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Experimental and Numerical Analysis of Polymer Matrix Composite Material for using in Automobile Bumper

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***Abstract* - Automotive design with safety, comfortness, economy and aesthetic is a great challenge to design engineer. In tune with this improvement in the bumper design and selection of material is very important. The proper design and material selection of bumper will increase the performance of the bumper, improve absorbing capacity during impact load and increase the protection of front car component. So the best material that can be used to fabricate bumper without sacrificing safety is fiber reinforced composite. In this work fabrication of jute polymer matrix composite and numerical analysis of bumper is carried out. Fabrication jute polymer matrix composite is done by using hand layup process by using Jute/Epoxy bidirectional laminates. Charpy impact test and tensile test are carried out to find out properties of composite. Ambassador car bumper is modeled using ANSYS 17.0 for numerical analysis. Static as well as impact analysis is done on this model. The materials used for this analysis are Chromium coated mild steel, Aluminium B390 alloy and Jute polymer matrix composite. During static analysis, Jute polymer matrix composite shows the lowest deformation and maximum von mises stress value. The composite shows the highest stress value, lowest deformation and the lowest strain value on compared with above materials after impact analysis. From these analyses, it can conclude that jute fiber composite is one of the best materials that can be use as the bumper material among the other materials used here.**

Key words: Jute fiber composite, bumper material, impact, static, analysis, fabrication

I. INTRODUCTION

Many car accidents are happening every day. Statistics shows that ten thousands dead and hundreds of thousands to million wounded each year. Improvement in the safety of the automobiles will decrease the number of accidents. Automotive bumper system is one of the key parts in passenger vehicles. An automobile bumper is the front-most or rear-most part, which is designed to sustain an impact without damage to the vehicle safety system. Automotive bumper are not capable to reduce injury of vehicle components during high speed collision. Bumper is made of steel, aluminum, rubber or plastic. The weight is more in existing bumper. The weight reduction is one of the main focuses of automobile manufactures. This can be achieved by introducing better material, better design concepts and better manufacturing process. By using good bumpers we can ensure safety of passenger up to a certain limit. At the same time this bumper will not massive in terms of weight contributing to increase the total weight of vehicle. Low passenger vehicles like cars are the most commonly used automotive vehicle. In these low passenger vehicles the bumper provide safety as well as aesthetic looks as compared to other vehicles. Steel bumper have many advantage such as good load carrying capacity and it has also low strength weight to ratio. Recent studies show that composite materials are a viable replacement material for conventional steel. By using composite material we can reduce weight with improved mechanical properties. Plenty of natural fibers are available in India. So we can consider a natural fiber composite material as an alternating bumper material. The objective of this work is to identify a best natural fiber composite material for bumper which will ensure passenger safety, with high strength to weight ratio through impact and static analysis using different engineering materials like Chromium coated mild steel, Aluminium B390 alloy, PEI Plastic and Jute composite. The thickness of composite bumper is calculated by using bending moment equation and other dimensions are same as the dimension of ambassador bumper.

II COMPOSITE BUMPER

Composite materials are experimented in almost all part of automobile in recent days. Composite materials are preferred over conventional steel bumper due to reduction in weight and these materials absorb more energy during collision. Excellent corrosion resistance, high impact strength, rapid response to induced or release stress are some of the advantage of composite materials.

A.Jute Fiber

Jute fiber is generally derived from the steam of a jute plant and it is multicelled in structure. It is an annual plant that grows to 2.5-4.5 m and flourishes in monsoon climates. Jute is a lingo-cellulosic fiber because its major chemical constituents are lignin and cellulose. The thermal and electrical conductivity, biological degradation, proneness to mildew and moths, ability to protect from heat, cold and radiation, reaction to sun and light, etc. are determined by cellular constitution and morphology. Jute fibers are easily obtainable in fiber and fabric forms with good thermal and mechanical properties among different natural fibers. The inborn properties of jute fiber such as low density, low elongation at break, high tensile modulus, its specific stiffness and strength comparable to those of glass fiber draws the attention of the world. Jute fibers are available in different form like raw jute, woven jute fiber mat, short jute fiber and needle punched nonwoven jute fiber. Woven mat reinforced composites are more popular due to its balanced properties in mat plane as well as their ease of handling during fabrication. The woven configuration improved the wear resistance of the composites. The laminated composite obtained from woven mat has good properties in mutually orthogonal directions and shows better plane impact resistance than multi directional laminate.

B. EPOXY RESIN

Epoxy resins are one of the most commonly used resin. Epoxy resins are low molecular weight organic liquids containing epoxide group. Epoxide has one oxygen and two carbon atoms in its ring. Hardeners are added to produce epoxies with wide range of properties of impact, viscosity, degradation etc. the epoxy is used as polymer matrix material because of the following reasons. Good compatibility, high strength, low shrinkage rates, low viscosity and low flow rate.

III FABRICATION OF COMPOSITE

For fabricating composite we need to know about dimensions and properties of existing steel bumper. Ambassador bumper is taken as benchmark. Dimensions and properties of bumper are given below.

Effective length	= 0.975 m
Total length	= 2.055m
Thickness	= 0.002m
Effective breadth	= 0.076m
Weight	= 5.16 kg
Material	= Mild steel (chromium coated)
Tensile strength	= 460 Mpa (design data book)
Density	= 7800 kg/m^3

The moment of composite bumper and steel bumper is assumed to be same. The moment for steel is

$$\frac{M}{I} = \frac{\sigma}{y}$$

Where,
M = Bending moment (Nm)
I = Moment of inertia (m^4)
σ = Tensile strength (N/m^2)
y = d/2
d = Thickness of bumper (m)
b = Breadth of bumper (m)
Moment of inertia of rectangular section I = bd^3/12
There are three sections in the bumper I_1, I_2, I_3 respectively.

$I_1 = 0.056 \times 0.002^3 / 12 = 3.73 \times 10^{-11}$ m^4
$I_2 = 0.076 \times 0.002^3 / 12 = 5.06 \times 10^{-11}$ m^4
$I_3 = 0.056 \times 0.002^3 / 12 = 3.73 \times 10^{-11}$ m^4
I = I+I+I = 1.252×10^{-10} m^4
The moment equation,

$$\frac{M}{1.252 \times 10^{-10}} = \frac{460 \times 10^6}{\frac{0.002}{2}}$$

M = 57.592 Nm

Thickness of composite bumper can be found out by the following formula

$$\frac{M}{I} = \frac{\sigma}{y}$$

By using the above formula find out the thickness of three individual sections.

$$\frac{57.592}{\frac{0.056 \times d_1{}^3}{12}} = \frac{490 \times 10^6}{\frac{d_1}{2}}$$

$d_1 = 3.548 \times 10^{-3}$ m

$$\frac{57.592}{\frac{0.076 \times d_2{}^3}{12}} = \frac{490 \times 10^6}{\frac{d_2}{2}}$$

$d_2 = 3.098 \times 10^{-3}$ m

$$\frac{57.592}{\frac{0.056 \times d_3{}^3}{12}} = \frac{490 \times 10^6}{\frac{d_3}{2}}$$

$d_3 = 3.548 \times 10^{-3}$ m
Average thickness (d) = $(d_1 + d_2 + d_3)/3$ = 3.398 mm
A layer of woven jute fiber mat thickness is 0.25 mm, so 14 layers are required for fabricating composite.

A. HAND LAYUP PROCESS

Jute fiber composite is fabricated by using hand layup process. In this process liquid resin is applied over the mould and then woven jut mat is placed on the top. To impregnate the resin over the fiber a roller is used. Another reinforcement and resin is applied until a suitable thickness is build up. This is very flexible process. The reinforcement is placed manually. This process requires less capital.

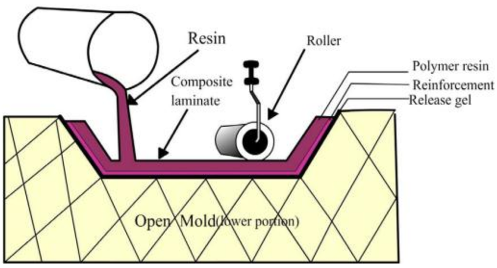

Fig 1: Hand layup process

The basic raw materials for this process are woven jute mat, epoxy resin, hardener and wax. This process requires room temperature to cure with low pressure. Thickness of composite is buit up by applying series of jute mat and liquid resin layer. The excess resin is squeeze out by rollers to create uniform distribution of resin throughout the surfaces. So we get homogeneous wetting. This part is cured at room temperature for about one week.

IV MECHANICAL TEST

Impact test and tensile test are conducted to find out the properties of jute fiber composite.

A. Impact Test

Impact test is done to measure the ability of material to resist impact. Impact testing consists of charpy and izod specimen configuration. The charpy impact test is also known as v-notch test. By this test we can determines the energy absorbed by a material during fracture and this energy absorbed is the measure of toughness. Charpy impact test is widely used in industry, it is easy to conduct and result obtained quickly.

Fig 1: Charpy Impact Test Machine

Charpy test specimen normally measures 55 x 10 x 6 mm and have a notch machined across one of the largest faces. The v shaped notch has 2 mm deep with 45˚ angle and 0.25 mm radius along the base. Figure 2 represent the impact test specimen before test and Figure 3 represent the impact test specimen after test.

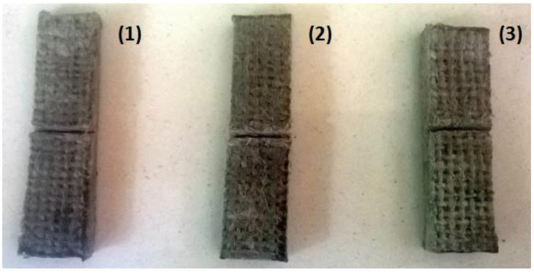

Fig 2: Impact test specimen before impact test

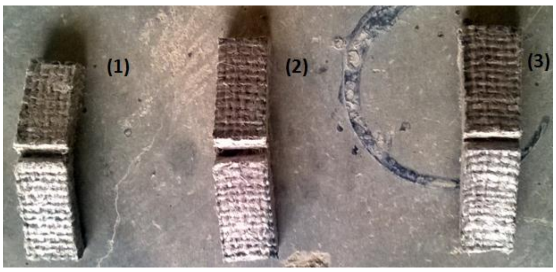

Fig 3: Impact test specimen after impact test

Table 1 represents the impact test result of jute composite.

Table 1 Impact test result

Description	Jute Composite
Cross sectional area, A (mm^2)	40
Impact value, I (J)	295
Impact energy (J/mm^2)	7.38

B. TENSILE TEST

The purpose of tensile testing is to determine how a material will react when it is pulled apart, when a force is applied to it in tension. This is one of the most widely and simplest mechanical test. Material properties can be determined by measuring the force required to elongate a specimen to a breaking point. The tensile test specimen is prepared according to the ASTM D638 standard. Figure 4 represent the tensile test specimen before tensile test. Figure 5 represent the tensile test specimen after tensile test.

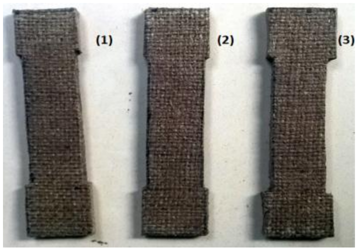

Fig 4: Tensile Test Specimen before Tensile Test

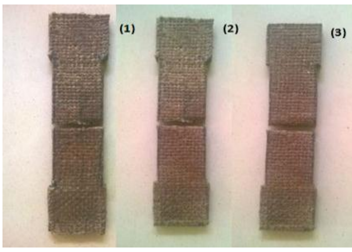

Fig 5: Tensile Test Specimen after Tensile Test

Table 2 represents the tensile test result of jute composite.

Table 2: Tensile test result

Material	Density (Kg/m^3)	Youngs Modulus (GPa)	Poissons Ratio	Fracture Stress (MPa)
Jute Fiber Composite	1390	51	0.26	120

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V FEM ANALYSIS OF COMPOSITE BUMPER

Various analyses like static analysis and impact analysis are required to identify the best material for automobile bumper. Finite Element Analysis is the practical application of Finite Element Method (FEM). This is used by scientist and engineers to numerically solve the very complex structural, fluid and multi physics problem scenario. Ansys is a multipurpose finite element programs and in this project work Ansys 17.0 is used as a tool to achieve the project target.

A. SOLID MODELLING

Solid modeling is a set of principles for computer and mathematical modeling of three dimensional solids. Solid modeling is distinguished from related areas of computer graphics and geometric modeling by its emphasis on physical fidelity. Figure 6 represent the solid model of the Bumper.

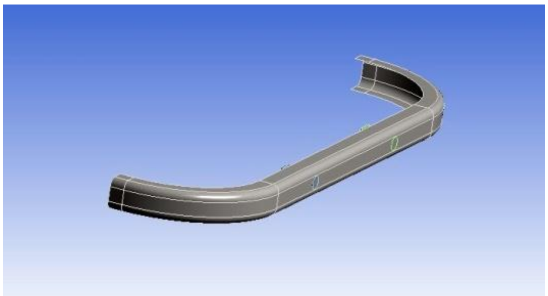

Fig 6: Solid model of the Bumper

Two ends of the bumper are fixed for supporting purpose. Bumper is arrested at 548.33 mm from center to both ends. Details of materials used for the analysis of bumper are shown in Table 3.

Table 3: Details of material properties

Material	Density (Kg/m^3)	Youngs Modulus (GPa)	Poissons Ratio	Yield Stress(MPa)
Mild Steel (chromium coated)	7800	210	0.31	300
Aluminium B390 Alloy	2710	81.3	0.33	250

B. STATIC ANALYSIS

Analysis is based on static type analysis. Values of different material properties are entered in to software. Meshing is another important step. While applying boundary condition, selection of area at which motions are arresting is important. The calculation of load is given below.

Mass of the car (Ambassador) = 1554 Kg
Average mass of five person = 350 Kg
Total mass = 1554+350
= 1904 Kg
Speed of the car = 36 Km/hr
= 10 m/s

Car hitting another identical one and it will stop in 0.1 sec

Deceleration of the car $= \frac{u-v}{t}$
$= \frac{10-0}{0.1}$
$= 100\ m/s^2$

v = Final velocity of car in m/s
u = Initial velocity of car in m/sec
t = time of impact in sec

Force acted during collision = m x a
= 1904 x 100
= 190.4 KN
Area of front face of the bumper = l x b
= 2055 x 78
$= 0.16025\ m^2$
l = length of front face of bumper in mm
b = breadth of front face of bumper in mm

Pressure acted on the bumper $= \frac{F}{A}$
$= \frac{190400}{0.16029}$
$= 1.1878 \times 10^6\ N/m^2$

F = Force acted during collision in Newton and
A = Area of the front face of bumper in m^2
The pressure 1.1878 Mpa is given to the front face of the bumper

C. IMPACT ANALYSIS

Dynamic explicit type analysis is used for the completion of impact analysis in Ansys 17.0. Material properties are entered and meshing is done. Boundary conditions are applied. Arrested the motion of the surface at which body is hitting and velocity of bumper set as 10 m/s. which is equivalent to 36 km/hr.

VI RESULTS

The results obtained during static analysis and impact analysis are shown below. Figure 7 shows the Von mises' stress distribution of jute composite during static analysis.

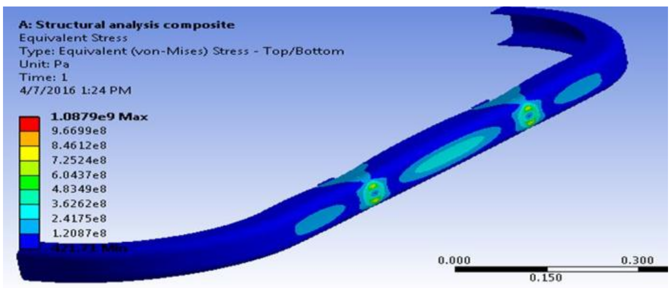

Fig 7: Von mises' stress distribution of jute composite during static analysis

Figure 8 shows the Maximum principal strain obtained for jute composite during static analysis.

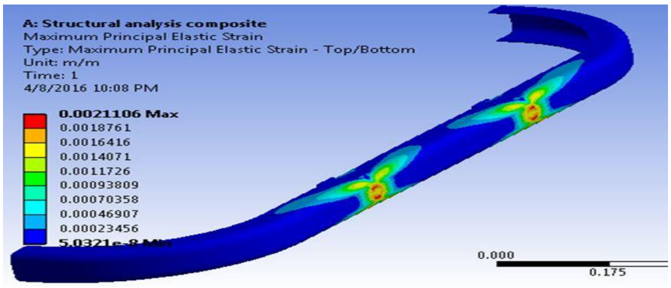

Fig 8: Maximum principal strain obtained for jute composite during static analysis

Figure 9 shows the total deformation obtained for jute composite during static analysis.

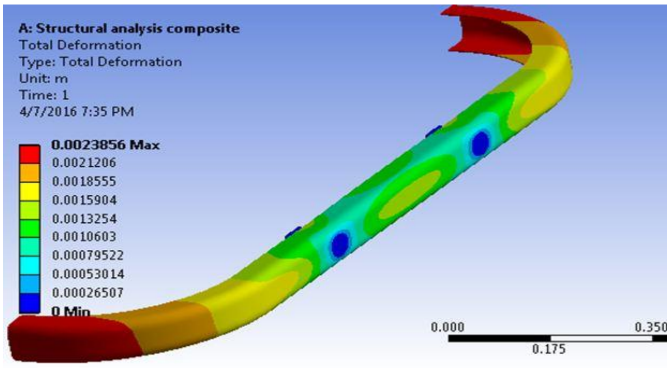

Fig 9: Total deformation obtained for jute composite during static analysis

Table 4 represents the static analysis result comparison of various materials.

Table 4: Static analysis result

Material	Max. Von mises Stress (MPa)	Max. Principal Strain	Deformation (mm)
Chromium Coated Mild Steel	821	0.0028	8.07
Aluminium B390 Alloy	753.8	0.0035	10.5
Jute Composite	1087.9	0.0021	2.38

Figure 10 represent the Max vonmises stress obtained for jute fiber composite during impact analysis.

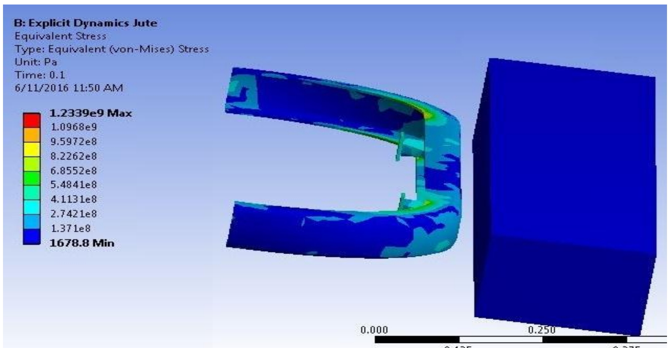

Fig 10: Maximum vonmises stress obtained for jute fiber composite during impact analysis.

Figure 11 represent the maximum principal elastic strain obtained for jute fiber composite during impact analysis.

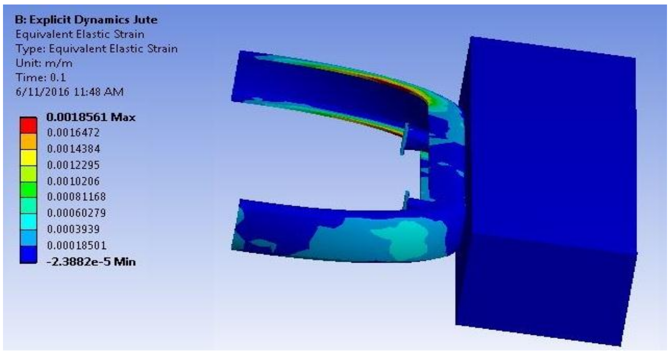

Fig 11: Maximum principal elastic strain obtained for jute fiber composite during impact analysis

Figure 12 represent total deformation obtained for jute fiber composite during impact analysis

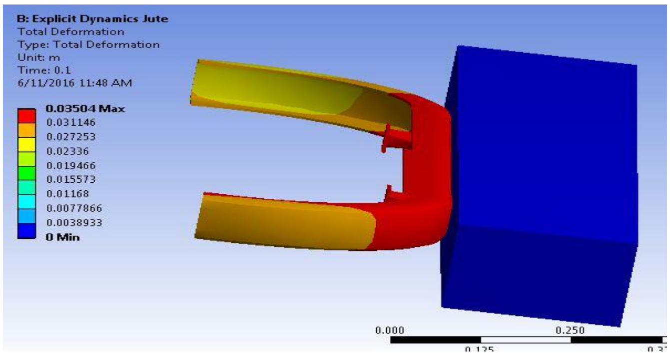

Fig 12: Total deformation obtained for jute fiber composite during impact analysis

Table 5 represents the impact analysis result comparison of various materials.

Table 5: Impact analysis result

Material	Max. Von mises Stress (MPa)	Max. Principal Strain	Deformation (mm)
Chromium Coated Mild Steel	823.55	0.0026	37.57
Aluminium B390 Alloy	516.06	0.0049	40.46
Jute Composite	1233.9	0.0019	35.04

VII CONCLUSION

A jute fiber composite with 14 layers of laminates is fabricated by hand layup process and successfully found out the material properties of composite by conducting impact test and tensile test. An Ambassador Car bumper is successfully modeled in ANSYS 17.0. Static analysis and impact analysis is successfully done on this model by using ANSYS 17.0. Among the three materials used for the static analysis, jute fiber composite possess highest vonmises stress value and the lowest deformation, which suit best among the three. During impact analysis, it is observed that jute fiber composite have the maximum vonmises stress than other

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materials like Chromium coated mild steel and Aluminium B390 alloy. The jute fiber composite also shows the lowest starin value and lowest deformation on comparison with the material like Chromium coated mild steel and Aluminium B390 alloy. Aluminium B390 alloy shows the minimum value of vonmises stress and maximum value for strain and deformation. But it is not suitable for this purpose. One of the major limitations of this work is that, various aerodynamic shapes are not used. From various analyses it is concluded that jute fiber composite meets most of the requirements like high strength to weight ratio, crashworthiness and high stiffness to weight ratio. The currently used ambassador bumper is chromium coated mild steel, which is having high weight. Jute fiber composite can reduce the weight up to five times for the same bumper. Jute fiber composite also provide less deformations and high vonmises stress than the other materials used here.

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