# Optimization of Strategies for Modelling of Energyabsorbing Structures in Vehicles

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**Article History**: Received: 11 January 2021; Revised: 12 February 2021; Accepted: 27 March 2021; Published online: 4 June 2021

**Abstract:** Crash performance is imperative to ensure safety of vehicle. A major challenge in the design and optimization of vehicle crash systems is the high computing costs needed for crash analysis. It is imperative that energy-absorbing structural principles can be introduced and optimized at the early stages of vehicle design in order to improve crash efficiency by creative and optimized vehicle architecture. Through developing rapid modelling strategies, this potential can be maximized. In this paper modelling approaches are investigated using Finite Element Method for one application. Description for energy absorption structures are studied and implemented into new user defined model description for an explicit Finite Element Crash Solver. The simplified energy absorbing structure is verified using Finite Element Models

**Keywords:** Energy Absorption Structures, Finite Element Models, Crash Performance, Optimization, Rapid Modelling

## 1. Background

With increase in the number of population, there is increase in the number of vehicles on road, leading to accidents. Passenger safety is of the topmost criteria. Vehicle design is incorporated with Energy Absorbing structures; these help is absorbing the impact caused due to sudden collision of car or violent deceleration. Hence design of Energy Absorption structure plays a crucial role in Vehicle validation. A computational cost for assessing Crashworthiness of the vehicle is very high. Hence to minimize the cost required for the Crash analysis of thevehicle, energy absorbing structures areoptimized at early stage of vehicle design.

## 2. Motivation

Lightweight vehicle structure has always been the interest of manufactures, as it increases the payload capacity and decreases the cost in manufacturing. Vehicle design or vehicle structure needs to be validated. Validation of the vehicle structure is done in three different ways namely – analytically, numerically and prototype testing. Numerical validation of the vehicle is given more importance as it gives accurate results than analytical method and the cost of prototype build is skipped. To reduce the computational cost involved in crash analysis of the vehicle structures, Energy Absorption Structures are optimized in the early phase of vehicle design to reduce the cost and get the optimum design of Vehicle.

## 3. Objective

The Objective of the paper is to optimize the design of Energy Absorption structures. The optimization process includes exploring the rapid modelling strategies by understanding the manufacturing capabilities for Laser Beam Melting additive manufacturing process. This is done to get a better visual of the design of the Energy Absorption Structure prototype made through Additive Manufacturing during the optimization process. The optimized design of the Energy Absorption Structure is validated structurally in Ansys to understand the deformation and stresses experienced by it.

## 4. Statement of Contribution and Methods

### 4.1 Optimization of Energy Absorption Structure

Energy absorption structures are the mechanical structures, designed to absorb maximum energy experienced by the vehicle during vehicle frontal crash. Optimal design of energy absorption structures complies to higher energy absorption capabilities of the structures. Hence, optimization of energy absorption structures, includes, optimal geometry and material selection for the structure. Rapid modelling strategies are explored at the design stage to understand the design closely for analysis and better visualization. When the vehicle is in motion, it acquires kinetic energy. After the collision of the vehicle, this kinetic energy gets converted into destructive mechanical energy due to sudden and violent deceleration of the vehicle. This destructive mechanical energy is absorbed by the energy absorption structures. In this paper we will be considering direct and oblique collision of the vehicle. For these two impacts what is the amount of loading or in other words amount of violent deceleration experienced by the energy absorbing structures is calculated. This is done to evaluate the stresses and deformation experienced by the energy absorption structures after the impact. The above criteria is used to validate the energy absorbing structures structurally.

During the vehicle crash, the kinetic energy of the vehicle is converted into destructive mechanical energy. Kinetic energy is defined as KE = ½ mv2. This equation implies, KE is directly proportional to the mass of the component. Hence, it is desirable to reduce the weight of the Vehicle and thereby mass of Energy Absorption Structures.

**4.2 Design of Energy Absorption Structures**

Design of Energy Absorption structures is an iterative design process. The objective of each step is identified with the technical requirements of the vehicle and by the use of dedicated software. Here, we have used the soft ware's PTC Creo and Ansys for 3-D modelling and Structural Analysis of the components.

The design process is a 5 step design process leading to a Crashworthy System.

1. Design of the Cross-sectional Area ofthecomponent- Software used is PTCCreo

2. Design of the Single member of the component – This is done by mathematical modelling the component using spring, mass anddamper system and Creo software for

3-D modelling and Ansys

3. Design of the structural component of the component – This achieved similar to the design of single member.

4. Design of the Structural Assembly - This is a combination of the design of Cross- sectional area, Single memberand Structural component. Structural assembly is modelled using spring, mass and dampersystem.

5. Full Crash Simulation – Full crash Simulation incorporates the validation of the Energy absorbing structures assembled on the vehicle. This is done with the help of Ansys software.

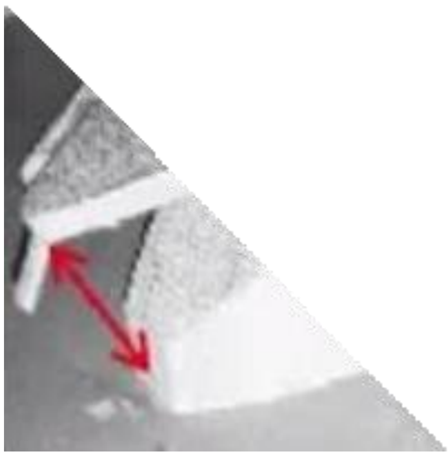
The design of the Energy absorption structure is divided into two sections Cross- section design and longitudinal member design. The cross section design of the Energy Absorption structures designed is Honeycombed structure considering the optimized manufacturing constraint for its Rapid Model also known as Biomimetic Structures. The Longitudinal structure is the thin walled structure.

**4.3 Design Guidelines for Rapid Prototyping**

The main objective is to optimize the design of Energy Absorption structures at early stage of vehicle design. Laser Beam Melting is one such strategy that is explored at the design stage to understand the design of Energy Absorption structures closely for analysis and better visualization. Design guidelines for Laser Beam Melting are studied. Design guidelines help to avoid partfailures and low quality builds of the prototype.

LBM Design guidelines are classified as below:

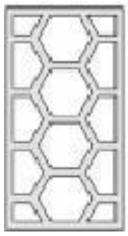
**Residual Stresses** – Residual stresses can endanger the safety of the process and can result in the cancellation of the process. The following images shows examples of failure of process due to residual stresses in the prototype.



Disconnection fromsupport Disconnection frombuilding platform

**Fig 1-** Examples showing failure of process due to residual stresses in the prototype.

Material accumulation leads to higher residual stresses due to high energy input, hence a model with higher materialaccumulation is rejected, hence a honey combed structure is considered as an optimized structure.



Honey Combedstructure



Not accepted

Also large horizontal surfaces that are exposed in one plane leads to high residual stresses. Hence, singular horizontal beam is bad for rapid prototyping of the energy absorption structure. Below figure shows the examples that can be adopted in place ofsingular horizontal beam.

**Accuracy and Surface quality**

The achievable accuracy for the build depends on the layer thickness. Maximum accuracy for Laser Beam Melting in Z- direction is 0.5 mm and in X/Y direction is

0.05 mm. Accuracy varies according to the case.

**Functional Surfaces**

High quality Functional surfaces are achieved after the prototype is build. The surface quality of the built is enhanced after the post processing. In other words, the Functional surfaces, bores and threads are to be post processed. Clearances have to bedrilled after the build.

**Support Structures**

Support structures are required when the prototype has the following prerequisites: Horizontal surfaces or the surfaces with a material dependent angle of below 25° to 45°. Horizontal drill holes Surfaces or edges that would be directly printed into the powder bed. Structures that are highly dependent on material and design of theenergyabsorption structure.

**Material Selection**

Optimal material selection includes three objectives to be satisfied namely; Lightweight, high strength and cost reduction.

Basis these properties two materials wereselected and analysed for desired results:

a. Magnesium alloy – It has low densitydue to which we achieve weight reduction and fuel efficiency.

b. A36 Steel- It is suitable for problems where the strain rate varies over a large range and the temperature changes due to plastic deformationcaused by thermalsoftening

**4.4 Methodology for Analysis of Optimized Energy Absorption Structures.**

Finite Element Method is a numerical simulation method in which we virtually simulate the practical condition that is loads and vibrations that Energy Absorption Structure faces in Crash.

Finite Element Analysis of the Energy Absorption structures includes structural analysis of the Optimized design and crash analysis of the vehicle assembled with the optimized Energy Absorption Structure. The numerical simulation on Energy Absorption Structure is divided into two categories – Solver and Process. The Solver part of the analysis includes; Material Modelling, Feature Modelling, Numerical Method and Connecting TechniquesModelling.

The process part of the crash vision is divided into the following topics: Load Cases, Pre-processing and Post processing. The design of Energy Absorption Structures is analysed for the material A36 Steel and Magnesium Alloy. Modal analysis is performed on the shortlisted design to calculated the natural frequency of the component. The objective to perform modal analysis is to avoid resonance of the Energy Absorption Structures with components of the vehicle design. Power Spectral Density Analysis is performed on the selected design of the Energy Absorption structures. The input given is the acceleration profile that we have obtained from on-road data of the vehicle. We calculate the amount of stress and deformation experienced by the model.

**5. Results**

The design of Energy Absorption Structure where the cross-section area is selected as honey-combed structure (Biomimetic Structure) gives the flexibility of printing it on 3D printer which helps in better visualization of the design that helped in understanding assembly / integration of the cross-section with structural tube and of the Energy Absorption structure with theVehicle.

We observed that the shortlisted design with Magnesium alloy as the material gives us weight reduction and thereby costreduction.

**6. Conclusion**

The design and validation process of Energy Absorption structures is summarized as follows:

a. Design of the Energy absorption structures aligning with the design guidelines of Rapid Prototyping.

b. Design guidelines of Rapid Prototyping for the ease of manufacturing mechanicalcomponents.

c. Material selection.

d. Modal and PSD analysis of the Energy Absorption structures for understanding the behavior of the structures on on-road vibrations and loading conditions.

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