m_1 is the impactor mass and m_2 is the vehicle mass and K_{eq} is the equivalent stiffness of the automobile bumper beam which can be obtained from the relationship of reaction forces and displacement from analysis of beam.

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Another important consideration in the case of momentum is that it can neither be created nor destroyed. Therefore, the momentum before the impact is as same as after impact. Principle of momentum conservation at the moment of its maximum deflection before and after the impact can also be expressed as follows:

$$m_1 v_1 = (m_1 + v_1) v_o \tag{2}$$

From the above equations (1) and (2), maximum deflection $\delta_{\max}$ can be obtained as follows:

$$\delta_{\max}^2 = \frac{1}{K_{eq}} \frac{m_1 m_2}{m_1 + m_2} v_1^2 \tag{3}$$

III. RESULTS AND DISCUSSIONS

The approach generally used for crash analysis of the mentioned models, i.e. with variation in shape, material and thickness are provided in LS_DYNA R7 (2012). This solid model of bumper beam is imported and creates surface followed by meshing. Shell element is the best element for the bumper to do meshing, because of its smaller average thickness when compared to other dimensions of bumper.

Here, contact velocity of the impactor is given as 5 km/h for straight and linear impact as mentioned in ECE standards (Yuxuan, 2003). Duration period of impact test begins at the first contact and lasts until the full separation and stress release occurs.

A. Stress Distribution for Different Materials

The stress distribution in the vehicle front bumper beam for GMT (Glass Mat Thermoplastic) can be observed as shown in the below Fig. 3 and maximum stress obtained is 215.064 N/mm^2 which is below the yield strength of the material. The stress distribution in the bumper beam for SMC (Sheet Molding Compound) can be observed as shown in the below Fig. 4 and maximum stress obtained is 273.387 N/mm^2 which is also below the yield strength of the material.

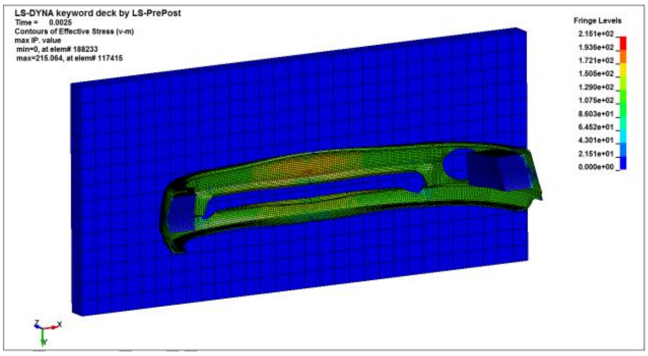

Figure. 3 Stress distribution for GMT

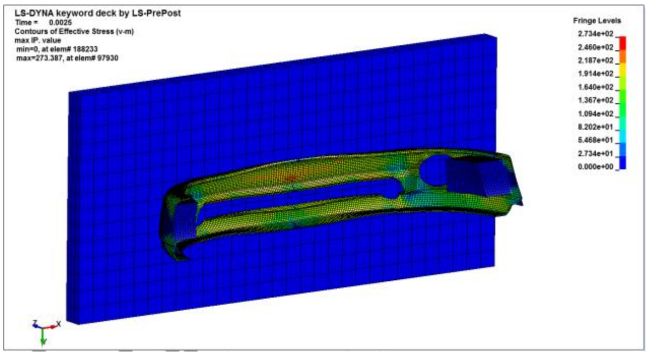

Figure. 4 Stress distribution for SMC

The stress distribution in the vehicle front bumper beam for Aluminum 3105-H18 can be observed as shown in the below Fig. 5 and maximum stress obtained is 151.744 N/mm^2 and is well below the yield strength of the material which says that there will not be an immediate failure.

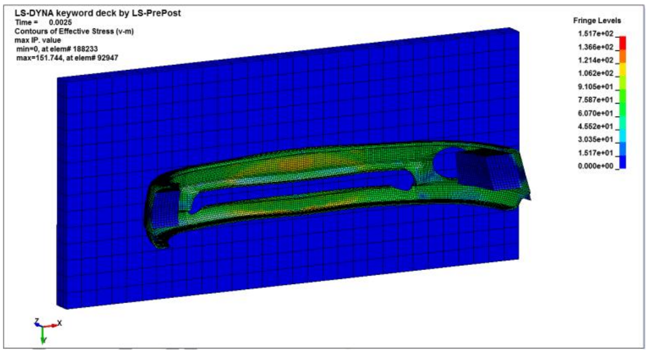

Figure. 5 Stress distribution for Aluminum

B. Deflections Occurred in Different Materials

The deflections occurred in the vehicle front bumper beam for GMT (Glass Mat Thermoplastic) can be observed as shown in the below Fig. 6 and maximum deflection obtained is 127.094 mm. The deflections occurred in the vehicle front bumper beam for SMC (Sheet Molding Compound) can be observed as shown in the below Fig. 7 and maximum deflection obtained is 130.756 mm.

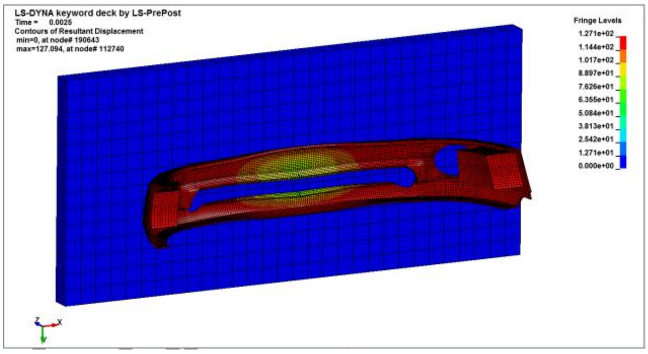

Figure. 6 Deflections occurred in GMT

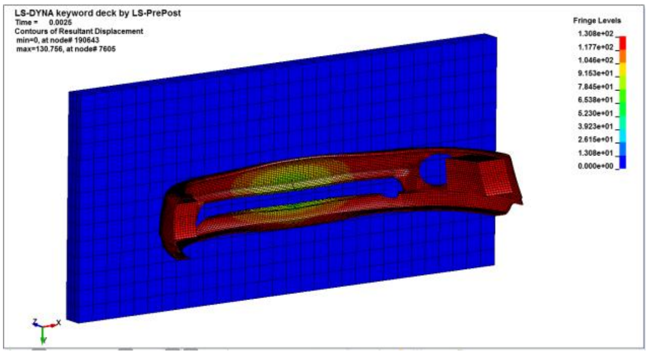

Figure. 7 Deflections occurred in SMC

The deflections occurred in the vehicle front bumper beam for Aluminum 3105-H18 can be observed as shown in the below Fig. 8 and maximum deflection obtained is 127.47 mm.

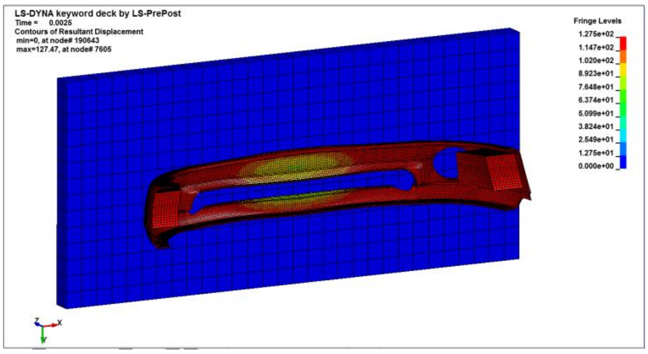

Figure. 8 Deflections occurred in Aluminum

Usually, two conditions are taken into consideration in the design of the automotive bumper beam. At first, bumper beam deflection should not cross a certain value. Second and the next condition is that, any kind of plastic deformation should not be occurred. Such that, it should provide the protection to the assembly of automotive vehicle such as fuel units, engine, cooling units etc., from damaging it. Here, yield stress of the material must always be above than the maximum stress occurred in bumper. By satisfying these conditions, total bumper mass should be reduced in the optimal design.

IV. CONCLUSIONS

In passenger cars, bumper beams acts as an important structure in order to absorb the impact forces during collisions, which are characterized with the help of FEM modeling under low-speed impact standards. Effect of different kinds of parameters on the behavior of impact for metallic bumper beams in low-speed impact produces results given below: (i) Materials with low Young's modulus leads to low rigidity and high strength materials produces good impact behavior because the yield stress is always higher than the maximum stress occurred in the bumper. Therefore, the best choice between metals is always aluminum in this case. (ii) Rise in the impact force and bumper rigidity can be achieved by increasing the bumper thickness. (iii) Increase in the rigidity of the bumper can also happen by the addition of ribs, which leads to the direct increase in the impact force, and reduce the deflection in the bumper. However, the manufacturers feel difficulty in producing the bumper along with ribs.

SMC composite is the proposed material, which replace GMT because of its unique characteristics like low cost and easy manufacturing when compared to GMT. Even the ribs of bumper structure are also removed which reduces the deflections. Maximum stress value is also occurred in SMC composite, which sustains even at little increase in the speed. The deflection values also explain the reason for SMC being the best material when compared to other two materials.

REFERENCES

[1] J. M. Marzbanrad, M. Alijanpour, and M. S. Kiasat, "Design and analysis of automotive bumper beam in low speed frontal crashes," Thin Walled Structures, vol. 47, pp. 902-911, 2009.

[2] S. S. Cheon, J. H. Choi, and D. G. Lee, "Development of the composite bumper beam for passenger cars," Composite Structures, vol.32, pp. 491-499, 1995.

[3] S. R. Reid, and G. Zhou, "Impact behavior of fiber-reinforced composite materials and structures," England: Woodhead Publishing, 2000.

[4] R. Maeda, S. Ueno , K. Uda, and T. Matsuoka, "Strength test of aluminum alloy bumper for automobile," Furukawa Review, 13, 1994.

[5] S. S. Cheon, G. L Dai, and K. S. Jeong, "Composite side-door impact beam for passenger cars," Composite Structures, vol.38, pp. 229–239, 1997.

[6] K. S. Cheon, T. S. Lim, and T. S. Lee, "Impact energy absorption of glass fiber hybrid composites," Composite Structures, vol.46(3), pp. 267–278, 1999.

[7] Z. S. Feng, and S. Q. Feng, "Research of CA1092 automotive body lightening," Journal of Automob Technol Mater, vol.58(62), pp.8-9, 2002.

[8] A. Jambor, and M. Beyer, "New cars-new materials," Materials & Design, vol.18 (4-6), pp.203–209, 1997.

[9] L. Yuxuan, "Automobile body light weighting research based on crashworthy-ness numerical simulation," Thesis (PhD). China: Shanghai Jiao Tong University, 2003.

[10] 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.

[11] R. Hosseinzadeh, M. Shokrieh Mahmood, and L. B. Lessard, "Parametric study of automotive composite bumper beams subjected to low-velocity impacts," Composite Structures, vol.68(4), pp.419–427, 2005.

[12] C. H. Lee, and C. K. Lee, “Low Speed Impact Analysis on Aluminum Bumper,” Proceedings PAM Users Conference, Korea HAMPAM, 1996.

[13] S. Das, “The cost of automotive polymer composites: A review and assessment of DOE’s lightweight materials composites research,” Energy Division, Oak Ridge National Laboratory, 2001.

[14] Automotive Composite Alliance (ACA), “2000 model year passenger car and truck thermoset composite components,” MI: Troy, 2000.

[15] J. Busch, “Composite technologies: an overview of business potentials,” White Working Paper, IBIS Associates, Inc., Wellesley: MA, 2000.

[16] CATIA V5R20 user manual.

[17] LS DYNA R7 user manual.