Design and impact analysis of a jeep bumper made of composite material

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Abstract While designing the bumper in the automobile considering the impact during the collision is important. The first part that gets involved in the collision is the bumper. The design of the bumper has to be optimized in a way that it absorbs more energy in order to reduce the impact on the car and passengers. Materials play a vital role in the resistance of a bumper, hence the material to be used has to be chosen wisely. Another important aspect of bumper design is that what percent it contributes to the total weight of the car. The usage of composite material can solve both the criteria of weight reduction and equivalent performance to existing bumper materials such as ABS (steel reinforced), and other metal bumpers.

Keywords: Front bumper, nylon 6 with Nano clay, ABS, SOLIDWORKS, ANSYS, AFRP.

1 Introduction
In automobiles structure it is the front most or the rear most part. It is used to sustain and absorb the energy during the collision. Generally steel and aluminum were used as bumper materials but in recent trends the composite materials are slowly replacing the conventional metals. In another way the front bumpers have more aesthetic value than the rear bumpers. As composite materials can be molded or casted in any shape they can sophisticatedly used as an alternative for the existing materials. Composite materials are also light in weight which makes it a preferable material to the bumper design.

2 Problem statement
Nowadays accidents are frequent and cause damage to the bumpers and the vehicle body. The crashworthiness of the bumper has to be ensured in order to reduce the damage caused physically to the vehicle and the passengers. Upon collision the bumper has to be replaced to ensure the safety of the passengers. The replacement costs of bumpers tend to be expensive as claimed by the consumers. It’s the prime duty of the automobile manufacturers is to satisfy the need of the customer in an effective manner. Composites materials have been in the lights of research in the past decade. Alternate materials which can withstand the impact of the collision and also add some aesthetic value to the bumper.

3 Literature survey
Until now many research and experiment have been done on bumper and materials. Alen John Sanu Alex, have studied on Composite Materials used for Automotive Bumper in Passenger vehicles, in which many plastic based composite materials and their properties are studied. In another study by Sarawut Rindusit1, Parkpoom Lorjia1, Kuljira Suijrote, and Sunan Tiptipakorn Physical and mechanical characteristics of Kevlar fiber reinforced-PC/ABS Composites, Kevlar reinforced fibers which are generally termed as Aramide fiber reinforced polyesters(AFRP) has similar impact properties as the current material being used in automotive front bumpers. Design and Strength Validation of Front Car Bumper Using Composite Material by Vishwanatha R H, Ajith A, Anand N, Punith Raju K B, Vasantha Kumar concluded that composite materials such as fiber reinforced plastics can be used in bumpers.
4 Solid modelling
The solid modelling of the front bumper of a jeep is done using SOLIDWORKS 2013 Edition. A solid model gives more information about the specific features of the component or the part. The geometric and topological information of the part can be easily interpreted and modified if needed. In the modern era of manufacturing more complex shapes are being used which can be only shown in a 3D model.

5 Impact analysis of bumper
5.1 Organization of the ANSYS software
For the analysis of bumper, we are using ANSYS WORKBENCH. In ANSYS, we use preprocessors to enter the basic data such as modelling, editing, copying the binary files etc... Then we proceed to the solution processor step to apply the various loads, constraints to the model and to evaluate the various results.

5.2 Performing typical ANSYS analysis
The ANSYS software has a range of finite element analysis capabilities ranging from a simple linear, static to complex nonlinear, dynamic model. In this analysis we have used explicit dynamic analysis of a front bumper. In this project we have done the modelling of the front bumper in the SOLIDWORKS software. The analysis consists of the following steps which can be classified in three categories as shown in table 1.

| Preprocessor | Solution Processor | Post Processor |
|--------------|--------------------|---------------|
| Assigning element type | Analysis definition | Read results |
| Geometry definition | Constant definition | Plot results on graph |
| Material definition | Load definition (velocity) | View animated results |
| Mesh generation | Model display |   |

The solid model is assigned the material and is meshed to divide the model into number of elements which makes the result to be accurate. The meshing of the model is shown in the figure 2.
Figure 2: Meshing of the components in ANSYS WORKBENCH 18.2

The solid model in workbench is used for impact analysis by applying a velocity of 10 m/s (36 km/hr.). It is impacted against a pole made of structured steel. The pole is a fixed support. It is shown in the figure 3.

Figure 3: Simulation of the Impact phenomena in ANSYS WORKBENCH 18.2

5.3 Materials properties
In this way the impact analysis of the bumper solid model is done using the following materials:

5.3.1 Acrylonitrile butadiene (ABS):
ABS composite is the currently used bumper material in the automotive industry. It is reinforced with steel.

Table 2: properties of ABS (steel reinforced)

| Property          | Value         |
|-------------------|---------------|
| Young's Modulus MPa | 2300          |
| Density Kg/m³     | 1140          |
| Poisson's Ratio   | 0.33          |
| Bulk Modulus MPa  | 2254.9        |
| Shear Modulus MPa | 864.66        |
5.3.2 Aramide fibre reinforced polyester composite

In Aramide fibers composites the Kevlar-49 fibers are reinforced in polyester resin which can yield resistance towards impact.

Table 3: properties of AFRP

| Young's Modulus MPa | Density Kg/m³ | Poisson's Ratio | Bulk Modulus MPa | Shear Modulus MPa |
|---------------------|---------------|----------------|------------------|------------------|
| 4500                | 1450          | 0.31           | 3947.4           | 1717.6           |

5.3.3 Nylon 6 with nano clay reinforcement

Nylon 6 (or polyamide 6) is a polymer possessing good toughness, high tensile strength, elasticity and luster. Nano clays are nanoparticles of layered mineral silicates. The most commonly used Nano clay for material reinforcement is montmorillonite, a 2-to-1 layered smectite clay mineral with a platy structure.

Table 4: properties of nylon 6 (Nano clay)

| Young's Modulus MPa | Density Kg/m³ | Poisson's Ratio | Bulk Modulus MPa | Shear Modulus MPa |
|---------------------|---------------|----------------|------------------|------------------|
| 5000                | 1130          | 0.39           | 7575.8           | 1798.6           |

5.4 ANSYS results

5.4.1 ANSYS results for ABS composite

Considering bumper material as acrylonitrile butadiene styrene plastic with steel reinforcements is impacted against pole made of structured steel the results are as follows which are shown in figure 4 and figure 5

5.4.1.1 Equivalent stress in ABS Composite

Maximum equivalent stress = 23.895 MPa

Figure 4: Equivalent Stress in ABS composite
5.4.1.2 Deformation in ABS Composite

Maximum deformation = 0.4mm

![Deformation in ABS Composite](image)

**Figure 5:** Total deformation of ABS composite

5.4.2 ANSYS results for AFRP composite

Considering bumper material as Aramide fiber reinforced polyester (kevlar29) is impacted against pole made of structured steel the results are as follows which are shown in fig. 6 and fig. 7

5.4.2.1 Equivalent stress in AFRP Composite

Maximum equivalent stress = 23.906MPa

![Equivalent stress in AFRP Composite](image)

**Figure 6:** Equivalent Stress in AFRP composite

5.4.2.2 Deformation in AFRP Composite

Maximum deformation = 0.45132mm

![Deformation in AFRP Composite](image)
5.4.3 *ANSYS results for nylon-6 with nanoclay composite*

Considering bumper material as Nylon 6 Nano clay is impacted against pole made of structured steel the results are as follows which are shown in fig. 8 and fig. 9

5.4.3.1 *Equivalent stress in Nylon-6 Nano clay Composite*

Maximum equivalent stress = 23.91MPa

5.4.3.2 *Deformation in Nylon-6 Nano clay Composite*

Maximum deformation = 0.159mm
5.5 Mathematical modelling and results

Let,

\[ M = \text{Mass of the Bumper in Kg} \]
\[ S = \text{Velocity of bumper in m/s,} \]
\[ V = \text{Volume of the bumper in m}^3, \]
\[ E = \text{Modulus of elasticity in N/m}^2, \]
\[ \sigma = \text{stress generated in bumper in N/m}^2, \]
\[ KE = \text{change in kinetic energy in bumper in J,} \]
\[ SE = \text{change in kinetic energy in bumper in J.} \]

5.5.1 Assumptions made

- The collision is perfectly elastic so that Momentum is conserved.
- The system is loaded within elastic limit to apply theories of failure.
- The time for collision is very less, that stresses generated rapidly and distribute in fraction of second.
- The whole kinetic energy of Bumper is converted into strain energy of Bumper only.
- The friction between Pole and Bumper is neglected.
- Neglecting effect of bending and shearing of Pole and Bumper for analysis

5.5.2 Formulation

Kinetic energy of bumper before collision,
\[ KE = \frac{1}{2} M S^2 \]  \hspace{1cm} (Equation 1)

Strain Energy of bumper after collision
\[ SE = \frac{(\sigma^2 V)}{2E} \]  \hspace{1cm} (Equation 2)

Since the total kinetic energy of Bumper is converted into strain energy of Bumper, so according to law of conservation of energy, total Energy of the system is constant. So, balancing energies of the Bumper.

\[ KE = SE \]
i.e.,

\[ \frac{1}{2} M S^2 = (\sigma^2 V)/2E \]  
(Equation 3)

From equation 3, we can find stress generated in Bumper

So, Stress generated by bumper is given by,

\[ \sigma^2 = M S^2 E / V \]

\[ \sigma = ((M S^2 E / V)^{0.5} \]  
(Equation 4)

\[ \sigma = K_f * (M S^2 E / V)^{0.5} \]  
(Equation 5)

Where, \( K_f = K_s * K_{sz} * K_c * K_e \).

\( K_f \) = Resultant Factors corresponding

\( K_s \) = Shape Factor

\( K_{sz} \) = Size Factor

\( K_c \) = Stress Concentration Factor

\( K_e \) = Endurance Limit Factor

### Table 5: Design factors of the bumper materials

| Shape Factor (Ks) | Size Factor (Ksz) | Stress Concentration Factor (Kc) | Endurance Limit Factor (Ke) | Resultant Stress Factor (Kf) |
|-------------------|-------------------|----------------------------------|-----------------------------|-----------------------------|
| ABS               | 1                 | 1.5                              | 1                           | 1.5                         |
| AFRP              | 1                 | 1.3                              | 1                           | 1.3                         |
| NYLON 6 NANO CLAY | 1                 | 1                                | 1                           | 1                           |

Now, Applying Material conditions for Bumper

**1) For ABS Plastic**

Mass, \( M = 8.954 \) Kg,

Velocity, \( S = 10 \) m/s,

Volume, \( V = 8.6108 \times 10^{-3} \) m³,

Modulus of Elasticity, \( E = 2300 \times 10^6 \) N/m²,

So, from equation 5,

\[ \sigma = K_f * (M S^2 E / V)^{0.5} \]

\[ \sigma = 24.28 \text{ N/m}^2 \]

\[ \sigma = 24.28 \text{ Mpa.} \]

**2) For AFRP Plastic**

Mass, \( M = 12.48 \) Kg,

Velocity, \( S = 10 \) m/s,

Volume, \( V = 8.6108 \times 10^{-3} \) m³,

Modulus of Elasticity, \( E = 1950 \times 10^6 \) N/m²,

So, from equation 5,

\[ \sigma = K_f * (M S^2 E / V)^{0.5} \]

\[ \sigma = 21.85 \text{ N/m}^2 \]

\[ \sigma = 21.85 \text{ Mpa.} \]

**3) For Nylon 6 Nano clay**

Mass, \( M = 9.726 \) Kg,

Velocity, \( S = 10 \) m/s,

Volume, \( V = 8.6108 \times 10^{-3} \) m³,

Modulus of Elasticity, \( E = 5000 \times 10^6 \) N/m²,

So, from equation 5,

\[ \sigma = K_f * (M S^2 E / V)^{0.5} \]

\[ \sigma = 23.79 \text{ N/m}^2 \]

\[ \sigma = 23.79 \text{ Mpa.} \]
Table 6: Comparison of results of Impact stresses

| Sr. No | Material                | Numerical Impact Stress (MPa) | ANSYS Impact Stress (MPa) | Percentage Error (%) |
|--------|-------------------------|-------------------------------|---------------------------|----------------------|
| 1      | ABS                     | 24.28                        | 23.80                     | 2.01                 |
| 2      | AFRP                    | 21.85                        | 23.906                    | -5.43                |
| 3      | NYLON 6 NANO CLAY       | 23.79                        | 23.91                     | -0.5                 |

6 Conclusion

From this report it can be concluded that computer model can be used to predict impact analysis of bumper and stress pattern within bumper system has been studied. Also, mathematical model results provide validation for ANSYS simulation model results. Depending on the outcome, composite materials for bumper are selected for impact strength analysis. From, impact analysis of bumper it is suggested that

- Nylon 6 Nano clay is suitable from repairing cost point of view, because it has minimum deformation and
- Aramide fiber reinforced polyester has minimum stress hence it is the best material for impact point of view and can absorb maximum collision energy.

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