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COMPARATIVE STUDY OF ALTERNATIVE MATERIALS FOR IMPACT ATTENUATORS

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ABSTRACT

The present study mainly focuses on the comparative study and analysis of alternate efficient materials for the design of an impact attenuator to reduce fatalities during vehicle impact. The geometric structure and the alternative materials chosen for the barrel structure of the impact attenuator are briefly summarized, followed by the design procedure and a description of the FEA Analysis.

The present study has been categorized into three, the research of an impact attenuator and their impact on road safety, the design of an impact attenuator and the impact absorbing capability of various materials at varying speeds of impact for an average size family saloon car.

KEYWORDS: Impact Attenuator, Kinetic Energy, Safety Barriers, Alternative Materials & Impact Absorbing Capabilities

Original Article

INTRODUCTION

Vehicle safety is one of the most important analytical areas in automotive technology. The automobile business is developing new safety systems and techniques to extend the protection of passengers.[1] Due to the ever-increasing interest in safety, comprehensive research has been conducted through simulation and experimental tests.[2] To reduce the magnitude of impact on the driver and passengers, special impact structures, namely, impact attenuators were designed to absorb the car's kinetic energy, which further reduces the impact on the human body.[3] An impact attenuator or crash attenuator is a device to reduce the damage done to the vehicle during a high-speed collision.

The impact attenuator acts as a safety barrier between the driver and the impacted surface and hence forms a crucial part of road infrastructure and safety. The attenuator absorbs the kinetic energy of the vehicle through deformation and further reduces the level of force. The energy absorption ordinarily takes place by indepth crushing and crumbling of the structure. Impact attenuators can be used in an array to reduce the fatalities and impact experienced in road accidents. Our research focuses on the sand barrel impact attenuators, as they have the lowest installation cost, an important consideration for a developing country with low budgets.[4]

DESIGN AND ANALYSIS

Design and Dimensioning of the Barrel

The barrel was designed based on industrial standards of currently used impact attenuators.[5] The modeling of the barrel was carried out using Autodesk Fusion 360. Initially, a barrel of 20, 30 and 50 mm thicknesses was analyzed.

The 50 and 20-mm thick barrel had higher stress than that of the 30-mm thick barrel. Hence, the 30-mm thick barrel was selected, as it optimized the structural integrity of the barrel and the stresses developed. Figure 1 shows the barrel structure after meshing.

Dimensions of the barrel are radius of barrel = 500 mm thickness = 30 mm, length of the barrel = 1350 mm, Area of the barrel = 1.750 m^2.

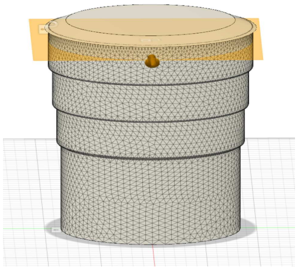


Figure 1: Meshed Barrel Structure Designed using Fusion 360.

Array Configuration

Based on the literature survey and existing impact attenuators, an array of 12 barrels was initially selected.[5] The barrels on either side of the center column were removed in order to simplify the FEA Analysis, as the collision was estimated to be heads-on. Figure 2 represents the array that was used in the simulations.

Figure 2: Array Configuration.

Selection of Striking Object

In order to simplify the analysis of a bumper of a car, a rectangular steel bar was used as a bounding box, as shown in figure 3.

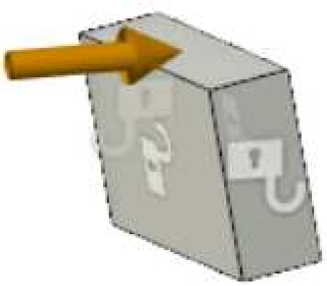


Figure 3: Striking Object.

The specifications of striking object are as follows: Area 2.156 E + 06 mm^2, Density 0.008 E-03 kg/mm^3, Mass 1.341 E + 03 kg, Volume 1.709 E + 08 mm^3. The mass of the bounding box is the approximate weight of an average sized car.

FEA Element

The barrel was meshed into elements by the software solver, of which the details are: Element type: 37357, Tetrahedra: 100.0% of elements, Face Angle min: 9.36, max: 154, Dihedral Angle minimum: 9.3, maximum: 161, Worst shape ratio: 10.8 on element 3677, Worst aspect ratio: 6.05 on element 1073, shortest edge: 0.0193, longest: 0.221, Lowest collapse ratio: 0.143 on element 3845, Worst Jacobian ratio: 1.71 on element 3677, Base mesh: 75096 nodes, 37357 elements, Solver mesh: 75096 nodes, 37357 elements.

Event Simulation

A collision was then simulated by providing an initial load velocity to the bounding box of 100 km/hr in the x direction. Further, the barrel was constrained as a rigid body. Then, the contact sets were set to ensure no surface passes through another and global contacts were set. The mesh size was set to 9% of the path and 10 data points were selected, for a quicker processing. The gravity force was applied on each barrel and appropriate study materials for the barrel were selected. This process was repeated for various materials chosen for the impact attenuator, both linear and non-linear.

MATERIALS SELECTION

The following are the required material properties to select the suitable material for an impact attenuator: material should be inexpensive, easily machined, high strength (tensile and compressive) and toughness, excellent heat and wear resistance and resistant to shock loads. The detailed analysis was categorized into linear and non-linear analysis.

Non-Linear Analysis

A nonlinear analysis is an analysis, where a nonlinear relation holds between applied forces and displacements. These effects result in a stiffness matrix which is not constant during the load application. The following materials undergo non-linear analysis:

- Aluminium – low strength
- Copper – Pure
- Titanium – Pure
- ABS Plastic
- Steel – carbon content

Linear

A linear static analysis is an analysis, where a linear relation holds between applied forces and displacements. This results in a stiffness matrix which is contant during load application. The following materials undergo linear analysis:

- Polyethylene – High-density
- PVC – Unplasticised
- PVC – Flexible
- PMMA Plastic

- PPS Plastic
- Polycarbonate
- PAEK Plastic

COMPARATIVE STUDY OF ALTERNATIVE MATERIALS

A comparative study of alternative materials of barrels was carried out and the nature of stresses and reaction forces acting on the barrel was analyzed. The results obtained from the event simulation using FEA Analysis of each material were tabulated and graphically represented. The study given below emphasizes on the suitable alternative to High-Density Polyethylene using trial and error method.

Polyaryletherketone Plastic (PAEK Plastic)

Table 1, as seen below, shows the material properties of PAEK plastic.

Table 1: Material Properties of PAEK Plastic

Material	PAEK Plastic
Density	1.32E-06 kg / mm^3
Young's Modulus	1100 MPa
Poisson's Ratio	0.42
Yield Strength	99.97 MPa
Ultimate Tensile Strength	210 MPa
Thermal Conductivity	2.5E-04 W / (mm C)
Thermal Expansion Coefficient	4.68E-05 / C
Specific Heat	1340 J / (kg C)

Figure 4 represents the reaction force acting on the striking object due to the PAEK Plastic barrel.

Figure 4: Reaction Force due to PAEK Barrel.

Figure 5 shows the stresses acting on the array of PAEK plastic barrels. The maximum stress developed in the barrel is 167.7 MPa.

Figure 5: Stress acting on PAEK Plastic Barrels.

Figure 6 graphically represents the reaction force at time intervals. As seen in the figure, the reaction force reaches its peak at 5 and then further decreases. The maximum value of reaction force was 13962.9N.

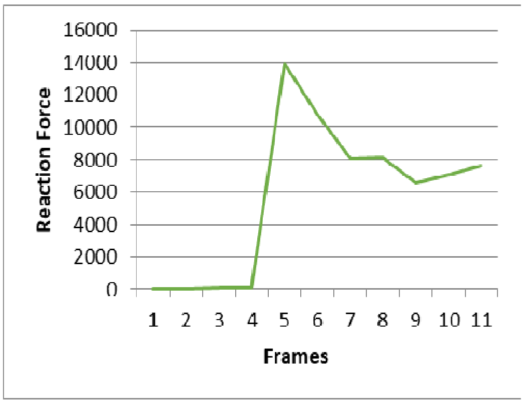
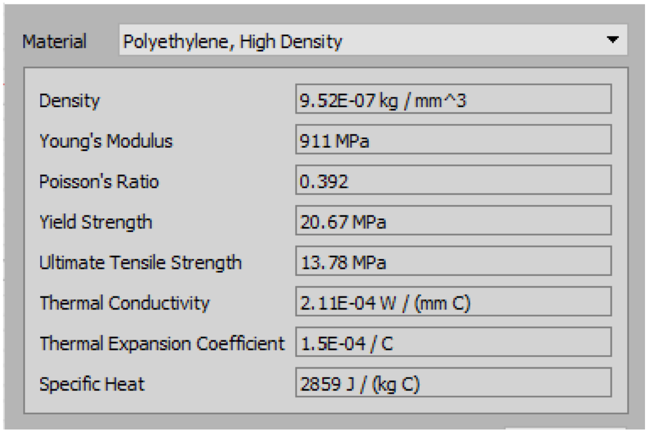


Figure 6: Reaction force vs. Frames for PAEK Plastic.

High-Density Polyethylene (HDPE)

Table 2, seen below, shows the material properties of HDPE.

Table 2: Properties of HDPE



Material	Polyethylene, High Density
Density	9.52E-07 kg / mm^3
Young's Modulus	911 MPa
Poisson's Ratio	0.392
Yield Strength	20.67 MPa
Ultimate Tensile Strength	13.78 MPa
Thermal Conductivity	2.11E-04 W / (mm C)
Thermal Expansion Coefficient	1.5E-04 / C
Specific Heat	2859 J / (kg C)

Figure 7 represents the reaction force acting on the striking object due to the HDPE Barrel.

Figure 7: Reaction Force due to HDPE Barrel.

Figure 8 shows the stresses acting on the array of HDPE barrels due to the striking object, the maximum stress was 164.6 MPa.

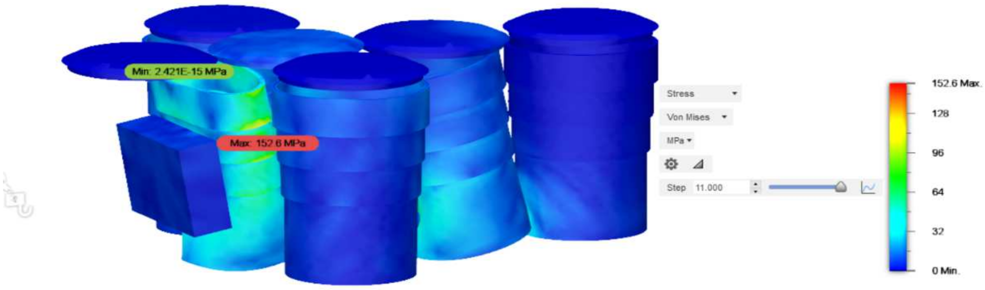


Figure 8: Stresses on HDPE Barrel.

Figure 9 graphically represents the reaction force. As seen in the figure, the reaction force reaches its peak at frame 5 and has a magnitude of 11754.9 N.

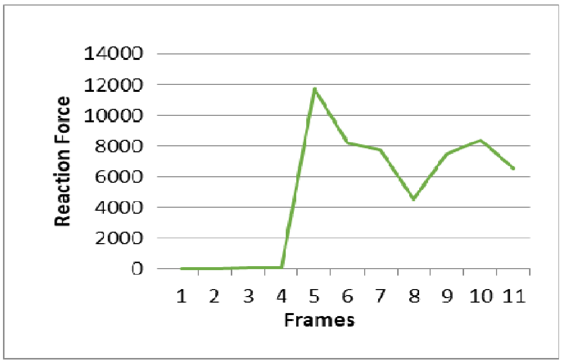


Figure 9: Reaction Force vs. Frames for HDPE.

Un-plasticized Polyvinyl Chloride

Table 3, shown below, shows the material properties of Unplasticized Polyvinyl Chloride**.**

Table 3: Material Properties of Polyvinyl Chloride

Material	PVC, Unplasticized
Density	1.29E-06 kg / mm^3
Young's Modulus	709 MPa
Poisson's Ratio	0.41
Yield Strength	40 MPa
Ultimate Tensile Strength	40 MPa
Thermal Conductivity	1.9E-04 W / (mm C)
Thermal Expansion Coefficient	4.19E-05 / C
Specific Heat	1004 J / (kg C)

Figure 10 represents the reaction force acting on the striking object due to the u-PVC Barrels.

Figure 10: Reaction Force due to u-PVC Barrels.

Figure 11 represents the stresses acting on the array of u-PVC barrels by the striking object. The maximum stress was found to be 129.7 MPa.

Figure 11: Stresses on u-PVC Barrels.

As seen in fig. 12, the reaction force rises sharply and reaches its peak at frame 6, before steadily declining and has a maximum magnitude of 10594.3 N.

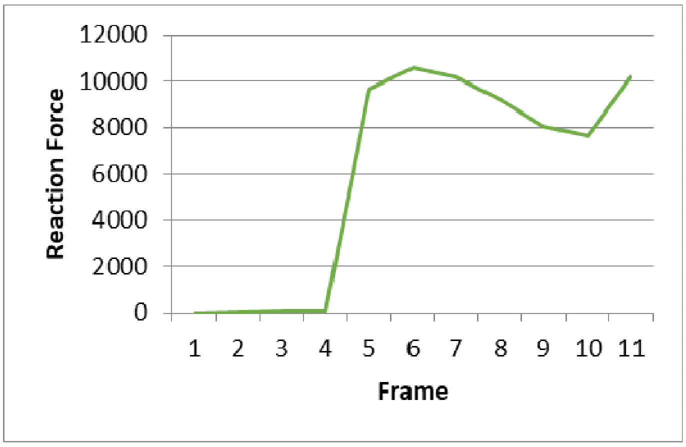


Figure 12: Reaction Force vs. Frames for u-PVC.

RESULTS & INFERENCE

The main aim of an attenuator is to reduce the force felt by the chassis of the vehicle, and hence the comparison of impact-absorbing capability of the material was made on the basis of the reaction force experienced by the striking object.

Table 4 represents the descending order of magnitude of maximum reaction forces for various materials acting on the striking object during impact.

Table 4: Maximum Reaction Forces on Bounding Box by Varying Materials

Material	Reaction Force (N)
Steel-Carbon	403722
Aluminium Pure	171142
Titanium – Pure	125815
Copper – Pure	100377
PMMA Plastic	31003.1
PPS Plastic	29009.5
ABS Plastic	26435.5
Polycarbonate	23044.8
PVC Flexible	17352.2
PAEK Plastic	13962.9
Polyethylene – High Density	11754.9
PVC – Unplasticized	10594.3

On comparison of the maximum reaction forces acting on PAEK Plastic, HDPE and u-PVC, we noticed that PAEK plastic had a relatively higher reaction force than the conventional HDPE and was then ruled out. Hence, the comparison was carried out between u-PVC and HDPE barrels.

As seen from the table above, PVC – Unplasticized applied a lower reaction force on the striking object than the conventional, industrial standard polyethylene – high-density barrels. Hence, PVC – Unplasticized was selected as a suitable alternative.

Further, PVC – Unplasticized was compared to Polyethylene – High Density at varying speeds of impact, ranging from 80 km/hr to 120 km/hr, the average range of speed of a crashing vehicle.

The reaction forces on the striking object for u-PVC at varying speeds were tabulated in table 5 as shown below:

Table 5: Reaction Forces on Striking Object at different Speeds for u-PVC

Initial Velocity (km/hr)	Reaction Force of u-PVC (N)
80	9648.89
90	17329.6
100	10594.3
110	26545.2
120	23018.3

The reaction forces on the striking object for Polyethylene high density at varying speeds were tabulated in table 6, as shown below.

Table 6: Reaction Forces on Striking Object at different Speeds for Polyethylene, High density

Initial Velocity (km/hr)	Reaction Force of Polyethylene, High Density (N)
80	10912.5
90	15272.4
100	11754.9
110	25881.2
120	21850.1

Further, the reaction forces were compared between the two materials and the difference was calculated in table 7. The reaction forces of both materials were observed to be comparable at various speeds, commonly seen on highways.

Table 7: Comparison of Reaction Forces on Striking Object at Different Speeds Between u-PVC and Polyethylene, High Density

Initial Velocity (km/hr)	Reaction Force of u-PVC (N)	Reaction Force of Polyethylene, High Density (N)	Difference between the Reaction Forces (kN)
80	9648.89	10912.5	1.2636
90	17329.6	15272.4	2.0572
100	10594.3	11754.9	1.160
110	26545.2	25881.2	0.664
120	23018.3	21850.1	1.1682

The reaction forces of u-PVC and Polyethylene – high density was comparable for the selected range of speeds. Thus, Unplasticized Polyvinylchloride was identified as a viable alternative to High Density Polyethylene as the material used for a Barrel Impact Attenuator.

CONCLUSIONS

The polyethylene barrel of industrial standards was analyzed and compared with u-PVC barrels using Fusion 360. It was noted that u-PVC caused a similar reaction force on the striking object as that was caused by Industrial Standard Polyethylene with high density. The u-PVC is durable, corrosion free and wear resistant and hence can be utilized for road applications. The fire-resistant property of the u-PVC material will allow the barrel to withstand crash fires during road accidents, as opposed to High Density Polyethylene, which has to be coated with other materials for it to withstand crash fires. u-PVC is sustainable, recyclable and can be reshaped into new products at high temperatures. Once the barrel has been impacted and deflected, it can be recycled and reshaped, hence has a long-term environmental benefit. The impact absorbing capability and high impact strength of u-PVC, along with its advantageous properties and cost effectiveness due to lower maintenance costs makes this material a suitable alternative for an impact attenuator.[6]

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