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Research Article

Impact Analysis of Frontal Car Bumper using Long Fibre Reinforced Thermoplastics

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Abstract

The front and rear of the vehicle should be protected in such a manner that low speed collisions will only damage the vehicle slightly, or not at all. In automotive components the use of natural fibers has increased to reduce the weight and increase the strength and safety of the automobile components. Natural Fiber Thermoplastic components in automotive industry can afford the advantages of weight, cost reduction and recyclability, compared to conventional materials. The purpose of this project is to design a bumper which is to improve crashworthiness of the bumper beam. These materials had been studied by impact modeling using Finite Element Analysis software, LS DYNA to determine the energy absorption by analyzing the kinetic energy, displacement and impact force. The selected materials are compared to each other for the design parameters like shape, material and impact condition to validate the crashworthiness.

Keywords: *LS DYNA, Natural Fibre Thermoplastics.*

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1. Introduction

Automotive bumper beam is a structural component placed behind plastic fascia either in front or rear ends of bumper system mainly to absorb kinetic energy during collision. In low speed collision bumper beam provides protection to occupant from severe injury. Bumper system is designed with the aim to absorb 80% percent of kinetic energy during collision. The main function of a bumper system is to protect the car body and passengers against collision. There are two main components of bumper beam, namely horizontal beam and axial beam or crush box and it is moulded in single piece. However in the mid 80's, the application of polymer composite material was introduced to replace conventional material such as plastic, aluminium and metal, as it can offer low weight, corrosion free, easier to produce complex shapes, high specific stiffness (stiffness/weight), and high impact energy absorption capacity over its metal counterparts. Furthermore, the use of polymeric based composite material for bumper beam is proposed for the quest of high fuel efficiency in automobiles, and having comparable properties to conventional glass fibers without sacrificing the safety of cars. The bumper beam is the key structure that helps to absorb the kinetic energy from a high-impact collision and to provide bending resistance in a low-impact collision; therefore the bumper beam is a structural component. The bumper system has to meet deflection and crash stability criteria, established by customers, legislation and insurance companies.

2. Problem Formulation

The purpose of this project is to develop a natural fiber reinforced thermoplastic composite as a bumper beam material and to investigate the mechanical, thermal and recycling properties. In the design and analysis the bumper specifications were taken from the standard passenger car, then the modeling of the bumper was done by the PRO E and, then the fine meshing was done by hypermesh software for accurate results. Then the impact loading was applied using LSDYNA to analyze the energy absorbing capacity of the bumper materials. In this research, the various bumper materials like Steel, Aluminum, Glass Mat Thermoplastics (GMT), Sheet Molding Compound (SMC) and Long Fiber Reinforced Thermoplastics (LFRT) were selected for the crash performance of front bumper beam using Finite Element Analysis. These materials were studied by impact modeling to determine the Kinetic Energy, displacement and impact force. The selected materials were compared to each other for the design parameters like shape, material and impact condition. Simulation was done using Finite Element Analysis software, LS DYNA.

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3. Mechanical Properties of Materials

The properties of steel, aluminium, GMT and LFRT KLFRT were taken from literature review (Mahmood et al 2008).

Table 1 Properties of materials

Material	Young s modulus (GPa)	Poisson ratio	Yield strength (GPa)	Density (Kg/ m^3)
Steel	210	0.3	700	7850
Aluminium	70	0.33	480	2710
GMT	12	0.41	230	1280
LFRT	9	0.45	190	1200
KLFRT	8.5	0.42	220	1240

4. Analysis of Bumper

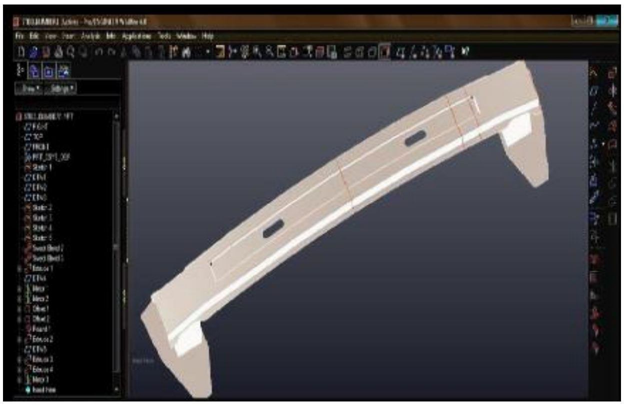

Fig.1 Model

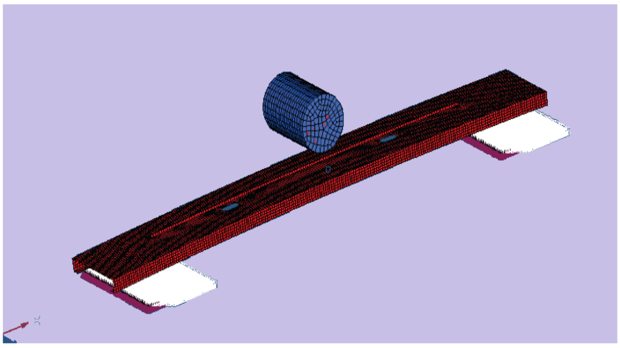

Fig.2 Meshed model of impactor and bumper

The distance between bumper beam and impactor is 40 mm. LSDYNA software was used for crash analysis. For FMVS velocity of impact barrier selected is 48kmph and for IIHS standard 68 kmph is selected. Crash type was frontal impact. Due to stretch there were residual stresses in bumper beam. From the simulation the bumper beam was shortened in axial direction. The model from PRO-E is imported into HYPERMESH for fine meshing and for analyzing LS DYNA software was used.

4.1 Development of Mathematical model for frontal Impactor

The pendulum is modeled simply as a rigid solid of mass M with an initial velocity of V. The car of equivalent mass M is a rigid solid. Bumper beam stiffness is included in the model as a spring of stiffness K. This stiffness can be identified either experimentally or analytically. From the mechanics of materials, the stiffness of the beam is K= 48EI/L^3 when the external loads applied on its center. Here the E is the Young's modulus of the materials, I is the moment of inertia and L the total length of the bumper beam.

$$K_B = \text{Load /deflection} = F/y \quad (1)$$

The governing differential equation for dynamic system is

$$Mx_1 \, K_B (x_1 - x_2) = 0 \quad (2)$$

$$Mx_2 \, K_B (x_1 - x_2) = 0 \quad (3)$$

$$x_1 = 0 \quad (4)$$

$$x_1' (0) = V \quad (5)$$

$$x_2 (0) = 0 \quad (6)$$

$$x_2' (0) = V \quad (7)$$

Linear equations lead to

$$x_1 = V/2 \, t + V/2\sqrt{2} \, \acute{\omega} \sin\sqrt{2}\acute{\omega}t \quad (8)$$

$$x_2 = V/2 \, t + V/2\sqrt{2} \, \acute{\omega} \sin\sqrt{2}\acute{\omega}t \quad (9)$$

t and $\acute{\omega}$ stands for time and angular velocity.

$$\acute{\omega} = \sqrt{K_B/M} \quad (10)$$

The total force exerted by the pendulum on bumper can be derived from (8) and (9) as $t \leq \pi/\sqrt{2}\acute{\omega}$ (11)

$$F = K_B(x_1 - x_2) \quad (12)$$

$$F = V\sqrt{K_B M/2} \sin\sqrt{2}\acute{\omega}t \quad (13)$$

$$F_{max} = V\sqrt{K_B M/2} \quad (14)$$

During impact event when force is zero and that total impact duration, τ_s can be expressed as from equation

$$\tau_s = \pi/\sqrt{2}\acute{\omega} \quad (15)$$

The equation states mass and velocity in terms of structural loads. Such loads are important for finite element analysis. For different impact velocities and masses of automobile the variation of structural loads can be clearly defined. During impact event the velocity of automobile increases and pendulum velocity decreases. Due to this bumper cannot absorb total kinetic energy of pendulum. During impact the amount of energy absorb U by the bumper can be defined as

$$U = 1/2 \, K_B \, [(x_1 - x_2)_{max}]^2 \quad (16)$$

$U = 1/2\ F^2_{max}/\ K_B = ¼\ MV^2$ (17)

Conservation of energy is used for elastic impact

Before impact K.E is converted to elastic energy. Therefore maximum deflection i.e.,

$1/2mV_1^2=1/2\ K_B\ [(x_1-x_2)_{\ max}]^2 +1/2mV_2^2+1/2MV_2^2$ (18)

Spring constant $K_B=48EI/L^3$ (19)

4.2 Displacement results

Table 2 Displacement for different materials

Material	Steel	Aluminium	GMT	LFRT	KLFRT
Displacements (mm)	262	273	264	273	269

Table 3 Impact Force for different materials

Material	Steel	Aluminium	GMT	LFRT	KLFRT
Impact Force (kN)	60.75	24.35	15.3	11	10

4.3 Distribution of energy for different materials

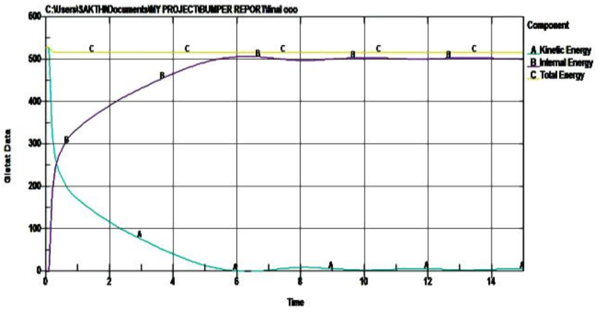

Fig.3 Steel as per FMVSS

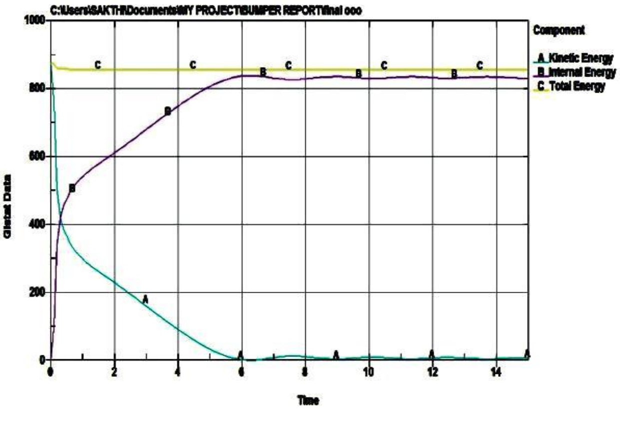

Fig.4 Steel as per IIHS

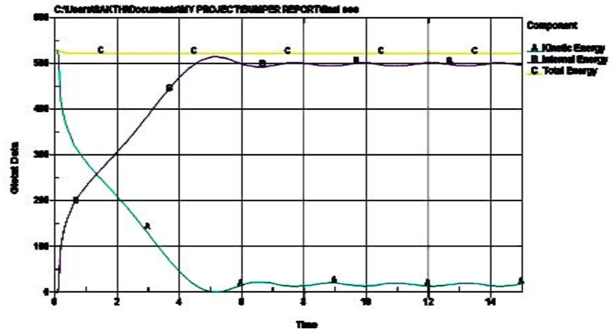

Fig.5 Aluminium as per FMVSS

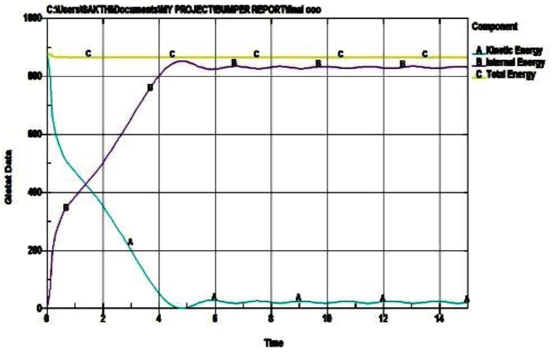

Fig.6 Aluminium as per IIHS

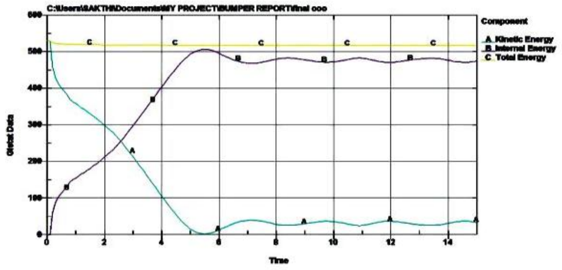

Fig.7 LFRT as per FMVSS

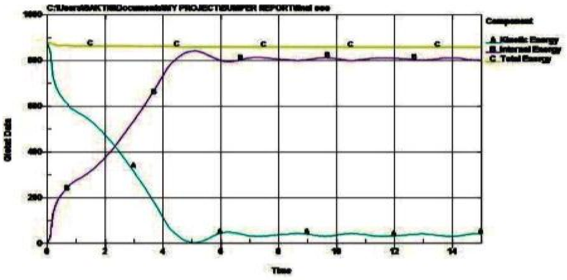

Fig.8 LFRT as per IIHS

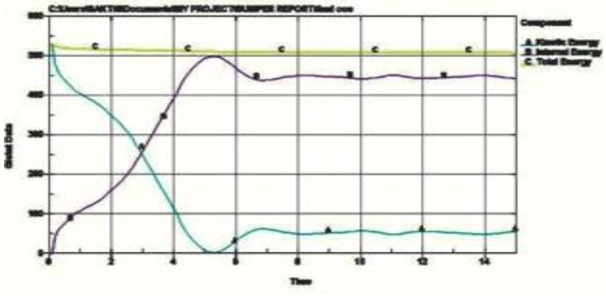

Fig.9 KLFRT as per FMVSS

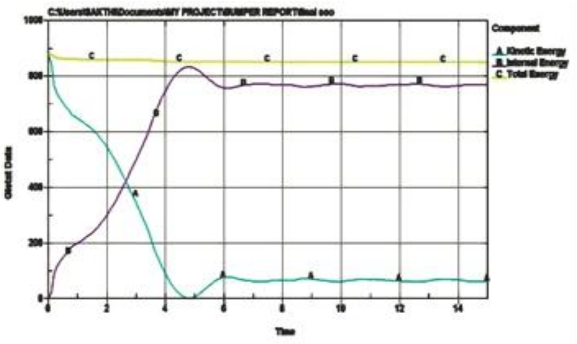

Fig.10 KLFRT as per IIHS

4.4 Displacement v/s time for different materials

The pendulum collides with bumper at a velocity of 48 km/hr and 64 km/hr.

Results were extracted from LSDYNA, according to the FMVS Standard and IIHS standard and comparison of the displacement with respect to time was plotted for the various types of materials. The pendulum hits the bumper with 48km/h velocity and 64km/h. The deflection is an important parameter to check the crashworthiness of the bumper beam material from a comparison of the graphs; it becomes clear that the KLFRT shows an increase in deflection. The deflection is directly proportional to material stiffness and yield strength. So the KLFRT can replace the conventional bumper materials. The maximum displacement of KLFRT was 61.2mm at 6.7ms as per FMVSS, 78.5mm at 6.2 ms as per IIHS.

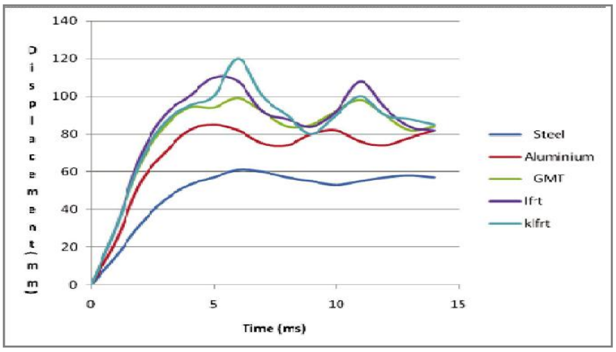

Fig.11 Displacement v/s time for different materials (FMVS)

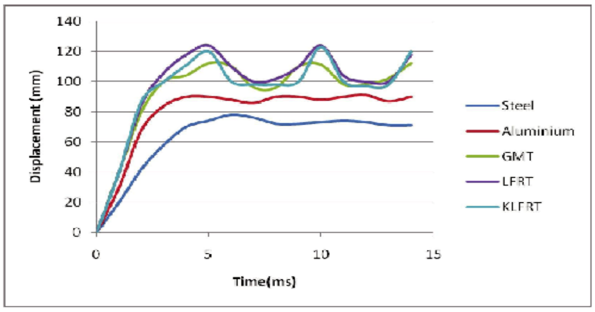

Fig.12 Displacement v/s time for different materials (IIHS)

4.5 Impact Force v/s time for different materials

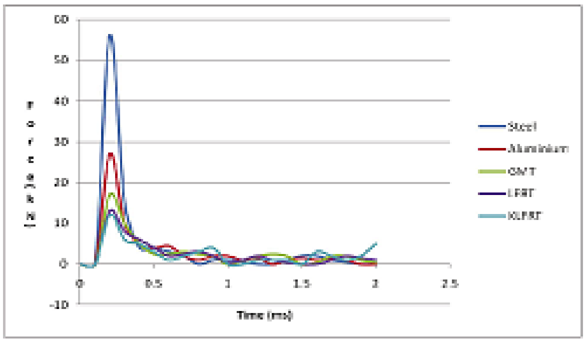

Fig.13 Impact v/s time for different materials (FMVS)

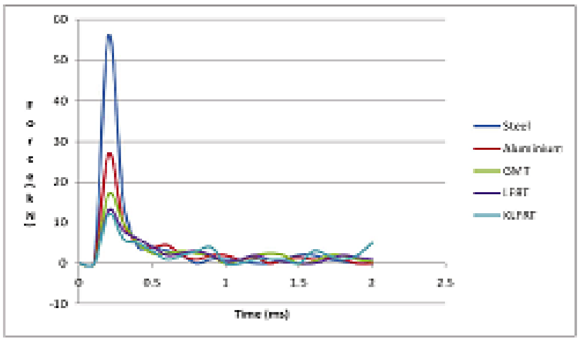

Fig.14 Impact v/s time for different materials (IIHS)

During collision impact energy is absorbed partly and remaining is converted to plastic deformation. Due to low rigidity, impact force for composites such as LFRT and KLFRT will have longer time interval. The thermoplastic materials will have more energy absorption compared with conventional material which is safe for the vehicle. From the above and due to less impact of collision natural fibre composites used for bumper can replace steel material.

Conclusion

Bumper was tested for frontal collision using FEA model to prove the ability of material for absorption of energy during collision.

1. This study focuses on comparison with conventional (steel, aluminium) and composite materials such as natural long fibres.
2. FMVSS and IIH standards were considered for impact test of bumper. LS Dyna software was used with various materials and regulations.
3. From the above analysis it is concluded that KLFRT material behaves good compared with other material and during frontal collision of bumper natural fibres have good energy absorption capacity.

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