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Design and Development of Frontal Impact Beam for Passenger Car Using Glass Fibre Epoxy Composite

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Abstract: **-- Automobile bumper is structural component of an automotive vehicle which is designed to prevent or reduce physical damage to the front or rear ends of passenger motor vehicles by absorbing the impact energy and distributing the stress perpendicular to the direction of impact. Beside the role of safety, fuel efficiency and emission gas regulations are being more important in recent years that encourage the manufacturer to reduce the weight of passenger cars. A well-designed car bumper must provide safety for occupant and essential elements of the vehicle and should have a low weight. The aim of this research is to enhance the performance of frontal impact beam (FIB) by optimizing the structural parameter using crash and modal analysis. It is proposed to manufacture FIB using Glass Fiber Epoxy (GFE) Hybrid composite material. New composite is developed to fit the design parameter. The mechanical properties like Young's Modulus, tensile strength and density are obtained by lab testing. Finally, obtained properties of (GFE) Hybrid composite material are used for simulation and modal analysis and results have been verified with existing FIB material. The careful design and analysis of FIB parameters are carried out in order to optimize the strength, and reduce the weight. The results shows that material can minimise the bumper beam deflection, impact force and stress distribution and also maximize the elastic strain energy. The analysis was done according to the conditions stated in Indian regulation Ministry of Shipping, Road Transport and Highways (Department of Road Transport and Highways), Government of India, and complies with the test condition given by Automotive Research Association of India (ARAI) norms. In this paper, modeling, meshing and crash analysis are carried out using software CREO, HyperMesh and LS_DYNA Respectively.**

Indexterms: **Load-sliding effect, RC column - S beam structure, Warehouse, Live load during earthquake**

I. INTRODUCTION

On 20th March 1958 United Nations at Geneva conference agreed to the adoption of uniform conditions of approval for motor vehicle equipment and parts, and on 1st June 1980 came up with uniform provisions concerning the approval of vehicles with regard to their front and rear protective devices like bumpers. This Regulation applies to the behavior of certain parts of the front and rear structure of passenger cars when involved in a collision at low speed. Exterior protection is assured by protective devices, which are essentially elements located at the front and rear ends of vehicles and designed in such a way as to allow contacts and small shocks to occur without causing any serious damage[1]. That exterior protective part came into existence as bumper and it is compulsory for all passenger cars. A bumper is a shield mounted on the front and rear of a passenger car. When a low speed collision occurs, the bumper system absorbs the shock to prevent or reduce damage to the car. Some bumpers use energy absorbers or brackets and others are made with a foam cushioning material. The car bumper is designed to prevent or reduce physical damage to the front and rear ends of passenger motor vehicles in low-speed collisions. Automobile bumpers are not typically designed to be structural components that would significantly contribute to vehicle crashworthiness or occupant protection during front or rear collisions. It is not a safety feature intended to prevent or mitigate injury severity to occupants in the passenger cars. Bumpers are designed to protect the hood, trunk, grille, fuel, exhaust and cooling system as well as safety related equipment such as parking lights, headlamps and taillights in low speed collisions [2].

II. IMPACT MECHANICS

There are two different kinds of impacts, that is, elastic impact and plastic impact. In an elastic impact, a little of energy that can be neglected is lost between the two impacting objects, while in a plastic impact; there is a great deal of energy dissipated in the collision. The type of impact which occurs between the front bumper system and a barrier in this article is elasto-plastic impact because the severe crash force exists. Since transient and nonlinear analyses are involved, the impact phenomenon is very complex. Of particular interest here is to study the impact behavior of the contact area. The impacting phenomenon between an barrier and the front bumper in a low-speed full crash could be very complicated, since transient and nonlinear analyses are involved. But, in designing the front bumper, 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 composite 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. A principle of energy conservation in the elastic impact is used; the kinetic energy before impact is conserved and converted to elastic energy and the kinetic energy of the barrier and the automobile at its maximum deflection, i.e.,

$$\frac{1}{2}m_A v_A^2 = \frac{1}{2}K_{eq}\delta_{\max}^2 + \frac{1}{2}m_A v_0^2 + \frac{1}{2}m_B v_0^2 \quad (1)$$

where m_A is the mass of the barrier, m_B the mass of vehicle, v_A the velocity of the barrier before impact and v_0 the final velocity of the barrier and 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:

$$m_A v_A = (m_A + m_B)v_0$$

From equations (1) the maximum deflection is obtained as follows:

$$\delta_{\max}^2 = \frac{1 \times m_A m_B}{K_{eq} m_A + m_B} v_A^2 \quad (2)$$

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

$$\frac{1}{2}m_A v_A^2 = \frac{1}{2}m_A v_{A2}^2 + \frac{1}{2}m_B v_{B2}^2 \quad (3)$$

$$m_A v_A = m_A v_{A2} + m_B v_{B2} \quad (4)$$

Where v_{A2} and v_{B2} are the final velocities of the barrier 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.

$$m_A v_A + m_B v_B = m_A v_{A2} + m_B v_{B2} \quad (5)$$

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.

$$e = \frac{v_{B2} - v_{A2}}{v_A - v_B} \quad (6)$$

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. (5) can be used to find the energy dissipated, ED, during an impact. This is found by subtracting the kinetic energy of the two masses after impact, and the kinetic energy of the barrier before impact.

$$E_{plastic} = \frac{1}{2}m_A v_A + \frac{1}{2}m_B v_B - \frac{1}{2}m_{A2} v_{A2} + \frac{1}{2}m_{B2} v_{B2} \quad (7)$$

Other energy involved during impact are kinetic energy, internal energy, sliding interface energy, rigid wall energy, damping energy, hourglass energy, initial kinetic energy, initial internal energy, external work. Advanced crash analysis software like LS Dyna are capable of plotting the energy data which is printed in the glstat files forms a useful check on an analysis. The following equation should hold at all times during an analysis.

$$E_{kin} + E_{int} + E_{si} + E_{rw} + E_{damp} + E_{hg} = E^o_{kin} + E^o_{int} + W_{ext} \quad (8)$$

E_{kin} = current kinetic energy
E_{int} = current internal energy
E_{si} = current sliding interface energy
E_{rw} = current rigid wall energy
E_{damp} = current damping energy
E_{hg} = current hourglass energy
E^o_{kin} = initial kinetic energy
E^o_{int} = initial internal energy
W_{ext} = external work

Internal energy includes elastic strain energy and work done in permanent deformation. External work includes work done by applied forces and pressures as well as work done by velocity, displacement or acceleration boundary conditions.
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III. DEVELOPMENT OF NEW BUMPER MATERIAL

A.Selection of material

In recent years, many alternative materials such as aluminum alloy, polymer, composit etc. are being considered as the new material of bumper beam to reduce weight of bumper beam without compromising the strength and functionality. Out of much material option available hybrid material is most preferred one. The concept of hybridization gives flexibility to the design engineer to tailor the material properties according to the requirements, which is one of the major advantages of composites. Composite materials are characterized by high specific strength, both in static and impact loading conditions, and high specific stiffness; they could be an interesting candidate material for this type of component, posing as targets the lightweight together with the maintenance of at least the same level of safety performance in comparison with the present steel solution. Natural fibers are easily available but cannot be used because of their average mechanical property [4]. Glass fibre reinforced polymer (EGFRP) is being considered as the new material of bumper beam to reduce weight of bumper beam because EGFRP has the higher specific strength under high impact load compared to other fibre available except carbon fibre. However, the carbon fibre is too expensive to replace entire structure of bumper beam compared to the glass fibre composites. As the bumper is designed for impact loading, prior to conduct numerical impact analysis at the component level, the impact performance of composite material are assessed. In general, impact responses and damage mechanisms for the whole group of composite materials are more complex comparing with the conventional metallic materials and depend on a number of different parameters: fiber and matrix type, section shape and dimensions, impact velocity, impact angle, shape of striker, target geometry and target material[5].

B. Manufacturing of composite Laminate

There are plenty of methods to cast a composite structure whether it is simple or complex, single or multiple. Each method has its own merits and limitations. Selection of particular manufacturing process is based on the type of matrix and fibers, temperature to form and cure the matrix, the geometry of the end product and cost effectiveness. The two important parameters that control the manufacturing techniques are temperature and pressure. High temperature is required for the chemical reaction of resin to prevail whereas pressure is required for the highly viscous resin to flow into the fibers and to bind the fibers which are initially unbounded. The chemical reaction of resin forming cross linking is called curing. The time required to complete the curing is called the cure cycle.

On curing, the viscosity of the matrix increases with increasing cure time and temperature. The rate of viscosity increase is low at the early stage of curing. After a threshold degree of cure is achieved, the resin viscosity increases at a very rapid rate. The time at which this occurs is called the gel time. For production the techniques chosen for manufacturing the composite is based on type of fiber, resin and the size of the product. For manufacturing of proposed bumper material Compression molding technique is used. It has the ability to produce parts of complex geometry in short periods of time. It allows the possibility of eliminating a number of secondary finishing operations, such as drilling, forming, and welding. Moreover the entire molding process can be automated[6]. Steps for compression molding are shown in fig.1

C. Characterization of developed material

The composite material developed EGFRC is characterised by different mechanical testing. For this material; tension test, compression test, flexural test, shear test and Izod Impact Test is carried out. Three samples are taken for each test and all were cut from the same laminate in order to get uniform result.

Tensile test was performed following the ASTM D638-2003 standard using the Universal Testing Machine (UTM) (Model No-STS248). Compression test was carried out following the ASTM D695-2002 standard using UTM with the capacity of 100kN. Flexural test was carried out using the universal testing machine (Model No-STS248) with an accuracy of ± 1% according to the ASTM D790-2003. The in plane shear test was performed by using same universal testing machine as per the ASTM D537. Procedure for shear testing is shown in fig. 2. For in plane shear stress, total three specimens were cut in to dimensions as 76mm x 20mm x 3mm having 450 notch angle at the center with depth of 4mm. Test was performed following the ASTM D 256-2005 standard[7]. The shear strength found for sample-1,2 and 3 are 59.88MPa, 62.19Mpa, 67.77MPa respectively.

Fig. 2. Shear Testing of Composite Specimen

Test was conducted in Government approved laboratory. The results obtained are tabulated in table 1.

Table 1 Mechanical Property of proposed bumper material

Sr. No.	Test Description	Sample 1	Sample 2	Sample 3	Average
1	Tensile strength MPa	404.00	426.62	443.28	424.63
2	Compressive strength MPa	305.00	304.80	303.64	304.48
3	Flexural strength	574.53	539.24	561.40	558.39

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	MPa				
4	Shear Strength MPa	59.88	62.19	67.77	63.94
5	Izod Impact MPa	2500.00	2233.30	2700.00	2477.76

Table 2 Physical properties of proposed bumper material

Material	Young's Modulus (GPa)	Poisson's ratio	Yield strength (MPa)	Density (g/cm^3)
Epoxy Glass Fiber Reinforced Composite	78	.31	685	1.94

The composite material has poor plastic properties; therefore, when energy absorbing components, like bumper beam, are designed using materials of this type, the energy dissipation can mainly take place through the material frustration. Therefore, more the component material is fragmented the larger amount of energy is dissipated. In this respect, Energy vs. time curve and the damage mode of EGFRC at perforation impact show a better fracture behavior.

IV. U BUMPER BEAM DESIGN

When designing bumper with composite material, it is not only the selection of appropriate material but to redesign the whole part with production technology, structural performance, the cost and the production rate in mind. Therefore material, design and manufacturing technology are strictly linked to each other and should be considered all together[3]. When metallic components are substituted by composite components, new design hypothesis is to be followed as both material have different mode of failure, this is how the advantage that comes from developing the new material can be optimized. Therefore, while designing current integrated bumper system in CAD software, the following three design considerations were made:

1. Overall rigidity of bumper structure manufactured from composite material is low. A new design approach has to be followed for this group of materials. By inserting more number of ribs in the structure over all stiffness and strength can be increased and the problem can be soundly addressed.
2. In case of small low velocity impact only the bumper beam should be involved and should behave fully elastic, without the direct involvement of the other part. Therefore, the clearance between the front of the beam and the front of the crash box need to be optimized. This led to the proper curvature design of the beam
3. Design of proper support mechanism so that bumper beam should always deform in a guided way during impact.

A new bumper structure is developed from scratch with all the above criteria in mind using Creo as shown in fig. III. Developed bumper have ribs throughout the structure to better structural stability. Clamping mechanism has given utmost priority during design for better performance during crash. Figure2 show the ribs and clamping hub.

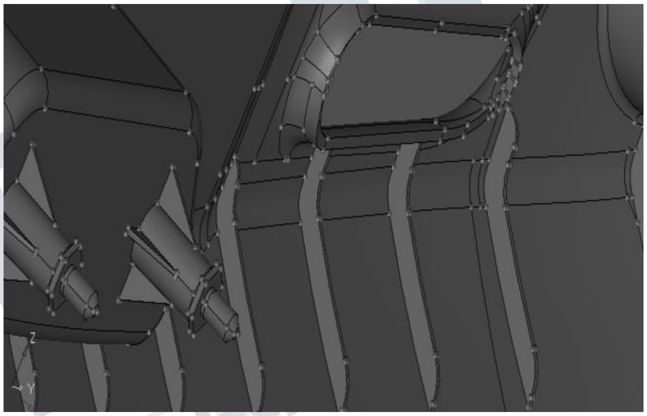

Fig. 3. Ribs and clamping mechanism of bumper

V. FINITE ELEMENT MODELING

After importing the CAD data of the bumper structure the surfaces were created and meshed in HyperMesh. Since the average thickness of bumper was much smaller than the other dimensions of the part, the best element for meshing was the shell element. For shell elements, a quadrilateral element type with sufficient amount of integration points in the element and through the thickness is considered to be efficient when simulating a crash. The study proved that shell elements were efficient in order to provide a good estimation of energy values with not too costly simulation times. Simulations with solid elements were not observed to provide similar results so it is not recommend using solid elements for simulations with this type of profile where the walls are very thin. Some various choices of impact elements can be considered like implicit and explicit model. Here, nonlinear explicit impact modelling elements were used for analysis.

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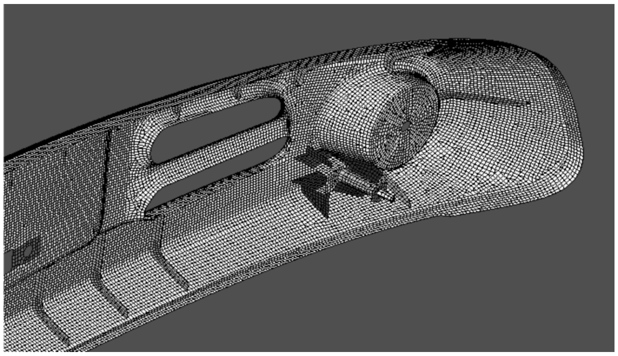

Fig. 4. Meshed model of bumper beam

VI. CRASH ANALYSIS

The model created in CREO software were imported into Hypermesh, using mesh tool the model is fine meshed and input parameters for the analysis the bumper beam were given and run using LS Dyna software. During the solution phase, finite element software assembles the governing algebraic equations in matrix form and computes the unknown values of the primary field variable(s). The computed values are then used by back substitution to compute additional, derived variables, such as reaction forces, element stresses etc. In this modelling, the mass of the car is assumed to be 1400kg and one fourth of the car weight was attached to each screwed node that located behind the holders as a point-mass element. The mass of the car was assumed rigid and lumped as opposed to the bumper structure. Bumper and holders meshed by shell element. The barrier, as a steel structure, was modelled with rigid solid impact elements according to precise dimensional drawings from the E.C.E. Standard. Material type 20 (mat-rigid) is used for simulation of barrier. Figure5 shows the model of bumper beam and the barrier.

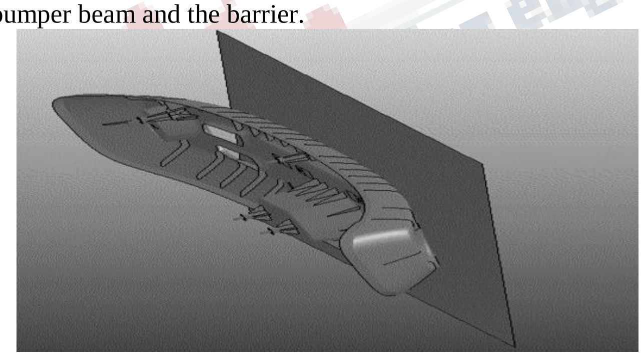

Figure 5. Bumper beam and impact wall

As shown, the car collide to the barrier in straight direction and perpendicularly. No friction was assumed between barrier and bumper surfaces and the car was taken to be lying on a flat and frictionless surface. The barrier contact velocity was 4 km/h for straight impact. The period of test modelling begins from first contact and lasted until full separation and stress release.

Table 3 FEM characteristic of the model

Part of model	Material	FEM element	Number of element	Number of node	Mesh type
Bumper beam	Steel, aluminum EGFRC	Shell	22859	6825	Quadrilateral
Barrier	Rigid steel	Solid	450	182	Brick

VII. RESULTS AND DISCUSSION

Result obtained during crash analysis of bumper beam is discussed here and results are compared to support the same.

A. Maximum stress developed

Maximum stress developed in bumper beam during impact is 71.4392MPa. This value is quite low in comparison to the yield strength of the material.

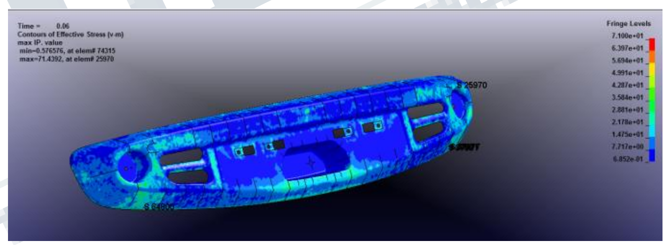

Fig.7 stress distribution in bumper beam

B. Maximum deflection

Maximum deflection observed during impact is 32.8687mm at time 0.06 second. The pictorial representation of displacement contour is given in fig. 6.

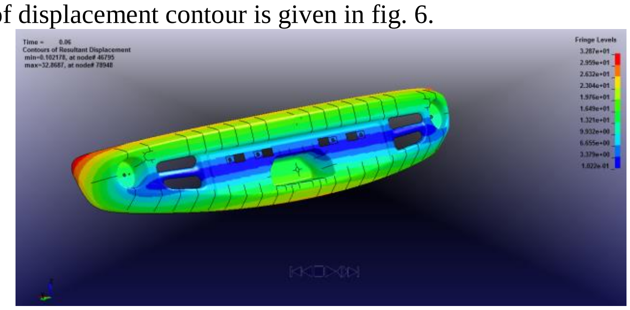

Fig. 7 Deflection in EGFRC bumper

Javad Marzbanrad et al. [] suggest that the permissible deflection of bumper beam is 50mm. For beam made up of different metal deflection are shown in figure 6.

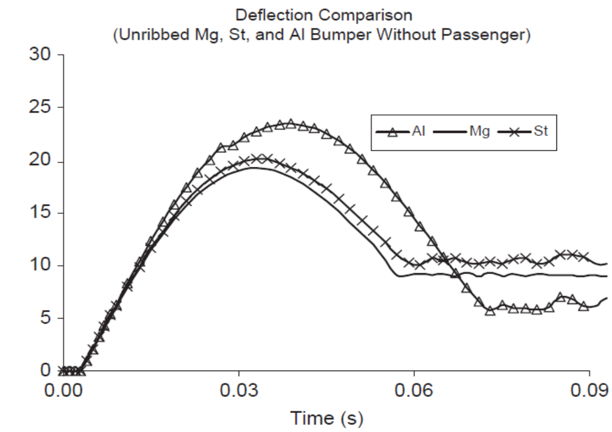

Fig.8 deflection comparion of different bumper material[]

The separation point takes place at 0.072, 0.058 and 0.054 s, for aluminum, steel and magnesium, respectively. This can be seen in the deflection vs. time diagram in Figure that maximum deflection point also occurs at 0.037, 0.034 and 0.033 s; with the deflections 20.25, 16.47 and 15.51mm, for aluminum, steel and magnesium, respectively. The deflation obtained in this case is 32.8687mm which is permissible(less than 50mm) and proposed bumper will deflect in permeable limit without fracture.

C. Energy data

Internal energy includes elastic strain energy and work done in permanent deformation. External work includes work done by applied forces and pressures as well as work done by velocity, displacement or acceleration boundary conditions.

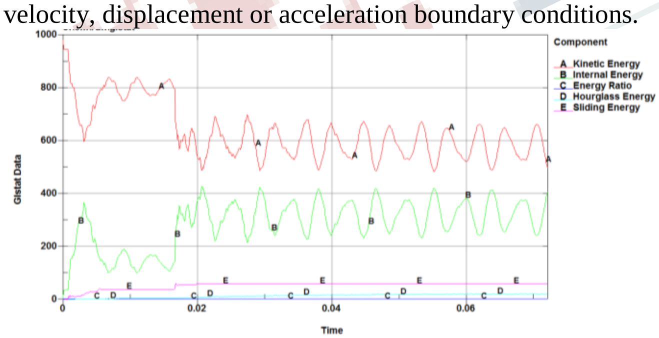

Fig 9. Energy plot for EGFRC bumper

From figure5 it is clear that the kinetic energy of bumper start to decrease and internal energy start to increase as soon the bumper come in contact with the barrier. The total kinetic energy of car does not transfer to the barrier and some portion of this energy converts to elastic and plastic strain energy as shown in Figure . Kinetic energy does not become zero after impact as deformation is very gradual. Gradual deformation of bumper beam is always desirable for better energy absorption.

VIII. CONCLUSION

Automotive frontal impact beam absorbs the impact energy by elastic deformation in low-speed impact. The bumper design must be flexible enough to reduce the passenger and occupant injury and stay intact in low-speed impact. Beside the role of safety, fuel efficiency and emission gas regulations are being more important in recent years that encourage manufacturer to reduce the weight of passenger cars. The geometry of bumper beam is benchmark for performance. The benchmark tool is based on implicit methodology. All aspect of design and material selection are leveraged to assess performance and eventually to validate the design. Two basic criteria that need to be considered while designing the automotive bumper beam are -the deflection of the bumper beam should not exceed 50mm and the beam should not go under plastic deformation during collision in order to protect other component of vehicle from damage.

For proposed beam maximum deflection is 32.8687mm during impact which is acceptable for our design and material proposed. The maximum stress induced in the bumper during impact is below the yield strength() of the material. One of the greatest advantages of composite material is flexibility to the design engineer to tailor the material properties according to the requirements and better efficiency at much reduced weight. For the same design the beam made up of EGFRC has the highest value of mass fraction (25.7%,)compared with other materials like steel , aluminum etc. Considering overall result it is proved that selection of epoxy glass fiber composite as material and proposed bumper design is the most optimum decision.

REFERENCES

[1] United Nations Agreement, Uniform Provisions Concerning the Approval of Vehicles With Regard to Their Front and Rear Protective Devices (Bumpers, etc.), 1980.

[2] www.nhtsa.gov [https://one.nhtsa.gov/cars/problems/studies/Bumper/Index.html]

[3] Belingardi, A., Beyene, A. T., Koricho, E. G. and Martorana, B., Alternative lightweight materials and component manufacturing technologies for vehicle frontal bumber beam, 2014, pp. 1-23.

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 12,December 2017

[4] Sature, P., Mache, A., and Wangikar, K., Studies on Mechanical Performance of Hemp/Jute Reinforced Epoxy Hybrid Composites, Journal of Mechanical Engineering and Automation, 2014.

[5] Davoodi, M. M., Sapuan, S. M., Ahmad, D., Aidy, A., Khalina, A. and Mehdi Jonoobi, Concept selection of car bumper beam with developed hybrid bio-composite material, *Material and Design*, 2011 (32), pp. 4857-4865.

[6] www.nptl.ac.in [http://nptel.ac.in/courses/101106038/mod02lec01.pdf]

[7] ASTM D3039 / D3039M – 17, Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

[8] Davoodi, M. M., Sapuan, S. M., Aidy, A., Abu Osman, N. A., Oshkour, A.A. and Wan Abas, W.A.B., Development process of new bumper beam for passenger car: A review, *Materials and Design*, 2012 (40), pp. 304-313.

[9] Hambali, A., Sapuan, S.M., Ismail, N., and Nukman, Y., Application of analytical hierarchy process in the design concept selection of automotive composite bumper beam during the conceptual design stage, *Scientific Research and Essay*,2009 (4), pp. 198-211.

[10] Do-Hyoung Kim, Hyun-Gyung Kim and Hak-Sung Kim, Design optimization and manufacture of hybrid glass/carbon fiber reinforced composite bumper beam for automobile vehicle, *Composite Structures*, 2015 (131), pp. 742-752.

[11] Matthias Goelke, Practical Finite Element Analysis, 2015.

[12] Altair University Tutorial, Crash bumper analysis, 2013.

[13] Hwa-Won Lee and Sung- Kuk Jang, Bumper design using computer simulation, Vehicle R and D Department Ssang Yong Motor Company, Korea, pp. 1-12.

[14] Neil Sharpe, Robert Vendrig, and Kees Houtzager, Improved design for frontal protection, *TNO Automotive, Crash Safety Centre*, 2004, pp. 1-10.